UK Carbon Capture and Storage Demonstration Competition

SP-SP 6.0 - RT015
FEED Close Out Report

April 2011
ScottishPower CCS Consortium
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Information provided further to UK Government's Carbon Capture and Storage ("CCS") competition to develop a full-scale CCS facility (the "Competition")

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SP-SP 6.0-RT 015 FEED Close Out Report
Foreword

ScottishPower, National Grid and Shell have now reached an important milestone in one of the world’s most advanced full-scale carbon capture and storage (CCS) projects. Developing this innovative technology is essential if we are to tackle climate change and we believe that by demonstrating CCS to the world, we will all benefit from the fresh skills and new jobs that stand to be created by a brand new industry. One in which the UK can truly lead the way.

ScottishPower began developing the Longannet Carbon Capture and Storage project in 2007 in response to the UK Government’s competition to demonstrate full-scale CCS on power generation in the UK. In the summer of 2009, the ScottishPower CCS Consortium, comprising ScottishPower, National Grid and Shell was formed to further develop this project, which could be one of the world’s first full-scale CCS demonstration plants.

In March 2010, the Consortium began an extensive Front End, Engineering and Design (FEED) study to assess what exactly would be required from an engineering, commercial and regulatory, perspective in order to progress the CCS project through to construction.

At the heart of that year long study was a commitment by both the Government and the Consortium to undertake one of the most extensive knowledge transfer programmes ever undertaken on CCS.

This FEED Close Out Report sets out in detail the key lessons learned and knowledge generated by a team of around 300 people who have lived and breathed the project. It sets out the challenges they have faced and the strategies and solutions they have employed to overcome them. It is not a developers’ template because there is no ‘one-size-fits-all’ solution for CCS, but, we believe the insight it contains will give others the confidence to participate in this ground-breaking technology.

For this reason we are proud of the contents and our thanks must go to everyone in the Consortium team and the many sub-contractors who worked so tirelessly on the project. We are particularly grateful to the Knowledge Transfer team for capturing what was being learned along the way and reflecting it so thoroughly in this document. Finally our thanks must go too, to the UK Government and staff at the Department for Energy and Climate Change for sponsoring this knowledge transfer programme and embedding it so firmly in the FEED study.

There can be no doubt CCS is a vital part of our battle to reduce CO₂ emissions. Our joint objective has always been to learn by doing and then to share what we know with others. This document is an essential first step on that journey.

Steve Marshall  
Head of CCS Development  
ScottishPower

Jim Ward  
Head of CCS  
National Grid

Arne De Kock  
UKCCS Project Director  
Shell
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Introduction

This document sets out in detail the key learning and knowledge generated by ScottishPower’s Carbon Capture and Storage Consortium (the Consortium) for work undertaken during the Front End Engineering and Design (FEED) Programme.

It presents an accurate account of the Consortium FEED study for other project developers, governments and ad hoc groups as they seek to introduce Carbon Capture and Storage technologies around the world.

What is CCS?

Carbon Capture and Storage (CCS) is a new technology being developed to reduce the contribution of fossil fuel emissions to global warming. The system uses well understood chemical processes to capture and isolate Carbon Dioxide (CO₂) from power or other industrial plant emissions, the gas is then transported to underground storage facilities where it will remain trapped under layers of solid rock for hundreds of thousands of years.

There are three main methods of capturing CO₂ emissions: post-combustion, pre-combustion and oxyfuel combustion. Post-combustion is the most advanced of the three technologies. It will therefore be the quickest to demonstrate and the easiest to apply to existing power generation and industrial processes, such as steel and cement manufacture. In most post-combustion capture systems, the CO₂ is removed from the flue gas using solvents, which absorb the CO₂ molecules and then release them when heated.

After the CO₂ has been chemically captured, it is dried, purified and compressed and then transported via pipelines or ships to geologically suitable porous rock formations such as depleted gas reservoirs or saline aquifers deep underground. In effect, putting the carbon (now in the form of CO₂), back where it came from.

Although CCS has yet to be demonstrated at commercial scale, at least three pilot schemes have shown the process to be both feasible and effective. These are The Mountaineer project in West Virginia in the United States; Vattenfall’s Schwarze Pumpe plant in Germany; and Total’s project at Lacq in South West France. There are also a number of established CCS projects globally, including Sleipner and Snohvit, Norway; Boundary Dam, Canada; Weyburn-Midale, Canada; and In Salah, in Algeria. In addition, the three separate CCS elements of capture, transportation and storage, have been successfully implemented by the oil and gas industry for many years. The challenge ahead for developers is how to unite the separate elements into a full chain in a commercially viable manner.

The Impact of fossil fuels on climate change

National governments around the world now consider climate change as perhaps the most significant challenge faced by the global community in the coming decades. Strategies to meet this challenge are being developed at both national and international levels.

Experts argue that doing nothing is not a viable option. According to The Stern Review (2006), the cost of doing nothing to address climate change is far greater than the cost of acting. It estimates that ‘if we don’t act, the overall costs and risk of climate change will be equivalent to losing at least 5% of global Gross Domestic Product (GDP) each year, now and forever. If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP, or more. In contrast, the costs of action –
reducing greenhouse gas (GHG) emissions to avoid the worst impacts of climate change – can be limited to around 1-2% of global GDP each year.’ In other words, it will cost more in the long-run to deal with climate change if nothing is done now. A more recent study by the Committee on Climate Change identified that adapting businesses to address climate change now may reduce the damage from future climate change impacts by about 50%.

The UK and Scottish Governments, along with many other developed nations, have set tough carbon emissions reduction targets. The Climate Change Act 2008 sets a legally binding target of at least an 80% cut in GHG emissions by 2050, to be achieved through action in the UK and abroad, and a reduction in emissions of at least 34% by 2020. Both of these targets are against a 1990 baseline. Under the Climate Change (Scotland) Act 2009, Scotland is committed to reducing emissions by 42% by 2020 and by 80% by 2050, also against a 1990 baseline.

Dealing with emissions from the energy sector is a key priority. Approximately 69% of all CO₂ emissions, and 60% of all GHG emissions, are energy-related. The International Energy Agency’s analysis in the ‘Energy Technology Perspectives 2008 Report’ indicated that the CO₂ emissions attributable to the energy sector will increase 130% by 2050 without new policies or supply constraints, largely as a result of increased fossil fuel usage. The 2007 Intergovernmental Panel on Climate Change 4th Assessment Report indicates that such a rise in emissions could lead to a temperature increase in the range of 4-7ºC, with major impacts on the environment and human activity.

Decarbonising (by removing or significantly reducing CO₂ emissions to the atmosphere) fossil fuel power generation through CCS will be vital to reducing CO₂ emissions. The International Energy Agency states: ‘The only technology available to mitigate GHG emissions from large-scale fossil fuel usage is CO₂ capture and storage’. Overall, the International Energy Agency recommends that CCS should contribute one fifth of the overall 80% GHG reduction target by 2050.

Security of supply

Coal-fired power with CCS is vital for a secure energy supply in the UK. In the Energy White Paper 2007, the UK Government stated: ‘Coal will continue to play a significant role in global electricity generation for the foreseeable future, partly because it is the most abundant global fossil fuel but also because it brings security of supply benefits. For example, coal-fired power generation is a flexible electricity source that can respond effectively to changing levels of demand. It also helps to maintain a diverse energy mix.’

Under the Large Combustion Plant Directive (LCPD), up to nine oil and coal power stations are due to close in the UK by 2015. These plants amount to about 12GW, which is roughly 15% of the UK’s installed capacity (about 76GW). At the same time, it’s estimated that 6 nuclear power stations will be decommissioned by 2016, totalling about 6GW, which is about 8% of the current estimated UK capacity. All of this adds up to 18GW of capacity potentially being withdrawn by 2016 in the UK.

Jobs, skills and opportunities

A CCS industry in the UK could lead to significant jobs and skills opportunities. The low carbon sector in the UK is growing rapidly. The sector is already worth £107 billion to the UK economy and supports over
880,000 jobs\(^1\). This could rise to over 1.2 million in the course of the next five years\(^2\). According to UK Government figures\(^3\), developing CCS would mean a new addition to the sector with an expected market value of £2 - 4 billion by 2030 and the creation of up to 60,000 new jobs. In addition, by continuing the life of the North Sea beyond the existing oil and gas industry, CCS will capitalise on the skills of the estimated 450,000\(^4\) people employed in this industry, and apply them to a new offshore CO\(_2\) storage industry. While CCS will not replace the North Sea oil and gas industry, it could go a long way towards offsetting some of the revenue and jobs which will be lost as the UK hydrocarbon sector diminishes over the coming decades.

### The UK Government’s Commitment to CCS

The UK Government has demonstrated strong and continued commitment to developing CCS in the UK. In the March 2010 report, ‘Clean coal: an industrial strategy for the development of carbon capture and storage across the UK’, the Government committed to supporting the construction of up to four full chain, commercial scale CCS demonstration projects in the UK by 2020. In November 2010, the Government announced that the selection process for these additional demonstration projects would begin shortly and be open to projects on gas-fired power stations as well as projects on coal-fired power stations.

In the Comprehensive Spending Review on the 20\(^{th}\) October 2010, the UK Government restated its commitment to funding up to four CCS demonstration projects. The first project will be selected via the present CCS Demonstration Competition process with up to £1 billion of public funding available.

### The UK Government’s CCS Competition

In the 2007 Budget, the UK Government announced a competition challenging industry to develop proposals to build and operate a full-scale CCS system before 2015 (the Competition). The Energy White Paper 2007: ‘Meeting the energy challenge’, provided further detail and the Competition was launched in November 2007. The paper called for projects that would demonstrate the following:

- Full chain CCS at commercial scale (min 300MWe) using post-combustion technology on a coal fired power station
- Capture and storage of 20 million tonnes of CO\(_2\) over a 10-15 year period
- Storage in an offshore storage site within the UK extended economic zone

Finally all bidders were required to commit to actively sharing knowledge on any future CCS demonstration project.

There were originally nine entrants, drawn from across the energy sector. In March 2010, two entrants, one of which was the ScottishPower CCS Consortium, were invited to develop their proposals through a FEED exercise that concluded in Q1 2011. The FEED exercise, and ultimately the Competition itself, requires each element of the CCS chain - capture, transport and storage - to be developed and demonstrated. The ScottishPower CCS Consortium became the sole remaining entrant in the competition on the 20\(^{th}\) October 2010 when the other competing developer withdrew during its FEED study, citing internal uncertainty over investment decisions.

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1 DECC, ‘Clean Coal: An industrial strategy for the development of carbon capture and storage across the UK’, March 2010
3 DECC, ‘Clean Coal: An industrial strategy for the development of carbon capture and storage across the UK’, March 2010
4 Oil and Gas UK, Economic Report 2009

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ScottishPower CCS Consortium project

The ScottishPower CCS Consortium is planning to install the world’s first full chain commercial scale demonstration of CCS on a coal-fired power station. In 2016, captured CO₂ emissions from Longannet Power Station in Fife, Scotland, will be transported by pipeline, injected and stored in a depleted gas field known as Goldeneye which lies over two kilometres below the sea bed. The gas will remain contained in the porous sandstone under at least 600 metres of cap rock for hundreds of thousands of years.
Figure I-2: The ScottishPower CCS Consortium project Map
The ScottishPower CCS Consortium Partners

ScottishPower is responsible for the management of the overall project as well as the construction and operation of the carbon capture plant (CCP) at Longannet Power Station. ScottishPower supplies electricity and gas to over 5 million private and industrial customers across the UK. It generates electricity from a range of sources including coal, gas, wind and marine. It's also part of the global energy company Iberdrola, one of Europe’s largest utility companies.

ScottishPower have been supported by Aker Clean Carbon as providers of the carbon capture technology.

National Grid is responsible for the onshore transportation of the CO₂ along new and existing pipelines, utilising compression facilities that drive the CO₂ to the offshore storage site. National Grid owns and operates Great Britain’s high pressure natural gas transmission system. The company designs and builds gas pipelines and is seeking to apply its knowledge and skills to CCS. National Grid is an international electricity and gas company playing a vital role in providing energy to millions of customers across Great Britain and the northeast US in an efficient, reliable and safe manner.

Shell will transport the CO₂ offshore and store it in an existing depleted gas reservoir under the Central North Sea that will have ceased production. Shell is a global group of energy and petrochemical companies. The core business of the oil and gas industry is the handling of gas and liquids above and below the surface and Shell’s transport knowledge and offshore expertise is a vital component in the delivery of a viable CCS solution.
Project Governance

Consortium management functions were co-ordinated by ScottishPower but relied on the active participation of both Consortium Partners and a host of subcontracted experts. A number of governing bodies were established to manage this process as shown in Figure I-3:

Figure I-3: Project Governance

- **Attendees**: cross-Consortium CCS leads and executive level managers.
- **Objectives**: Senior decision making body and forum for escalating issues.

- **Attendees**: cross-Consortium CCS leads and workstream leads.
- **Objectives**: progress reporting, identifying and addressing cross-Consortium risks and issues.

- **Attendees**: cross-Consortium technical leads
- **Objectives**: validate and approve technical design changes/decisions.

- Cross-Consortium workstreams e.g. Technical, Knowledge Transfer, Communications, Consents/Regulatory, Commercial, Consortium Management Office (CMO).

Source: ScottishPower Consortium

Knowledge Sharing

An essential requirement of the UK Government's funding for CCS Demonstration is a commitment from participating organisations to share knowledge and the lessons learned through demonstration, to improve understanding of the technology, accelerate global deployment and support the development of a competitive CCS industry in the UK.

The ScottishPower CCS Consortium fully supports the UK commitment to sharing knowledge from CCS demonstration, and has included development of a knowledge transfer programme to capture and disseminate demonstration learning as an integral part of the project design process. In order to capture and share the key learning from FEED, the ScottishPower CCS Consortium has produced this FEED Close Out Report.
FEED Close Out Report

The FEED Close Out Report is a collection of the documents, registers, technical drawings, knowledge and learning generated by the ScottishPower CCS Consortium during FEED, that are to be made publicly available at the award of the CCS Project Contract.

The report contains over 300 reports and documents, covering all sections of the CCS chain and encompassing learning from the 11 key areas developed during FEED including:

- The programme for FEED and for full demonstration
- The cost of performing the FEED study
- The CCS chain design
- Operation of the CCS chain and its individual elements
- Decisions and design changes
- Health, safety and environment
- Risk management
- Consents and permitting
- Knowledge transfer stakeholder profiling
- The cost of the full demonstration project
- Lessons learned from FEED

The body of the report is a narrative that guides the reader through each of these sections, with supporting documents created during FEED in correlating appendices at the back. Each narrative section clearly identifies and explains the contents of that section and the scope of the reports contained within the appendices.

The FEED Close Out Report has been produced for an informed reader with an interest in the development of CCS, as such, no attempt has been made to standardise the formats of the deliverables for the individual CCS chain elements which are contained in the appendices of this report, since they provide realistic examples for future CCS developers.

Inconsistencies regarding programme dates are likely to exist between this FEED Close Out Report narrative and the supporting appendix documents. The Overall Project Programme contained within this report was the up-to-date programme at the close of FEED, whilst the appendix documents were completed at different stages throughout the FEED process. The Overall Project Programme is subject to further evolution post-FEED which may result in significant changes to programme dates.

This report captures the key developments to the ScottishPower Consortium’s CCS solution during FEED so others can learn and join in the drive to make CCS a global reality.

Where relevant, full chain (End-to-End) reports have been provided to present the complete picture of the work completed during FEED. Documentation representing the project status prior to commencing FEED have also been included where relevant for comparison purposes.

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1. Programme

This section of the FEED Close-Out Report provides a summary of the programme schedules for the two key phases of the UKCCS Demonstration Project namely:

1) The Front End Engineering Design phase just completed by the Consortium. This is discussed in Section 1.1

2) The implementation phase of the UKCCS Demonstration Project denoted as the Engineering, Procurement and Construction (EPC) programme. This is discussed in Section 1.2.

The programmes are loaded as P6 Primavera schedules and managed such that key interface milestones are monitored by the programme managers, with activities updated so as to be able to track progress. Performance metrics were measured and reported on a monthly basis during FEED to manage actual progress against the programme. A similar approach is planned for the implementation stage of the project.

Programme related support materials for all Consortium Partners and ScottishPower's selected carbon capture technology provider Aker Clean Carbon are contained within Appendix A.
1.1 FEED Programme

This section describes the programme followed by the Consortium over the course of the FEED phase of the project, between March 2010 and March 2011. Consortium Partner aspects are also detailed in each sub-section, regarding their specific issues and challenges encountered during FEED.

Please refer to the programmes in Appendix A.1 comprising of the following:
- UKCCS - KT - S2.0 - CMO - 001 Outline Solution FEED Programme
- UKCCS - KT - S2.0 - CMO - 002 Post-FEED Level 3 FEED Programme

The Post-FEED Level 3 programme is the complete and final version of the schedule at the close of FEED and is discussed in detail within this section. For comparison, the Outline Solution FEED Programme is also provided.

1.1.1 Overview and Execution Strategy

Each Consortium Partner developed their own programme for FEED. These were then linked by an overarching programme containing the key milestones, interface points and End-to-End activities so as to be able to manage the overall FEED programme timeline and key deliverables. The FEED scope was developed to meet the requirements of the UKCCS Demonstration Competition for the FEED phase of the project.

The FEED programmes were developed to support the requirements of the FEED completion date at the end of March 2011, based on an effective commencement date of the 15th March 2010. These programmes were regularly updated and monitored to meet the requirements of achieving the overall target completion date.

During FEED a number of cross-Consortium key interface milestones were identified. These were points in the overarching programme where two (or more) of the Partner programmes had a critical dependency on each other (e.g. for passing / receiving information related to the design efforts etc.). It was a significant challenge to define the scope of and agree the interface milestones and dates between the Partner companies and this required close co-operative working across the entire Consortium.

