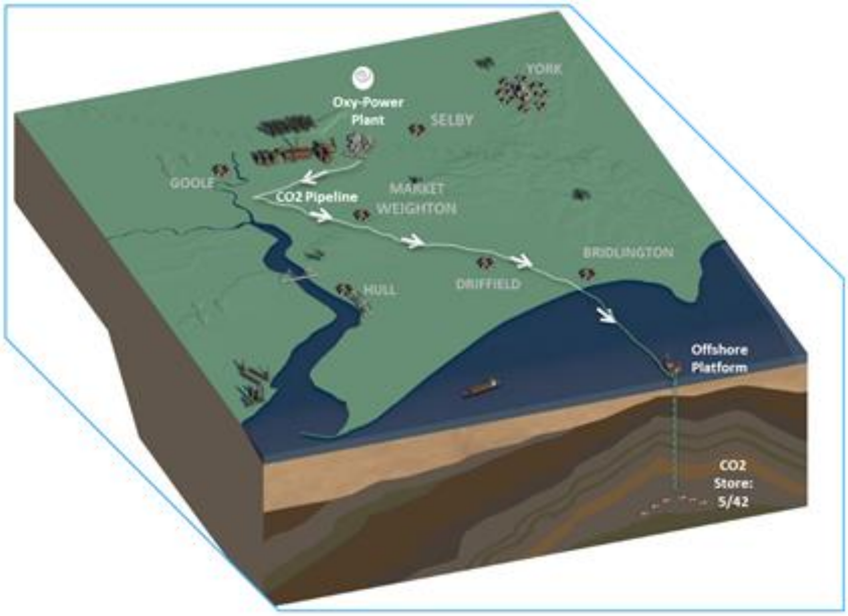
December 2015

K03 Full Chain Operating Philosophy

Key Knowledge Deliverable, Technical – Full Chain



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Contents

Chapter	Title	Page
Executive Summary		i
1	**Introduction**	1
1.1	Background	1
1.2	Purpose of the Document	3
2	**Commissioning Philosophy**	5
2.1	Introduction	5
2.2	Objectives and Philosophy	5
2.3	Approach to Commissioning	6
2.3.1	Mechanical Completion	6
2.3.2	Commissioning	6
2.3.3	COMAH (Control of Major Accident Hazards) Readiness	6
2.4	Roles and Responsibilities	6
2.4.1	Overall / Full Chain	7
2.4.2	Oxy Power Plant and Interconnections	7
2.4.3	Transport and Storage	7
2.4.3.1	Onshore Pipeline, Pumping Station and Offshore Pipeline System	8
2.4.3.2	Offshore Storage System	8
2.5	Full Chain Commissioning	8
2.5.1	OPP Overall Commissioning Sequence	8
2.5.1.1	OPP Functional and Protection Testing In Oxy Mode	9
2.5.1.2	Performance Tests in Oxy Mode	10
2.5.2	T&S Commissioning and Testing	10
2.5.2.1	Pipeline Commissioning	10
2.5.2.2	Readiness for CO_2 Commissioning Into the Storage Facility	11
2.5.2.3	Storage CO_2 Commissioning and Testing	11
2.6	Full Chain Performance Testing	12
3	**Operation Philosophy**	14
3.1	Objectives	14
3.2	Normal Operating Philosophy	14
3.3	Normal Operation	15
3.4	Flexible Operation	16
3.5	Line Packing	17
3.6	CO_2 Injection	17
3.6.1.1	Injection Strategy for Future CO_2 Emitters	18
3.7	System Start-up	18
3.7.1	OPP Start-up	18
3.7.2	T&S System Start-up	19
3.7.3	Pumping Station Start-up	19
3.7.4	Platform System Start-up	19
3.7.4.1	Restart after Well Washing	20
3.7.4.2	Re-Start after Shutdown	20
3.7.4.3	Nitrogen Wellhead Pressurisation	20
3.7.4.4	MEG Injection	21

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3.8 Full Chain Planned Shutdown 21
3.9 Non-planned and Emergency Shutdown 22
3.10 Emergency Arrangements 22
3.11 Non-routine Activities 23
3.11.1 CO_2 Venting 23
3.11.1.1 Venting Responsibility Allocation 23
3.11.1.2 CO_2 Venting Facilities 24
3.11.1.3 Venting Design Considerations 25
3.11.1.4 Depressurisation 25
3.11.1.5 Low Temperature 26
3.11.1.6 Dispersion 26
3.11.1.7 Noise 26
3.11.2 Transport System Bypass Arrangements 26
3.11.3 Pipeline Inspection 27

4 Control Philosophy 28

4.1 Introduction 28
4.2 Objectives 28
4.2.1 Principal Functions 28
4.2.2 Additional Design Requirements 29
4.3 Full Chain Control Philosophy 29
4.3.1 System Interfacing Strategy 30
4.3.2 Signal Interfacing 30
4.3.3 Coordination 30
4.3.4 Start-up and Shutdown 31
4.3.5 Load Control 31
4.3.6 Response to Faults 31
4.4 Generic Control System Requirements 31
4.4.1 General Design, Technology and Reliability 32
4.4.2 Operational Requirements 32
4.4.3 Operation and Monitoring 32
4.4.4 Alarm and Events Management 32
4.4.5 Automation 33
4.5 Systems for Safe Operation 33
4.5.1 ESD systems 34
4.5.2 CO_2 Composition Analysis 34
4.5.3 Fire and Gas Detection System 34
4.5.4 CO_2 Detection Systems 34
4.5.5 High Integrity Pressure Protection System (HIPPS) 35
4.6 Management Information System 35
4.7 OPP Control Philosophy 35
4.7.1 T&S Control 36
4.7.2 Platform Control 36
4.7.2.1 Well Injection Control 37
4.7.2.2 Down-hole Gauging 37
4.7.3 Emergency Shutdown System (ESD) 37
4.7.3.1 ESD General 37
4.7.3.2 Shutdown Requirements 37
4.8 CO_2 Metering 38

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5 **Operations Management Philosophy** 39
5.1 Operations Management 39
5.2 Operational Communications and Planning 39
5.3 Nominations 40
5.4 Operational Balancing 40
5.5 CO_2 Quality Management 40

6 **Decommissioning of CO_2 Store** 42
6.1 Overview 42
6.2 Pipelines 44
6.3 Wells 44
6.4 Monitoring 45
6.4.1 Monitoring Area 45
6.4.2 Monitoring Phases 45
6.4.2.1 Post Injection 45
6.4.2.2 Post Closure 45
6.4.2.3 After Transfer 45
6.4.3 Monitoring Technologies 45
6.4.3.1 Wellhead Pressure and Temperature 46
6.4.3.2 Downhole Pressure and Temperature 47
6.4.3.3 Inert and Isotopic Tracers 47
6.4.3.4 Casing Annulus Pressures and Temperatures 47
6.4.3.5 3-D Seismic 47
6.4.3.6 Micro Seismic Network 47
6.4.3.7 Tiltmeter Network 48
6.4.3.8 Global Positioning System (GPS) 49
6.4.3.9 Bubble Stream Detection 49
6.4.3.10 Seawater Chemistry 49
6.4.3.11 Ground Water Monitoring 49
6.4.3.12 Seabed Sampling and Gas Analysis 50
6.4.3.13 Ecosystem Monitoring 50

7 **Key Availability Assessment** 51
7.1 Key Definitions 51
7.2 Operational Availability 51
7.3 Assumptions 51
7.4 Maintenance 51
7.5 Targets 52
7.6 Approach 52
7.7 Calculation of Full Chain Intrinsic Availability 53
7.8 Summary 54

8 Glossary 55

Appendices 58
Appendix A Future Energy Scenarios in Great Britain 59

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Tables

Table 3.1: OPP CO_2 Export Operational Limits 15
Table 3.2: OPP CO_2 Export Operational Limits 17
Table 6.1: Technologies and Applicable Decommissioning Phases 46
Table 7.1: Full Chain Intrinsic Availability 53

Figures

Figure 1.1: Key Elements of the Full Chain 1
Figure 1.2: White Rose CCS Project Artist Impression 2
Figure 1.3: Geographical Overview of the Transportation System 3
Figure 2.1: Commissioning and Testing Overview 13
Figure A.1: Estimate Future Power Supply 59
Figure A.2: Current and Future Thermal Demand with Increasing Wind Deployment 60

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Key Words

Key Word	Meaning or Explanation
Carbon Dioxide	A greenhouse gas produced during the combustion process
Carbon Capture and Storage	A technology which reduces carbon emissions from the combustion based power generation process and stores it in a suitable location
Coal	The fossil fuel used in the combustion process for White Rose
Dense Phase	Fluid state that has a viscosity close to a gas while having a density closer to a liquid Achieved by maintaining the temperature of a gas within a particular range and compressing it above a critical pressure
Full Chain	A complete CCS system from power generation through CO_2 capture, compression, transport to injection and permanent storage
Interconnections	Links for supply between existing Drax and Oxy Power Plant (OPP) facilities
Key Knowledge	Information that may be useful if not vital to understanding how some enterprise may be successfully undertaken
Storage	Containment in suitable pervious rock formations located under impervious rock formations usually under the sea bed
Transport	Removing processed CO_2 by pipeline from the capture and process unit to storage
Operation	Utilising plant/equipment to produce/provide the designed output commodity/service
Operating Mode	The method of operation of the OPP, which can operate in air or oxy-firing mode
Oxy Boiler	The boiler within the OPP capable of producing full load in either the air or oxy-fired mode of operation
Oxy-firing	The use of oxygen (instead of air) in the combustion process
Oxyfuel	The technology where combustion of fuel takes place with oxygen replacing air as the oxidant for the process, with resultant flue gas being high in CO_2
Oxy Power Plant	A power plant using oxyfuel technology
Maintenance	Preserve the utility of plant/equipment by cleaning or replacing degraded components on a regular schedule or as discovered during routine inspections
White Rose	The White Rose Carbon Capture and Storage project

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Executive Summary

The Full Chain Operating Philosophy was generated as part of the Front End Engineering Design (FEED) contract with the Department of Energy and Climate Change (DECC) for the White Rose Project (White Rose). This document is one of a series of Key Knowledge Deliverables (KKD) from White Rose to be issued by DECC for public information.

White Rose is an integrated Full Chain Carbon Capture and Storage (CCS) Project comprising a new coal-fired ultra-supercritical Oxy Power Plant (OPP) of up to 448 MWe (gross) and a Transport and Storage (T&S) network that will take the carbon dioxide (CO_2) from the OPP and transport it by pipeline for permanent storage under the Southern North Sea. The OPP captures around 90% of the CO_2 emissions and has the option to co-fire biomass.

Delivery of the project is through Capture Power Limited (CPL), an industrial consortium formed by GE, BOC and Drax, and National Grid Carbon (NGC), a wholly owned subsidiary of National Grid.

This report provides an overview of the operating philosophy for the Full CCS Chain, including how the chain will handle the flexible operation expected from the power plant to anticipate with the long term requirements of the UK electricity market.

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

- K02 – Full Chain Basis of Design;
- K27 – Oxy Power Plant Process Description;
- K29 – Transport Process Description;
- K30 – Storage Process Description; and
- K34 – Flow Assurance.

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1 Introduction

1.1 Background

The White Rose Carbon Capture and Storage (CCS) Project (White Rose) is an integrated full-chain CCS project comprising a new coal-fired Oxy Power Plant (OPP) and a transport and storage (T&S) network that will take the CO_2 from the OPP and transport it by pipeline for permanent storage under the southern North Sea.

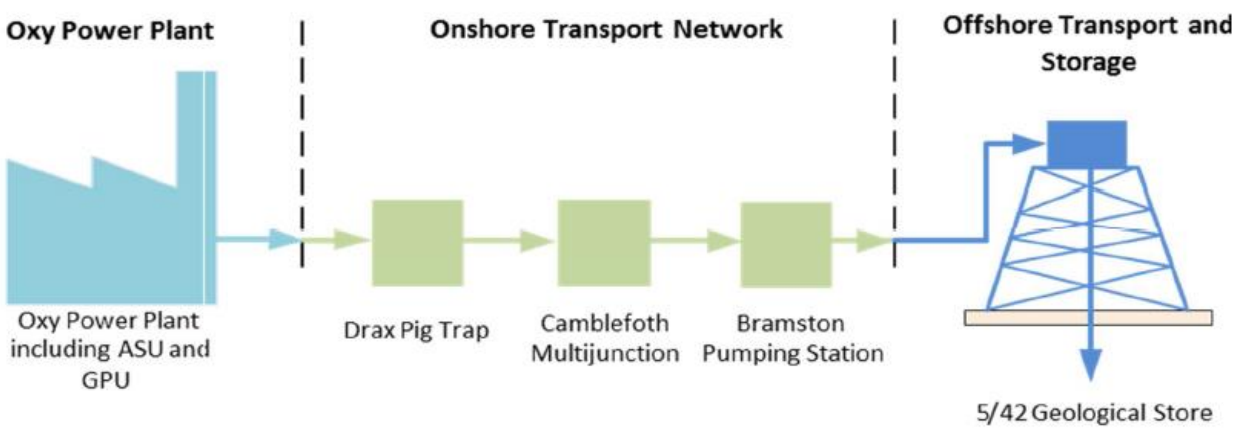
The OPP is a new ultra-supercritical power plant with oxy-fuel technology of up to 448 MWe gross output that will capture around 90% of CO_2 emissions and has the future potential to co-fire biomass.

One of the first large scale demonstration plants of its type in the world, White Rose aims to prove CCS technology at commercial scale as a competitive form of low-carbon power generation and as an important technology in tackling climate change. The OPP will generate enough low carbon electricity to supply the equivalent needs of over 630,000 homes.

White Rose is being developed by Capture Power Limited (CPL), a consortium of GE, BOC (a member of the Linde Group) and Drax. The project will also establish a CO_2 transportation and storage network in the region through the Yorkshire and Humber CCS pipeline being developed by National Grid Carbon Ltd (NGC).

The full chain and its component parts, as shown in Figure 1.1, are designed to be operated such that the target of two million tonnes of CO_2 per year can be safely stored.

Figure 1.1: Key Elements of the Full Chain



Source: CPL

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

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Figure 1.2: White Rose CCS Project Artist Impression

Source: CPL

CPL is a new company formed by the consortium partners to develop, implement and operate the White Rose CCS Project. GE will have responsibility for construction of the power plant together with the CO_2 Gas Processing Unit (GPU) and BOC will have responsibility for the construction of the Air Separation Unit (ASU) that supplies oxygen combustion. For the T&S elements of the project, NGC will construct and operate the CO_2 transport pipeline and, with partners, the permanent CO_2 undersea storage facilities at a North Sea site.

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

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Figure 1.3: Geographical Overview of the Transportation System

Source: NGC

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

- Demonstrating oxy-fuel CCS technology as a cost effective and viable low-carbon technology;
- Reducing CO_2 emissions in order to meet future environmental legislation and combat climate change;
- Improving the UK's security of electricity supply by providing a new, flexible and reliable coal-based low-carbon electricity generation option;
- Generating enough low-carbon electricity to supply the energy needs of the equivalent of over 630,000 households; and
- Acting as an anchor project for the development of a CO_2 T&S network in the UK's most energy intensive region thereby facilitating decarbonisation and attracting new investment.