The Partner programmes (their activities and interface milestones) were separately managed and were reviewed and updated monthly. Each was submitted to the Consortium planner every month to inform the overarching FEED programme. Progress was monitored and reported to the Consortium Management Committee to identify and manage the activities that fell behind plan (sometimes attributable in part to an aggressive original FEED programme, and sometimes due to new emergent issues), and also to highlight those activities progressing ahead of schedule.

Due to the nature of managing such a dynamic project, a degree of flexibility was required to manage any change in activities within the available float and to monitor the critical path.
1.1.1.1 ScottishPower

ScottishPower’s role on this project generally related to support activities, including the reporting and coordination of key tasks, and management of the overarching End-to-End activities.

The ScottishPower section of the Post-FEED Level 3 FEED Programme is included in Appendix A.1.

The ScottishPower programme details the specific activities and deliverables that were undertaken during the FEED phase of the project and was produced at Level 3 (an activity duration of no more than 14 days). The programme was broken down into nine main elements with various sub-elements as described below:

- ScottishPower Reporting Deliverables
  - Monthly Review Meetings with DECC and Monthly Reports

- FEED Delivery Owners Engineer Support
  - Containing various sub-elements relating to Design Interface Management, End-to-End CCS Chain Deliverables, Health and Safety Reporting, Risk Register and Support, Consolidated End-to-End FEED Report, Management of Consents and Permitting

- FEED Delivery Environmental Consents
  - Containing various sub-elements relating to Environmental Consents

- Commercial/Legal
  - Containing various sub-elements relating to Commercial and Legal Aspects

- Financial and Economic Model Development

- Energy and CO₂ Supply Contracts
  - It is assumed that the capture facilities to be located within the boundary of Longannet Power Station (LPS) will be physically, commercially and operationally separate from normal day to day activities at LPS. As a result, interfaces exist between LPS and the capture facilities and contracts will be required to govern the commercial relationships surrounding the interfaces. One of these interfaces is the supply of flue gas (CO₂) from LPS to the capture facilities and as a result, a CO₂ Supply Contract between LPS and the capture facilities will be required. In the event that the SPS plant and the capture facilities are in different ownerships and not in one commercially integrated package, a separate contract (the Energy Supply Contract) between the SPS plant and the capture facilities will be required to govern the commercial relationship for the supply of such energy.

- Regulation

- FEED Close Out Report

- Stakeholder Profiling

During the initial period of FEED, the programme was developed in-line with emergent requirements and activities were added to the programme to capture this information.

Overall, the programme progressed to plan and there were no significant issues with the deliverables. However, there were some challenges experienced throughout FEED, particularly in relation to...
development of the End-to-End CCS chain deliverables which involved bringing together inputs from Partners and consolidating these inputs into the final suite of End-to-End CCS chain deliverables.

### 1.1.1.2 Aker Clean Carbon

The strategy adopted as the basis for the FEED Level 3 programme covering the Aker Clean Carbon specific scope of work is detailed below.

The Aker Clean Carbon section of the Post-FEED Level 3 FEED Programme can be found in Appendix A.1.

The programme was developed based on the Aker Clean Carbon standard methods of working as dictated by their in-house project execution process. Design deliverables produced for FEED are typically covered within the Aker Clean Carbon system.

The following points were applicable to the FEED programme which in some instances required updating and expanding during the FEED period:

- Aker Clean Carbon endeavoured to show activities at a level of detail where durations were of 2 weeks or less. In some cases this was not practical based on the Aker Clean Carbon methods of working and programme management, as information was expanded and confirmed during FEED the level of detail within the programme was amended to suit.

- The proposal to investigate the tie-ins to the existing units at Longannet during FEED was expanded to take advantage of the planned shutdown of Unit 2 during the FEED study period. The revised workscope involved site surveys to identify tie-in points as well as a complete list of anticipated tie-ins.

- Site surveys of the proposed construction site applicable to unexploded ordinance (UXO) and decontamination and preparation of the site for the commencement of construction activities were completed during FEED to confirm design requirements for civil works to support the estimate requirements. This involved the award of sub-contracts for the survey work.

- The programme only reflects activities relating to obtaining quotes from vendors for the supply of main equipment and materials. It did not reflect bidding and negotiation periods required under European Economic Community (EEC Public) Procurement regulations. Non-regulated UK energy companies are exempt from European Union Procurement Directives, therefore ScottishPower is not required to formally register tenders with the Official Journal of the European Union (OJEU).

- Discussion with potential construction contractors took place to support the preparation of the project cost estimate.

- Development of design documentation was carried out during FEED to support the estimation requirements of the FEED process.

### 1.1.1.3 National Grid

The National Grid section of the Post-FEED Level 3 FEED Programme is included in Appendix A.1.
The National Grid section of the programme was divided into the three distinct elements for the Onshore Transportation System:

- Construction of two new sections of pipeline connecting Longannet Power Station to the point of connection with the existing National Grid No. 10 Feeder pipeline.

- Modification works to the existing National Grid No. 10 Feeder pipeline to allow onshore transportation of CO₂.

- Construction of a new compressor station at Blackhill, adjacent to the existing National Grid natural gas terminal at St. Fergus, and connecting pipework to No. 10 Feeder.

To further develop the cost certainty and de-risk the project, National Grid programmed the following non-engineering activities during FEED:

- Preparation of the planning application for the new compressor station at Blackhill, including preparation of the Environmental Impact Assessment (EIA).

- Preparation of the planning applications for the new Above Ground Installations (AGI’s) associated with the new pipeline and No. 10 Feeder.

- Preparation of the Environmental Statement required for consent for the pipelines under the Pipe-Lines Act 1962, including all surveys required to support the application.

- Third party consultation in respect of all consent requirements.

In the final FEED programme update submission, the Environmental Impact Assessment (EIA) and planning and land use activities/surveys were collated into one area under the new pipeline (but covering all three elements of the onshore pipeline construction) as these were performed outside the scope of the principle FEED design contractor. The only requirement for the FEED design contractor was to produce planning drawings and these were included in the relevant discipline design sections.

The FEED scope included all investigations and surveys necessary for the development of the design and the preparation of the required consents, including the following:

- Intrusive site surveys for the new pipeline, No. 10 Feeder and compressor station
- Mining surveys
- UXO surveys
- Environmental surveys
- Archaeological surveys

As part of its ongoing research into CO₂ transportation, National Grid funded a programme of research and development to further the safety case for the transportation of CO₂ in gaseous phase through the Onshore Transportation System. The research and development (R&D) programme was progressed in parallel with FEED. The results from this research were not reported on directly as this is a privately funded piece of work, however, the FEED work has benefited from the learnings from this research. The R&D programme will extend through to the implementation phase of the project.

To ensure that the timescales for FEED were met, assumptions were made regarding the design basis for the new pipeline, the new compressor station and conversion of the existing No.10 Feeder. The design
assumptions made by National Grid were closed-out upon receipt of the initial research and development findings.

Prior to commencing FEED, National Grid commissioned a Feasibility Study for the new compressor station at St. Fergus, and a Route Corridor Investigation Study for the new pipeline. These studies commenced in November 2009, with initial reports received in March 2010. The Feasibility Study for the new compression facility was to identify the preferred option for the compressor and primary drive. The Route Corridor Investigation Study for the new pipeline identified a preferred 1km wide route corridor for the pipeline. These studies represented the starting point for the FEED engineering activities. The FEED programme charts the activities that flow from the Feasibility Studies through FEED and development of the solution as required by the UKCCS Demonstration Competition. The programme flowed through the activities outlined in Figure 1.1.3-1.

In parallel with these activities, Formal Process Safety Assessments and investigations and surveys were completed. These activities interfaced and informed the design process though FEED with any resulting design changes incorporated into the final FEED deliverables.

1.1.1.4 Shell

The Shell FEED programme may be sub-divided into 4 main areas:

- **Facilities**
  - Technical work to assess the suitability of the existing offshore pipeline and facilities. This included design of the modifications required for change of service from hydrocarbon production (and “export” to the mainland) to CO₂ injection (and transportation offshore to the platform).
- Work has included innovative field-testing (at Spadeadam) of the dispersion characteristics of dense phase CO₂, allowing proper calibration of dispersion models for the very first time.

- **Subsurface**
  - Considerable effort has been required to model the subsurface environment, despite the fact that a mature reservoir model already existing from the field’s 7-year history of producing hydrocarbons.
  - Much of the additional work has concentrated on the “overburden” above the reservoir, and the “aquifer” below – areas that have required much greater scrutiny than in a conventional hydrocarbon development.
  - The main objectives were to confirm the capacity of the storage site would be adequate for the UKCCS Competition requirements (20 million tonnes), to verify that the storage site would safely contain the CO₂ within a pre-determined 3D space, and to assess whether the reservoir properties would allow CO₂ to be injected at the required flowrates.
  - It has also been necessary to develop a Monitoring, Measurement and Verification (MMV) Plan, and to engage with the Regulator around the Storage Licence and Permit, both of which are areas with little or no precedent. The resultant Storage Development Plan is – we believe – essentially a global first of its kind.

- **Wells**
  - Assessment of the integrity of the 5 existing production wells drilled from the platform, along with the 13 abandoned Exploration and Appraisal (E&A) wells drilled elsewhere in the vicinity. This work concluded that the 5 platform wells would need to be “worked over” to change out the completion for one that would pre-empt the very low temperatures that would otherwise be encountered (as a result of Joule-Thomson expansion of the CO₂), and which would probably lead to a variety of integrity concerns. Again, we believe this work and ultimate solution to be a global first.
  - The Corrective Measures Plan is also a relatively new concept.

- **Project management**
  - “Non-engineering” work that included regulatory, legal and commercial items.

Good technical progress was maintained throughout FEED. The novelty of the subsurface work in particular meant that it took slightly longer elapsed time than expected, and more hours were liquidated than planned (albeit at a lower than budgeted hourly rate). Some work that was originally expected to be conducted by third parties was actually carried out in-house.

### 1.1.2 Critical Path

Critical Path Analysis calculates the longest path of planned activities to the end of the project, and the earliest and latest that each activity can start and finish without making the project duration longer. This process determines which activities are "critical" (on the longest path) and which have "total float" (can be delayed without making the project longer). Any delay of an activity on the critical path directly impacts the planned project completion date (there is no float on the critical path) and as such, progress along the critical path is monitored closely.
1.1.2.1 ScottishPower

The ScottishPower critical path activities were those concerning the submission of an Environmental Statement (ES) for the Longannet elements of the End-to-End CCS chain. This is part of the process leading up to the granting of the Section 36 Permit (and Deemed Planning Permission) from the Government together with the implementation of any pre-commencement conditions.

The ES was submitted during FEED and will continue to be progressed in the post-FEED period in order to secure the regulatory consents and permits prior to commencing the construction of the Longannet portion of the End-to-End CCS chain. If these cannot be secured, then construction cannot start as planned and the project will be delayed.

1.1.2.2 Aker Clean Carbon

The critical path for FEED for Aker Clean Carbon encompassed the following activities:

- Process studies
- Clarification of utility requirements
- Defining control, relief and waste handling philosophies
- Process Flow Diagram development
- Equipment list development
- Piping & Instrumentation Diagram development
- HAZOP reviews
- Preparation of material specifications and plot plan studies

In the main, these activities and their timing dictated the completion of the FEED phase of the project for Aker Clean Carbon.

Float within the programme was managed through the FEED period to ensure that the overall FEED completion date was met.

1.1.2.3 National Grid

The National Grid critical path for the FEED Onshore Transportation System related to the design work for the new compressor station. The critical path was identified as encompassing the following activities:

- Compressor station feasibility study
- Compressor design philosophy
- Piping design specification
- Discipline design activities
- Process and safety design approvals
- Safety design appraisal

The critical path followed the programme flow as identified in Figure 1.1.1.3-1. The critical path through the new pipeline for FEED followed the same logic as the new compressor station.

The overall National Grid FEED programme, for both the new pipeline and new compressor station, did not contain any float. The completion dates for each of the Level 2 activities within the FEED programme were determined by the latest deliverable within the activity. The float for each deliverable was determined by
the latest activity completion date. This allowed float for all but the latest activity deliverables within the date constraints identified for each activity.

1.1.2.4 Shell

A number of Shell activities were executed out of sequence when compared with the original FEED programme. This was done to progress overall FEED scope more efficiently and could be accomplished due to the high number of independent work packages required by the Shell scope. Due to this opportunistic deployment method, the critical path alternated between different areas, but generally it varied between the originally identified critical areas of:

- Basis of Design
- Gas Dispersion Studies
- Wells
- Subsurface Modelling.

On the whole, there was no float for the delivery of the Shell FEED programme in the original baseline.

1.1.3 Key FEED Programme Risks

Prior to commencing FEED, each Partner identified the key risks with the potential to delay their FEED programme. A common context for each Partner’s programme was the scarcity of expert CCS resource and knowledge. Given the novel, demonstrative nature of the project, programmes built on previous FEED experiences had to be flexible to adjust to the specific needs and challenges of a CCS FEED. Each Partners specific programme risks, and their subsequent outcomes, are outlined within this section.

ScottishPower
- Production of the End-to-End deliverables and Knowledge Transfer was subject to risk of delay as it was dependant on the delivery of the individual programme elements to allow completion of these packages of work.
  - Individual programme elements impacting End-to-End and Knowledge Transfer deliverables were prioritised and managed to minimise delays.

Aker Clean Carbon
- Poor quality records of underground obstructions at Longannet site
  - A Geotechnical survey was carried out during FEED. This allowed the ground conditions to be mapped. The results of this survey allowed the piling and foundation designs to be progressed to match the local conditions.

- Flue Gas ducting constraints
  - A Computational Fluid Dynamic study was conducted early in FEED. The results from this study indicated the ducting criteria to be used in the design and allowed the ducting design to be incorporated into the current Longannet system.

- Integration with existing Power Plant
  - A detailed analysis and identification of the various infrastructure tie-in points was completed during FEED. The analysis identified that most existing Longannet systems could be utilised for the project but that a separate fire water system would be required for the CCP plant.
UK Carbon Capture and Storage Demonstration Competition
FEED Close Out Report

- Longannet Site knowledge
  - ScottishPower site personnel allowed access to the existing power station documentation which provided a firm foundation for integration design.

- Existing contaminated ground conditions
  - Groundwork investigations were carried out during FEED which identified areas of contamination on the site. Provision for the clean up of the contamination has been allowed within the Engineering Procurement Construction (EPC) programme.

National Grid
- Late delivery of the Feasibility Study for the new compressor station
  - This could have impacted negatively on progression of the Compressor Station specific FEED deliverables. Although the Compressor Feasibility Study was delivered late, the associated risk was successfully managed by prioritisation, a focus on key data and re-scheduling of FEED activities within a declared Recovery Programme.

- Late delivery of the Route Corridor Investigation Study (RCIS) and related activities
  - This study was required to confirm project and design assumptions in a timely manner to facilitate progression and ultimate delivery of the FEED deliverables. The timely production of these documents helped to develop and mature the Onshore Transportation System solution, so therefore did not directly impact on FEED progression and avoided the realisation of the risk.

- Design changes resulting from research and development
  - No major design changes have resulted from the research and development work to date. This risk is still relevant for the post-FEED development of the project.

- Access to land for investigations and surveys
  - Access was available to 70% of the required land. For land where access was not available for intrusive investigation work, a robust desktop study was completed using the British Geological Survey and the Coal Authority borehole information. There was no impact on the FEED programme. However, further work will be required during the projects implementation phase.

- Environmental constraints identified through investigations and surveys
  - There was no impact for FEED. A potential badger set was identified at the proposed connection location between National Grid and Shell. A badger survey will be completed before the implementation phase commences.

- Unforeseen archaeology
  - A Roman fort was encountered at the west of Dunipace that required the proposed pipeline route to be amended. However this had no impact on the schedule as it was identified early during FEED, before the pipeline route was finalised.

- CO₂ specification
  - There was no impact in FEED. However, this risk will continue into the next phase of the project.

- River Forth crossing methodology
  - Although the original scope was to use a Horizontal Directionally Drilled (HDD) crossing, results of boreholes revealed that ground conditions were unsuitable for HDD. Tunnelling is now the preferred
option. Subsequently, National Grid organised an independent tunnelling design study due to risk and high cost of tunnelling. Cost and schedule were affected but not the overall end date. The risk is greatly reduced for the post-FEED phase of the project.

- Third party constraints
  - A schedule and cost impact was incurred due to third party delay in confirming the location of Longannet AGI. This was mitigated by using design assumptions to continue to progress the design works. However, subsequent rework had to be undertaken when the location was confirmed as different to the assumed location. The impact did not affect the FEED finish date.

- Impact of Safety Case development on the design
  - No impact for FEED. This was mitigated early in FEED by treating the pipeline as equivalent to an 85 barg natural gas pipeline.

Although the timely production of certain documents (e.g. RCIS) mitigated direct FEED progression risks, they did in themselves identify new risks that were recorded and progressed accordingly. For example, the aforementioned RCIS highlighted unexploded ordinance, contaminated ground, flooding, etc. as items that would require further consideration during FEED and subsequent project phases.

Shell

- Late delivery of Basis of Design document
  - The Basis of Design document was delivered later than originally planned, but with some mitigation its impact was negligible.

- The Full-Field Dynamic Modelling met with some problems, but deployment of an additional resource recovered some of the backlog. Completion of this was delayed, but impact was minimal.

- The CO₂ dispersion field test programme at the Spadeadam Test Centre suffered delays for various reasons, including adverse weather. Recommendations from the final report will be incorporated into the design during the next project phase.
1.2 Post-FEED Programme for Overall Project

The Post-FEED Overall Project Programme reflects the accumulation of 11 months of development and knowledge during FEED and is the Consortium’s current view on the schedule of events that will lead to operation of the first full-scale End-to-End CCS demonstration.