1.2 Purpose of the Document

This document provides an overview of the operating philosophy for the Full Chain, including how the chain will handle the flexible operation expected from the power plant to anticipate with the long term requirements of the UK electricity market.

The document includes:

- Commissioning philosophy outline;
- Normal operation philosophy outline including start-up and shutdown;
- Control philosophy outline including a high level summary of key control loops, description of control and performance monitoring systems and key safety systems;

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- Approach to development of technical concepts unique to an abated plant e.g. flexible operation outline including turndown. This section also considers line packing, short term (in the event of trip) and long term shut downs (during maintenance);
- Philosophy for how operations communication and decision making will be handled between the individual operating parties in the Full Chain during start-up, shutdown and for changes in operating parameters;
- Non-routine activities such as well intervention, pigging, venting and depressurisation;
- Decommissioning of CO_2 store (including post injection monitoring); and
- Key availability assessment results of the Full Chain (including availability of each key section of the Full Chain: OPP, T&S).

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

- K02 – Full Chain Basis of Design;
- K27 – Oxy Power Plant Process Description;
- K29 – Transport Process Description;
- K30 – Storage Process Description; and
- K34 – Flow Assurance.

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2 Commissioning Philosophy

2.1 Introduction

This chapter outlines philosophy for the Full Chain commissioning and testing of the White Rose Project, in terms of the dependencies and requirements of the components of the Full Chain, and provides:

- A high level description of the commissioning steps; and
- A high level description of the concept for proving tests including performance testing, functional testing and the reliability testing.

2.2 Objectives and Philosophy

The Full Chain commissioning and testing must address the needs of:

- Health and Safety:
  - During all phases of commissioning and testing;
  - For all stakeholders, both outside and inside the project;
  - Inside and between chain elements;
- Statutory & Legislative Requirements:
  - Engineering Procurement and Construction (EPC) Environmental Management Plans (commissioning noise limitations);
  - Environmental Permit, etc.;
  - Reflect the requirements of the electrical System Operator (National Grid Electricity Transmission - NGET) for commissioning plant on to the Grid;
  - Requirements for commercial trading of the electricity;
- Long Term Operability and Reliability:
  - Commissioning should be undertaken within the design limits of the plant;
  - To the extent possible and cost effective, include demonstration of all functional capabilities that the project is expected to deliver during its operating lifetime;
  - Contribute to the development of procedures and manuals to support long term operability and reliability of the plant;
- Timeliness:
  - The commissioning programme must be undertaken in a timely manner, while delivering against the other objectives listed above;
- Cost Effectiveness:
  - The commissioning programme must be undertaken in a manner designed to optimise, to the extent reasonably possible, the costs incurred while delivering against the other objectives listed above;
  - Within the constraints of the commissioning programme and the above requirements releases of CO_2 will be minimised, particularly where CO_2 might otherwise reach storage;
- Learning - The commissioning and testing programme shall be designed and implemented to facilitate:
  - Training and development of operations and maintenance staff who will later have long term operations and maintenance responsibilities;
  - Recording and analysis of events and upset condition responses of the plant so as to provide a basis for future training of operational staff who were not part of the teams directly involved in the commissioning programme; and
  - Collection and analysis of project and process data.

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2.3 Approach to Commissioning

2.3.1 Mechanical Completion

Mechanical Completion of an installation means that the installation is built and installed in accordance with relevant drawings and specifications. Once all specified tests and inspections have been carried out and documented the installation is Ready for Commissioning (RFC).

2.3.2 Commissioning

Full Chain commissioning is undertaken in two major stages:

- Commissioning of the OPP to the stage where the CO_2 specification and quantity are sufficient for the T&S system to begin its commissioning; and
- Commissioning of the T&S system.

Commissioning begins after mechanical completion. The Full Chain is naturally split between the scopes of the various EPC subcontracts, but within this further system separation can be defined for the purposes of mechanical completion and commissioning.

Each element in the Full Chain will be commissioned by the EPC Contractor for that chain element, but they will come under the co-ordination of the Joint Commissioning Board (JCB) which will be the single party in overall charge from an operational perspective.

Once all inspections and tests to verify and document that the functionality and operability complies with the design, the element is Ready for Operation (RFO). Once RFO, the performance testing can commence.

2.3.3 COMAH (Control of Major Accident Hazards) Readiness

The OPP will be an upper tier COMAH site. Therefore in order to comply with COMAH regulations all the prerequisite Health and Safety statements, emergency plans, maintenance systems and organisation charts detailing specific roles and responsibilities will be in place before commissioning can begin. Moreover the off-site emergency plans and safety cases will need to have been reviewed and accepted by the Health and Safety Executive (HSE) prior to commissioning.

2.4 Roles and Responsibilities

The EPC Contractors will be responsible for preparation and general operation of the systems within their particular element of the Full Chain. However, the start of commissioning activity marks the end of construction and the start of the operational phase at which point there is a clear handover of lead responsibilities from construction to commissioning within their teams.

For the purposes of commissioning, the key roles and responsibilities are shown below.

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2.4.1 Overall / Full Chain

Overall responsibility for coordinating the commissioning of the Full Chain will be facilitated and coordinated by the JCB, including the commissioning leads from the EPC Contractors.

The JCB will have the following key roles and responsibilities;

- To develop an approach for testing and validating the Full Chain;
- To produce an End-to-End commissioning plan for the Full Chain. The plan will clearly define requirements at interfaces; and
- To combine and develop the individual Commissioning Programme into a Full Chain Commissioning Programme.

The Full Chain Commissioning Programme will consider 'what if' scenarios. It will also try to meet the specific requirements of each EPC Contractor so far as is reasonably practical, but it is recognised that there could be situations where the requirements of power station operation and electricity export onto the grid do not exactly match the T&S system requirements and vice versa.

Each EPC Contractor will have the following key roles and responsibilities:

- To produce a Commissioning Programme for their part of the Full Chain; and
- To provide representation and input into the JCB, to support commissioning meetings, workshops and safety assessments.

2.4.2 Oxy Power Plant and Interconnections

Reporting to the JCB, GE (the OPP EPC Contractor) is the party responsible for the overall OPP commissioning, but within that BOC (the ASU EPC Sub-Contractor) is responsible for the commissioning of the ASU within the overall agreed Commissioning Programme.

Drax is responsible for the commissioning of the Interconnections within the overall agreed Commissioning Programme.

GE is responsible for the overall OPP. This will include managing / coordinating the following:

- Commissioning of the OPP (in air mode initially) including the interfaces with Drax;
- Commissioning of the OPP (in oxy mode) & initial operation with CO_2 venting to demonstrate production of a CO_2 stream at the specified conditions for T&S;
- Demonstration of reliable and stable operation of the OPP, to allow commencement of the commissioning of the onshore and offshore pipeline;
- Provision of CO_2 at conditions suitable for commissioning / filling of the onshore and offshore pipeline;
- Operation of the OPP to provide CO_2 at the specified composition, temperature and within the pressure and flow ranges required for entry into the onshore transportation system under normal end-to-end chain operating conditions; and
- Calibration and proving of CO_2 metering systems in conjunction with NGC.

2.4.3 Transport and Storage

NGC are responsible for the commissioning of all the elements of the T&S system. This will include managing / coordinating the following:

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2.4.3.1 *Onshore Pipeline, Pumping Station and Offshore Pipeline System*

- Acceptance of the CO_2 at the project specification from the OPP into the onshore pipeline system;
- Filling of the onshore and offshore pipeline systems with CO_2 and the removal of the super-dry air preservation medium;
- Operation of the onshore pipeline to provide CO_2 at the specified composition, temperature and within the pressure and flow ranges required for entry into the pumping station;
- Commissioning of the pump by-pass;
- Commissioning of the pumping station to ensure that the operation is stable and reliable, without trips or upsets that may affect the commissioning and subsequent operation of the downstream systems;
- Supply CO_2 into the offshore pipeline at the specified composition, particulate level, pressures and temperatures required for commissioning and for filling the pipeline to establish conditions suitable for dense phase CO_2; and
- Operation of the pumping station to provide dense phase CO_2 at the correct composition, temperature and within the pressure and flow ranges required for entry into the offshore pipeline.

2.4.3.2 *Offshore Storage System*

- Acceptance of the CO_2 at the project specification from the offshore pipeline system; and
- Commissioning of the offshore storage facility, to ensure that the operation is stable and reliable, without trips or upsets.

2.5 Full Chain Commissioning

Full Chain commissioning is undertaken in two major stages:

- Commissioning of the OPP to the stage where the CO_2 specification and quantity are sufficient for the T&S system to begin its commissioning; and
- Commissioning of the T&S system.

The following sections discuss the commissioning strategy first for the OPP and its associated systems and then for the T&S elements.

2.5.1 OPP Overall Commissioning Sequence

The main steps in the OPP Commissioning Programme will be in the following sequence:

- Interconnections and Balance of Plant (BoP);
- Power block cold commissioning;
- ASU Commissioning (parallel activity);
- Gas Processing Unit (GPU) pre-commissioning (parallel activity);
- Air mode protection testing;
- Hot commissioning in air mode;
- Functional testing in air mode;
- Shutdown;
- Protection testing for oxy combustion specific systems;
- Hot commissioning in oxy mode including GPU commissioning;
- Functional testing in oxy mode; and
- Performance testing in oxy mode.

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BoP systems and interconnections need to be ready for use before commissioning of the main power block.

The power block cold commissioning will be made up of three main sections:

- Air Quality Control Systems (AQCS);
- Power block; and
- Boiler.

These activities are expected to take place in parallel with the commissioning and pre-commissioning of the other main parts of the OPP, for example the ASUs, GPU and ash handling systems. Once the individual functional systems are pre-commissioned, a testing period of overall protection required for air mode shall be undertaken prior to first fire.

It consists of a cold test of inter-function trips and interlocks involved in the air mode operation with Distributed Control System (DCS) and Programmable Logic Controllers (PLC) energised.

Once cold commissioning is completed, fuel is introduced and the power block reaches “First Fire”.

Pre-commissioning of the GPU can take place in parallel with similar work on the power block. This could include test running of the machine on air and molecular sieve adsorbers filling.

Commissioning of the process elements cannot begin until boiler flue gas is available with the plant in oxy mode for processing.

Once the OPP is commissioned and tested in air mode, commissioning in oxy mode will begin.

The plant is shutdown to allow a period of functional and protection testing of additional systems required for oxy mode that were not tested in air mode.

For oxy mode hot commissioning to begin, O_2 from the ASU must be available.

The plant will start-up in air mode and transition to oxy mode with recycled flue gas and oxygen from the ASU replacing the combustion air. When this transition is complete, CO_2 rich flue gas can be fed to the GPU.

GPU hot commissioning requires continued operation of the boiler in oxy-mode to supply CO_2 rich flue gas to the GPU.

Power generated during hot commissioning will be exported to the grid.

Once the CO_2 specification is achieved and has past the reliability tests, the CO_2 can be supplied to the pipeline for pipeline pressurization.

2.5.1.1 *OPP Functional and Protection Testing In Oxy Mode*

- Start-up times;
- Ramp rates;
- Minimum stable generation;

- Minimum stable generation (fully environmentally compliant);
- Effluent treatment plant;
- Run back checks;
- House load (opening of the Line Breaker, Generator will supply the auxiliaries of the Plant);
- Grid code compliance;
- Protections tests with simulation of a general outage;
- CO_2 capture rate; and
- CO_2 purity.

2.5.1.2 *Performance Tests in Oxy Mode*

Once all functional tests have been successfully passed, the plant passes to performance testing. In the case of the OPP the characteristics requiring performance testing are:

- Gross power output
- Auxiliary power consumption by consumer including ASUs and GPU;
- Net power output;
- Gross heat rate;
- Net heat rate; and
- Reliability run.

Emissions compliance, noise levels and other environmental performance characteristics must all be met throughout the performance testing regime. Also CO_2 capture rate and purity must be achieved at all times.

Once performance tests in oxy mode are complete, the output from the GPU should be stable and of suitable quality to allow all aspects of T&S system commissioning to be undertaken.

During the reliability run, gaseous emissions and CO_2 specification and flow rate will be monitored continuously.

2.5.2 T&S Commissioning and Testing

The following sections address the balance of the Full Chain system.

T&S commissioning and testing will commences following demonstration that the T&S system has reached Mechanical Completion (MC), with certificates in place to show full system is RFC. This includes testing and confirming the integrity of the pipeline through hydrostatic tests before any commissioning activities commence.

2.5.2.1 *Pipeline Commissioning*

Once CO_2 is available from the OPP at the required specification and for periods long enough to allow the step wise pressurisation of the system, then commissioning of the pipeline may commence.

- Pressurise entire pipeline between the OPP Terminal Point up to the platform with super dry 25 barg air;
- Isolate the sections of the pipeline by closing the valves at the block valve and pumping stations;

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- Further pressurise the section between the OPP tie-in point and the Tollingham Block Valve Station (BVS) with super dry air up to a pressure of 50 barg. This is the pressure that will prevent flashing of the liquid CO_2 when fed forward from the OPP;
- Once the CO_2 from the OPP meets the pipeline specification and the reliability of supply is deemed satisfactory, filling up of the onshore transportation system with CO_2 can commence. The CO_2 from the OPP is admitted into the first section of the pipeline i.e. up to the Tollingham BVS. As the CO_2 starts to fill the pipeline section it also compresses the air in the section;
- In order to minimise the amount of mixing of CO_2 with air and hence the amount of venting required offshore and associated CO_2 loss, separation pigs are used between the air in the pipeline and the CO_2 being introduced;
- Once the first section of pipeline is pressurised to ~ 65 barg, pressurisation of the next section can commence. This stepwise pressurisation continues until all sections of the onshore and offshore pipelines, up to the platform, have reached 65 barg;
- CO_2 flow continues until all the air has been has been displaced via the vent on the platform and the transport network is filled with CO_2, and confirmed through sampling. At this point the CO_2 flow to the pipeline from the OPP is stopped and the system checked the for any leaks;
- Once satisfied that the system is leak tight, the entire network can be further pressurised with CO_2 from the OPP until the desired first fill injection pressure is achieved;
- Once the system is up to pressure, and the commissioning of the upstream transportation system is complete, the storage facilities are ready for operation and the combined reliability achieved by the upstream chain is deemed satisfactory, commissioning of the offshore facilities may commence i.e. injection in to the storage site. This will commence once the CO_2 stream composition meets NGC specification and is at a suitable pressure for injection.

Operation of the pumps at the pumping station may not be required to achieve injection at the rates expected from the OPP for the first 5 years of operation. This could allow a delayed commissioning of the pumps with CO_2 routed via the pump bypass with sufficient pressure for injection being provided by the OPP.

2.5.2.2 *Readiness for CO_2 Commissioning Into the Storage Facility*

When the commissioning of the upstream transportation system is complete, the facilities are in operation and the combined reliability achieved by the upstream chain is deemed satisfactory, commissioning of the offshore facilities may commence.

Injection into the storage site will commence once the CO_2 stream composition meets NGC's specification and is at a suitable pressure for injection.

2.5.2.3 *Storage CO_2 Commissioning and Testing*

The injection wells and associated systems will be commissioned in accordance with procedures developed during FEED and detailed design.