In Appendix A.2 of this report, the following documents are provided:
- UKCCS - KT - S6.1 - E2E - 001 Post-FEED Overall Project Programme
- UKCCS - KT - S6.2 - OS - 001 Outline Solution Overall Project Programme
- UKCCS - KT - S6.2 - OS - 002 Outline Solution Overall Project Programme Report

The Post-FEED Overall Project Programme is the complete schedule submitted to DECC at the close of FEED and is discussed in detail within this section. For comparison, the Outline Solution Overall Project Programme is also provided with a supporting narrative.

It should be acknowledged that this section covers the programme in use at the end of FEED (March 2011). The Overall Project Programme will be subject to further review and change as the planning of the overall programme evolves and develops.

There are a number of activities, processes and procedures that will benefit from early definition and agreement. Although this phase and scope of work has yet to be fully defined across the Consortium, it is referred to as ‘project mobilisation’. An indicative allowance for this phase has been included to facilitate delivery of the Overall Project Programme. If any of the activities associated with the project mobilisation phase are undertaken prior to the effective Engineering Procurement Construction (EPC) start date of the 5th January 2012, then it may be possible to reduce the programme timescale. However, a thorough assessment of the impact of any pre-works on the Overall Project Programme would need to be undertaken.

1.2.1 Programme Execution Strategy

The post-FEED phase of the Overall Project Programme has been developed during FEED and is presented here as the current view of the Post-FEED Programme for the overall project.

The Consortium Partners have worked closely together to understand the interactions between the different Partners. In order to produce the Post-FEED Programme, the Partners’ programmes have been integrated, although they are still individual entities that can be updated by each of the Consortium Partners - the programmes relate to one another through common interface milestones.

The programme structure comprises of the Partner’s programmes as shown in Table 1.2.1-1. The work breakdown structure (WBS) of each Partner’s programme generally follows the WBS phasing shown in the table, although Partners’ individual WBS varies according to their respective scope and business practice.
Table 1.2.1-1: Programme Structure

<table>
<thead>
<tr>
<th>Programme Name</th>
<th>Owner</th>
<th>Programme Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>One page level 1 programme</td>
<td>SP</td>
<td>One page programme highlighting the period up to commissioning and the completion of performance testing (handed over to operations).</td>
</tr>
<tr>
<td>Overarching programme</td>
<td>SP</td>
<td>This programme is a brief overview of the complete programme arranged as follows:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Overall key dates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Proposed DECC monthly meeting dates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Forecast Longannet outages</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Interface milestones</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Key dates by project phase are taken from each of the Partner's programmes as follows:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Consents key dates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Design engineering key dates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Procurement key dates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Sub-contracts key dates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Construction key dates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Commissioning key dates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Operational key dates</td>
</tr>
<tr>
<td>ScottishPower and Aker Clean Carbon</td>
<td>SP/ACC</td>
<td>The scope comprises of Longannet site equipment up to the interface connection to the National Grid pipeline. Additionally, the ScottishPower programme contains cross-Consortium related co-ordination and support activities for the overall project.</td>
</tr>
<tr>
<td>programmes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Grid</td>
<td>NG</td>
<td>The scope comprises of the Onshore Transportation System from the interface with Aker Clean Carbon up to the interface connection with the Shell Offshore Transportation System.</td>
</tr>
<tr>
<td>Shell</td>
<td>SH</td>
<td>The scope comprises of the Shell onshore and offshore pipelines and facilities from the interface to the National Grid onshore compressor station to offshore injection facility.</td>
</tr>
</tbody>
</table>

1.2.1.1 ScottishPower

The ScottishPower programme includes cross-Consortium reporting and co-ordination activities. The definition of the deliverables that will be required during the implementation phase of the project are still in development and subject to change.

The format of the ScottishPower section of the Overall Project Programme is as follows:
- Key dates are shown at the start of the programme WBS.
The proposed DECC monthly meeting dates and report submission dates follow a date pattern largely similar to that employed during FEED. However, these are yet to be fully defined.

Various disciplines comprising Health Safety and Environment, Risk Management and Consents & Permitting are contained within the programme. These discipline activities have been nested to provide the necessary differentiation between Longannet related activities and cross-Consortium related activities.

The programme concludes with a WBS relating to commercial / legal and knowledge transfer activities.

The programme critically revolves around when the Section 36 Permit and pre-commencement conditions are achieved, and this therefore drives the timescales. It is anticipated that project Mobilisation would be completed within the timeframe for achieving Section 36 during 2012.

ScottishPower’s role in the UKCCS project changes upon commissioning and performance testing completion, when the project is handed over to operations, scheduled for the 6th June 2016. ScottishPower will then be involved in the extraction of flue gas from Longannet Power Station for the operating phase of the project.

### 1.2.1.2 Aker Clean Carbon

The Aker Clean Carbon programme reflects the following high level WBS phases:

- **Milestones**
  - General Milestones, Gate Review Milestones

- **Engineering**

- **Procurement**
  - Vessels, Machinery, Fire Protection, Piping, Electrical, Instrumentation, Control Systems

- **Subcontracts**
  - General Milestones, Formulation and Administration

- **Construction**
  - Site Preparation and Enabling Works, Milestones, Train 1 Capture and Compression, Train 2 Capture and Compression, Common, SPS, E&I Buildings, Longannet Tie-in’s, Miscellaneous

- **Commissioning**
  - E&I Buildings, Common Areas, SPS Plant, Train 1 Capture and Compression, Train 2 Capture and Compression

### 1.2.1.3 National Grid

National Grid’s responsibility for delivering the EPC programme of work is for the Onshore Transportation System to deliver CO₂ to Shell for onward offshore transportation and subsequent injection.
The scope of the National Grid works has been separated into 3 sections as per the following:

- **New pipelines**: Construction of two sections of new pipeline between Longannet Power Station and the designated connection location for the existing No. 10 Feeder pipeline.
  - This will involve a major crossing of the Firth of Forth, as well as construction of new AGIs incorporating pig traps.

- **No. 10 Feeder**: Modifications and work required to convert approximately 280 km of No. 10 Feeder from natural gas service to CO₂.
  - Modifications will be required at all Block Valve and multi-junction AGIs that currently exist along the No. 10 Feeder, as well as the construction of some new facilities.

- **Compressor station**: Construction of a compressor station at Blackhill adjacent to the existing National Grid St. Fergus natural gas terminal.
  - CO₂ to be received from the No. 10 Feeder pipeline will be compressed to the required state / pressure and delivered to Shell at the boundary of the compressor station.

### 1.2.1.4 Shell

Following on from FEED, the Shell programme will comprise of the following:

- Submission of the Environmental Statement for the Goldeneye storage site.

- Consultation with the UK “Competent Authority” on the site specific details of the license and permit requirements for CO₂ storage with specific focus on monitoring, corrective measures and transfer. After a process of clarification (and potentially additional modelling) the application for the storage permit will be lodged. The permit application will then be sent to the EU commission for comment. Failure to be awarded a permit would lead to cancellation of the project.

- Determine the feasibility of using tracers in CO₂ stream and make decision on whether to employ them. This will have a knock on effect on the detailed design and operations.

- Subject to the requirements for monitoring set out in the storage permit, detailed design of the monitoring programme will take place. In addition, a number of techniques for sea bed sampling need to be proven in a development setting. The tenders for monitoring will be submitted.

- Base line monitoring – seismic and benthic – over the base line monitoring area.

- Interpretation of 4D baseline, 3D seismic, benthic results, pressure build up and neighbouring field data. Update to the subsurface models including uncertainty analysis to refine conformance monitoring programme. Update risk assessment. Modify monitoring plans if required. The interpretation of the baseline data could expose issues with containment that might require remediation (additional capital expenditure). Results will need to be approved by the “Competent Authority”.

- Construction of a new 1.4 km 20” pipeline around the Shell site at St. Fergus that will then receive dense phase CO₂ from the neighbouring National Grid Blackhill Compressor Station.

- Connection of this new pipeline on the Shell site at St. Fergus into the existing 20”Goldeneye pipeline, to transport the CO₂ 100km to the offshore platform.
Minor topside structural modifications on the offshore platform to support new filtration units, pipeline pigging facilities, a new injection manifold and other utility equipment.

Re-completion of the 5 platform wells, using a heavy duty jack-up rig, to render them suitable for injecting CO₂ into the Goldeneye reservoir. One of the wells will be initially designated as a monitoring well.

Compressed captured CO₂ from Longannet Power Station will be delivered from the neighbouring National Grid Blackhill Compressor Station into the new 1.4 km pipeline which will connect to the existing offshore pipeline leading to the platform structure. A new sub-sea isolation valve and expansion pipework will be required in the offshore pipeline adjacent to the platform. CO₂ will flow up the existing platform riser and through new filters which will be designed to remove any transport contaminants before they reach the wells. Following filtration, the CO₂ is passed through the new manifold and injected via new individual flowlines into the reservoir via 3 or 4 injection wells. Hydrocarbons from the field were originally produced via five production wells which were drilled and completed on the platform using a jack-up drilling rig. These wells will be worked over (using a jack-up rig) and re-completed with new injection tubing.

1.2.2 Key Dates

The dates in Table 1.2.2-1 below outline the key milestones within the Overall Project Programme.

As part of the post-FEED activities, the programme will be developed further as discussions with DECC continue, and the project mobilisation phase will be defined and agreed. As such, the key programme dates listed below are subject to review and change.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Contract Execution</td>
<td>Expected no later than December 2011</td>
</tr>
<tr>
<td>Effective EPC programme start date</td>
<td>05 January 2012</td>
</tr>
<tr>
<td>Commit to hire of Jackup Rig (Shell)</td>
<td>05 July 2012</td>
</tr>
<tr>
<td>Section 36 permit in place &amp; pre-commencement conditions completed</td>
<td>01 October 2012</td>
</tr>
<tr>
<td>starting construction of the Longannet portion of the End-to-End CCS chain</td>
<td></td>
</tr>
<tr>
<td>Start construction of the Longannet portion of the End-to-End CCS chain</td>
<td>29 January 2013</td>
</tr>
<tr>
<td>Compressor Units order placed (by National Grid)</td>
<td>11 June 2013</td>
</tr>
<tr>
<td>Tie-in connection – Aker Clean Carbon to National Grid (Interface Milestone)</td>
<td>10 April 2015</td>
</tr>
<tr>
<td>CO₂ to pass – Aker Clean Carbon to National Grid (Interface Milestone) - #1 Aker Clean Carbon train commissioned</td>
<td>16 December 2015</td>
</tr>
<tr>
<td>Activity</td>
<td>Date</td>
</tr>
<tr>
<td>-------------------------------------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Tie-in connection – National Grid to Shell (Interface Milestone)</td>
<td>19 March 2015</td>
</tr>
<tr>
<td>CO₂ to pass – National Grid to Shell (Interface Milestone)</td>
<td>04 April 2016</td>
</tr>
<tr>
<td>Aker Clean Carbon full operation - #2 Aker Clean Carbon train commissioned</td>
<td>13 April 2016</td>
</tr>
<tr>
<td>Commissioning and performance testing completed (handed over to operations)</td>
<td>06 June 2016</td>
</tr>
<tr>
<td>Full operational period (14 years or by 2029)</td>
<td>07 June 2016</td>
</tr>
<tr>
<td>Sidetracking of wells (carried-out halfway through operational period)</td>
<td>to 20 June 2029</td>
</tr>
<tr>
<td>Commence de-commissioning</td>
<td>30 April 2030</td>
</tr>
</tbody>
</table>
1.2.2.1 ScottishPower

Further key ScottishPower programme dates are listed in Table 1.2.2.1-1 below.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longannet Unit 3 Outage 2013</td>
<td>01 April 2013</td>
</tr>
<tr>
<td>Longannet Unit 2 Outage 2014</td>
<td>01 April 2014</td>
</tr>
<tr>
<td>Longannet Unit 1 Outage 2015</td>
<td>01 April 2015</td>
</tr>
</tbody>
</table>

The Longannet unit outages will be used to tie-in the CCP as well as the required auxiliary services. The actual tie-in dates will be identified during the implementation phase.

1.2.2.2 National Grid

Further key National Grid programme dates are listed in Table 1.2.2.2-1 below.

Table 1.2.2.2-1: National Grid key dates

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline &amp; Feeder No. 10 design contract award</td>
<td>15 June 2012</td>
</tr>
<tr>
<td>Compressor EPC contract award</td>
<td>27 November 2012</td>
</tr>
<tr>
<td>Pipeline &amp; Feeder No. 10 construction contract award (detail design complete)</td>
<td>17 April 2013</td>
</tr>
<tr>
<td>Detail design complete (Blackhill Compressor Station)</td>
<td>29 January 2014</td>
</tr>
<tr>
<td>New pipeline &amp; Feeder No. 10 mechanical completion (commence commissioning)</td>
<td>07 November 2014</td>
</tr>
<tr>
<td>Compressor station mechanical completion (commence commissioning)</td>
<td>19 March 2015</td>
</tr>
<tr>
<td>Complete commissioning (whole system)</td>
<td>04 April 2016</td>
</tr>
</tbody>
</table>

1.2.2.3 Shell

Further key Shell programme dates are listed in Table 1.2.2.3-1 below.

Table 1.2.2.3-1: Shell key dates

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete IP run to check integrity of offshore pipeline</td>
<td>23 July 2012</td>
</tr>
<tr>
<td>Existing Goldeneye facilities handed over to project</td>
<td>30 July 2012</td>
</tr>
<tr>
<td>Commence onshore pipeline construction</td>
<td>07 April 2013</td>
</tr>
</tbody>
</table>
1.2.3 Assumptions

Each Partner has made assumptions concerning different aspects of the programme. The key, overarching assumptions are listed below, with any additional Partner specific assumptions listed in the following sections:

- The EPC contract award by DECC will be by the 31st December 2011
- The effective programme start date is the 5th January 2012
- An indicative allowance has been built into the Overall Project Programme for project mobilisation. A review of this phase, including the associated activities and timescales, will be necessary to ensure that they accurately represent the requirements of the project. If any of the activities associated with the project mobilisation phase are undertaken prior to the effective EPC start date of the 5th January 2012 (for example, as part of an advanced works contract), then it may be possible to reduce the Overall Project Programme timescale.
- Any work packages to be carried out during the gap period, between completion of FEED and effective EPC start date, as part of an advance works contract, is subject to further discussions with DECC. None have been assumed in the project programme.
- The permitting and consents work will cease at the end of FEED, recommencing after the effective EPC start date and resulting in the Section 36 Permit and pre-commencement conditions being established by November 2012.
- All planning applications, permits and consents will not encounter major problems or delays.
- The procurement dates and lead times used are subject to change. Estimates based on previous experience have been used and may not be suitable for current market data.
- According to current indications, there is no equipment that needs to be ordered prior to the effective programme start date of the 5th January 2012.
- The full impact of seasonality on all programme activities needs to be assessed to ensure that scheduled delivery can be accommodated. The timing of outages for Longannet Power Station will also need to be reviewed to ensure that the programme aligns accordingly. This work will be undertaken post-FEED and may impact upon programme timescales.
- The programme should not be considered to be the definitive guide as to when and how the design and construction will happen. Design contractors will have their own methodology and procedures to adhere to and subsequently this programme may experience major changes throughout its lifecycle.
- Contractually, the operational phase can last up to 15 years, although it is anticipated that the target 20 million tonnes of CO₂ will be captured within a shorter timeframe. The programme activities for the operational and subsequent monitoring, verification and decommissioning phases of the project are subject to further development during the implementation phase of the project.
1.2.3.1 Aker Clean Carbon

The Aker Clean Carbon section of the programme assumes that no advance works contract is carried out before the effective EPC start date on 5th January 2012. Opportunities to have the Aker Clean Carbon Train 1 in full operation earlier will be possible if certain activities of work are completed in the period between FEED completion and the effective EPC start date on 5th January 2012.

1.2.3.2 National Grid

The National Grid section of the Overall Project Programme assumes the following:
- The No. 10 Feeder pipeline has had control transferred for CO₂ service and all required preparations for this from the National Transmission System (NTS) have been completed.
- Material Take Offs (MTO) and Equipment Lists utilised in this programme and schedules of equipment packages that will be sub-contracted are not yet finalised. As such, the configurations and structure of this programme are subject to change and revision up to the point that all schedules and lists are finalised. Some of these items may not be fully scoped until the detail design stage.

1.2.3.3 Shell

The Shell section of the Overall Project Programme assumes the following:
- The lead time for the sub-sea isolation valve (SSI V) is 12 months based on direct supplier advice.
- The lead time for securing the rig is 24 months, drill tubulars 18 months, Xmas trees and down-hole tools 12 months.
- The offshore platform, normally un-manned has 12 beds, 6 available for direct labour use.
- The main construction accommodation will be provided by the Jackup-rig (150 beds) and DSV (150 beds). Some optimisation will be required.
- The permit to traverse the St. Fergus MoD fencing requires 6 months and sits within council planning approval of 12 months.
- As a guide, the lead time between the start of design and start of construction is 24 months.

1.2.4 Critical Path

The Consortium critical path is subject to caveats regarding project mobilisation and programme dates that are subject to further development. However, following a December 2011 contract award, Aker Clean Carbon expects to have CO₂ available for transport from Longannet Power Station on the 16th December 2015. When this is available, the full commissioning and testing of the National Grid Onshore Transportation System will commence on the new pipeline, followed by the No. 10 Feeder pipeline and through to the compressor station. Following the commissioning of the compressor station, National Grid will supply CO₂ to Shell by the 4th April 2016 to allow Shell to commence commissioning. Shell will carry out commissioning and performance testing and hand over to operations (including CO₂ injection) on the 6th June 2016.
Any additional Partner specific critical paths are listed in the following sections.