Procedures and tests to assess reservoir and well performance will be included in the commissioning programme. Subject to technical and operational viability, assessment of the following aspects of well and reservoir performance is expected to be included in the commissioning programme:

- Reservoir injectivity and bottom hole pressure at various injection rates;

- Reservoir pressure dynamics in response to variance in injection rates (well test);
- Commissioning and function testing of all in-hole equipment and instrumentation;
- Commissioning and testing of all other equipment and instrumentation as may eventually be required pursuant to the reservoir Measurement, Monitoring and Verification (MMV) Plan; and
- Calibration of CO_2 fiscal metering.

2.6 Full Chain Performance Testing

The performance testing of the Full Chain will demonstrate that the CO_2 produced by the OPP can be successfully stored for all the operating cases.

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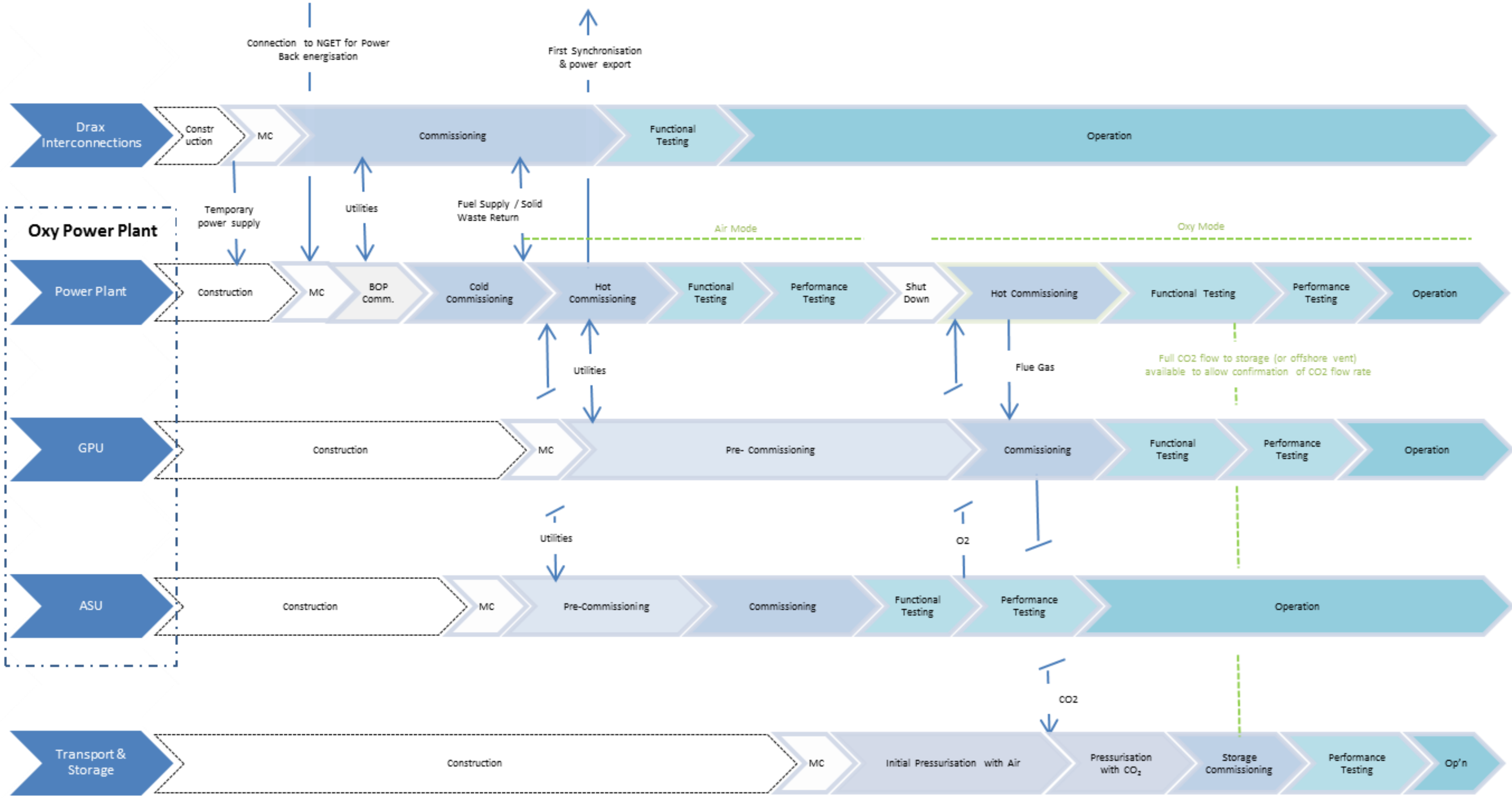
Figure 2.1: Commissioning and Testing Overview



Source: CPL

3 Operation Philosophy

This chapter describes the overall, coordinated operation of the Full Chain, including how operations communication and decision making would be handled between the operating parties in the Full Chain during start-up, shut-down and for changes in operating parameters.

3.1 Objectives

The principle operational and maintenance objectives of the project are to:

- Ensure a high standard of Health, Safety and Environmental performance including the management of risks to personnel to be As Low As Reasonably Practicable (ALARP);
- Comply with UK regulations and legislation, and also the sub-contractors (i.e. GE, BOC, Drax, NGC) policies and procedures;
- Achieve and maintain an overall availability so that the CO_2 can be safely stored over the project life time;
- Safeguard the technical integrity of all assets;
- Operate and maintain the End-to-End chain assets in the most cost-effective manner;
- Minimise the number of planned chain shutdowns as far as is practicable by harmonising and scheduling the maintenance of major equipment within the Full Chain elements at the same time;
- Minimise the number of equipment starts and stops;
- Minimise unplanned shutdowns, and the volume of any associated vented CO_2;
- Minimise the shutdown times (planned or unplanned shutdowns) by implementing an appropriate maintenance philosophy and spares strategy;
- Ensure competent persons are utilised across the Full Chain operations and maintenance activities, and that they are provided with appropriate training and tools; and
- Respect others in the neighbouring areas of the operation and maintenance works.

3.2 Normal Operating Philosophy

OPP operation in oxy-mode, with CO_2 flowing to the T&S system, is normal operation for the Full Chain.

OPP air mode operation, with no CO_2 production, is only for:

- initial commissioning and functional testing;
- start-up and shut-down; and
- upset conditions.

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

The design and operational intention is to run the Full Chain continuously (minimise number of starts).

Dense phase CO_2 is produced by the OPP up to the design flowrate of 2.68 Million Tonnes Per Annum (MTPA).

The OPP is designed for flexible operation allowing a power net output adjustment between 0% and 100% in certain conditions. The “zero” power output can be reached without shutting down the plant and while the CO_2 is provided continuously at a reduced rate (about 35% during the night) to the T&S system.

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3.3 Normal Operation

Base load is expected to be the usual operating mode.

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

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

At base load the OPP is expected to export around 300 MWe to the grid and export around 263 Tonnes Per Hour (TPH) CO_2 to the T&S system.

The OPP is able to ramp up and down with a normal loading and unloading ramp rate of 2% per minute.

In normal operation, the most efficient operation of the OPP is expected to be between 75% and 100% load. This is due to the ASU and GPU compressors operating ranges as below 75% load the compressors are in recycling mode, or for the ASU main air compressor may need to blow off excess air.

In base load operation all the ASU oxygen production is Gaseous Oxygen (GOX) with no production of Liquid Oxygen (LOX) and no use of the stored LOX. At reduced ASU load LOX production from the ASU can be initiated if required.

Table 3.1 lists the operational envelope limits for the CO_2 stream from the OPP with respect to flowrate, operating conditions and compositional limits.

Table 3.1: OPP CO_2 Export Operational Limits

Parameter	Limit
Minimum Flowrate	0.81 MPTA
Maximum Flowrate	2.68 MTPA
Minimum Operating Pressure	90 barg
Maximum Operating Pressure	135 barg
Minimum Operating Temperature	5ºC
Maximum Operating Temperature	20ºC
Maximum H_2O Content	50 ppmv
Maximum O_2 Content	10 ppmv
Maximum H_2S Content	20 ppmv

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

The pressure in the T&S system network is governed by the offshore injection pressure controller, which regulates the choke valve to each of the online injection wells, and by the control logic for the Barmston Pumps, which would react to any variation in the suction pressure of the pumps by adjusting the speeds of the pumps and/or by bring one into operation or stopping one.

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The set pressures of the controllers would ensure that the demand flowrate of CO_2 in the transport network from the OPP and, as they join the system, other industrial emitters, would continue to be injected into the offshore reservoir site whilst ensuring the CO_2 always remains within the dense phase throughout the network.

Depending on the CO_2 flowrate through the T&S system, the booster pumps at Barmston may or may not be required. For the expected design flowrates for the first 5 years of operation, the flow assurance work (KKD K34 – Flow Assurance) has shown that the booster pumps may not be needed and the pressure generated at the OPP would be adequate to ensure fluid arrived at the storage platform at sufficient pressure to inject. In this instance the pumps at Barmston could be bypassed and the flow to the injection wells achieved by the pressure generated at the OPP.

When the flowrate through the transport network exceeds that which is possible in the bypass mode of operation, the Barmston pumps would be required to ensure injection in to the reservoir wells and the suction pressure control of the pumps, by way of the pump control logic, would bring online the number of pumps required and adjust the speed of each using the Variable Speed Drive (VSD) to ensure injection of the demand flowrate is feasible.

3.4 Flexible Operation

The OPP has been designed in order to demonstrate the flexible operation that will likely be required from CCS enabled fossil fuel power plants within the long term requirements of the UK electricity market. This requirement was determined by considering the future energy scenarios in Great Britain and the effect of the planned increases in wind deployment on thermal demand and is discussed further in Appendix A. To accommodate this requirement the Full Chain has been designed to have the capacity to allow flexible operation in each element of the system.

The OPP is designed to operate flexibly in a way that mimics the traditional “two shifting” of conventional power plants. When power demand is low, the plant can move to a position that results in nearly no net power exchange with the grid while still generating the clean power needed to operate the ASU and GPU and providing an uninterrupted flow of CO_2, at a reduced rate, to storage. During this period some energy is stored as liquid oxygen and this can be recovered within the process when demand returns giving an enhanced net output from the OPP.

The economics of this operating mode are enhanced by the savings realised due to the reduction in the number of start-ups and shut-downs (lower fuel oil consumption, lower stress to the mechanical equipment), as well as by “electrical energy storage” in the form of liquid oxygen.

The Full Chain can adjust to match the OPP’s flexible operation:

- CO_2 Pumping Station: The CO_2 pumps at Pumping Station can modulate to adjust to the CO_2 production rate and the process requirements of the pipeline.
- Injection wells:
  - The combination of injection wells in use will change the range of injection rates to accommodate the full range of CO_2 from the OPP.
  - The overall injection rate range will vary as the reservoir pressure increases over the injection period; and The wells maximum supply pressure of up to 182 barg and minimum of 90 barg to prevent phase separation occurring within the pipeline.

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In addition, to the normal and flexible operation described above, the OPP could on occasions be required to turn down to a 50-60% Stable Export Limit (SEL), in order to comply with the electrical Grid Code requirements.

Table 3.2: OPP CO_2 Export Operational Limits

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

3.5 Line Packing

As mentioned in Section 3.2, the compressibility of the CO_2 in the dense phase is significantly less than for traditional gas pipelines. However, it is possible that 'line-packing', the ability to compress the fluid, in the pipeline by a small additional margin, could be used, to a very limited extent, to manage abnormal conditions and small transients due to time lags between balancing supply and demand.

Inventory (the fluid being transported) may be held ("packed") in a pipeline within the operating pressure range to allow resumption of its transportation on an immediate basis. The CO_2 could be "line packed" if there were to be a need to suspend transport (see Section 3.6).

3.6 CO_2 Injection

Continuous CO_2 injection is desirable, as regularly turning wells on and off for flow control could result in repeated pressure and temperature cycling.

If there is an event in the Full Chain resulting in the overall CO_2 mass flow ceasing or being reduced, the injection rate will be reduced so that well injection can be maintained during the event. The well injection duration will be dependent on the change in OPP output and any available line-pack in the pipeline system. Reducing the well injection rate extends the time available for the Full Chain to resume normal operation before the wells must be shutdown. If wells have to be taken out of service temporarily, a strategic selection of the wells which need to be shut in will be made to reduce overall well cycling.

The well injection pressure will rise as the storage formation fills throughout its operational life. It is possible that water production from the formation will be required to maintain an acceptable pressure to ensure the reservoir cap rock integrity.

The Full Chain equipment will be designed to accommodate the maximum pressures anticipated over the project lifetime and any required rise in well injection pressure will be delivered through the NGC Pumping Station.

The start-up and shutdown of the downstream systems will normally be by remote operation (depending on the prevailing system pressures and temperatures).

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3.6.1.1 *Injection Strategy for Future CO_2 Emitters*

From Year 10 onwards, it is anticipated that CO_2 would be supplied by additional sources up to a total of 17 MTPA, which is the maximum design load for the T&S system

However, it is estimated that as the storage pressure increases following prolonged CO_2 injection, the pressure required to transport the CO_2 and maintain injection rates of above ~ 10 MTPA, even with the number of injection wells from the original platform increased from 3 to 6 would likely exceed the offshore pipeline maximum operating pressure. Under these circumstances a significant proportion of the CO_2 would have be routed to an additional remote injection facility, another platform, the location of which is yet to be determined.

3.7 System Start-up

Start-up may be from a pressurised state or a depressurised one, depending on the circumstances of the preceding shutdown. Normally the system will be retained full of the dense phase CO_2 in a pressurised state for ease of restart. In the case of maintenance activities, only the isolated system or equipment item(s) would require complete depressurisation.

During a normal start-up sequence, the CO_2 would be vented through the OPP vent stack to atmosphere until the pipeline entry specification criteria are met.

Communications would be established between the Control Centres to carry out the necessary start up checks. The OPP Control Centre would initiate the start-up sequence and progress to the point at which the CO_2 may be verified as meeting the T&S entry requirements and the data available made available to the T&S Operator prior to CO_2 delivery. Concurrently, the T&S Operator would configure the T&S system to accept delivery of the CO_2. If required, then the T&S Pumping Station would also be brought to a state of readiness to accept delivery of the CO_2. At that point the OPP Control Centre would manipulate their system to start delivery of CO_2 into the T&S system and begin re-pressurisation (if required) and delivery of CO_2 to the T&S system. The T&S Control Centre would monitor the data provided by the OPP on the condition of the CO_2 as it enters the T&S system and verify that it meets the entry requirements.

3.7.1 OPP Start-up

The time to start-up the OPP depends on how long it has been offline:

- Cold Stand-by: >48 hours offline (all electrical, utility and fuel supply systems must be re-established before a restart);
- Warm Stand-by: between 8 and 48 hours offline (with sufficient services maintained to keep the process in a warm condition during this period); and
- Hot Stand-by: less than 8 hours offline (with the utilities remaining online).

The following steps are required to start-up the OPP:

- The OPP systems are brought on line in air mode, and the OPP is warmed through, with the steam headers brought up to full temperature. If the steam systems have remained in a warm or hot stand-by condition, with only a minimal fall in temperature or pressure, then warming up of the OPP will be greatly reduced or not necessary;
- Transfer of operating regime from air mode to oxy mode requires availability of the ASU system;

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- Produced CO_2 will be vented to atmosphere from the OPP vent stack until it is within the required specification for transfer to the T&S system. The venting duration should be minimised as far as is reasonably practicable; and
- Once CO_2 is within specification, venting can cease and transfer to the Transport System can commence.

The start-up of the plant is in air mode. The normal transition from air to oxy mode takes place at around 50% load. The normal transition load range from oxy mode to air mode will take place in the same range.

In the transition from air mode to oxy mode, the oxidant streams supplied to the boiler are progressively transitioned from air drawn from the atmosphere to a mixture of GOX from the ASUs and recirculated flue gases. Switching from air mode to oxy mode takes about one hour. Once oxy-firing is established, the resultant CO_2 rich flue is introduced to the GPU, and once the CO_2 specification is achieved full CCS operation can commence.

3.7.2 T&S System Start-up

On start-up, the CO_2, with confirmation of within composition limits, will proceed through the pipeline, passing the Drax Above Ground Installation (AGI), Camblesforth Multi-Junction, and Tollingham, Dalton and Skerne Block Valve Stations. The booster pump station at Barmston will increase the operating pressure and the CO_2 which will be pumped to the offshore facility, where it will be filtered and injected into the aquifer.

3.7.3 Pumping Station Start-up

It is noted that the Pumping Station will consist of a number of booster pumps, which are individually known as pump units.

In accordance with the LOPs, communications will be established between the control centres to carry out the necessary pre-start checks. The selected Pumping Station pump units are available to be selected to start once they are initiated (i.e. auxiliary systems such as lubrication oil systems have reached operating temperature).

The selected pump units can be started at any time post initiated. The pump units can then be loaded (set points enabled) remotely by NGC control centre prior to commencement of delivery or as required after delivery has commenced at the Entry Point.

3.7.4 Platform System Start-up

The key factors for start-up at the platform are:
- low temperature limits of the materials and the wellhead pressurisation system; and
- Mono- Ethylene Glycol (MEG) requirements for hydrate suppression.

The start-up scenarios are:
- first start-up;
- start-up after well washing; and
- re-start after shutdown.

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The platform may be shut-down and re-started remotely by operators at the T&S Operator control centre; however the following would be manned activities:

- first start-up, well washing, start-ups after well washing, and re-starts after prolonged shutdowns during cold periods; and
- when the start-up follows an Emergency Shut Down (ESD) of sufficient level where ESD systems require manual resetting on the platform.

3.7.4.1 Restart after Well Washing

Annual well washing would be required to prevent the build-up of halite in the well bore area. Halite forms due to the dry CO_2 absorbing the water from the saline water down the well borehole. Halite build up would impede the injection flow reducing the system capacity.

The wells would be washed with de-aerated seawater over a one week period. MEG would be injected before and after the washing activity for the prevention of hydrate formation. A 57% by weight MEG solution would be used for this operation.

After the washing process and the final MEG solution injection, nitrogen would be injected into the wellhead until a pressure of 40 barg is reached. At that point the well choke would be opened; this would be done in stage-wise flow increments while monitoring upstream and downstream pressures and temperatures.

3.7.4.2 Re-Start after Shutdown

For platform shutdowns, other than those for well washing, the injection wellheads would have been closed in with CO_2 held at pressure in the offshore pipeline up to the manifold. The CO_2 at the wellheads, after a period of settle-out, would be at least 40 barg (40 barg is expected for the year 1 production scenario, with higher pressures of around 55 barg and 60 barg expected for year 5 and year 10 production). Since in this condition, there are no concerns with hydrate formation or with cold temperatures after the chokes, the re-start operation is simplified as the chokes may be opened with no MEG injection or nitrogen pressurisation required.

A 90% MEG solution may be injected into the wellheads prior to a re-start (opening of the chokes) after a long shutdown during winter (i.e. for a ‘cold re-start’). Longer shutdown duration may increase the possibility of water migrating up the tubing to the wellhead and this, combined with colder wellhead temperatures, would increase the possibility of hydrates forming.

3.7.4.3 Nitrogen Wellhead Pressurisation

Wellhead pressurisation would be a manned activity. Nitrogen would be stored on the platform in a quad of cylinders. When required, for wellhead pressurisation, the cylinders would be connected by hose to a network supplying nitrogen directly to the wellheads.

3.7.4.4 *MEG Injection*

MEG would be used to reduce or stop hydrate forming during start-up and is used before and after well water wash. Hydrates can form in the well tubing when cold CO_2 contacts directly with either the water, which wold have been found in the geological feature, or seawater from the water wash.

The MEG injection pumps would deliver up to 4m^3/h of a 90% weight MEG solution. This concentration would be used for the injection of MEG plugs into the wellhead for:

- first start-up; and
- re-start after prolonged shutdowns during cold periods.

Operators would be in attendance during the 4 hours of injection before well washing starts, then leave the platform and return for the 4 hours of injection after the well washing has finished.

The pumps would be of a positive displacement type. Operators would monitor the pump discharge pressure during the injection operations as any blockages in the discharge piping can quickly lead to a reliance on overpressure protection systems.

3.8 Full Chain Planned Shutdown

On receipt of a zero Input Nomination the T&S control centre will establish communications between the other control centres to carry out the necessary checks in accordance with Local Operating Procedures (LOP)s. The control centres will begin their shutdown procedures in the agreed sequence at a suitable time prior to the zero Input Nomination time. At the zero Input Nomination time the offshore storage will be stopped and the T&S control centre will bring the Pumping Station pump unit(s) to a stop.

Once offshore storage and the Pumping Station pump unit(s) have stopped, the NGC control centre will instruct the OPP to isolate the pipeline. Doing it in this order will ensure the static shutdown pressure is as close as possible to the operational envelope in preparation for a re-start.

If the shutdown was for a decommissioning or depressurisation exercise the order may be reversed and would be the subject of a detailed procedure. Each Party shall consider the shutdown sequence and timings to ensure operating conditions do not exceed design limits.

A planned shutdown will result in stopping of any Pumping Station running pump units. The de-initiating of any Pumping Station pump units will be subject to operator decision based upon next known scheduled CO_2 delivery.

A planned shutdown will not initiate the automatic closing of any T&S system CO_2 isolation valves with the exception that closing of the offshore storage platform topsides well(s) isolation valves may be necessary dependent upon the duration of the shutdown.

A planned shutdown will not initiate any T&S system automatic CO_2 venting.

A planned shutdown will leave the T&S system in a state ready for use via remote control centre commands and without local intervention being necessary.

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Platform shutdown may be initiated remotely from the T&S Operator control centre, locally at the Human Machine Interface (HMI) within the platform Local Equipment Room (LER), or automatically by way of platform Fire and Gas (F&G) system and ESD system.

Depressurisation of the platform systems would be a manual operation.

3.9 Non-planned and Emergency Shutdown

A non-planned or emergency shutdown of the T&S system can fall into two categories: lockout and non-lockout. A non-lockout will allow a control centre remote restart command to be sent once the trip condition has cleared whereas a lockout does not allow a remote restart and requires asset attendance and manual intervention.

For both categories (lockout and non-lockout) the emergency shutdown will result in:
- stopping of any Pumping Station running pump units; and
- closing of the appropriate offshore storage platform topsides CO_2 ESD valves and well(s) isolation valves.

The de-initiating of T&S Pumping Station pump units will be subject to operator decision based upon the cause of the emergency shutdown and the next known scheduled CO_2 delivery.

An emergency shutdown will not initiate the closing of any T&S CO_2 onshore pipeline isolation valves.

An emergency shutdown will not initiate any T&S system CO_2 venting.

For any emergency shutdown NGC control centre will immediately inform the OPP control centre and the offshore storage operator control centre.

For emergency shutdowns which result in a lockout, NGC control centre and/or the offshore storage operator will arrange for local attendance to investigate the reason for the trip and reset if possible.

A trip of an individual T&S Pumping Station running pump unit will be managed by the NGC control centre that will endeavour to promptly start standby pump units without having to stop CO_2 delivery.

3.10 Emergency Arrangements

NGC will coordinate the preparation of the emergency arrangements for the T&S system while CPL will coordinate all activities for the OPP, the interfaces with Drax services and NGC. These protocols will establish the actions necessary to restore the system or the affected part of the system to a safe condition and once agreed will be communicated to other appropriate parties for approval/acceptance – such as neighbouring facilities, regulatory bodies, emergency services and local communities.

These emergency arrangements will be tested annually. Control centre contingency and disaster recovery arrangements will also need to be developed with appropriate parties.

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3.11 Non-routine Activities

3.11.1 CO_2 Venting

Venting of CO_2 from the Full Chain is required for safety, process, operating and maintenance reasons.

The overall requirements of the venting systems are to:

- Support start-up and shutdown of the Full Chain;
- Prevent out-of-specification CO_2 entering the T&S system;
- Provide a means for removing out-of-specification CO_2 from the T&S;
- Support maintenance activities;
- Provide overpressure/thermal relief;
- Provide a means for controlled system depressurisation;
- Support the isolation of high pressure systems (e.g. using double block and bleed arrangements); and
- Support commissioning of the Full Chain.

Additionally, the venting system will be designed to meet a number of objectives, namely:

- Maintain operation of the OPP during loss of T&S service, whenever possible, to minimise start-up or transition times between operating modes and maintain availability at the OPP;
- Minimise the quantity of CO_2 released into the atmosphere; and
- Prevent/ minimise/ withstand adiabatic cooling effects.

The venting strategy and the required venting system performance should satisfy the needs of:

- Health and safety;
- Plant protection (avoidance of damage);
- Plant operability and maintainability (both routine and in upset conditions);
- Minimising fiscal loss due to loss of CO_2; and
- Environmental impact.

The venting system must achieve a high standard of health, safety and environmental and engineering performance while complying with UK regulations and legislation and with operating organisations' policies and procedures.

3.11.1.1 Venting Responsibility Allocation

CO_2 venting would require co-ordination between the parties as venting would affect the operation of the End-to-End CCS chain. It would be necessary for all parties to agree what constitutes relevant status and data signals, which need to be repeated between each of the parties control centres.

Each element of the CCS chain would manage its own venting system design and implementation, subject to the following two requirements:

- Impacts of potential cumulative releases are taken into account; and
- Venting systems (and the underlying processes) are designed to ensure that there are no venting event "knock on" effects across inter element boundaries.

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The various CCS venting systems are not controlled via an integrated End-to-End control system. Each Party in the End-to-End chain would design, install, maintain, operate and control its own plant and equipment, including venting systems, with overall system management being performed by NGCL.

The venting system would be required to support activities normally associated with a pressurised system, such as depressurisation and thermal relief. It also would be required to support activities specific to operating the End-to-End chain such as venting to support start-up and venting to prevent out of specification CO_2 entering the chain. Venting of any section of the main pipeline, such as during start-up or which would interrupt the transport operation, would only occur during a major procedure and would be undertaken in line with an agreed procedure, which would detail the required coordination of the operations of the major elements of the system, CCP, transport and storage.

3.11.1.2 CO_2 Venting Facilities

Venting of CO_2 from the Full Chain is required for safety, process, operational and maintenance reasons. To achieve this, permanent venting systems and vents will be installed at a number of locations along the chain.

Permanent vents would be located at:
- the OPP;
- the pumping facility; and
- the offshore storage facility.

In addition to the permanent vents, temporary vents will be installed, when necessary, at locations along the onshore pipeline. It is anticipated that temporary vents will predominately be utilised for the manual venting of equipment and systems such as Pipeline Inspection Gauge (PIG) traps on the onshore pipeline transportation system.

The offshore facility will require the design to take account of the requirements for venting and it is expected that a permanent facility would be installed for both topsides equipment venting and any requirement for pipeline depressurisation. Separate systems for topsides venting and pipeline depressurisation are expected to be provided, due to the very different conditions and requirements of their use.

The permanent venting system at the OPP will be sized for the design mass flow of CO_2 which will allow the OPP to operate at full output. All vents from the OPP CO_2 venting system, other than those for fugitive releases, will be connected to the OPP main stack.

The permanent vents located at the pumping station and the offshore storage facility will not be sized to discharge the Full Chain's rated CO_2 mass flow. These venting locations will be used predominately for maintenance depressurisation and emergency relief cases, as well as any requirement for pipeline depressurisation after flow has been stopped.

The venting systems at the pipeline installations, the pumping station and the offshore storage facility will be suitable for venting CO_2 in operational and upset conditions.

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Permanent venting facilities for thermal relief will also be available at the OPP, pipeline installations, pumping station and at the offshore storage facilities.

Equipment such as isolation valves, small thermal relief valves, valve cavity vents and relief valve bonnets will have small local vents which will be potential sources of fugitive releases of CO_2. All local vents shall be routed to safe location.

3.11.1.3 Venting Design Considerations

The venting system is required to comply with relevant UK Health and Safety legislation and must provide for the controlled release of CO_2, ensuring safe dispersal and engineering integrity of the venting system.

3.11.1.4 Depressurisation

The venting system will be required to allow depressurisation / venting down of individual sections or elements of the Full Chain.

The OPP, pumping station and offshore storage facilities may be fully or partially vented during routine maintenance. During these activities it is intended that both the onshore and offshore pipelines will be appropriately isolated and left in the pressurised state.

If maintenance is required for a section of the pipeline, in order to avoid and / or minimise venting, methods should be considered to depressurise that section of the pipeline as far as possible prior to venting. These may include:

- Recompression: Using recompression to compress the CO_2 into other sections of the chain, reducing the pressure in the section to be vented; and
- Chain configuration: Configuring the chain / system to reduce or decay the pressure in the section of the chain to be vented.

The pipeline cannot be depressurised through the OPP venting system.

Depressurisation of the onshore and offshore pipelines would only be performed in emergency. The operational intent is to maintain the pipelines in a pressurised state throughout their lifetime. However, should depressurisation of the pipeline systems be required, the inventory of CO_2 released to atmosphere will be minimised by isolating the relevant pipeline section or sections using the pipeline valves available.

The largest section inventory, ~ 24,000 te CO_2, is contained in the offshore pipeline between the Barmston Pumping Station and the platform

Depressurisation of the onshore pipeline will be a manual operation of the affected section by way of a temporary vent stack at the appropriate block valve station and will be carried out under a safe system of work.

In addition to manual venting for depressurisation, some of the equipment in the Full Chain may include automatic depressurisation as part of their operating sequence. Components within the Full Chain that require automatic depressurisation will have a permanent venting system to facilitate this requirement. It is

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anticipated that venting of this nature will only involve the release of small inventories of CO_2 to atmosphere.

3.11.1.5 Low Temperature

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

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

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

3.11.1.6 Dispersion

An Environmental Impact Assessment (EIA) study is required for permanent vents and should include CO_2 dispersion modelling, which should consider wind strength, wind direction, topography, vent height and vent orientation.

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

In addition to permanent venting locations, temporary venting locations will also require assessment prior to installation to confirm that the location chosen is suitable for venting. The design and siting of temporary vents will also take into account dispersion patterns, wind, topography, vent height and vent orientation.