1.2.4.1 ScottishPower

It is necessary to have regulatory consents and permits in place prior to commencing construction of the Longannet portion of the End-to-End CCS chain, otherwise construction cannot start and the project will be delayed. One of the relevant consents for the Longannet portion is the granting of Section 36 (and Deemed Planning Permission) from the Government, together with the implementation of any pre-commencement conditions.

Activities for Section 36 are shown in the Longannet Related Consents and Permitting section of the ScottishPower programme. This involves starting work on permitting activities following the effective EPC start date on the 5th January 2012.

Completion of any Section 36 pre-commencement conditions is scheduled for the 1st October 2012 with construction of the Longannet portion of the End-to-End CCS chain commencing on the 29th January 2013.

Additionally, the Consortium Partners are responsible for obtaining any permits for works within their respective scopes. ScottishPower will monitor the Partners’ permitting activities. Activities for ScottishPower monitoring of the Partners’ permitting activities are shown in the cross-Consortium Related Consents and Permitting section of the ScottishPower programme.

1.2.4.2 Aker Clean Carbon

The Aker Clean Carbon critical path activities include:
- Issue of enquiries, receive bids, terms & conditions appraisal, place purchase order, manufacture and deliver of the Priority 1 Long Lead Equipment
- Train 1 Equipment Installation
- Train 1 Piping Installation and Testing
- Train 1 Painting and Insulation
- Train 1 Punch Clearance and Mechanical Completions
- Train 1 Commissioning and Acceptance Testing Activities

1.2.4.3 National Grid

The National Grid programme currently shows only the tender process, contract award and the commissioning of each area through to the compressors on the critical path. This is due to the availability of CO₂ from Longannet Power Station for commissioning purposes.

The critical path runs through the mechanical design, specifications and order of the compressor package; construction of the compressor building and subsequent installation and commissioning of the compression system.

1.2.4.4 Shell

The primary critical path for Shell nominally runs through drill-workovers, subsea installation, topsides modifications and commissioning. However the programme shows seven months float in the availability of
CO₂ for testing and commissioning and the critical path runs through commissioning activities after the gas is available for pre-commissioning testing.

### 1.2.5 Overall Project Programme Description

The following section details Partner specific activities that should be acknowledged in the context of the Overall Project Programme.

#### 1.2.5.1 ScottishPower

**Longannet Power Station – Implementation of NOₓ reduction technology**

At present, the Longannet Power Station (LPS) is capable of meeting the 500 mg/Nm³ emission limit for NOₓ as described in the Large Combustion Plant Directive (LCPD). ScottishPower is currently developing its plans to retrofit abatement technologies to Units 1, 2 and 3 to meet the planned future NOₓ emission limit reduction to 200 mg/Nm³ which is scheduled to be implemented in the LCPD by the end of 2016. The UK Government recently indicated that it intends to extend the deadline for implementation of these reduced NOₓ limits until 2019. ScottishPower will make a final decision on NOₓ Reduction Technology (NRT) once deadlines are confirmed. NOₓ Reduction Technology will therefore not necessarily be installed and operational at LPS prior to commissioning the UKCCS Demonstration Project.

**Longannet Power Station – Implementation of supercritical power plant**

The UKCCS Demonstration Project requires demonstration of CCS on a supercritical power plant. The option to implement a new supercritical power plant at the Longannet site and capture some of the CO₂ in its flue gases using CCS was considered during development of the Outline Solution. The investment environment for new coal-fired generation is unclear. Investment in supercritical plant at Longannet will be reviewed when market conditions are clarified. Further detail on this decision is provided in section 5 of this report.

**Longannet Power Station – Furnace bottom ash lagoons**

The permitting required for increase in capacity of the existing Longannet Power Station ash lagoons, associated with the extension of the operating life of Longannet Power Station, is in progress. ScottishPower intend to complete this work prior to starting construction of the Longannet portion of the End-to-End CCS chain.

**Longannet Power Station – Relocation of outage contractor’s compound**

ScottishPower intend to relocate the existing Longannet outage contractor’s compound prior to starting construction of the Longannet portion of the End-to-End CCS chain since this compound presently lies within the area at LPS which has been chosen for the CCS project location.

#### 1.2.5.2 National Grid

National Grid requires a 6-month mobilisation period following the effective EPC award start date. This is required to ensure that the design teams can be appointed and have time to develop the required CO₂ and project-specific knowledge, and to allow work that has been dormant since the closure of FEED to be restarted. Some of these activities are outlined below:

- Ground investigation work on the Firth of Forth crossing, including an over-water Borehole Survey (and consent from Forth Ports & Marine Scotland) and a Mine Probing Survey;

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- Outstanding Environmental Impact Assessment activities required across the study area due to impeded and late access during the 2010 survey seasons. This work includes Phase One Habitat Surveys, Bat Surveys, Amphibian Surveys and Badger Surveys. Further assessments may also be required for other environmental aspects, depending on refinements to the project design prior to detailed design;

- Engineering and design activities required to provide the design specifications and procedures necessary for detailed design to commence. National Grid will need to perform preliminary design and engineering work on the No. 10 Feeder disconnections to produce a Conceptual Design Report. Work on the rationalisation of the No. 10 Feeder Block Valves is required to optimise and confirm the number of Block Valves, and associated spacing, that will be required; and

- Development of the power supply assessments for the Blackhill Compressor Station and further consultations with Scottish & Southern Energy to ensure a 132kV connection can be provided within the project timescales.

The expectation is currently that National Grid will place separate contracts for the Engineering and the Construction of the new pipeline and No. 10 Feeder works.

The high-level strategies adopted for the Onshore Transportation System infrastructure work packages have been identified to reduce interfaces, gain efficiencies, and increase leverage during negotiations:
- Blackhill Compression Facilities (Integrated Design and Build)
- New pipeline, Forth river crossing, Above Ground Installations (AGIs), and No. 10 Feeder modifications (Detailed designs to be tendered separately prior to Main Works Contractor construction activities)

The strategies outlined herein build upon extensive experience gained through utilising varying contracting strategies for past gas pipeline and compressor schemes. As such they are broadly consistent with the latest thinking that is applied within National Grid for capital schemes.

For the Blackhill Compression Facilities, the proposed contract strategy is integrated design and build and has been based on the following:
- Risks / liabilities can be passed through to a single Main Works Contractor
- Single point of responsibility for interfaces (process and third party with Shell / ScottishPower
- Dependable Programme
- Reduced interfaces (‘one stop shop’)  
- Reduced procurement activity and associated programme impact
- Better continuity and cost certainty
- Promotes wider competition, complemented by existing ‘approved’ Main Works Contractors with in-house design capability

For the new pipeline, Forth river crossing, AGIs and No 10 Feeder modifications, the proposed contract strategy is to complete the detailed design stage (through a spot tender) prior to tendering separately for construct only (potentially in lots / multiple fronts for the No 10 Feeder modifications to incorporate greater flexibility to meet project deadlines) and has been based on the following:
- There is limited competition in the comparatively low value design activity compared with the higher value construction activity. Therefore disaggregation of the two should enable greater competition to be
leverage in tendering for the construction activity. This promotes more competitive commercial tension and more robust Main Works Contractor costs (based on detailed designs).

- Improved forecasting / more influence on outturn costs (avoiding overspend and re-sanctions)
- Fit for purpose designs (as oppose to ‘preferential engineering’)  
- More cost effective (no fee on fee, etc.)
- Direct contractual relationship with Design House (warranty of design liability)
- More control in design process provides greater clarity / accuracy of costs

Detail design for the new pipeline is currently scheduled to last approximately 12 months and it is estimated that this would be the minimum period required. This timeframe has the potential to increase dependant upon information that will be received from the contractor who will be undertaking the design element. The detail design of the AGIs for the new pipeline will take approximately 15 months. The detail design for the No. 10 Feeder is currently expected to be 7 months. The disconnections, modifications to existing Block Valves and pipeline diversions detail design is expected to be complete within 6 months, with the new Block Valve installations and multi-junction modification taking 7 months. The man-hour estimates and peak engineering manpower requirement will be assessed once the detail design period has been finalised. The detail design for the compressor station is expected to have a duration of 15-16 months (not including any construction support and/or built work that will be required throughout construction).

During the detail design phase, additional long lead procurement item requirements will be identified and all procurement lead times will be confirmed and amended (where necessary). Currently, procurement of long lead items already identified show that orders for items such as the compressor units and the pipe lengths need to be placed approximately 6 months into the detail design stage. Orders for the new valves and related equipment for the Block Valve modifications along No. 10 Feeder are expected to commence after 2-3 months of detail design.

It is anticipated that advance works and mobilisation construction of the new pipeline will commence 10 months (April 2013) after the award of the detail for the required surveys, access preparations and all associated temporary works. The main pipeline construction activities will not start until March 2014 as there is insufficient time to construct the pipeline in the 2013 seasonal window. This is due to the additional period required to complete the design following the inclusion of the mobilisation period in the programme. The construction of the new pipeline is expected to be completed before the end of September 2014, with the exception of the tunnel crossing of the Firth of Forth. This crossing will have a duration of 15-18 months for construction, with an expected finish date of October 2014, the pre-commissioning of the new pipeline can commence once this crossing is complete.

The initial activity to be completed to enable construction / modifications to proceed on the No. 10 Feeder is to disconnect the pipeline at various locations along the route. The expectation for this work is to perform 3 cleaning runs and isolate / recompress the required sections during the mobilisation period to allow the disconnections to be made December 2012 – June 2013.

The construction required along the No. 10 Feeder pipeline consists of modifications to 13 existing Block Valve sites, insertion of a Block Valve at an existing multi-junction AGI, construction of 3 new pigging stations and a new block valve AGI. The modifications of the Block Valves (and new Block Valve) are scheduled to be completed by 3 teams working in parallel with each completing work on 5 sites one after the other. Each team will commence work in August 2013, completing construction / modification of their final site in September 2014. The final works to be done are at a multi-junction and a pigging station, and
are expected to be completed in November 2014. Upon completion of this work, pre-commissioning activities for the No. 10 Feeder pipeline can commence.

Mobilisation for the compressor station construction is scheduled to start 8 months after detail design for enabling works and site establishment. Construction of piling, foundations and other civil works are expected to start around December 2013, followed by steelwork, building erection and installation of ancillary equipments with a view to placing the compressor units into the buildings in September – October 2014. Tie-ins and electrical / control & instrument installation are expected to finish March 2015, after which pre-commissioning can commence.

1.2.5.3 Shell

Subject to discussions with DECC, Shell plans to conduct their own governance activities in the period between the end of FEED and the project contract award. This will be primarily creation of the Invitation to Tender (ITT), issue and evaluation of tenders for design and execution contracts and activities associated with value assurance processes. Further subsurface studies, surveys, commercial and regulatory activities will also feature during this time.

Upon award of the contract on the 5th January 2012, detailed design will commence. It will take 12 months with a peak engineering workforce of 40 (this includes a 6 month mobilisation period with detailed design commencing on the 5th July 2012). Simultaneously, site visits will be conducted to familiarise and validate design assumptions. Site access and other logistical issues will be further defined during these visits. Any additional long lead items will be identified during this detailed design phase and those identified earlier confirmed. Enquiries for procurement of these long lead items should start approximately six months after EPC start. All long lead items are available within 12 months except for drilling tubulars at 18 months and jack-up rig which requires 24 months notice. The jack-up rig will not require pre-FID commitment unless there is an improvement to the availability of CO₂ date or if rig availability in the market tightens to a critical point, in which case an earlier commitment is warranted.

ITT and contract documents for the various major contracts including onshore construction and control room modifications at St. Fergus, offshore modifications on Goldeneye, subsea remote operating vehicle (ROV), and drilling will be prepared to allow for a construction start in July 2013. The onshore works at St. Fergus will be the first to commence after decommissioning and flushing of the Goldeneye hydrocarbon lines, starting with pipeline construction around the St. Fergus perimeter. The pipeline which is about 1.4 km, is buried and requires Ministry of Defence (MoD) permission to burrow under security fencing. A new pig launcher (possibly designed by Shell) will be installed by National Grid.

Four months of drilling workovers will follow over the 5 injection wells. As it is not possible to schedule drilling and other work simultaneously in the well bay, other work can only be performed after the well workovers have been completed. There is however an overlap where work is possible on the filtration unit, pig receiver replacement and structural modifications, these situated away from the well-bay. As a base case, accommodation will be provided by the drill rig which will be contracted to remain after the well workover work is complete. The other options available are to utilise the DSV accommodation and a flotel for the remaining topsides work, effectively de-linking the jack-up rig for accommodation purposes. As a parallel activity to the topsides work, the DSV contractor commences installation of the new SSIV, spools, umbilical and all subsea work. Leak testing will be done in stages owing to the different pressures involved.
CO₂ will be available from National Grid on the 4\textsuperscript{th} April 2016 for pre-commissioning and acceptance testing which requires 3 months. CO₂ injection follows on the 6\textsuperscript{th} June 2016. Depending upon reservoir performance, activities following first injection may include the sidetracking of up to 4 wells to improve flow conditions halfway through the injection life. Following 10 to 15 years of injection service, the platform and facilities are expected to be decommissioned by 2029, and the injection wells abandoned.

1.2.6 Resource Requirements for the Implementation Phase of the Project

The Implementation phase of the project can be sub-divided into the following:

- Detailed design (including procurement)
- Construction
- Commissioning
- Operations

The Consortium have developed the following high level resource estimates for the implementation phase of the project. The resource estimates capture the peak manning requirements for each project Partner but not the total requirements. The estimates are based on information developed during FEED and experience from other large construction projects.

<table>
<thead>
<tr>
<th>Project Partner</th>
<th>Detailed Design</th>
<th>Construction</th>
<th>Commissioning</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>ScottishPower</td>
<td>280</td>
<td>920</td>
<td>80</td>
<td>50</td>
</tr>
<tr>
<td>National Grid</td>
<td>200</td>
<td>450</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Shell</td>
<td>100</td>
<td>170</td>
<td>10</td>
<td>14</td>
</tr>
</tbody>
</table>

These estimates will be refined further as the project begins the implementation phase and the Consortium has a more informed view of the project requirements.
2. FEED Cost

This section of the report contains a high-level monthly summary of the total costs incurred performing the ScottishPower CCS Consortium’s FEED study. This information is provided with the aim of enabling potential developers of CCS projects to estimate up front FEED costs.

A detailed cost breakdown is also provided for each of the key parties within the Consortium in the form of Cost, Time and Resource (CTR) information in Appendix B of this report, under the following references:
- UKCCS - KT - S1.0 - SP - 001 ScottishPower CTR Summary
- UKCCS - KT - S1.0 - ACC - 001 Aker Clean Carbon CTR Summary
- UKCCS - KT - S1.0 - NG - 001 National Grid CTR Summary
- UKCCS - KT - S1.0 - Shell - 001 Shell CTR Summary

The detailed CTR information provides a breakdown of the actual labour effort used for the totality of the FEED scope of work, presented by month and by CTR activity, the type of expertise used, the number of hours worked and the associated costs. The split between internal and external costs is shown, together with the original budget estimates developed for each CTR prior to commencing FEED.
2.1 Cost Summary

This section of the report consolidates provides a consolidated summary of the detailed cost information for each of the key parties within the Consortium. The ScottishPower scope is split between ScottishPower Management (the Consortium lead team) and ScottishPower Longannet (the carbon capture design team where Aker Clean Carbon were principal contractors).

2.1.1 FEED Budget

The original budget for the ScottishPower Consortium FEED study was £40m, this was split amongst each of the key parties as shown diagrammatically in Figure 2.1-1:

Figure 2.1-1: FEED Budget

2.1.2 FEED Actual Cost

The cost for the totality of the FEED scope of work was £38.6m. The cost split amongst the key parties is represented diagrammatically in Figure 2.1-2:

Figure 2.1-2: Actual Costs
2.1.3  Hours Expended

The total number of hours spent during the totality of the FEED scope of work was 393,544. The split amongst the key partners is represented diagrammatically in Figure 2.1-3:

![Figure 2.1-3: Hours Expended](image)

2.1.4  Monthly Summary

The monthly hours and cost split for each organisation are summarised in Table 2.1-1.

<table>
<thead>
<tr>
<th>Month</th>
<th>ScottishPower Management</th>
<th>ScottishPower Longannet</th>
<th>National Grid</th>
<th>Shell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours</td>
<td>Costs (£000s)</td>
<td>Hours</td>
<td>Costs (£000s)</td>
</tr>
<tr>
<td>Feb-10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mar-10</td>
<td>819</td>
<td>38</td>
<td>1,212</td>
<td>158</td>
</tr>
<tr>
<td>Apr-10</td>
<td>3,292</td>
<td>220</td>
<td>3,989</td>
<td>507</td>
</tr>
<tr>
<td>May-10</td>
<td>3,580</td>
<td>248</td>
<td>4,578</td>
<td>549</td>
</tr>
<tr>
<td>Jun-10</td>
<td>4,169</td>
<td>285</td>
<td>6,293</td>
<td>687</td>
</tr>
<tr>
<td>Jul-10</td>
<td>5,480</td>
<td>380</td>
<td>9,345</td>
<td>862</td>
</tr>
<tr>
<td>Aug-10</td>
<td>4,942</td>
<td>335</td>
<td>9,774</td>
<td>886</td>
</tr>
<tr>
<td>Sep-10</td>
<td>5,663</td>
<td>407</td>
<td>10,304</td>
<td>910</td>
</tr>
<tr>
<td>Oct-10</td>
<td>6,839</td>
<td>463</td>
<td>15,606</td>
<td>1,381</td>
</tr>
<tr>
<td>Nov-10</td>
<td>6,390</td>
<td>437</td>
<td>13,753</td>
<td>1,227</td>
</tr>
<tr>
<td>Dec-10</td>
<td>5,958</td>
<td>429</td>
<td>11,433</td>
<td>1,025</td>
</tr>
<tr>
<td>Jan-10</td>
<td>5,750</td>
<td>388</td>
<td>9,305</td>
<td>868</td>
</tr>
<tr>
<td>Feb-10</td>
<td>6,445</td>
<td>424</td>
<td>7,799</td>
<td>849</td>
</tr>
<tr>
<td>Mar-11</td>
<td>8,076</td>
<td>568</td>
<td>1,309</td>
<td>110</td>
</tr>
<tr>
<td>TOTAL</td>
<td>67,403</td>
<td>4,622</td>
<td>104,699</td>
<td>10,019</td>
</tr>
<tr>
<td>BUDGET</td>
<td>53,660</td>
<td>4,856</td>
<td>100,471</td>
<td>10,020</td>
</tr>
<tr>
<td>Budget Variance</td>
<td>+13,743</td>
<td>-234</td>
<td>+4,228</td>
<td>-1</td>
</tr>
</tbody>
</table>

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2.2 Observations

This section provides commentary on the monthly spend profile incurred by the Consortium throughout FEED, highlighting key areas of variance against original budgets and manpower estimates.