3.11.1.7 Noise

The noise generated at the vent tip as a result of CO_2 venting operations will require consideration with reference to limits agreed with the Local Planning Authority (LPA) and occupational health limits. Noise will be considered during the implementation phase.

3.11.2 Transport System Bypass Arrangements

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

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

3.11.3 Pipeline Inspection

To ensure a high level of safety and reliability in operation of the transportation of CO_2, it is essential that a system of inspection and maintenance exists. For the pipelines this In Line Inspection (ILI) will be achieved using Pipeline Inspection Gauges (PIGs), intelligent pipeline inspection devices, which would be designed to monitor for localised/general corrosion (internal/external) or damage to the pipeline wall.

The purpose of ILI would be to determine and monitor the pipeline system to provide an accurate description of all significant defects, such as metal loss. Each defect would then be considered and repaired as necessary. The inspection would be carried out primarily to identify metal loss due to corrosion, but could also identify other features in the pipeline.

The ILI of the pipeline would require a specified constant flow rate of CO_2 within the system which would be provided by the OPP after prior discussion to ensure that the flow rate is maintained for the period.

It is envisaged that ILI on the CO_2 pipelines would initially be undertaken once every five years and would typically involve 4 to 5 ILI runs over a 2-week period. Over time the inspection frequency may be adjusted on the basis of the body of inspection data: the inspection intervals may be extended or reduced to meet the needs of maintaining of safe operation.

It should be noted that all but the most severe pipeline damage can usually be repaired without the need to shut down the pipeline system, although some reduction in pressure and flows may be required for the duration of the repair works.

PIG launching facilities would be also be provided on the platform to enable the internal inspection of the future pipeline from the platform to an alternative CO_2 injection/storage site.

PIG procedures would be a manned activity.

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4 Control Philosophy

4.1 Introduction

The control philosophy defines the manner in which the individual control systems would interact to provide an overall control approach to ensure safe, stable, reliable and consistent operation so that the operational, business and design objectives (production rate, product quality, availability and safety) of the Full Chain can be achieved.

The philosophy includes the approach adopted for:
- Start-up;
- Shut-down;
- Steady state operation of the OPP;
- Transient and ramping of the OPP; and
- Fault scenarios of the OPP, T&S systems.

The document covers aspects that affect the Full Cain control and does not cover the control aspects within each element of the chain. The control system will be complex reflecting the specific process requirements, regulations, international standards and guidelines and company standards.

The adjoining control systems are connected through hard wired and serial link interfaces to achieve a coordinated control scheme.

4.2 Objectives

Each of the main Full Chain elements will be equipped with an individual control system. These will include the Drax Power Plant (DPP) material handling systems PLCs, the GE OPP DCS, the BOC ASU control system, and the T&S control systems.

The individual control systems for the elements of the Full Chain will be designed to communicate and interface as necessary with the adjacent systems to facilitate safe and secure control of the entire system and to provide monitoring and management information to the various control centres.

Wherever practicable, the control systems for each element will be based on standard control system technology that is established in the respective industry and novel or unproven technology will be avoided.

Each control system will be designed based on the operational needs of the process, taking into account the applicable regulations, industry sector standards and the embedded good practices of the host organisation. As a result it is considered that there is no need to attempt to harmonise the control system design across the project.

4.2.1 Principal Functions

Generally each element control system will be designed to provide the following functions:
- Support the operation of the Full Chain element;
- Ensure automatic, safe, secure and efficient operation of the Full Chain element under all conditions;
- Ensure the Full Chain element remains within operational constraints;
- Raise and manage alarms when the process or equipment are out of normal limits;
- A sufficient level of automation reducing dependence on operators activities;

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- Allow remote control of the equipment (via a remote HMI);
- Operation, start-up, shutdown, control and monitoring of process equipment, instruments, electrical plant, and proprietary control systems; and
- Emergency shutdown.

4.2.2 Additional Design Requirements

The CCS control systems will be based on standard, developed control system technology which has already been established in the respective industries for each element of the chain. Novel techniques or systems will be avoided where practicable.

The systems will be designed such that the start-up, operation and shutdown of the OPP and the T&S system can be carried out remotely (i.e. from a control room location) to avoid a requirement to perform routine local operations to the plant and reduce the risks to operators as a result of working in the field.

In addition to remote control, the systems will be automated, where appropriate, with the operator normally involved in a supervisory capacity only during steady state operation. However, manual interventions may be required to start and stop some of the equipment within the CCS chain.

In order to reduce operator workload the systems will include:

- Fully and semi-automatic sequences - These will be used for start-up and shutdown to achieve correct and consistent Full Chain element operations;
- Automatic regulation functions - These will be used to continuously monitor and regulate the process to maintain the process parameters at the desired set point; and
- Ergonomics and alarm management - The operator displays and prioritisation of alarm messages will be developed according to recognised best practice.

4.3 Full Chain Control Philosophy

The Full Chain control philosophy has been designed to support the operations philosophy from the fuel and services supplied by DPP through the production and treatment of on-specification CO_2 in the OPP and the T&S system.

Each element of the chain will be supervised and operated in an independent fashion from its own permanently-manned control rooms according to local operating procedures.

This solution was chosen as the preferred control option due to the diverse operating environments and specialist skills required for each element of the chain. The proposed scheme will reflect the control solutions deployed for similar applications – such as National Grid's existing natural gas pipeline networks. Integration of the chain control systems into one unified system was not considered suitable as the approach would not support the system ownership and local operational requirements.

In order to allow the chain to realise the overall CCS function, a degree of system interfacing and operations coordination is required and is as described in the following section.

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4.3.1 System Interfacing Strategy

The Full Chain control systems will be interfaced, rather than integrated. This means that they will be entirely independent of each other but will include the signal exchange required to provide reliable coordination of the overall process and appropriate responses to emergency or out of limits measurements. These signals will be transmitted directly between the control systems for each element of the CCS chain. Other communications, including telephone, will also be used to facilitate start-up and transient control regimes.

Key operational monitoring and records data will also be transmitted from each control system to the Management Information Systems (MIS) databases. Key data from the MIS will be available to operators across the chain. The Full Chain elements are interconnected such that a start, controlled stop or trip of any component within the chain can provide information and alarms to both the upstream and downstream process systems. Interfacing signals between the chain elements are therefore required to ensure the process is managed safely and efficiently.

4.3.2 Signal Interfacing

Signal exchange will be established between the chain systems such that key operating parameters, permissive signals and trips are immediately communicated and displayed on HMI in the various control centres. Executive action will, however, only be taken from the control room responsible for each element of the Full Chain, (i.e. no cross boundary executive actions).

Signal interfacing between the systems will be implemented by a combination of hard wired and serial communications links. The serial links may be cabled, fibre optic, satellite, radio or microwave depending on link distances and geography. Generally serial links are used for analogue and digital signal exchange for process and status monitoring whereas hard wired connections are used for safety functions, such as ESD and permissive interlocks, and also for command signals such as start and stop. However, serial links may be used for control or safety related functions provided the link and associated equipment can be demonstrated to provide sufficient security for the function. This can be achieved by subjecting the design to rigorous analysis using procedures set out in standards such as IEC 61508 and 61511 for the design of safety instrumented functions.

The signals to be exchanged, the choice of technology and the detailed design of the interfaces will be defined during the implementation stage of the project.

4.3.3 Coordination

The signals and data exchanged between control systems will not execute directly control actions on the receiving party's system. The individual element control system and the operators in charge will respond to signal inputs from other elements according to the requirements of the process. This may include adjustment of target set points and starting or stopping the Full Chain element as necessary.

Controlling actions required between parties will be requested via a manual instruction process with the subsequent controlling actions carried out by the operator in charge of the relevant CCS chain element.

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CPL will manage the OPP operations and electrical dispatch, while NGC will coordinate the overall system operations to manage the flow of CO_2 throughout the T&S system, the responsibility for carrying out control actions will be retained by the relevant chain element operator.

The details of the chain coordination will be developed during the implementation design phase as necessary for process and safety reasons.

4.3.4 Start-up and Shutdown

The control systems for each of the elements of the Full Chain will undertake the start-up and shutdown sequences necessary for the safe and efficient operation and longevity of the associated plant.

Once the element has reached a stable operational state a suitable signal will be sent to the adjacent element control system notifying readiness for integration (such as "OPP ready to export CO_2"). The adjacent element will then respond accordingly (such as "NGC ready to accept CO_2"). The integration sequence will be initiated by the operators once the plant and conditions for each element are suitable.

Similarly, in the case of controlled shutdown, each element control system will send the appropriate signal to the adjacent element control system to initiate disengagement (such as "NGC shutdown initiated"). In the case of an unplanned shutdown a similar signal will be initiated and the adjacent control system will need to react accordingly to protect the element plant under its control.

4.3.5 Load Control

The OPP control system will send signals to the adjacent element's control systems as necessary to manage load changes. For example target load patterns will be sent to NGC so that the necessary preparations can be made to the T&S system. This will be based on the market trading dispatch predictions. Fuel and materials inventory at the OPP to allow ramping of loads will be maintained through request signals to Drax as necessary. The OPP is designed to retain fuel and materials inventory sufficient for many hours' operation at full load allowing adequate time for batch controlled replenishment when required.

4.3.6 Response to Faults

The Full Chain control philosophy is for each chain element control system to respond to fault scenarios and ESD initiations independently. Signals indicating unplanned shutdowns will be exchanged between the elements (such as "NGC shutdown initiated"). In the absence of such a signal the chain element control system will nevertheless react to the consequential process conditions as necessary, such as the OPP GPU detecting loss of CO_2 flow.

4.4 Generic Control System Requirements

For process control, the control systems will be connected to field mounted instrumentation and process control elements and actuators (such as electrical plant, pumps, fans, valves etc.). The systems will utilise control logic through logic solvers to automatically control the process. This is undertaken by plant actuators, which respond to the outputs set by the control system that in turn depend on the process conditions measured by the Full Chain element instrumentation. The operator interfaces with the process via the control systems HMI (operator stations/local control panels).

4.4.1 General Design, Technology and Reliability

Each section of the Full Chain will be supplied with a complete control system that will include all facilities and systems necessary to operate the associated process and electrical plant. These will generally comprise of the following:

- Operation and monitoring system facilities;
- Automated control and protection equipment (including safety instrumented systems, alarm/event management etc.);
- Communication systems;
- Data storage and retrieval systems; and
- Instrumentation to monitor the process and electrical/mechanical plant.

Each control system will be designed to achieve the required reliability, availability and performance of the Full Chain. A fault tolerant design approach will be adopted to ensure that a single failure will not cause the operator to lose control of and/or communication with the plant. This will be achieved by including sufficient processor, communications buss and power supply redundancy in the control system designs. For systems where mechanical redundancy is provided in the field equipment e.g. duty and standby pumps the input and output signals will be physically split between separate Input/ Output (I/O) cards supplying appropriate redundancy.

4.4.2 Operational Requirements

The control systems will be required to support the operational philosophy of each chain element. Each control system will have several operating modes:

- View only;
- Operator;
- Supervisor; and
- Engineer (Maintenance/Administrative).

Under the operator's mode, there will be access to automatic and manual controls.

4.4.3 Operation and Monitoring

Operator workstations will be provided to include colour graphic displays and a means of entering commands and changing displays. Each workstation will have the capability to control major pieces of equipment, the auxiliaries and selected balance-of-plant equipment within the specific chain element. The operators will have the capability to start/stop, and change the set points of the equipment from the workstation. The operator work stations will also have the ability to display a selection of agreed alarms, signals and target set points from the adjoining parts of the Full Chain system.

4.4.4 Alarm and Events Management

Each supervisory control system will have an alarm management system.

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The alarm management system will bring undesirable process conditions and events to the attention of the operator. The alarm condition is initiated by a process measurement passing a defined alarm setting as it approaches undesirable or potentially unsafe values or by a digital input.

Alarms will be annunciated to the operator by a combination of audible sound, visual flashing indication and/or a message on the control screen. Each alarm should have a clearly defined operator response. Alarm and event data will also be archived in the Historian.

The alarm system development will be carried out according to recognised practices, standards and guidelines as regards the presentation and prioritisation of alarms. Where alarms also signify an impact on other systems within the Full Chain system, the operating procedure must ensure that the other relevant control rooms are made aware.

4.4.5 Automation

Where practicable, each control system will be automated (using auto sequencing logic) primarily to reduce the workload of the operators and also to help ensure the systems are protected from unsafe process conditions and mal-operation.

Auto-sequencing logic will be incorporated within each system to automatically start up and shutdown plant with minimal operator activities reducing the operator's workload. The sequences will automatically start equipment in a pre-determined order depending on the process, guiding the operator through a series of manual interventions. Prior to commencing the sequences, the operator may need to perform a number of manual activities, to prepare the element and establish the sequence entry conditions.

Under special circumstances the operator may manually control certain elements within their portion of the Full Chain. Careful consideration must be given in the design with regard to the effect of both manual and automatic control on other elements within the Full Chain System.

4.5 Systems for Safe Operation

Each installation in the Full Chain will have a number of industrial safety systems installed that are designed to protect the personnel, the environment, and plant (equipment and structures) from the inherent dangers of the process.

Safety control systems will be independent from their respective process control systems and may be certified by a relevant third party organisation. The key safety systems for the project comprise the following:

- ESD system;
- CO_2 composition analysis;
- F&G detection system;
- CO_2 detection; and
- High Integrity Pressure Protection System (HIPPS).

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4.5.1 ESD systems

Stand-alone ESD systems will be provided for each of the main plant control systems including the OPP and GPU, ASU, materials handling systems, and T&S system.

The ESD systems ensure that the Full Chain elements remain in a safe state (a mandatory requirement) and are based on fail safe technology. The systems are responsible for tripping the associated plant and equipment in the event of dangerous conditions occurring or if the critical process variables are outside their normal safe operating range.

The ESD systems will be designed in accordance with standards IEC 61508 and IEC 61511 which set out the generic approach for safety strategies to be followed for the process industry sector. The safety strategy requires that a hazard and risk assessment will be carried out for each of the Full Chain elements to enable the Safety Integrity Level for each safety function to be derived.

Safety systems will include all of the components necessary to carry out the safety function from the sensors through to the logic controllers and to the final control elements. It may also provide high resolution data logging facilities to assist in the diagnosis of trip events.

4.5.2 CO_2 Composition Analysis

For safe operations, the CO_2 composition will be analysed at the transfer point between the OPP and T&S system. The CO_2 entering the transportation system at the OPP AGI will be required to comply with the CO_2 composition specification.

Should the produced CO_2 approach any of the specification limits an alarm will be transmitted to the OPP Central Control Room (CCR), and will be sent to T&S CCR for information.

4.5.3 Fire and Gas Detection System

Dedicated F&G detection systems will be provided for the OPP (and its associated systems i.e. ASU and GPU) and for the T&S systems.

The systems at each site will be independent systems that will reliably detect, alarm and if necessary initiate an orderly system control or shutdown in the event of emergencies (via the ESD systems). Generally, the system will comprise of F&G detectors, workstations, F&G alarm panels, audible and visual alarms and all necessary cabling. Principal alarm and monitoring signals will be transmitted from the F&G panels to the integrated control systems (OPP DCS and T&S control system) for alarm and recording purposes.

The system design and installation will comply with relevant international standards.

4.5.4 CO_2 Detection Systems

Dedicated CO_2 detection and monitoring schemes will be implemented where appropriate on each chain section for the safety of the personnel (including the local populace) from the risks of CO_2 exposure.

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4.5.5 High Integrity Pressure Protection System (HIPPS)

OPP and the Barmston Pumping Station will be equipped with HIPPS to protect downstream systems from potential overpressures from compressors. HIPPS will isolate the pipeline before an unacceptable pressure level occurs.

The HIPPS will be a packaged control system comprising of a shut-off isolation valve(s) (which will close rapidly), pressure sensing transmitters and a logic controller (to perform safety functionality).The HIPPS will be designed to comply with the requirements of IEC 61508.

4.6 Management Information System

As there will be two separate businesses (CPL and NGC) operating across the Full Chain, there will be two separate MIS to provide high level operational monitoring and business information. Each of the two MIS will be provided by the relevant chain partner and be able to access the relevant data from the central, data repositories (data historians) for process measurements, status indications and other data transmitted from each of the chain elements as well as their own trading and invoice data to generate the required trends and analyses. The data transmitted to the MIS is not considered critical to ongoing operations, and it is not envisaged that this system would replace the data historians that are normally provided as part of the chain control systems. Each chain partner will transmit their operational data, which will include the data required to generate a real-time End-to-End overview of chain operation.

The basic functions of the Full Chain MIS will include:

- Data acquisition from all chain control systems in real-time and a system to recover data following loss of communications;
- Archiving of the acquired data;
- Provision of a data retrieval system including tools to search the database and generate reports from the stored data;
- Generation of a real-time graphic overview of the Full Chain process, presented on a display in the visitor centre; and
- Provision of a data set to be sent to each chain control centre to permit generation of a real-time visualisation of the Full Chain process, for display to the operators within the chain.

The objectives of the system include the provision of operating status details for the Full Chain to each chain partner. This is to promote system understanding and aid chain coordination.

In addition to the purpose built visitor facility located at the OPP, the database will give the parties the ability to showcase the system from their own control centres. The database will be used for analysis of the Full Chain performance for optimisation purposes, post-trip investigation, etc.

4.7 OPP Control Philosophy

The OPP is operated from the single CCR. The CCR is equipped with an overall plant process control system based on DCS technology. This system enables safe and reliable operation, control and supervision of the process with a high degree of automation.

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The ASU will operate as a standalone system and will interface with to the OPP DCS. The ASU will have a local control room and remote control from the BOC Remote Operations Centre in Sheffield via the BOC Technical Network.

The OPP control system interfaces with NGC T&S control system to exchange relevant operational parameters.

The OPP control system interfaces with NGET for grid operator control operation and to exchange relevant operational parameters.

The OPP control system interfaces with Drax's control system for the conveyors and for the raw water supply.

4.7.1 T&S Control

The Transportation and Offshore Storage elements of the Full Chain would each have independent Information, Control and Protection systems.

The Transportation and Offshore Storage elements would consist of normally unmanned installations.

HMI/ Supervisory Control and Data Acquisition (SCADA) systems for the Transportation and the Offshore Storage element would be located at a remote Control Centre.

The pressure in the T&S system network is controlled by the offshore injection pressure controller, which regulates the choke valve to each of the online injection wells, and the Barmston Pumps suction pressure, which controls the pump speed and the number of pumps operating by way of the pump control logic. The set pressures of the controllers ensure that the demand flowrate of CO_2 in the transport network from the OPP, and in future other industrial emitters, is injected into the offshore storage whilst the fluids remains, within the dense phase.

4.7.2 Platform Control

As the platform is a Normally Unattended Installation (NUI), the platform Integrated Control and Safety System (ICSS) would be configured to operate in a manned or unmanned mode. When in unmanned mode, all offshore pipeline, platform and storage facilities would be remotely operated and controlled with executive actions initiated from the T&S control centre by the control room operator.

When manned, all such actions normally would be managed locally by way of the platform ICSS system except for the platform shutdown, which would generally be managed remotely by a T&S control centre operator. However, the personnel on board would be able to manually shut the platform down by operating one of the emergency push buttons provided at various locations across the platform.

The ICSS would be supplied complete with local HMI to allow local control of the facility as and when required. The HMI would be located in a heated and ventilated LER that would also house the control and safety system equipment cabinets and system marshalling. The LER would be located adjacent to the platform Emergency Overnight accommodation

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The ICSS would consist of the following system functional elements:

- Process Control System (PCS);
- ESD; and
- F&G.

The communication route from the onshore transportation sites to the T&S control centre would be provided by dual redundant Very Small Aperture Terminal (VSAT) satellite links. The VSAT would interface with the T&S control centre by suing a third party onshore service provider.

AC electrical power for the platform would be provided by diesel generators supplying a UPS system for critical instrument supplies. These power systems would be controlled by local package controls and remotely controlled and monitored by the SCADA system.

4.7.2.1 Well Injection Control

Individual well injection rates would be controlled by the associated electrically actuated choke valve operated using the PCS. The choke valve and associated flow data would provide the offshore mechanism for balancing the well flows and offshore pipeline pressure.

4.7.2.2 Down-hole Gauging

To monitor storage data, the platform wells would be equipped with dedicated sensors to measure pressure and temperature at well bottom. The associated down-hole gauge panel would connect to the platform ICSS by way of an Ethernet link. The ICSS would pass data to the T&S Operator corporate Local Area Network (LAN) for supervisory and reservoir management purposes.

4.7.3 Emergency Shutdown System (ESD)

4.7.3.1 ESD General

The platform ESD system would be part of the ICSS located in the LER offshore and would be based on a programmable system, which would provide flexibility and full facilities for remote monitoring. It is mandatory that the ESD system should be independent from platform control and monitoring system.

It would provide means of protection for the personnel, the environment and the plant and equipment on the facility from the inherent dangers of the process by way of automatically shutting down the platform in the case of process upsets.

ESD system outputs would initiate shutdown actions in response to specific inputs from field devices and from manual ESD initiation (pushbuttons) on the platform and from the T&S control centre. The ESD status would be displayed at the T&S control centre on the SCADA HMI screens.

4.7.3.2 Shutdown Requirements

The safety system would be configured as 'fail safe'. Loss of power or utilities or open-circuit on inputs and/or outputs would result in external equipment going to a safe condition.

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If there was a loss of communication between the T&S control centre monitoring system and the platform systems while operating in the unmanned mode then a production shutdown of the platform would be initiated after a set period of delay.

4.8 CO_2 Metering

For Full Chain CO_2 metering arrangements see KKD document:

- K02 – Full Chain Basis of Design.

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5 Operations Management Philosophy

5.1 Operations Management

Communications and LOPs will be developed collectively by the parties to cover all operational aspects of the Full Chain (i.e. start-up, normal and abnormal operation and controlled and emergency shutdowns) such that key operating parameters and trips are immediately communicated to and displayed on the HMI in the various control centres but with no executive action enabled on other plant. The procedures will include a hierarchy of operational responsibilities, communication procedures and protocols will be established between all Parties and elements of the Full Chain. The design of the Full Chain and its control systems need to be developed to handle these issues for all operating scenarios.

The elements of the Full Chain will be controlled separately by CPL and NGC.

NGC will coordinate the preparation of the emergency arrangements for the T&S system while CPL will coordinate all activities for the OPP, interfaces with Drax services and NGC. These protocols will establish the actions necessary to restore the system or the affected part of the system to a safe condition and once agreed will be communicated to other appropriate parties for approval/acceptance – such as neighbouring facilities, regulatory bodies, emergency services and local communities. The emergency arrangements will be tested regularly, as appropriate for each element of the system.

5.2 Operational Communications and Planning

The operating regime of the Full Chain will be set by the operating requirements of the CO_2 emitters (current & future) and/or the T&S system. This applies equally to the routine operation of the plant and its dispatch regime and to the planning of maintenance outages. Short notice or emergency outages will be subject to case by case management depending on the nature, extent and severity of the cause of the unplanned outage.

Communications will be required between the following parties for the management and coordination of Nominations and subsequent T&S system operations:

- OPP control centre and NGC control centre; and
- NGC control centre and offshore storage operator control centre.

Real time and historical nomination and process data information will be available to all parties. This data will then be used for overall coordination of the Full Chain.

Planned shutdown will be managed to the extent possible by prior notification using agreed communications protocols and procedures, between chain elements.

When operational constraints in the T&S system result in operational constraints on the OPP, these will be notified to the OPP operator by similar procedures.

Management of plant responses to:

- Upset conditions;
- Emergency conditions

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will be achieved using standard automation, alarms, partial trips and unit trips based on suitably robust instrument and control systems, and procedures for notification and response to upset and emergency conditions need to be implemented across the chain.

5.3 Nominations

Nominations are defined as quantities of CO_2 for delivery to (via Entry Point) and from the T&S system each day for the purposes of enabling the T&S operator control centre to plan and carry out the operation of the system and operational balancing required. When one or more additional emitters connect to the transport system, these figures would be used to balance the flows.

The various daily nominations envisaged are as follows:

- Input Nomination - the quantity of CO_2 to be delivered to (via Entry Point) the T&S system in the day (defined as from midnight to midnight);
- Output Nomination - the quantity of CO_2 that will be delivered to (via Exit Point) the T&S system in the day and which can be accepted for injection into the store; and
- Re-Nomination - a revision of an earlier Input or Output Nomination. These can be made at any time up to one (1) hour before the flow rate nominated is delivered. These may be due to technical or commercial reasons associated with the capture, transport or storage operation respectively. This needs a communication process to the offshore storage operator and an approval process.

Such nominations may be revised due to technical or commercial considerations.

5.4 Operational Balancing

Operational balancing is maintaining the balance between the quantities of CO_2 delivered to (via Entry Point) and off taken from (via Exit Point) the T&S system during and at the end of each day within a specified tolerance.

It is possible that 'line-packing', the ability to compress the fluid in the pipeline by a small additional margin, could be used, to a limited extent, to manage abnormal conditions and small transients due to time lags between balancing supply and demand.

5.5 CO_2 Quality Management

The OPP is responsible for producing CO_2 at the correct specification for input to the T&S system. Out-of-specification CO_2 will be diverted to OPP stack to prevent it being exported to the onshore pipeline.

NGC will also monitor the CO_2 composition (using OPP data measurements) into the T&S system against the key elements of the CO_2 quality specification. If required, NGC will take action to shut down the T&S system (i.e. stop Pumping Station pump units and shut valves) to prevent out-of-specification CO_2 from entering (or further entering) the T&S system.

Where CO_2 quality measurement equipment indicates that CO_2 quality specification limit is about to or has been being exceeded, actions will be implemented in three main stages:

- Stage 1: This represents a warning of impending action. Efforts should be made to ensure these warnings are communicated to the OPP control centre and offshore storage operator at the earliest opportunity to enable them to react to a potential breach. This is a critical part of the NGC control centre action plan as it allows the OPP control centre to act in time to avoid any excursions.

- Stage 2: A reduction or cessation of flow due to a CO_2 quality breach at the T&S system Entry Point.
- Stage 3: Isolation (closing of CO_2 pipeline isolation valves). The NGC control centre will act on OPP instrument readings and will act promptly. Any disputed readings will be investigated as soon as is practical. The OPP control centre has a duty to cooperate and system safety must come first.

6 Decommissioning of CO_2 Store

6.1 Overview

Project life is expected to be 40 years, following which time the Endurance NUI, pipeline and wells would be decommissioned consistent with the prevailing legislation and regulator guidance at that time. Under the current decommissioning regime the NUI would need to be removed and returned to shore for reuse or disposal, and the pipeline would be subject to a comparative assessment as to whether all or part of the pipeline would need to be removed or could be left in place. The removal of the facilities and pipeline would be subject to options appraisal at the time of decommissioning, and while a meaningful assessment of such options cannot be made at this time, they would be subject to EIA during preparation and update of relevant decommissioning programmes/post-closure plan for the facilities.

The site facilities would be decommissioned following cessation of CO_2 injection in keeping with a decommissioning programme as required under the *Petroleum Act 1998*. In addition to the Petroleum Act requirements, the CCS Directive15 (transposed through *The Storage of Carbon Dioxide (Licensing etc.) Regulations 2010*) requires the submission of a provisional post-closure plan, covering the period following cessation of CO_2 injection and during subsequent monitoring, to be approved prior to the issue of a storage permit. An updated post-closure plan would be required towards the end of project life which would detail how the site is to be sealed and how injection facilities would be removed. The directive states that the post-closure period will be, unless otherwise agreed with the competent authority, a minimum of 20 years, within which time the site would be monitored and maintained by the operator and routinely inspected by a competent authority. Following this period, the legal obligations of the site are transferred to the competent authority if all evidence suggests the CO_2 would be permanently contained.

The T&S system CO_2 pipeline shutdown for decommission would not be a routine operation. For this exercise it may be necessary to generate new and untested procedures for working with plant, processes and substances, all of which may present hazards. Such procedures would be the subject of a detailed safe system of work reviews.

At the end of the operational cycle of the CCS chain, each element of the CCS chain would be brought off-line and decommissioned. Where parts and elements of the CCS chain are to be reused or retained for future possible uses, the equipment would be made safe and 'mothballed' in accordance with the owner company's standard procedures.

Where possible, to return and reduce project costs, equipment and systems would be sold on for reuse elsewhere. This would apply in particular to the equipment and systems that typically have a longer design life than the operational life of the project.

It is currently anticipated that the decommissioning plan for the CCS chain would generally follow the following sequence:

- shut down the Carbon Capture Plant (CCP) and stop the CO_2 flow to the onshore pipeline system;
- operate the offshore storage facility until they trip on low supply pressure to maximise the stored CO_2 and minimise the quantity of CO_2 to be vented to atmosphere;
- the CO_2 in the offshore pipeline would be vented in a controlled manner until the CCS chain is at atmospheric pressure;
- all sections would be purged of CO_2 using clean dry air;
- the onshore pipeline would be filled would nitrogen or similar; then
- the offshore pipeline would be depressurised and filled with inhibited sea water.

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During decommissioning all parts and elements of the CCS chain would be put into a safe condition with services isolated as appropriate.

However, certain aspects of the IMO Guidelines and Standards are still relevant. These are:
- following the initial decommissioning, but before complete removal any disused installation or structure, or part thereof, which projects above the surface of the sea, would be adequately maintained;
- an unobstructed water column of at least 55 metres must be provided above the remains of any partially removed installation to ensure safety of navigation;
- the position, surveyed depth and dimensions of any installation not entirely removed should be indicated on nautical charts and any remains, where necessary, properly marked with aids to navigation;
- Carbon Sentinel Limited (CSL) would nominate the person responsible for maintaining any aids to navigation and for monitoring the condition of any remaining material should be identified;
- the liability for meeting any claims for damages which may arise in the future would be clarified; and
- The topsides of all installations would be returned to shore. The jacket would be completely removed for re-use, recycling or final disposal on land.