The monthly spend profile for each Consortium Partner and Aker Clean Carbon is presented in Figure 2.2-1.

**ScottishPower Management**

The ScottishPower monthly spend generally followed a linear profile throughout FEED. This was principally due to the fact that ScottishPower were responsible for the management of the End-to-End design and coordination of monthly reporting activities, which required a steady level of resource over the duration of the project.

The highest costs were incurred at the end of FEED (February/March), as at this time, efforts were being made to finalise the FEED design deliverables and prepare the knowledge transfer documents which are included in the appendices of this report.

The ScottishPower FEED costs came in £0.3m below budget. This was principally due to cost savings made against the Environmental Impact Assessment work and a less than predicted spend against the Project Management Office CTR allowance. This was largely offset by additional spend on the technical scope and engineering assurance resource.
The split between internal and external labour costs for ScottishPower was 12%:88%, showing that ScottishPower outsourced the majority of the work. This was principally through the following sub-contractors:

- Iberdrola Engineering and Construction – Engineering Assurance
- Mott MacDonald – End-to-End CCS Chain Integration and Project Management support
- McGrigors – Legal/Commercial support
- Accenture – Development of the Knowledge Transfer solution

A detailed CTR breakdown for ScottishPower is provided in Appendix B with the following reference:
- UKCCS - KT - S1.0 - SP - 001 ScottishPower CTR Summary

ScottishPower Longannet

The ScottishPower Longannet monthly spend peaked in October 2010. A peak was always expected at this point as the majority of the work was to be completed mid project. However, labour costs were more back ended than originally planned as a result of design decisions and changes that were agreed during FEED, such as definition of the CO2 specification for the Onshore Transportation System and the finalisation of the SPS requirements. This impacted on the schedule and resulted in additional resources being spent from October to December in order to maintain the FEED completion date.

Despite having to incorporate these changes into the Longannet FEED scope, this was balanced by other elements of the FEED scope which were originally anticipated but were identified as not being required early in the FEED process.

The split between internal and external labour costs for Aker Clean Carbon was 87%:13% showing that Aker Clean Carbon completed the majority of the work in-house. The principal Aker Clean Carbon subcontractor was Mott MacDonald who were responsible for the Longannet site integration design work.

A detailed CTR breakdown for Aker Clean Carbon is provided in Appendix B with the following reference:
- UKCCS - KT - S1.0 - ACC - 001 Aker Clean Carbon CTR Summary

National Grid

The National Grid monthly spend illustrates the time taken during the first few months of FEED to effectively mobilise the Design House (AMEC) and to establish a robust financial reporting system that enabled the efficient collation of costs and subsequent reporting thereof. The spike in costs during October was the result of accruals for work undertaken during August and September to bring the National Grid programme back on track following early delays in mobilising the design team.

National Grid FEED costs were £0.3m over budget. This was principally due to effort required in March 2011 to finalise cross Consortium FEED documents, which resulted in a requirement to maintain resources beyond the period initially anticipated, increasing associated man hours and costs.

National Grid’s approach to managing works of this nature is to outsource the bulk of activities to specialist organisations. The split between internal and external labour costs for National Grid was 21%:79%, illustrating this strategy. National Grid had a large number of sub-contractors working on FEED, but two of these played a major role and attributed for a significant proportion of the overall cost. These organisations were:

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Rhead Group – Design Coordinator
AMEC – Principle Design House

A detailed CTR breakdown for National Grid is provided in Appendix B with the following reference:
- UKCCS - KT - S1.0 - NG - 001 National Grid CTR Summary

Shell

The Shell spend profile generally increased throughout FEED and peaked in October 2010. In February 2011, a minor peak resulted from a post-holiday ramp-up, both to complete work and to participate in a full technical review of the project. The Shell spend profile then progressively reduced towards achieving final completion in March 2011.

Shell FEED costs were £1.0m below budget. This was principally due to lower than planned external spend. Some of the external contracts were either reduced or deleted after parallel results from in-house engineering negated their use. Various workshops, such as meetings to discuss subsurface issues, were not required and contributed to the under spend. Shell internal manhour costs were greater than planned due to the transfer of external contracts.

A detailed CTR breakdown for Shell is provided in Appendix B with the following reference:
- UKCCS - KT - S1.0 - Shell - 001 Shell CTR Summary

Other Costs

Costs other than labour costs have been identified in the CTR breakdown where this information was readily available. However expenses have generally not been broken out separately from the totals as they are considered negligible in comparison to the overall labour costs. For example, ScottishPower Management expenses were less than 3% of their overall FEED costs.
3. Design

This section of the report provides details on the organisation and management of the design as well as key design information for the End-to-End CCS chain. This includes the following:

- Organisation of the design teams
- The End-to-End Basis of Design
- The design life
- The End-to-End CCS chain process
- Piping and instrumentation diagrams
- Plant and site layout drawings for the various sites
- Equipment
- Plant and equipment specifications
- Subsurface engineering design reports

No attempt has been made to generalise design data. All of the design information presented is specific to the ScottishPower CCS Consortium Project and has been presented to provide an insight into the development of the End-to-End CCS solution.

The FEED design study was based on the Outline Solution developed by the ScottishPower CCS Consortium prior to FEED. The Outline Solution was a conceptual design for the End-to-End CCS chain that was considered to be technically feasible within the constraints of the knowledge available at the time. It included a series of optioneering studies to identify the preferred design for this particular project. During FEED, the Outline Solution design was developed in greater detail to reduce the cost and technical uncertainty, and consequently reduce the financial, programme and technical risks prior to commencing the implementation stage of the project.

It must be stressed that a FEED study is carried out to develop a design to a degree that the technical and programme risks are reduced to the agreed limits to better inform the project cost estimate. The current status is that the design has been progressed as far as is practicable within the time and cost constraints of the FEED study. Specifications and datasheets for major equipment have been developed in order that they can be issued to potential suppliers during the implementation phase of the project. The FEED study identified further activities that cannot be performed at the FEED stage of the project but which have been recorded as actions for further investigation during the implementation stage.

The FEED study has advanced the development of the application of CCS technology considerably. Though research and conceptual studies are essential to the development of any new technology, they cannot identify many of the difficult design issues that are identified and addressed during a FEED study. Similarly the progress from FEED to the implementation phase is expected to present further challenges for a project of this novel nature. However, the advantage of a FEED study is that the main issues that could present high cost or programme difficulties or even potential “show stoppers” should already have been identified and, where possible, addressed. Key decisions and design changes taken during the FEED study are explained in Section 11 of the report.
3.1 **Organisation of the Design Teams**

From the outset of the UKCCS Demonstration Project, the ScottishPower CCS Consortium identified that the correct organisation of the various design teams would be one of the key factors in achieving successful implementation of the project.

The key challenge was ensuring that design teams from a number of large organisations, each with their own histories, technologies, regulations, drivers and company cultures, could work together to produce a consistent and robust design for the End-to-End CCS chain. In particular, each Partner is used to being the end customer or project design lead. This is generally not a problem for companies from similar fields working together where design philosophies are similar, but, attempting to achieve an overall standard by applying oil industry design practice to the power industry or vice versa is problematic. However, all Partners agreed there were great advantages to applying best practices from each industry across the CCS chain while retaining their own well proven standards, practices and procedures within their own elements of the CCS chain.

To meet these aims the design teams were organised as follows:

3.1.1 **The Consortium Design Authority**

A Consortium Design Authority (CDA) was set up compromising the design leads from each of the Consortium Partners, namely ScottishPower, National Grid and Shell, plus the carbon capture technology provider Aker Clean Carbon. The CDA met once a month or additionally as and when required.

The CDA was responsible for taking any technical decisions that were raised by the Consortium's Technical Steering Group (TSG) as being technically difficult or contentious for the Consortium, as having a major financial impact, or where agreement could not be reached within the TSG. The CDA also had responsibility for approving and signing off the End-to-End CCS chain deliverables.

3.1.2 **The Technical Steering Group**

The TSG comprised of the members of the CDA together with technical leads and other nominated representatives from the Consortium. In addition, one member from the commercial workstream was present to ensure information transfer and coordination between the technical and commercial work streams. Other technical experts were invited to individual meetings as required.

The TSG met by teleconference on a fortnightly basis. Once each month the teleconference was replaced by a face-to-face meeting. Additional meetings or teleconferences were arranged as required.

The TSG was responsible for agreeing all cross-Consortium technical matters that did not need to be forwarded to the CDA for formal approval. It was the forum for raising and agreeing any technical matters that were End-to-End chain or impacted upon other members of the Consortium. The TSG was also the means of disseminating key technical knowledge across the Consortium. It was the responsibility of the TSG members to feed back the results of the discussions and agreements to their respective design teams.
3.1.3 **The Individual Design Teams**

Each Consortium Partner was responsible for setting up and managing their own design team for their scope of supply. It was the responsibility of the Partner design teams to arrange meetings between themselves as appropriate to cover interface matters. Health and safety considerations required formal interface meetings to cover areas such as the Formal Process Safety Assessments (HAZID, HAZOP).

3.1.4 **Engineering Assurance Teams**

Each Consortium Partner had an engineering assurance team\(^6\) to review and check the output of their design team. The engineering assurance role was performed by either an in-house engineering team or by a subcontracted engineering team.

3.1.5 **End-to-End CCS Chain Integration Engineering Team**

A small team of engineers were employed to oversee the integration of the various design activities as well as providing an End-to-End oversight. This was to ensure that the project produces an integrated End-to-End solution for the UKCCS Demonstration project. The core of this team worked on the project from the development of the Outline Solution - ensuring continuity through each stage of the project and across the CCS chain.

\(^6\) The Engineering Assurance role is performed by an Owners Engineer in the generation industry
3.2 End-to-End CCS Chain Basis of Design

3.2.1 Outline Solution End-to-End CCS Chain Basis of Design

An End-to-End CCS Chain Basis of Design document was developed during the Outline Solution phase of the project. This was based on the best available data at the time and summarised project design data utilised by all Consortium Partners at the commencement of the FEED study. It was developed on the basis of the minimum necessary requirements so as not to constrain designers with requirements that may later prove to be unnecessarily onerous in the light of the FEED study.

The End-to-End Basis of Design as developed at the start of FEED is included within Appendix C.1.1 under the following reference:
- UKCCS - KT - S7.2 - E2E - 001 Outline Solution End-to-End Basis of Design

3.2.2 Post-FEED End-to-End CCS Chain Basis of Design

This document was developed from the Outline Solution End-to-End CCS Chain Basis of Design and defines indicative key project design data and criteria, and the process conditions at the principal interfaces between the various Partners’ scopes of responsibility. Consequently it provides potential developers with the basic design of a large scale CCS system. It incorporates the lessons learned during FEED and includes changes to data that were identified as design requirements during FEED. It does not define the basis of design for individual plants or parts of the CCS chain.

Each Consortium Partner was responsible for the design of the individual capture, transport and storage aspects of the overall CCS chain. However, it was necessary to produce an End-to-End Basis of Design document which would concentrate on presenting both the design aspects which encompass the entire chain (such as operations and control) and also design interfaces across the CCS chain. The interfaces could impact on the downstream and/or upstream chain elements. This document is therefore being utilised as a tool to develop and maintain the integrity of the overall CCS chain design and to try and ensure that the desired CCS chain performance will be achieved by the integration of the individual Consortium Partners' designs.

As detailed in the End-to-End Basis of Design document, it is proposed that the CCS chain will be set up as a network arrangement with currently one feeder and one offtake rather than as a single unique point-to-point system.

The End-to-End Basis of Design document is also a means of identifying any design standard issues and areas where there are potential differences in design approach between sectors (e.g. generation vs. gas transportation vs. offshore oil and gas) and also between legal and regulatory requirements since the same standards and regulatory frameworks are not applied universally across the entire CCS chain.

Lastly, as the project has moved from the Outline Solution stage into FEED, there were a number of areas where there were known disconnects across the CCS chain design - for example the initial estimate of the purity of CO₂ which would be produced by the CCP was lower than the first estimate of the required CO₂ purity for the onshore and offshore pipelines (which both had their own particular requirements) and the injection wells. During FEED, the End-to-End Basis of Design document has been used to track and, where possible, resolve these issues prior to the implementation phase of the project.
The Post-FEED End-to-End CCS Chain Basis of Design is included in Appendix C.1.2 under the following reference:
- UKCCS - KT - S7.1 - E2E - 001 Post-FEED End-to-End Basis of Design

Section 5 of this report contains a summary of the design changes that have occurred during FEED. This outlines some of the key differences between the Outline Solution and Post-FEED End-to-End Basis of Design.

3.2.3 Design Life

The contract between DECC and the ScottishPower CCS Consortium stipulates that the End-to-End CCS chain shall permanently store 20 million tonnes of CO₂ in a minimum period of 10 years and a maximum period of 15 years. On this basis the design life of all equipment is taken as 15 years and this value is defined in the plant and equipment specifications.

Following the completion of operations, it is envisaged that the onshore equipment will be decommissioned.

At this stage, Shell’s preference for decommissioning of the offshore elements of the CCS chain would be early removal, but this is largely dependent upon the following variables:
- development of monitoring technology over the next 15 to 20 years
- The development of storage site monitoring legislation within the EU

The proposals for the post-operation period will be further developed during the implementation phase.
3.3 The End-to-End CCS Chain Process

3.3.1 Process Description

The following sections provide an overall process narrative that includes:

- A process description of the overall End-to-End CCS chain solution
- A process description of each section of the CCS chain
- A process description of the heat and power source to be provided to the capture plant from the steam and power (SPS) plant
- A process description of the integration between the power plant and the CCS chain and between each section of the CCS chain

The proposed CCS facility will capture and store the CO₂ from the existing coal-fired sub-critical units at Longannet Power Station (LPS). The carbon capture plant (CCP) will be connected to both Unit 2 and Unit 3 and will treat approximately 50% of the flue gases from either Unit 2 or Unit 3, but not both simultaneously.

Once captured, the CO₂ will be transported using new pipelines and existing National Grid and Shell infrastructure from Longannet Power Station to the Goldeneye reservoir in the North Sea.

For comparison, the Outline Solution process description is contained within the Outline Solution Basis of Design in Appendix C.1.1.

3.3.1.1 Sub-critical Coal Fired Power Plant

LPS comprises of four sub-critical pulverised coal fired units rated at 600 MWe each. The CCP will treat the flue gas from either Unit 2 or Unit 3, depending on which is operating, in order to maximise the CCS chain availability.

3.3.1.2 Flue Gas Clean Up

All four generating units at Longannet are equipped with Electrostatic Precipitators (ESPs) to comply with present emission limit values for particulates.

ScottishPower is currently developing its plans to retrofit abatement technologies to Units 1, 2 and 3 by the end of 2015 in expectation of compliance with the Large Combustion Plant Directive (LCPD) and the Industrial Emissions Directive (IED) which will be introduced in 2016. Sea Water Flue Gas Desulphurisation (SWFGD) will reduce the emissions of SOₓ to comply with the LCPD emission limit values and also with the SOₓ limits described in the IED. The SWFGD plants presently being installed on Units 1, 2 and 3 will be fully commissioned by the end of 2011 with a guaranteed SO₂ recovery of at least 90%. The particulate levels in the flue gas will also be further reduced after the SWFGD plants are installed.

The UK Government recently indicated that it intends to extend the deadline for implementation of the reduced NOₓ limits in the IED until 2019. ScottishPower intend that NOₓ Reduction Technology (NRT) will be installed to meet the future UK deadline when agreed.
Once operational, flue gases from the selected generating unit will be directed through the ESP, SWFGD and NRT plant before a portion of the flue gas is directed to the CCP.

### 3.3.1.3 Carbon Capture Plant

The CCP will be designed to capture at least 90% of the CO₂ in the flue gases diverted to the CCP.

Flue gases leaving the SWFGD Unit 2 or Unit 3 will be connected with isolating dampers to enable flue gases from either unit to be abstracted into the CCP through a single duct.

A 3D image of the CCP which displays some of the main process equipment is shown in Figure 3.3.1-1.

**Figure 3.3.1-1: 3D Image of the CCP**

![3D Image of the CCP](Source: Aker Clean Carbon)

**Direct Contact Cooler (DCC)**

The DCC is a flue gas polishing device, and the first process unit in the flue gas path through the CCP. The purpose is conditioning of the flue gas, before the flue gas enters the CO₂ absorber. The DCC system consists of a packed bed direct contact cooler, a liquid circulation system with cooling through a heat exchanger and an alkali make up system for pH control. The flue gas flows counter-currently to liquid in the packed bed, and acid gases such as SO₂, HCl, HF are efficiently removed by maintaining the pH in the circulating liquid close to 7. The flue gas pressure drop is less than 1000 Pa (10 mbar) through the entire DCC.