The following approach would be taken to decommission the pipelines:
- the potential for reuse of the pipeline in connection with further CCS developments should be considered before decommissioning together with other existing projects. If reuse is considered viable then suitable and sufficient maintenance of the pipeline would be detailed;
- all feasible decommissioning options would be considered and a comparative assessment made;
- any removal or partial removal of a pipeline would be performed in such a way as to cause no significant adverse effects upon the marine environment;
- any decision that the pipeline may be left in place would have regard to the likely deterioration of the material involved and its effect on the marine environment; and
- account would be taken of other uses of the sea.

Where it is proposed that a pipeline should be decommissioned in place, either wholly or in part, then the decommissioning programme should be supported by a suitable study, which addresses the degree of past and likely future burial/exposure of the pipeline and any potential effect on the marine environment and other uses of the sea.; the study should include the survey history of the line with appropriate data to confirm the current status of the line including the extent and depth of burial, trenching, spanning and exposure.

No technical difficulties are anticipated in conforming to abandonment legislation. All lifting points would be left in place and remain accessible following installation.

The goal would be the removal of all structures, subject to assessment of the practicality of complete removal. However, there is general acceptance that complete removal may not be practical and therefore, elements of the production facilities may be left in situ. If this were then case then it is the responsibility of the operator to justify any decision to leave infrastructure in place with each application reviewed by the regulator on a case by case basis. The information on decommissioning options is normally recorded via a comparative assessment that considers:
- technical feasibility, complexity and risk;
- safety;
- environmental impacts;

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- effects on other users of the sea; and
- cost.

6.2 Pipelines

The options for decommissioning pipelines are similar to those for the decommissioning of platforms: either to leave in situ, or partial or total removal. The decision on whether the pipeline would be removed would be taken nearer the time and would depend on a number of site specific factors, such as:

- the extent to which it remains or becomes buried;
- the environmental impacts of local site disturbance;
- any on-shore landfill requirements;
- the risks that leaving them unburied might pose for other users of the sea, especially the fishing industry;
- the depth of water (not considered a problem for Endurance);
- size and service of the pipeline;
- safety considerations;
- the risks posed by decommissioning to any other pipelines and cable crossings; and
- the risk of their movement over time, which is closely related to water depth and the strength of local currents.

For the purpose of decommissioning, the base case is normally assumed to be complete removal of all pipelines, where practical to do so. Areas where this may prove difficult include crossings, areas subject to rock dump and areas where the pipelines are buried. For any pipeline left in situ, the most likely requirement is for remaining pipelines to be buried to a minimum depth of 0.6m above the top of the pipeline unless it can be demonstrated that they pose no risk to other users of the sea.

In addition to other requirements of the above mentioned Acts, under the Marine and Coastal Access Act 2009 a license application would be required at the time of decommissioning and the supporting EIA updated to reflect detailed engineering design and specific mitigation measures.

6.3 Wells

For decommissioning of the injection wells, we would have the option to suspend the wells, that is, to put abandonment plugs in place, but continue to monitor for leaks inside the well. This process of monitoring for leaks would probably be in two parts or phases:

1. the abandonment of the reservoir section, with monitoring until it is time to decommission the platform; and
2. provided that the regulator accepts that, after a period of monitoring, during which no leaks are detected, the wells are secure from leakage and may be permanently abandoned; if the regulator does not accept the wells are secure from leakage then, upon removal of the jacket and topside, the wells would be converted to subsea monitoring wells and monitoring for leakage would continue until the regulator is satisfied that the store as a whole is being leak free; at which time the subsea monitoring of the wells would be removed and the wellheads cut off.

There would be a third phase after the Competent Authority accepts responsibility for the store during which monitoring may continue for further 30 years.

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6.4 Monitoring

6.4.1 Monitoring Area

The Monitoring Area is not defined in the EC Directive. Within the context of this document however, it refers to the geological volume, including the store, complex and beyond the complex which is subject to monitoring and measurement.

6.4.2 Monitoring Phases

6.4.2.1 Post Injection

The full history match simulation would be used to predict the rate of decay of the pressure after injection ceases. If the pressure decay trajectory does not match the prediction it may be necessary to increase the post-injection duration before the decision is made to abandon the injection infrastructure.

6.4.2.2 Post Closure

After the wells are sealed and the infrastructure has been removed, the ability to monitor the storage complex is limited to short term pressure measurement within the site, checking for evidence of leakage of CO_2 at the seabed and time lapse seismic to confirm the migration of the CO_2 plume. If the behaviour of the Storage Complex is shown to be evolving towards a state of permanent storage as expected, arrangements would be made for the transfer of the responsibility for the CO_2 Store from the Operator to the Competent Authority.

If no significant deviations from predictions are experienced during the post injection period then it is extremely unlikely that any would be detected during the Post-Closure period as the pressure would continue to drop and the integrity of the Storage Site and Storage Complex would increase not only from the decaying pressure, but also from the permanent abandonment of the injection wells removing the possibility of well failure.

6.4.2.3 After Transfer

After the Competent Authority accepts responsibility for the Store, it is anticipated that monitoring and measurement tasks continue for 30 years to confirm the evolution of the system to long-term stability in accordance with the Directive.

Similarly, to Post-Closure above, it is anticipated that the pressure decay would continue and thus steadily improve the integrity of the Storage Site and Storage Complex.

6.4.3 Monitoring Technologies

The guidance associated with the EU CCS Directive (GD-2) contains a list of technologies that are recommended to be assessed for their appropriateness for a site specific Monitoring, Measurement and Verification (MMV) Plan. Some additional items (e.g. tiltmeters, tubing and casing condition logs) which are not included on the GD-2 list have been added.

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There is also some consolidation and rearrangement (e.g. operational measurement of wellhead flow and composition and well CO_2 sampling and analysis have been combined to Wellhead flow and composition; side scan sonar is combined with sonar bubble stream detection; Environmental monitoring encompasses water sampling and geochemistry, soil/sediment sampling/ atmospheric CO_2 flux and ecosystem monitoring). Table 6.1 provides a summary of technologies that would be applied over the three decommissioning phases.

Table 6.1: Technologies and Applicable Decommissioning Phases

Monitoring Method	Primary or Contingent	Baseline Survey	Post-Injection	Post Closure	After-Transfer
6.5.2.1: Wellhead pressure and temperature	Primary		Applies		
6.5.2.2: Downhole pressure and temperature	Primary		Applies	Applies (1)	
6.5.2.3: Inert and isotope tracers	Contingent		Applies (2)		
6.5.2.4: Casing annulus pressures	Primary		Applies		
6.5.2.5: 3-D seismic	Primary	Applies	Applies	Applies (3)	Applies (3)
6.5.2.6. Micro seismic network	Primary	Applies	Applies (4)		
6.5.2.7: Tiltmeter network	Primary	Applies	Applies (5)		
6.5.2.8. Global Positioning System (GPS)	Primary		Applies		
6.5.2.9: Bubble stream detection (sonar)	Primary	Applies	Applies	Applies	Applies
6.5.2.10: Seawater Chemistry	Primary	Applies	Applies	Applies	
6.5.2.11. Ground water monitoring	Primary				
6.5.2.12. Seabed sampling and gas analysis	Contingent				
6.5.2.13. Ecosystem monitoring	Primary				

Notes:

1. available for approximately five years after closure
2. only required if gas seeps are identified prior to injection
3. only required if an irregularity is identified
4. decommissioned approximately two years after injection ceases
5. decommissioned with micro seismic network

6.4.3.1 *Wellhead Pressure and Temperature*

For each injection well, equipment for the continuous recording and transmittal of pressure, temperature and flowrate would be provided. This data is high priority and would be transmitted to shore for real-time assessment of operating conditions. Flow meters for each well would not be as accurate as the fiscal metering implemented on the shore, but would be used for well allocation, for reservoir engineering and for the recognition of failures or leakage across the system. These are primary measurements and not subject to a baseline survey.

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6.4.3.2 *Downhole Pressure and Temperature*

There is limited requirement for well stream sampling as the composition of the CO_2 input into the pipeline is continuously monitored. Occasional samples may be used to check whether any contamination from pipeline corrosion is present, but as the requirement is for the water content of the CO_2 to be less than 50 ppm it is unlikely. In any case, these samples should then be taken upstream of the platform filters (5 micron).

6.4.3.3 *Inert and Isotopic Tracers*

If the baseline sea bottom survey and baseline environmental sampling all confirm the absence of native CO_2 or of any artefacts that could indicate that CO_2 has recently emanated from the overburden, tracers to identify the origin of any future CO_2 at the seabed are probably not required. If there is evidence of recent emissions, then it is recommended that tracers would be used.

6.4.3.4 *Casing Annulus Pressures and Temperatures*

The annulus pressures and temperatures on each well would be measured and transmitted continuously. The objective is to detect any indication of leakage of CO_2 outside the production tubing and production packer. The pressure and temperature would vary depending on the injection rates and the arrival temperature of CO_2. These are primary measurements and not subject to a baseline survey.

6.4.3.5 *3-D Seismic*

3-D seismic is recommended as the preferred technology for monitoring plume development and the development of the free CO_2 cap at the crestal location of the Endurance structure.

The baseline survey was acquired using very high energy air gun arrays so that the seismic could provide high resolution imaging below 4,000 m. For the Endurance Storage Complex, imaging down to only 1,500m is required and in order to minimise environmental impact air gun arrays with much lower peak energy output would be used. The choice of optimum gun configuration and streamer geometry would be based on modelled to be finalised after the reprocessing of the baseline survey.

As the development of the plume and the migration of the injected CO_2 to its crestal location is not critical for the operation of the injection wells and would not affect either the rate or volumes of CO_2 injected. It is recommended to minimise the frequency of the 3-D surveys and the area that they cover would be constrained to the injection wells and the crest of the structure. The first survey should be undertaken approximately 4 years after injection commences so as to be sure that enough CO_2 would have accumulated in the free CO_2 cap to be clearly imaged. After that, and after calibration of the dynamic reservoir model with the first survey results, further surveys would be proposed. The recommended timing based on the current version of the model would be 12 years, 18 years after injection commenced and 3 years after injection has ceased given the anticipated injection period of 20 years and a total volume of 54 MT.

6.4.3.6 *Micro Seismic Network*

There is no requirement for a passive micro seismic network for the White Rose Project, but as it would be required in the event of any potential future expansion of the Endurance store. It is recommended for

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installation before any injection commences (similarly to the provision oversized pipeline and the provision of spare injection wells slots). This is particularly important for the acquisition of a baseline survey prior to injection start-up.

The basis for the operation of the micro seismic network is that changes in the stress state of the subsurface rocks caused by pressure changes can cause small-scale shear slippage and generate low amplitude seismic events (micro earthquakes) which the network is designed to detect. The location of these events can be indicative of planned re-pressurisation or unplanned pressure build up, or failure of seals, faults or well bore cement. The micro seismic events are detected on arrays of permanent geophones in sensor nodes placed on the seabed.

A micro seismic monitoring project would have three objectives:

- to determine/understand the baseline (background) seismicity of the area prior to CO_2 injection;
- to monitor the injection process for cap rock integrity assurance and possibly geomechanical model history matching; and
- detection of near wellbore events as part of the well integrity monitoring systems.

A feasibility study has assessed the capabilities of subsea and downhole monitoring networks in terms of sensitivity (minimum magnitude) and location accuracy, and recommends deploying a subsea network (minimum 31 nodes), for a homogeneous coverage of the cap rock integrity together with a shallow downhole array, for the monitoring of the fracture opening (micro seismic events with low energy) in the vicinity of the injection zone. Micro seismic recording is a primary measurement and would require a baseline survey of at least six months.

6.4.3.7 Tiltmeter Network

As with the micro seismic network, there is no requirement for tiltmeters for the White Rose Project but it would be required for any potential future expansion. Therefore, so that a pre-injection baseline can be established and also as the tiltmeter network can be more economically installed at the same time as the micro seismic nodes it is recommended for installation prior to injection commencing.

The tiltmeters primarily confirm the predictions of overburden deformation made by the geomechanical modelling but also provide independent evaluation of fracturing and faulting events

The co-located micro seismic and tiltmeter networks would be established in the area of the platform over the injection wells and from there up over the area of the crest of the Endurance structure.

Each of the planned 31 nodes would be established in short conductor pipes drilled into the seabed and the interconnecting cabling would be installed using a seabed plough. The distance between the nodes is planned to be 1,200 m and the total cable length would be less than 50 km. The conductor and cable network would then be protected from the nets of fishing trawlers.

The network would be connected back to the platform where the data would be recorded but pre-processed and filtered before being transmitted to the control room.

Although the micro seismic and tiltmeter network is not required for the White Rose Project, once it has been installed the additional cost to run it is relatively small and would provide information on natural

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seismicity and possibly on thermal fracturing when injection is being established. Tiltmeters are a primary measurement and no pre-injection baseline survey is required.

6.4.3.8 *Global Positioning System (GPS)*

GPS receivers would be installed on the platform to independently confirm vertical movements caused by seabed deformation. The accuracy and resolution of these systems is better than 1 mm and can, cost effectively, confirm seabed deformation, which is expected to be a maximum of approximately 100 mm during the White Rose Project. GPS is a primary measurement and no baseline survey is required.

6.4.3.9 *Bubble Stream Detection*

Sonar devices have been developed to detect subsea leakages of gas by identifying streams of bubbles. The bubble streams vary greatly depending on the flux of the leakage and the pressure and temperature of the water. In the case of low flux CO_2 leakage the gas is rapidly adsorbed into the water and the bubble stream disappears as it get shallower. These various effects have been well described and the algorithms associated with the sonar detectors are able to determine to a high degree of accuracy the flux of a detected leak.

Sonar devices can be installed on stationary landers that monitor an area with a radius of approximately 1km or can be installed on an Autonomous Underwater Vehicle (AUV) that can be deployed to follow a coverage pattern across the entire area of the store.

For the Endurance Storage Complex, given the very low probability of a leakage, it is recommended that an AUV is deployed annually and that it would additionally carry other sensors monitoring pH, salinity across the area of the Storage Complex and the nearby Bunter Sandstone Formation subsea outcrop. Permanent stationary landers are not recommended.

Bubble stream sonar is a primary measurement. A baseline survey would need to be acquired prior to injection commencing and a number of surveys would be included in order to record seasonal variations in the recorded parameters.

6.4.3.10 *Seawater Chemistry*

The monitoring of seawater chemistry would be by both the acquisition of physical samples and from the annual AUV surveys. Of most importance is the possible by likely displacement of formation water in the vicinity of the subsea outcrop of the Bunter Sandstone Formation.

Seawater chemistry is a primary measurement and a baseline survey is required.

6.4.3.11 *Ground Water Monitoring*

Only of relevance at the subsea outcrop, ground water monitoring would only be by grab sample deployment in the event of the detection of significant changes in seawater chemistry.

It is a contingent measurement and a baseline survey is required.

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6.4.3.12 *Seabed Sampling and Gas Analysis*

Seabed and vadose zone grab samples would be analysed for changes in soil and potential contaminants. Specialist samples for gas analysis may also be obtained.

Grab samples are a primary measurement but soil samples for gas analysis are contingent, a baseline survey is required.

6.4.3.13 *Ecosystem Monitoring*

Marine and sediment biota would be monitored for a significant change in numbers, species and tissue concentrations and if changes are detected, investigative procedures to ascertain the reasons for changes would be put in place.

These are primary samples and baseline sampling is required.

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7 Key Availability Assessment

7.1 Key Definitions

Availability is defined as the fraction of time in which a unit is capable of providing service and accounts for outage frequency and duration. The outage here includes forced outage and preventive maintenance outage. Specifically, Full Chain availability for White Rose means the ratio of actual operational hours with power to grid and CO_2 to storage to the maximum theoretical operation. Credit is given for part load availability.

Reliability is the fraction of time in which a unit is capable of providing service and accounts for forced outage frequency and duration.

7.2 Operational Availability

Operational availability is a measure of the average availability over a period of time; it includes logistics time, ready time, waiting or administrative downtime and both preventive and corrective maintenance downtime. It is the probability that an item will operate satisfactorily at a given point in time when used in an actual or realistic operating and support environment.

The operational availability of the T&S network is the availability that the OPP Operator (or the operator of a future emitter) would actually experience: the “uptime”.

The target reliability and availability may not be achieved immediately but would progressively improve in the first few years of operation. The Full Chain reliability and availability analysis reported below covers the period following the initial commercial proving.

7.3 Assumptions

All availability assessments are based on assumptions on the equipment state, operating conditions, maintenance regime etc. The Full Chain availability assessment makes appropriate assumptions which need to be consistent with contractual requirements and the proposed method of operation.

7.4 Maintenance

Efficient operations and maintenance planning will be of paramount importance to maintain acceptable levels of availability and reliability (production efficiency).

The Routine Maintenance Scheme, which provide details of how the maintenance inspections will be performed and to which standards would be closely linked to the System Integrity monitoring plan. One of the Maintenance Scheme objectives will be to monitor equipment integrity and detect measure and locate changes in the condition of the equipment.

O&M manuals will capture the scheme, the objectives and the agreed philosophy and they would be regularly amended to reflect experience gained during operation.

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7.5 Targets

The following project availability and reliability targets were set for the Full Chain:

- Full Chain availability factor target ≥85%;
- Full Chain unavailability ≤15%. This consists of planned outages and unplanned outages. The breakdown of the outages is estimated as 5.6% Planned Outage Hours (POH) and 9.4% Forced Outage Hours (FOH); and
- Full Chain reliability target is 90%.

The target for planned outages takes into account planned maintenance which would be aligned across the Full Chain. The target of planned outage is an annual average of 20.4 days per for the Full Chain averaged over a six year maintenance cycle.

The following reliability targets have been identified as starting points:

- Drax interfaces: 99.5%;
- OPP: 91.4%; and
- T&S: 99.0%.

It is recognised that the desired reliability and availability may not be achieved immediately but would progressively improve during in the first few years of operation. The analysis assesses the reliability and availability after this initial commercial proving period.

7.6 Approach

The development of a Full Chain Reliability, Availability and Maintainability (RAM) model was facilitated by individual chain element assessments, appropriate to that element of the chain, against their targets, and which could then be combined to determine the theoretical availability for the Full Chain.

Equipment reliability and maintainability characteristics were used to optimise equipment selection and redundancy/sparing requirements, and to establish operating and maintenance strategies essential to maintaining the target availability level.

The analysis for each element of the chain was undertaken such that:

- Appropriate to FEED stage of the project and the level of engineering being undertaken;
- Process driven / optimised against Value Engineering factors to meet targets;
- Done early in FEED so that the RAM study could influence FEED design;
- Outputs for each element of the chain to be combinable for Full Chain analysis;
- Considers interactions between elements of the Full Chain;
- Reflects and verifies requirements to meet the outage schedule
- Considers sparing, options selection, redundancy and maintenance/opex issues; and
- Part of a staged approach to get to the end deliverable.

Separate studies have been performed for the following chain elements:

- Interfaces – a plant life integrity and redundancy assessment to assess the residual life and reliability of existing systems as well as a high level failure and effect analysis to identify critical systems and a high level redundancy concept for critical systems to meet the reliability and availability targets were carried out. The new assets were similarly evaluated and separately reported before combination in a wider integrated study;

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- OPP – a RAM model for the OPP was developed to include lower level fault tree interactions between the power plant/ASU/GPU so that reduced throughput fault scenarios can be modelled; and
- T&S network. – For transport 1000 life cycles were simulated with each life cycle representing the performance of the facilities over a 40-year production time frame and the results being an average of these 1000 lifecycles. For Storage the performance of all the wells equipment and workover scenarios considered critical to production have been incorporated in a RAM model. The report looked at the criticality based on the individual well and the overall system, with consideration of the effect of redundancy of wells.

The output from these studies has been combined and a Full Chain analysis has been performed.

7.7 Calculation of Full Chain Intrinsic Availability

In order to calculate the Full Chain availability a Full Chain Reliability Block Diagram (RBD) was created. to define of the overall chain as a series of functional blocks interconnected according to the effect of each block on the overall chain reliability. The high level Full Chain RBD has been used to gain an understanding of how the chain will operate.

OPP work has been combined with work from interconnections and T&S system and input into the Full Chain RBD. This has allowed Full Chain reliability and availability to be calculated from the information provided on the individual unit level.

The assessment has taken into account the ability of the Full Chain to tolerate short term losses of some elements. Using the AvSim Monte Carlo analysis availability modelling package has allowed integration of the Full Chain elements' availability calculations in a coherent and accurate manner. Thus, the assessment included:

- availability modelling information for each element of the chain;
- potential areas of common cause failure; and
- consideration of design and site features that provide effective redundancy and/or buffer capacity in the event of a system failure.

The White Rose assessment gave a Full Chain intrinsic availability (i.e. without planned outages) of 90.9%. This equates to a predicted unavailability due to forced outages of 9.1%. The chain elements contributions to the Full Chain are shown below.

Table 7.1: Full Chain Intrinsic Availability

Full Chain Element	Intrinsic Availability %
Drax interconnection	99.89
OPP	91.77
T&S	99.24
Full Chain	90.9

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7.8 Summary

The RAM Study has demonstrated that the intrinsic availability target of 90.6% for the Full Chain is likely be met. The Full Chain's ability to tolerate short term interruptions in some of the systems has been considered as a part of the availability study and is reflected in the figure.

When combined with the average planned maintenance requirements the analysis also confirms that the overall availability target of 85% is achievable with the predicted value slightly above the target at 85.3%.

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8 Glossary

AGI	Above Ground Installation
ALARP	As Low As Reasonably Practicable
AQCS	Air Quality Control Systems
ASU	Air Separation Unit
AUV	Autonomous Underwater Vehicle
bara	bar absolute
barg	bar gauge
BOC	The BOC Group Ltd
BoP	Balance of Plant
BVS	Block Valve Station
C	Degrees Celsius
CCR	Central Control Room
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
COMAH	Control of Major Accident Hazard
CPL	Capture Power Limited
DCS	Distributed Control System
DECC	Department of Energy and Climate Change
DPL	Drax Power Limited
DPP	Drax Power Plant
EIA	Environmental Impact Assessment
EPC	Engineering Procurement and Construction
ESD	Emergency Shut Down
FEED	Front End Engineering Design
F&G	Fire and Gas
GOX	Gaseous Oxygen
GPU	Gas Processing Unit
GPS	Global Positioning System
Halite	An isometrically crystalline form of salt (Sodium Chloride, NaCl)
HIPPS	High Integrity Pressure Protection System
HMI	Human Machine Interface
H_2O	Water

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H_2S	Hydrogen Sulphide
HSE	Health and Safety Executive
Hydrates	Crystalline materials made up of water and one or more hydrate forming substances such as CO_2, nitrogen and methane
ICSS	Integrated Control and Shutdown System
IEC	International Electrotechnical Commission
ILI	In Line Inspection
I/O	Input/ Output
JCB	Joint Commissioning Board
KKD	Key Knowledge Deliverable
LAN	Local Area Network
LER	Local Equipment Room
LOP	Local Operating Procedures
LOX	Liquid Oxygen
LPA	Local Planning Authority
MC	Mechanical Completion
MEG	Mono-Ethylene Glycol
MIS	Management Information System
MMV	Measurement, Monitoring and Verification
MTPA	Million Tonnes Per Annum
MWe	Megawatt (electrical)
NGC	National Grid Carbon
NGET	National Grid Electricity Transmission
NUI	Normally Unattended Installation
O_2	Oxygen
O&M	Operation and Maintenance
OPP	Oxy Power Plant
PCS	Process Control System
PIG	Pipeline Inspection Gauge
PLC	Programmable Logic Controller
ppmv	Parts per million by volume
RAM	Reliability, Availability and Maintainability
RFC	Ready for Commissioning

RFO	Ready for Operation
SCADA	Supervisory Control and Data Acquisition
SEL	Stable Export Limit
TPH	Tonnes Per Hour
T&S	Transport and Storage
VSAT	Very Small Aperture Terminal
VSD	Variable Speed Drive

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Appendices

Appendix A Future Energy Scenarios in Great Britain ____ 59

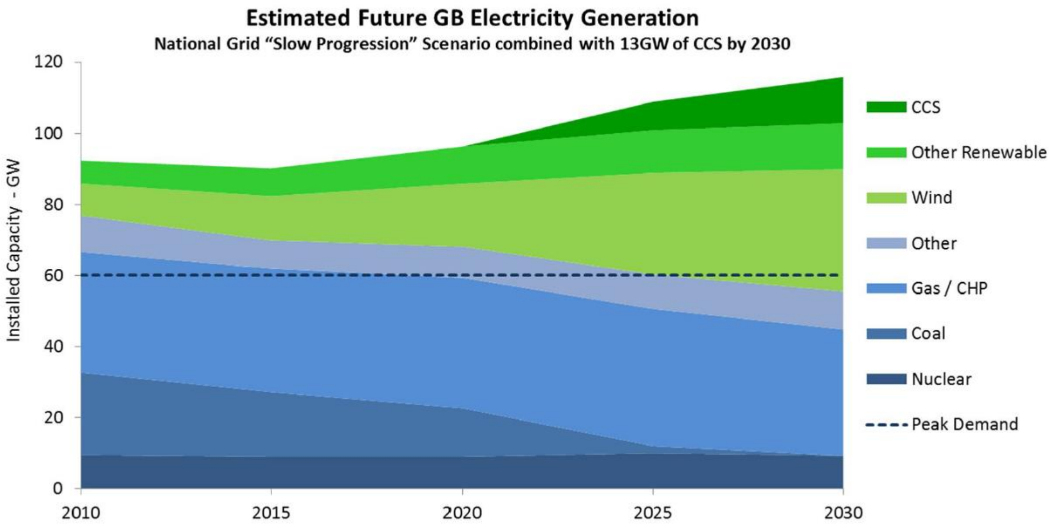
Appendix A Future Energy Scenarios in Great Britain

The OPP has been designed in order to demonstrate the flexible operation that will likely be required from CCS enabled fossil fuel power plants within the long term requirements of the UK electricity market.

This requirement has been determined by considering future energy scenarios in Great Britain and the effect of planned increases in wind deployment on thermal demand, currently provided by unabated coal and gas power generation.

Figure A.1 illustrates the possible development of power supply within Great Britain, using estimated annual installed power generation capacity figures from National Grid's 2013 Future Energy Scenarios workbook. The graph uses the figures for the "Slow Progression" scenario, with the addition of the UK Government's estimate of 13GW of CCS by 2030. (The total installed capacity is also therefore increased by 13GW from the Slow Progression estimate but falls short of increased capacity projection under the alternative "Gone Green" scenario that assumes higher levels of renewables deployment).

Figure A.1: Estimate Future Power Supply



Source: Data from Gone Green UK Future Energy Scenarios from National Grid (July 2013) and DECC EMR Delivery plan (De 2013)

The actual capacity development will likely differ from that shown depending on economics and incentive mechanisms; however, the objective is to highlight the significant expected trends. In addition to the incorporation of CCS, key predicted changes in future power provision include nearly 40% reduction in total thermal capacity from unabated coal and gas and an increase in wind capacity from around 10% to 30% of the total. The overall installed capacity increases over the period to almost double the current peak demand of 60GW.

The growth of intermittent energy sources such as wind increases the variability of supply, which must be met by sufficient flexible power in order to provide a balanced energy system and grid stability. By using flexible CCS as a low carbon energy supply, there is lower reliance on renewables to meet emissions

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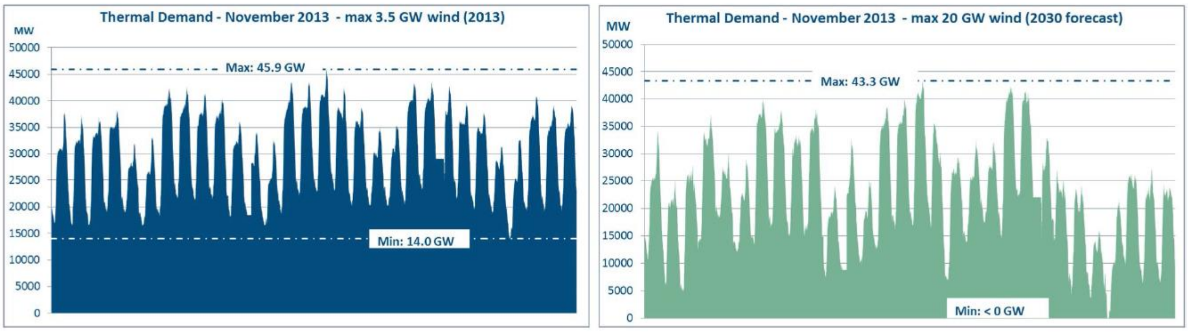
targets and as CCS does not need its own back-up, the installed capacity is reduced, with associated savings in electricity generation and transmission costs.

The effect of increased wind deployment can be illustrated through considering current energy demand for thermal generators compared to projected future demand, given the forecast expansion of wind supply over the period (Figure A.2). Thermal demand alone is illustrated, as the only significant source of mid-merit supply in Great Britain that can provide controllable flexible operation. The graphs shown are generated using data from Gridwatch, where the actual power demand from each source used in Great Britain is provided at 5 minutely intervals.

Figure A.2: Current and Future Thermal Demand with Increasing Wind Deployment



Source: Data from UK Gridwatch

Figure A.2 a shows a recent demand profile for thermal power, in November 2013, with each significant oscillation within the graph representing a day and smaller fluctuations being due to consumer demand variance and effects of fluctuating wind supply. For this month in 2013, the maximum wind supplied at any recorded point in time is 3.5GW. Figure A.2 b assumes the same total demand profile in November 2030; however the wind provision is increased with higher levels of deployment replacing thermal supply and generating an estimated maximum wind supply of around 20 GW.

Evaluating the two graphs, it can be seen that the overall maximum thermal demand reduces only slightly from 46 GW to 43 GW from 2013 to 2030, such that the maximum capacity required to balance wind supply remains similar to today's installed capacity, assuming the same level and pattern of demand. The variability however, significantly increases over the period due to wind intermittency, from 32 GW to 43 GW, an increase of around 30%. Should current flexible thermal capacity be replaced by base-load generation, such fluctuations in demand could not be met, leading to significant energy waste.

Whilst actual values are dependent on the chosen future energy scenario, this evaluation clearly shows that the most efficient way to balance the increase in variability of supply is through flexible generation capacity, the only current viable low-carbon option within the UK being through thermal generation with CCS.

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