There are two main functions of the DCC:
1. Cool the incoming flue gas and saturate the gas. The gas leaving the DCC is water saturated at the desired temperature. The benefits from flue gas cooling are reduced re-boiler heat consumption and reduced emission of amines from the CO₂ absorber. The specific re-boiler duty is decreased because the temperature in the bottom of the absorber bed is lower with low inlet gas temperature, and higher rich loading is obtained. Higher rich loading reduces the amount of water vapour in the stripper overhead. The effect of a cold DCC is similar to the effect of absorber intercooling.

2. As far as practicable, remove impurities such as SO₂, SO₃, NO₂, HF, HCl and particles (fly ash, corrosion products, etc), that otherwise would enter the absorber and accumulate in the solvent. Such impurities have a detrimental effect on the solvent. SOₓ and NO₂ form heat stable salts (HSS) when reacting with the amine. Fly ash and corrosion products may leach metals into solution that potentially increase amine degradation through catalytic effects.

The flue gas leaving the tower is water saturated at practically the same temperature as the inlet water. The pH in the recycling DCC liquid loop is controlled by adding sodium hydroxide (NaOH). The pH shall be maintained close to 7. Below pH 6, the capture rate of SO₂ declines. The pH must be below 8 in order to avoid capture of CO₂ and formation of sodium bicarbonate, which would substantially increase consumption of Sodium Hydroxide (NaOH) and eventually result in precipitation.

The flue gas leaving the Seawater FGD is cold and has low water content due to the operation with relatively cold seawater. The treated flue gas is then reheated, before a portion of the gas is extracted into the CCP. The Direct Contact Cooler (DCC) cools the gas again, but increases the water content through evaporation of water into flue gas. The DCC is a net water consumer, and water makeup is therefore required. In addition, a slip stream bleed from the DCC circulation loop is required in order to remove sodium sulphate which is formed from the absorption of sulphur dioxide (SO₂) within the sodium hydroxide solution in the DCC.

Nitrogen monoxide (NO) will not be removed by the DCC and the removal rate of nitrogen dioxide (NO₂) is uncertain at present. For the estimation of the DCC effluent composition, it is assumed that NO₂ ends up as nitrite (NO₂⁻) and nitrate (NO₃⁻) in equal concentrations. This will be clarified during the implementation phase.

**Absorber**

The CO₂ Absorber is located downstream of the flue gas fan and is a rectangular concrete tower with internal lining. The absorber tower is approximately 60 m high. The internal footprint is dictated by the flue gas flow rate and concentration of CO₂ in the incoming feed gas. The flue gas vents via a new stack which also takes flue gas from the Steam and Power Supply (SPS) Plant and CO₂ from the relief and vent header.

The absorber comprises an absorber sump, gas inlet section, an absorption section and a conditioning section. The CO₂ absorption section shall ensure 90% of the CO₂ in the processed flue gas is captured.

The conditioning section above the absorption section contains wash steps to minimise amine slip and to cool the flue gas in order to control the water balance in the entire CO₂ capture plant. The wash sections remove any alkaline compound such as amines and ammonia in the flue gas which would otherwise pass to atmosphere.
CO₂ lean amine is fed to the top of the absorption section and flows downward through the absorber, counter-current to the flue gas, and ends up as CO₂-rich amine in the absorber sump in the bottom of the absorber tower. The liquid distribution and redistribution system ensure proper distribution of the amine, which is essential to achieve optimised energy performance of the process.

The liquid to gas ratio is carefully controlled to achieve the required capture rate with the highest possible rich loading of the amine in the bottom of the absorber. This reduces the specific re-boiler duty due to higher CO₂ partial pressure at the top of the stripper and consequently reduces the water evaporation into the stripper overhead condenser.

A demister is included at the top of the absorber to ensure no carry-over of amine droplets. The flue gas leaving the tower is water saturated.

Demineralised water make-up, condensate from the stripper overhead receiver and condensate from the CO₂ compressor intercooler knock out drums are routed to the wash systems, and a bleed is cascaded downwards through the tower, ending up in the amine solvent. The amount of demineralised water make-up will normally be close to zero.

At the bottom of the absorber, a sump is provided with sufficient volume to protect the downstream rich amine pump.

Sufficient instrumentation (level-, temperature- and pressure transmitters) is included to monitor and control the absorber. The amine circulation loop is controlled by flow control valves. The rich and lean amine pumps are fixed speed, with flow control by use of control valves.

Sampling points are included to enable gas and liquid sampling.

**Stripper**

The stripper unit is used to separate the CO₂ from the amine solution.

CO₂ rich amine solution is withdrawn from the absorber sump and pumped through the plate and frame type Lean/Rich Amine Heat Exchangers and into the Stripper by the rich amine pump. The design is optimised to give high heat transfer coefficients. Significant heat is removed in the rich amine in this exchanger, contributing to the energy efficiency of the plant. The rich amine flow control valve is placed on the discharge of the exchangers to ensure no vapour production within the exchangers. The rich amine flashes over the flow control valve resulting in two phase stream entering the Stripper. The Stripper distributor is designed for two phase inlet flow.

CO₂ is released by addition of heat and the amine solvent is regenerated in the Stripper. Heat required for the CO₂ stripping process is provided by condensing low pressure steam (~3.0 barg) in the re-boilers. The re-boiler duties, regulated by the stripper bottom temperature in order to achieve the specified lean loading, are controlled by control valves on the steam supply side.

The amine leaves the stripper as lean solution. The stripper operates such that the top temperature is the same as the rich amine inlet temperature. This will ensure optimal operating condition and low water content of CO₂ leaving the stripper and hence less energy required for the re-boilers.
The pressure in the stripper is controlled by capacity control of the downstream CO₂ compressor train. The stripper will operate at a positive pressure with a small pressure drop across the column. When operating the capture plant at reduced load it will be possible to reduce the operating pressure to enable use of lower pressure steam in the re-boiler. This may be an important feature to demonstrate, as the counter pressure from the LP turbine section decreases at reduced turbine load. CCP operation at lower steam supply pressure is then clearly attractive, even if the specific power consumption for the CO₂ compression increases.

Before leaving the stripper, the produced CO₂ is conditioned in order to minimise amine carry over to the stripper overhead condenser. The stripper condenser cools the CO₂ stream down to 30°C and condensed water is collected in the stripper overhead receiver where a portion is used to provide reflux to the stripper and a portion is re-used elsewhere in the CCP. The stripper overhead condensate is highly enriched with CO₂, which in turn improves the amine capture performance in the absorber conditioning section.

The amine solvent regenerated to CO₂ lean amine in the stripper process is transferred by the lean amine pump back to the CO₂ absorber via the Lean/Rich heat exchangers and the Lean Amine Cooler. Low temperature heat is rejected to the closed cooling water system in the lean amine coolers.

The solvent is optimised for minimising the steam content in the stripper overhead section, which in turn reduces the energy required for CO₂ stripping. This is achieved by the high (and close to equilibrium) CO₂ loading in the rich amine leaving the absorber bottom section.

**Amine Reclaimer**

The solvent in a CO₂ capture process will, over time, accumulate impurities absorbed from the flue gas and solvent degradation products. This may influence solvent characteristics such as density, viscosity, CO₂ capture capacity, etc.

In order to remove these unwanted components, a bleed from the main solvent circulation loop is withdrawn and fed to a thermal reclaiming unit. Acidic solvent degradation products are neutralised by addition of a base (NaOH) which recovers solvent components. The solvent is heated to its boiling point and water and other solvent components are boiled off and returned to the stripper column in the main solvent circulation loop. Non-volatile impurities and solvent degradation products are not boiled off, and accumulate in the Reclaimer System as reclaimer waste. When reaching a maximum reclaimer waste inventory, the reclaimer unit is emptied to a waste handling system.

The capacity of the reclaiming unit is dimensioned based on solvent degradation rates and reclaimer storage/inventory exchange frequency, as well as choice of operation mode.

Medium pressure steam will be required for the operation of the reclaimer module and the energy utilised will be recovered in the stripping process.

**Amine Filter**

In addition to the thermal reclamation, purification of the amine solution will be performed by filtration of the amine solution by continuous mechanical and activated filtration of a side stream by a filtration unit.
The filtration unit consisting of a pre-filter (upstream mechanical filter), a carbon bed (activated carbon filter) and an after filter (downstream mechanical filter) shall treat a side stream of the lean amine stream. The lean amine side stream will be taken downstream of the lean amine cooler, and the feed to the filter will be supplied by a Filter Feed Pump.

The pre-filter upstream of the activated carbon filter shall be designed to remove smaller particles, a 5 microns retention size is to be used.

The after filter downstream of the activated carbon bed shall be rated for larger particles, a 10 microns retention size is to be used.

There will be one filter package for each CCP train.

Relief and Vent Handling

A single common vent header is provided serving both trains of the CCP and CO2 compression systems at Longannet. This line is used to vent out-of-specification CO2 to the new stack during start-up or in case of down-stream plant failure (e.g. a compressor trip or a valve closure in the pipeline).

The vent system is designed to handle the full CO2 production rate from both trains simultaneously, vented from either the stripper overhead systems in the CCP or from downstream of the compression and drying systems. In the latter case, depressurisation of the CO2 may lead to very low temperatures in the vent header and to ensure adequate dispersion of the cold, dense gas from the top of the stack, the vented gas is mixed with the hot flue gas from the SPS plant.

Mechanical relief devices are used to protect equipment from over-pressure in the CCP and CO2 compression sections. All relief devices having the potential to discharge CO2 gas are connected to the main vent header and are therefore routed to the stack. Instrumented safety systems are also provided to reduce the likelihood of relief devices operating to the minimum practicable level.

Where feasible, equipment design pressures are selected to provide inherent protection. The stripper and re-boilers, for example, have a design pressure matching that of the steam supply, thus eliminating tube rupture as a potential source of over-pressure.

Amine-containing vents are limited to the low pressure storage tanks, reclaimer waste handling system, process drain tank and amine drain sump. All are intermittent vents, low in amine content, and are discharged to atmosphere at safe locations.

3.3.1.4 Steam and Power Supply Plant

The carbon capture and CO2 compression and conditioning plant require supplies of process steam and electrical power. In a new build power station it is anticipated that steam and electrical power will be obtained from the power plant itself. This option is not available for the ScottishPower Consortium CCS solution due to the technical design of the steam turbines at Longannet Power Station. Consequently an independent steam and power supply (SPS) plant is included as part of the CCP design.

The SPS consists of two gas turbine generator sets each equipped with a heat recovery steam generator (HRSG) fitted with supplementary firing. A back pressure steam turbine generator set is used to reduce the
steam pressure to the low pressure required by the CCP and generates further electricity to improve the overall thermal efficiency of the SPS. In addition a package boiler is installed.

The arrangement of the SPS was developed following a technical and economic analysis of various possible options. The particular problem of the Carbon Capture Plant is the high ratio of thermal energy demand in the form of steam compared with the electrical energy demand.

To accommodate the high thermal to electrical energy ratio, the SPS was sized such that the HRSGs supplied sufficient steam for normal operation. The auxiliary boiler will be used to supplement steam supply for peak demand and also to supply steam for starting up the CCP and maintaining it in the hot standby condition when the rest of the SPS is not operational.

Selection of a separate SPS for the CCP rather than integrating steam supply with the main power station was made on the basis of feasibility. Obtaining steam from a mature asset such as LPS would have involved unacceptable risks in the execution of the project. This arrangement is of particular relevance to older coal fired power stations where original design data may be limited. This arrangement could also help overcome the perceived problems of inadequate engineering resources worldwide for bespoke solutions for retrofitting to every individual power station and also the issues of warranty for major modifications to old plant.

**Natural Gas System**

The purpose of the natural gas Above Ground Installation (AGI) is to receive and condition the gas such that it is suitable for supply to the gas turbine generators, Heat Recovery Steam Generators (HRSGs) and the auxiliary boiler. The natural gas will be supplied to the AGI from the existing LPS high pressure supply from National Grid. The AGI will process the gas so as to supply the gas at a pressure of between 27 and 30 bara at a temperature with a minimum of 20°C superheat (based on the selected gas turbine) above the water or hydrocarbon dew point of the gas so as to meet the requirements of the downstream gas turbines.

The gas supply from the AGI will flow to each of the gas turbines via a coalescing filter. The coalescing filter is provided for final protection to remove liquid droplets from the gas stream. The coalescing filters are also provided with a knock-out pot for safe collection of any condensate. The piping system downstream of the coalescing filter is constructed from stainless steel to avoid any potential for corrosion products entering the gas turbine(s).

The gas turbine supply gas train includes a block and vent configuration which acts to isolate and vent the gas supply to the gas turbine on a shutdown or trip. The gas train also includes flow measurement to enable plant performance monitoring.

The gas from the AGI is also supplied to the HRSGs for supplementary firing and subsequent steam generation and to the auxiliary boiler for steam generation. The pressure reduction station reduces the pressure of the incoming gas to both the HRSGs and the auxiliary boiler. The target pressures are less than 7 barg and less than 0.4 barg respectively. This skid will include dual redundant pressure reduction systems each of which will comprise of 2 gas pressure regulating valves, over pressure slam shut valve and relief valve. Redundancy of equipment will be provided by utilisation of different set points for each of the pressure regulators. The gas pressure to the auxiliary boiler is anticipated to be of the order of 500 mbarg. A further dual redundant pressure reduction skid, similar to that described above for the HRSG, is provided to condition the gas for supply to the boiler.
The gas lines to each HRSG and to the auxiliary boiler are also provided with a fire valve to isolate the gas supply in the event of a fire.

**Gas Turbines**

The gas turbines for the SPS plant will be natural gas fired. At base load conditions and reference site ambient conditions each gas turbine generator will have the capability of generating circa 47 MWe of electrical power output at 50Hz. The power will be generated at a voltage level of 11kV by an AC generator.

The gas turbines generator packages will be installed within their own enclosure. To provide the CCP process steam requirements, both gas turbines be required to operate continuously at base load. The gas turbines will have the facility to operate at reduced load but turndown will be restricted by the allowable emissions levels to atmosphere. At base load and reference ambient conditions the gas turbines will generate hot flue gas at a temperature of circa 544°C. From each gas turbine the hot flue gas flows to a common plant stack which is located between the gas turbine exhaust gas discharge and the inlet to the associated HRSG.

**Common Plant Stack**

The common plant stack, which includes a modulating damper, acts to either divert the turbine exhaust gas to atmosphere or direct the gas towards the HRSG inlet. By providing the facility to divert all or part of the turbine exhaust gas to atmosphere the plant is provided with the capability to generate power from the Gas Turbines while controlling the flow of exhaust gas to the HRSG and subsequently the quantity of steam generated. The common plant stack, which is provided as part of the CCP, is a multi flue configuration through will receive exhaust gas and vented CO₂ from the CCP, and exhaust gas from the SPS plant.

The common plant stack will be of significant benefit during start up operations when power and steam demands are imbalanced.

**Heat Recovery Steam Generators**

Under normal operating conditions, the flue gas from the two gas turbines flows to the associated HRSG where the heat from the flue gas is used for steam generation and then to the common plant stack. The HRSGs are both single pressure horizontal gas path units with supplementary firing capability. The HRSGs each generate HP steam at 26 barg nominal pressure and 325°C. If required, the gas turbine flue gas can be diverted directly to the common plant stack.

As the flue gas flows through the HRSG heat is provided to various sections of heat transfer piping. These sections include superheater sections for superheating the steam from the high pressure (HP) steam drum, evaporator sections for heating the HP steam drum and economiser sections for preheating of the inlet boiler feed water.

Feedwater will be supplied to the HRSG packages from a common deaerator by a set of boiler feedwater Pumps. Each HRSG package will include a feedwater piping system comprising a boiler feedwater control valve, flowmeter and all necessary isolations for system maintenance.
From the feedwater piping, the feedwater will flow to the HP steam drum via the economiser. The HP steam drum, which is connected to the HRSG evaporator piping sections, is provided for hold-up of boiler feedwater and for generation of saturated steam. The HP steam drum will include all necessary instrumentation for drum level control and boiler trip and will be provided with an appropriate relief valve for over pressure protection.

From the HP steam drum the saturated steam will subsequently flow to the discharge steam piping via the HRSG superheater which acts to raise the steam temperature. The superheater section of the HRSG also includes a de-superheater spray for injection of boiler feedwater for final steam temperature control. The subsequent HP steam piping will include a steam flowmeter, start up vent, non-return valve, boiler motorised stop valve, over pressure relief valve and appropriate isolations.

The HRSG steam drums and associated feedwater piping will be dosed with various water treatment chemicals. The selected chemicals could potentially include sodium phosphate for pH control, carbohydrazide as an oxygen scavenger and amine for corrosion protection.

Each HRSG is also provided with a blowdown system. Continuous and intermittent blowdown from the HRSG is discharged to an atmospheric blowdown tank where it is cooled directly with potable water prior to discharge to a blowdown sump. The blowdown tank will also receive condensate and flash steam from adjacent steam trapping systems and warm up lines. The flash steam is discharged to atmosphere at a safe location via a suitable vent.

Steam Turbine Generator

The steam turbine will receive HP steam generated from each HRSG. The turbine will reduce the HP steam (24 barg and 320°C allowing for HP steam header temperature and pressure losses) to LP steam at the exit of the steam turbine. Discharge steam conditions at base load steam turbine operating conditions will be circa. 165°C at 5.3 bara. This provides a degree of margin for subsequent supply of steam to the CCP at a nominal pressure of 4.8 bara and a temperature of 160°C. At reduced steam turbine load the discharge steam temperature will be higher and will require de-superheating to meet the requirements of the CCP. The steam turbine will produce additional electrical power at 50 Hz driving an 11kV generator.

High Pressure (HP) Steam

HP steam from each of the HRSGs is either routed to a common HP steam header which subsequently supplies the Steam Turbine or via bypass Pressure Reduction De-superheater Stations (PRDS) which conditions the steam for supply directly to the LP steam header. The HP steam header includes a start up vent valve, a steam flowmeter at the inlet to the Steam Turbine and all the necessary manual and motorised isolations to facilitate system operation.

Separate bypass PRDS are provided from each HRSG. The bypass PRDS, which are installed in a duty / standby configuration (2 x 100%) are provided for both start-up of the HRSG prior to supply of steam to the Steam Turbine or as Steam Turbine bypass stations. Each bypass PRDS comprises a pressure reduction valve and a downstream de-superheater section which is supplied with spray water for steam de-superheating.
Medium Pressure (MP) Steam

MP steam is used to supply the CCP at a pressure of 10.5 bara. The CCP steam demand is intermittent. The MP steam header is also the source of deaeration steam for deaerator. In normal plant operation the MP steam will be provided from the HP steam header via a single PRDS. Alternatively MP steam can be supplied from the Auxiliary Boiler.

Low Pressure (LP) Steam

LP steam is used to supply the CCP at a pressure of 4.8 bara and 160°C. The CCP steam demand is a continuous requirement of up to 345 t/h. However, the SPS Plant has been designed with a 10% LP steam flow margin giving a potential supply of up to 379 t/h to ensure that the CCP steam demand can be met under all envisaged operating scenarios. In normal plant operation the LP steam will be provided from the exhaust of the Steam Turbine. Alternatively LP steam can be supplied from any of the HP to LP steam bypass PRDS (4 off 2 per HRSG) or from the MP to LP bypass PRDS.

Auxiliary Boiler

The duty of the auxiliary boiler package is to provide steam for maintaining the steam lines warm when the SPS Plant is out of service and for provision of low steam demands to the CCP. The capacity of the Auxiliary Boiler is anticipated to be circa 60 t/h.

The auxiliary boiler will be fired on natural gas at a gas pressure anticipated to be of the order of < 100 mbarg. As with the HRSGs, the auxiliary boiler and associated piping will be dosed with various water treatment chemicals. The selected chemicals could potentially include sodium phosphate for pH control, carbohydrazide as an oxygen scavenger and amine for corrosion protection.

The auxiliary boiler is also provided with a blowdown system similar to that described for the HRSGs. Continuous and intermittent blowdown from the auxiliary boiler is discharged to an atmospheric blowdown tank where it is cooled directly with potable water prior to discharge to a blowdown sump. The blowdown tank will also receive condensate and flash steam from adjacent steam trapping systems and warm up lines. The flash steam is discharged to atmosphere at a safe location via a suitable vent.

Steam Exported to CCS Chain

LP and MP steam is required within the CO₂ capture plant.

Table 3.3.3-1 and Table 3.3.3-2 summarise the flow rates and conditions of LP steam and MP steam supplied to the CO₂ capture plant for the maximum, minimum and normal design cases.

Table 3.3.3-1: Total LP steam supplied to the CO₂ capture plant

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<td>Temperature</td>
<td>ºC</td>
<td>144</td>
<td>144</td>
<td>144</td>
</tr>
<tr>
<td>Flow</td>
<td>t/hr</td>
<td>373</td>
<td>206</td>
<td>339</td>
</tr>
</tbody>
</table>

Notes:
1. Design flowrate includes 10% margin.
Table 3.3.3-2: Total MP steam supplied to the CO₂ capture plant

<table>
<thead>
<tr>
<th>Design case</th>
<th>Units</th>
<th>Maximum (All Cases)</th>
<th>Minimum (All Cases)</th>
<th>Nominal³, ⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>bar(a)</td>
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<td>9.0</td>
<td>9.0</td>
</tr>
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<tr>
<td>Flow</td>
<td>t/hr</td>
<td>19.4</td>
<td>0</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Notes:
1. Intermittent usage.
2. Design flowrate includes 10% margin.

3.3.1.5 Transport Conditioning and Drying

CO₂ Compression at Longannet

CO₂ from the stripper overheads will be routed to the CO₂ compression and conditioning systems where the CO₂ will be compressed, cooled and dried prior to export.

Two 50% rated compression and drying trains are proposed to meet the project’s availability requirements and to match the operating philosophy for the CCP. Integrially geared compressors with fixed speed electric motor drives will be used. The CO₂ compressor is likely to be a 5 stage integrally geared machine, supplied as a complete package with all supporting ancillaries. The controls are also provided as part of the package but will interface with the CCP distributed control system (DCS).

Between some of the compression stages, the gas is cooled in intercoolers and condensate is removed in knock-out vessels. Heat rejection in the intercoolers is to sea water. Where the pressure is sufficient, process condensate is returned to the upstream absorber in the CCS train.

There is a necessity to protect the compressor from surge. A recycle stream via the anti-surge cooler is provided, returning to the knock-out vessel.

An adsorption dryer package, as described below, will reduce the maximum moisture level in the CO₂ to less than 50 parts per million by volume (ppmv) in order to protect the downstream equipment.

The CO₂ will be compressed to between 31 and 34 barg and exported via the National Grid pipeline system in the gaseous phase. The temperature will vary between 5 ºC to 30 ºC.

Dehydration

Free water combined with CO₂ forms carbonic acid which is detrimental to carbon steel components, such as pipelines, as it can cause corrosion on the internal surfaces. Additionally, at elevated pressures and ambient temperature, hydrates can form which could cause blockages in equipment, valves, pipelines and wells. To minimise the formation of carbonic acid or hydrates during CO₂ transportation, a dehydration plant will be included following CO₂ compression at Longannet.

The dryer package design will typically consist of:
- Inlet gas filters
- Two or more molecular sieve dryers
- Outlet filters
The design includes an inlet cartridge filter capable of filtering particles greater than 30 microns in size from the CO₂ gas stream to be dried. CO₂ gas then flows up through the bed of the online dryer. Any fine particles will be captured in an outlet guard filter.

The regeneration gas fraction is compressed to provide a driving force through the regeneration equipment, heated in an electrical heater and routed backwards through the molecular sieve bed. After cooling, the regeneration gas and majority of the moisture will be separated by a scrubber and the gas fed back into the dryer package inlet stream.

A condensate line operating at a pressure of 1.2 bara will be available for returning the condensate to the stripper overhead condenser.

Upstream of the dryer package, a pre-conditioning vessel (containing a fixed bed catalyst) is provided for the conversion of any free oxygen (to protect well tubulars from pitting corrosion) to water using hydrogen. The catalyst proposed uses the heat from the CO₂ compression process to attain the required operating temperature.

**Metering and Analysis**

The CO₂ exiting the CCP will be analysed to provide confirmation that its composition meets the export specification. The analysis will be carried out on a continuous basis by automatic analyser systems fitted to each CCP train. The mass flow of CO₂ exiting each CCP train will be quantified by flow meters to allow the performance of each train to be monitored.

The mass of CO₂ transferred from the CCP to the transportation system must be quantified for fiscal reporting purposes. This will be carried out by certified flow meters located at the Valleyfield pipeline AGI. Gas analysers will be fitted at the entry point to the pipeline system to measure selected components of the CO₂ stream. The measurements will be monitored as required to ensure safe operation by the pipeline operator, as an independent back-up measure to the analyser equipment provided at the CCP.

### 3.3.1.6 Onshore Transport System

**National Grid Pipeline**

The Longannet compression facility will inject gaseous CO₂ into the National Grid pipeline system at a maximum allowable operating pressure of 34 barg and maximum operating temperature of 30°C.

The connection from LPS to the Blackhill Compressor Station will be via:
- A new 600 mm (24") diameter buried steel pipeline from LPS to the proposed Valleyfield installation
- A new 900 mm (36") diameter buried steel pipeline from Valleyfield to the proposed Dunipace installation which is adjacent to the existing National Transmission System (NTS) pipeline (No. 10 Feeder) to the North of Denny
280 km of the existing 900 mm (36") diameter buried steel NTS No. 10 Feeder which currently runs from the existing compressor station at Avonbridge/Bathgate to the onshore natural gas terminal facilities at St. Fergus
- The existing No. 10 Feeder was designed for transportation of natural gas using National Grid (formally Transco / British Gas) and the Institute of Gas Engineers standards and specifications applicable at the time.
- The existing No. 10 Feeder from Kirriemuir to Bathgate is currently rated at 85 barg for the transportation of natural gas, with 85 barg being the maximum allowable pressure. The existing No. 10 Feeder from Aberdeen to Kirriemuir is rated at 84 barg, and from St. Fergus to Aberdeen it is rated at 70 barg.

Due to a pressure drop along the onshore pipeline, the expected National Grid pipeline exit conditions for arrival at Blackhill Compressor Station are operating pressures between 28.5 to 31 barg (due to the pressure drop in the pipeline) and likely operating temperatures in the range of 3 to 14°C.

The existing NTS No.10 Feeder pipeline system between Bathgate and St. Fergus consists of 3 main pipeline sections and each individual section includes manually operated block valve installations at several locations along the pipeline route. Modifications will be required to disconnect No. 10 Feeder from the natural gas NTS pipeline network at existing multi-junction sites and compressor sites, and to cross-connect the various pipeline sections. The existing block valve installations will also require modifications to convert them from natural gas to CO2 duty.

**Blackhill Compressor Station**

The existing No. 10 Feeder is to be diverted outside the St. Fergus onshore natural gas terminal to the site of the proposed Blackhill Compressor Station.

Two 50% rated, multiple stage, integrally geared compressor units which will be installed in parallel configuration are proposed to compress the CO2 from the gaseous phase at the arrival condition at Blackhill Compressor Station to a dense phase fluid with an outlet pressure of between 80 to 120 barg. There is also a back-up gas turbine unit available.

An aftercooler and refrigeration/chiller unit installed on the outlet/discharge of the compressor station will reduce the discharge temperature of the CO2 within a maximum allowable temperature of 29°C to protect the subsea pipeline integrity. The refrigeration/chiller unit will operate during periods of relatively high ambient temperature. The CO2 will also require cooling between each compressor stage, for which intercoolers will be installed.

Each compressor unit will be isolated by automatically actuated emergency shut down (ESD) valves, with a vent stack installed in a safe area to enable the units to be depressurised as and when required. The compressor station will be similarly isolated from the process.
3.3.1.7 Offshore Transport and Storage

Onshore Pipeline at St. Fergus

Dense phase compressed CO$_2$ will be discharged from the new National Grid Blackhill Compressor Station at an outlet pressure of 120 barg and a maximum temperature of 29°C. It is proposed to meter the CO$_2$ to fiscal standards on the National Grid compressor station. In addition to metering, quality checks of the purity of the CO$_2$ on receipt will be carried out; water and oxygen are the key contaminants of interest for the offshore transportation and storage of the CO$_2$.

A new pig launcher is proposed for installation at the point of discharge from Blackhill, thus permitting the operation of intelligent pipeline pigging in the offshore pipeline.

The compressed CO$_2$ will be transferred from the compressor station into a new 1.4 km section of underground piping that initially runs around the perimeter of the current Shell site.

Connection of this new section of piping to the offshore pipeline will be made via a new isolation valve installed in a new valve pit within the Shell St. Fergus site.

Offshore Pipeline to Goldeneye

The existing Goldeneye 500 mm (20") nominal diameter hydrocarbon export pipeline will be re-used to transport the captured dense phase CO$_2$ to the existing Goldeneye offshore platform.

Re-use of the Goldeneye platform and offshore pipeline has been assessed and is thought to be feasible for the duration of the UKCCS Demonstration Project, given that the Goldeneye facilities have only been in service since 2004 and the line has been operated in accordance with accepted practice. Desktop studies have confirmed that the corrosion risk is low, however, it is proposed to carry out internal and external inspection early in the implementation phase of the project in order to confirm its condition. The pipeline has an existing non-return valve located 150 m from the riser base, which will need to be removed and replaced with an actuated sub-sea isolation valve (SSIV). The pipeline between the SSIV assembly and the riser base will also be replaced with higher pressure-rated spools to accommodate CO$_2$ thermal expansion. Commissioning of the pipeline for CO$_2$ injection service will be carefully planned to ensure that the pipeline is swept of any debris and residual hydrocarbons/water, in order to reduce the risk of well contamination.

Goldeneye Platform

The dense phase CO$_2$ arrives onboard the Goldeneye platform via the existing pipeline riser. The existing pig launcher on the platform will be converted to a pig receiver by extending the small barrel length to accommodate intelligent pigs. The system will be capable of supporting intelligent pigging through the offshore line. The dense phase CO$_2$ will pass through a flowmeter and a back-pressure control valve that will maintain the pipeline contents in dense phase. The fluid will then pass through one of 2x100% dense phase CO$_2$ filters to a new injection manifold and flowlines to the injection wellheads. The topsides pipework and equipment downstream of the carbon steel pipeline will be made from stainless steel. This material has good toughness and corrosion resistant properties throughout the range of temperatures expected in CCS operations.
The flowlines will include new allocation metering and new choke valves.

New vent systems will be provided for:
- Pipeline depressurising
- Individual vents from thermal PSVs protecting blocked inventories on the topsides
- Individual vents from maintenance vents topsides
- Depressurising the wells for the purpose of Subsurface Safety Valve (SSSV) leak off testing

For hydrocarbon production, the Goldeneye platform was operated as a Normally Unattended Installation (NUI) with occasional visits by maintenance crews utilising helicopter transportation. It is proposed that this arrangement will be continued in injection service, and the platform and offshore pipeline will be controlled from the Shell-operated St. Fergus terminal using remote satellite telemetry. Additional control interfaces with the new Blackhill Compressor Station are envisaged.

No offshore heat input is required for injection into the system and the only power consumption is from instrumentation (which is negligible), hence the existing offshore surface/topsides platform facilities are adequate for re-use in injection service.

**Goldeneye Wells**

Goldeneye was originally completed with five hydrocarbon production wells, which were all drilled and completed in the same drilling campaign from the platform location using a heavy duty jack-up rig. The completions and wellhead facilities of all five wells are currently similar, although the drilled deviations and well depths differ. The existing wells and their associated tubing and completions have been assessed for injection duty, and it is proposed that four of the existing production wells will be re-used for injection. The remaining (fifth) existing well will be re-used for monitoring the reservoir only (with augmented instrumentation). This well may be completed to allow injection later on in the project life.

The injection wells will require workover and upgrading and adapting to meet the specific demands of the new CO2 service. In particular, each of the wells will require the replacement of the existing upper completion with a new completion arrangement designed to accommodate the injection design requirements (including corrosion resistance and low temperature operation) and maintain single phase flow in the well tubing. Existing valves may also need to be replaced or modified for CO2 service. Re-use of the existing wells is proposed, as this is much more economic than drilling and completing entirely new wells for CO2 injection service.

The four injection wells will transport the CO2 down into the reservoir approximately 2.5 km below ground for permanent storage. No changes are proposed to the existing casing and gravel pack arrangements. The surface filtration facilities will be specified such that injectivity will be unaffected by contaminants.

The depleted Goldeneye hydrocarbon reservoir is located in the UK Continental Shelf (UKCS) blocks 14/29a and 20/4b and is 7 km by 4.5 km in extent at a depth of approximately 2.5 km below surface. The reservoir is high permeability turbidite sandstone. The depleted initial reservoir pressure is approximately 140 bara and this is predicted to increase over the life of the CO2 storage, with a final value close to the initial reservoir pressure (265 bara).

The field is a combined structural and stratigraphic trap within the Lower Cretaceous Captain Sandstone Member of the South Halibut Trough.
The top seal to the reservoir (indeed to the whole Captain fairway) is provided by a 60-85 meters thick succession of laminated, calcareous mudstones forming the Rødby Formation. Mudstones within the Valhall and Kimmeridge Clay Formations provide an additional lateral seal.

Injectivity into the Goldeneye reservoir is anticipated to be high. The operating envelopes of the wells will be designed to cover the full range of envisaged flow rates from the minimum CCS plant output to the maximum delivery rate when the reservoir has re-pressurised to its initial value.

**Operation of the Goldeneye Platform**

For hydrocarbon production, the Goldeneye platform was operated as a NUI with occasional visits by maintenance crews utilising helicopter transportation. It is proposed that this arrangement will be continued in injection service, and the platform and offshore pipeline will be controlled from the Shell-operated St. Fergus terminal using remote satellite telemetry. Additional control interfaces with the new Blackhill Compressor Station are envisaged.

### 3.3.2 Process Flow Diagrams

Process flow diagrams (PFDs) are key documents in process design and represent a diagrammatic model of the system process and equipment. Once finalised, PFDs are used by the specialist design groups as the basis for their design, this will include piping, instrumentation, equipment design and plant layout. A typical PFD displays the relationship between major equipment but does not show minor details such as piping details, instrumentation and minor valves. They will also be used by operating personnel for the preparation of operating manuals and operator training. The next step after the development of the PFDs and heat and mass balances is the preparation of the piping and instrumentation diagrams (P&IDs). These are shown in section 3.4.

The appendices of this report contain the post-FEED PFDs covering the main process equipment and the main process lines of the CCS chain.

The PFDs are prepared alongside the mass balances made over the complete process and each individual unit. Energy balances are also made to determine the energy flows and the service requirements. The heat and material balances are shown in Section 3.3.3 and the stream numbers correlate with the PFDs.

The End-to-End chain PFDs are provided in Appendix C.2 and include:

**End-to-End CCS Chain:**
- UKCCS - KT - S7.8 - E2E - 001 End-to-End Process Flow Diagram

**Capture plant, SPS plant, CO₂ compression and drying plant and associated ancillary services:**
- UKCCS - KT - S7.8 - ACC - 001 Aker Clean Carbon Process Flow Diagrams

**National Grid Onshore Transportation System:**
- UKCCS - KT - S7.8 - NG - 001 National Grid Process Flow Diagrams
Shell offshore transportation and storage:\n- UKCCS - KT - S7.8 - Shell - 001 Shell Process Flow Diagrams

It should be noted that the stream numbers shown on these documents cross reference to the heat and mass balances discussed in Section 3.3.3.

For comparison, the PFD drawings developed during the Outline Solution phase of the project are provided in Appendix C.2.5.

### 3.3.3 Heat and Mass Balances

This section presents the post-FEED heat and mass balances (HMB) that correlate with the PFDs identified in section 3.3.2. Where possible, the HMBs have been developed for maximum, minimum and nominal design flow. However, further work is required during the implementation phase to fully establish the minimum flow conditions of the End-to-End CCS chain.

The suite of heat and mass balances are shown in Appendix C.3 and include:

**End-to-End CCS Chain:**
- UKCCS - KT - S7.10 - E2E - 001 End-to-End Heat and Mass Balance

**Capture plant, SPS plant, CO₂ compression and drying plant and associated ancillary services:**
- UKCCS - KT - S7.10 - ACC - 001 Aker Clean Carbon Heat and Mass Balance

**National Grid Onshore Transportation System:**
- UKCCS - KT - S7.10 - NG - 001 National Grid Heat and Mass Balance

**Shell offshore transportation and storage:**
- UKCCS - KT - S7.10 - Shell - 001 Shell Heat and Mass Balance

For comparison, the HMB drawings developed during the Outline Solution phase of the project are provided in Appendix C.3.5

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7 It should be noted that the Shell PFD drawings are referred to as process flow schemes (PFS). However, the appendix titles have been termed as PFDs for consistency

8 A selection of the Aker Clean Carbon HMB information is presented on the PFD drawings in Appendix C.2.2 and not collated in this drawing package
3.4 Piping and Instrumentation Diagrams

Piping and Instrumentation Diagrams (P&IDs) are detailed design schematics that show piping, equipment and instrumentation connections within a process. They are developed from the PFD drawings discussed in section 3.3.2 and represent the design effort from the process, mechanical, piping, control and Instrumentation engineering disciplines.

Appendix C.4 contains a full suite of drawings representing all sections of the End-to-End CCS chain. This includes the following design documents:

**SPS plant, CO₂ compression and drying plant and associated ancillary services:**
- UKCCS - KT - S7.12 - ACC - 001 Aker Clean Carbon P&IDs

**National Grid Onshore Transportation System:**
- UKCCS - KT - S7.12 - NG - 001 National Grid P&IDs

**Shell offshore transportation and storage**:
- UKCCS - KT - S7.12 - Shell - 001 Shell P&IDs

The P&IDs for the Carbon Capture Plant have not been included as these are considered to be the intellectual property of Aker Clean Carbon and at this stage of the project are classified as propriety and confidential.

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9 It should be noted that the Shell P&ID drawings are referred to as process engineering flow schemes (PEFS). However, the appendix titles have been termed as P&IDs for consistency.
3.5 Layout and Construction

The plant and site layouts have been developed based on technical and process factors plus the requirements for constructability, access and maintenance. These diagrams will be developed further during the implementation phase of the project.

Due to the novel demonstration aspect of the project, the layout of the CCP and other Longannet facilities were optimised with respect to flexibility of future requirements. This will permit future development of the site and allow modifications to the existing plant if necessary.

The accessibility that has been built into the design allows for future optimising and change-out of key equipment, if required, as the carbon capture process is refined and better understood.

Plant and site layout drawings for the various parts of the CCS chain are included as part of the End-to-End Layout document (UKCCS - KT - S7.14 - E2E - 001 End-to-End Plant and Site Layout Drawings) and located in Appendix C.5.

The drawings included with this deliverable are as follows:

**Longannet Site:**
- Longannet Site Plan
- Overall Site Plan Carbon Capture
- View of Longannet Site looking North

**The Onshore Transportation System including above ground installations (AGIs):**
- Typical Pig and Off-take (planning drawing)
- Typical Pig and Off-take (elevation drawing)
- Typical Block Valve (GA Drawing)
- Proposed New Pipeline Route Map
- Typical Intermediate Pig Trap (GA drawing)
- Typical Intermediate Pig Trap (Elevation drawing)

**Blackhill Compressor Station:**
- Typical Compressor Station (GA drawing)
- Typical Compressor Station (elevation drawing)

**The offshore transportation system and Goldeneye platform:**
- Onshore Piping General Arrangement
- Onshore Plot Plan
- Onshore Equipment Layouts
- Offshore Piping General Arrangement
- Offshore Equipment Layouts

Figure 3.5-1 on the following page displays a schematic of the End-to-End layout outlining locations of key equipment.
Figure 3.5-1: UKCCS Demonstration Project Schematic

Source: National Grid

Access to and use of the information in this document is subject to the terms of the disclaimer at the front of the document
3.5.1 Constructability

During FEED, Aker Clean Carbon completed a constructability review for Longannet site on behalf of ScottishPower. The review focused on the use of modularised construction methods and covered the following particular aspects:

- Review of the current FEED design and proposed layout to identify opportunities for construction optimisation via degrees of modularisation and construction techniques involving pre-assembled units (PAU), pre-assembled racks (PAR) and pre-fabrication.

- Review of the barging / transportation logistics to identify available options and associated constraints

- Identification of a preferred construction method

- Evaluation of the potential impacts of implementing this preferred construction method

- Development of a recommended construction strategy, for review and acceptance by the project stakeholders

The main conclusion from the study was that a PAU/PAR construction approach should be adopted for the works at Longannet site. This would require a transportation strategy utilising roll on – roll off barges to deliver the equipment via the Firth of Forth. This construction approach is subject to approval by the relevant environmental regulatory bodies.

The constructions strategy will be considered further during the implementation phase. The Aker study is available in Appendix C.5.2 under the following reference:

- UKCCS - KT - S7.14 - ACC - 001 Modularisation Study
3.6 Equipment List

During FEED, an equipment list was developed based on the End-to-End CCS chain process flow diagrams.

The major equipment list provides technical details for all the major equipment in the End-to-End CCS chain. The equipment list brings together the physical and process information from the individual equipment specifications and cross references these with the relevant process flow diagrams. The equipment list contains information such as:

- Equipment type
- The associated system where the equipment is installed
- Normal operating conditions
- Design conditions
- Materials of construction
- Dimensions
- Weight

Additionally, the equipment list is used to provide an overview of where the equipment is located in the CCS chain and, since the design is being developed by a Consortium, it also identifies the Consortium member responsible for the design of each item of equipment.

At the FEED stage of the project, the equipment list is a useful tool for calculating the capital expenditure required for the major components of the CCS process. When moving towards implementation, the equipment list can be updated and expanded to include all the equipment required in the CCS project and thus can be used in the procurement process. When the project is complete, the equipment list can be used as a basis for developing a minimum equipment list which can be used for operational and maintenance purposes such as ensuring there are sufficient spare parts available.

The End-to-End Major Equipment List can be found in Appendix C.6 with the following reference:

UKCCS - KT - S7.13 - E2E - 001 End-to-End Major Equipment List
3.7 Plant and Equipment Specifications

Specifications define the technical requirements for the relevant plant and equipment. They exclude commercial or contractual requirements and agreements which are normally covered by other documents.

Specifications for the principal plant and equipment for the ScottishPower CCS Consortium Project are presented in Appendix C.7. They provide the minimum technical requirements that are considered essential for the safe, economical and correct performance of the plant and as such provide designers of future CCS plants with the type of key information which should be included in their specifications.

In general, process and other data that is specific to the ScottishPower CCS Consortium Project has been omitted as it is contract and plant specific and as such is of no value for other future plants, though in some cases project specific information has been included where it is considered of guidance to other designers (for example, the voltage levels for drive motors). Similarly, references to company internal standard specifications have been removed as such specifications are proprietary and as such are not available in the public domain or for other projects. It is assumed that competent CCS design teams will have access to their own proprietary standard specifications applicable to their projects. Where company proprietary internal specifications are quoted this is to indicate the title of the document so that designers of other plant may substitute their own corresponding internal proprietary documents.

Specifications for minor equipment and standard items are not included as these are generally available as company internal standard specifications applicable to the specific contracts.

The datasheets and specifications included in Appendix C.7 are largely based on the items listed in the End-to-End Major Equipment List and include the following:

**SPS plant, CO₂ compression and drying plant and associated ancillary services:**
- UKCCS - KT - S7.15 - ACC - 001 Aker Clean Carbon Datasheets

**National Grid Onshore Transportation System:**
- UKCCS - KT - S7.15 - NG - 001 National Grid Datasheets

**Shell offshore transportation and storage:**
- UKCCS - KT - S7.15 - Shell - 001 Shell Datasheets
3.8 **Subsurface Engineering**

A high level summary of the Shell subsurface design reports is provided in this section of the report. The summaries are arranged in sections in a way that either includes the same umbrella topic or maintains the sense of the dynamic workflow in the order in which the results were obtained:

- Material and Concept Select Reports
- Well Reports
- Production Technology Reports
- Geosciences, Reservoir Engineering, Production Chemistry, Monitoring and Reservoir Management Reports

It is worth noting that the total time expended by the Shell team on these four areas was ca 35,000 hours. Of these the first 3 areas (essentially the Materials, Well Engineering and Production Technology) accounted for nearly 7,000 hours, whilst the fourth and final theme (Petroleum Engineering and Production Chemistry) required ca 28,000 hours.

Please note that **DIRECTIVE 2009/31/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009** on the geological storage of carbon dioxide states, in Article 4(3) and 4(4) that:

1. (3) *The suitability of a geological formation for use as a storage site shall be determined through a characterisation and assessment of the potential storage complex and surrounding area pursuant to the criteria specified in Annex I.*

2. (4) *A geological formation shall only be selected as a storage site, if under the proposed conditions of use there is no significant risk of leakage, and if no significant environmental or health risks exist.*

The subsurface engineering has been aimed at addressing the above in preparation for the application for a storage permit.

The complete reports can be found in Appendix C.8 to Appendix C.11.

### 3.8.1 **Material and Concept Select Reports**

This section documents the various concepts and materials that have been evaluated and selected in terms of wells, pipelines, topsides etc. This section includes summaries of the following reports:

- Material Selection Report
- Cement Concept Select
- Component Concept Selection
- Completion Concept Select

#### 3.8.1.1 **Material Selection Report**

The Material Selection Report defines material selection and corrosion control measures based on a detailed analysis of the possible degradation modes of the assets considered for CO₂ transport and injection. The results of the material selection report study are summarised below.

- CO₂ Export Pipeline:
The existing carbon steel (CS) 20” pipeline with external coating and cathodic protection (CP) is suitable for the intended CO₂ service within the defined operational parameters, including maximum and minimum temperatures and CO₂ water content. The maximum temperature is currently set at 29 °C, based on a detailed analysis of mitigating the risk of running ductile fracture. The actual wall thickness (and corrosion allowance) of the pipeline upon cease of hydrocarbon production needs to be confirmed by an Intelligent Pig run to be performed before CO₂ service commences. The internal epoxy flow coating is expected to be sufficiently resistant against disbonding under typical pipeline decompression. A testing programme will be performed to increase confidence in coating performance.

Onshore Sections:
- CS with 3 mm corrosion allowance is a suitable material selection for the extension of the existing CS 20” pipeline.
- The new pig launcher can be designed similarly to the existing one, constructed in CS with 3 mm corrosion allowance, which is suitable for the intended CO₂ service within the given operational parameters, including minimum design temperature, and contact with wet CO₂ is avoided or minimised sufficiently.
- Vents will be produced from 316L stainless steel.

Offshore Piping and Equipment:
- All CS used on the platform is low temperature carbon steel (LTCS) with a minimum specified temperature of -26°C and 3 mm corrosion allowance (CA) and includes pipework and the pig launcher. This is acceptable for CO₂ service if operational procedures ensure that temperatures do not drop below -26°C and contact with wet CO₂ is avoided or minimised sufficiently.
- Grade 316L stainless steel pipework is suitable for CO₂ service down to -100°C. All new pipework and the injection manifold will be constructed in 316L, as well as the vents.

Valve material compatibility with CO₂:
- Non-metallic materials in valves, including elastomers, used for seals, gaskets, O-rings, etc., may not be suitable for dense phase CO₂ service. An assessment has been carried out to determine valves which require refurbishment or replacement, and indicates where seals will need to be replaced in CO₂ compatible materials with ED resistance.

Flow lines:
The main issues are low temperature embrittlement and external corrosion. The existing flowlines are constructed in duplex stainless steel. None of these will be reused in the new design. Instead, they will be constructed in Grade 316L stainless steel. Grade 316L stainless steel has adequate toughness down to -100 °C and external corrosion shall be mitigated by coating.

Well Casing
- CS for casing is a suitable material selection.
- Low temperature properties of the CS production casing were assessed by the Wells team and certificates demonstrate that the installed Grade L80 material is suitable down -40 °C, well below the worst case lowest casing temperature of -10 °C.

Well Completion:
The existing 13%Cr steel completion materials are a suitable choice for CO2 resistance as long as wet exposure to CO2 with more than 1ppmv O2 is avoided.

Low temperature properties of 13%Cr steel are adequate to avoid embrittlement at the worst case lowest tubing temperature of -15°C.

The full report is available in Appendix C.8.1 under the following reference:
- UKCCS - KT - S7.16 - Shell - 001 Material Selection Report

### 3.8.1.2 Cement Concept Selection

The effect of CO2 injection on the cement in the Goldeneye Platform wells and the selection of cement type for wells yet to be abandoned are discussed in the Cement Concept Selection.

There are three categories of wells in the Goldeneye area;
- Abandoned Exploration and Appraisal (E&A) wells. There are thirteen E&A wells in the Goldeneye area, but only five that will be affected by the ‘CO2 plume’ created by injection of CO2 into the Goldeneye reservoir. All of these E&A wells are abandoned, with cement plugs in place.
- Existing Goldeneye Wells. There are five Goldeneye Platform wells, all of which have been drilled and then the casing strings have been cemented in place. At some point in the future (possibly following CCS duty) these wells will need to be abandoned.
- New wells or sidetrack wells may yet be drilled.

Each well type has been reviewed for suitability of injection of CO2, with the conclusion that all types of well will be fit for CO2 injection.

The conclusions of the study are:
- The cement in the existing wells will protect against CO2 leaks
- Special CO2 resistant cements may be qualified to decide on suitability and improvements over Portland cement
- A Portland cement programme adapted for CO2 resistant properties can be put together for the expected future operations and downhole conditions

A specialist mechanical cement model has been run to ascertain the effects of CO2 injection on the Goldeneye Platform. The results indicate that there will be no mechanical problems due to CO2 injection.

Due to the absence of water in the injected CO2 (once water and hydrocarbons have been displaced); there is no chemical mechanism to create corrosive carbonic acid. Later in the life of the wells (after the injection phase) reservoir dynamics such as gravity, miscibility and reactions with downhole formations, will result in carbonic acid reappearing at the base of the cement in the Goldeneye wells. This is not expected to be a problem for Goldeneye wells.

After cessation of CO2 injection, Goldeneye wells and the Goldeneye platform will be abandoned. The choice of cements for abandonment and the style of abandonment will be decided by cementing technology and Governmental requirements in place at the time.

For concept selection, there has been investigation into the cement type that would be used in the event that a new well is drilled. The area of interest is any portion of the well where the cement would be in
contact with CO₂. From preliminary investigations, it is concluded that existing Portland cement is suitable for CO₂ injection and its formulation can be improved in the event that a new well is drilled.

Specialist cements could be qualified to see if they are significantly better than Portland cement in CO₂ service. If so, a new well or a sidetrack from an existing well may be cemented with a CO₂ resistant cement in any portion of the well where the cement would be in contact with CO₂.

As workovers on the Goldeneye Platform will not occur until 2013 / 2014 it is recommended that qualification of CO₂ resistant cement be followed up after the storage contract has been awarded. This would give greatest benefit to emerging research in this new area.

The full report is available in Appendix C.9.5 under the following reference:
- UKCCS - KT - S7.16 - Shell - 007 Cement Concept Selection

3.8.1.3 Component Concept Selection

The Component Concept Selection document seeks to define the major completion components being considered for Goldeneye CCS wells, to confirm that completion components are compatible with the injected fluids over a range of critical pressures and temperatures for the lifecycle of the well, and to identify components or parts thereof that may require further testing and qualification.

The existing Goldeneye completions are not suitable for CO₂ injection operations. Pressure and Temperature modelling suggests that injecting CO₂ into the current Goldeneye completions below the saturation point would cause a Joule-Thomson effect that would cool the wellhead and upper section of tubing to around −25°C, to a depth of circa 2,500 ft [762m] MD (Measure Depth). This very low temperature raises concerns with the current completion design. Of particular concern are material specification, tubing contraction, well bore freezing, and Polished Bore Receptacle (PBR) integrity.

The temperature above refers to the CO₂ injection using the existing completion (no friction) where the top part of the well will be at subzero temperature. Wellhead temperature of -25°C is estimated for 2500psi reservoir pressure – design pressure of the CCS and -30°C for 2100psi – current reservoir pressure. Initial temperature calculations were made with the current reservoir pressure but later calculations were made using reservoir pressure predictions. The implications form the well design/integrity are the same considering both minimum temperatures.

To combat the problems associated with the Joule-Thomson effect and maintain CO₂ above the saturation point, the Goldeneye wells will be worked over to remove the existing completion tubing. The wells will be re-completed using a combination of smaller tubing sizes which will introduce sufficient frictional pressure losses into the system to maintain the supplied CO₂ above the saturation line over range of operating conditions required.

However until further pressure and temperature modelling has been completed the final configuration of the tubing string cannot be confirmed; final well modelling cannot be completed for the same reason.

Whilst essentially fit for purpose within a CO₂ environment, The following items will require further qualification, calibration and or testing before they can be used in Goldeneye CCS completions:
- Xmas Tree/Wellhead
- 13Cr Tubing

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3.8.1.4 Completion Concept Selection

Injecting CO₂ through the existing completion tubing at a pressure below the saturation point will cause a Joule-Thomson effect that will cool the wellhead and upper section of tubing to around -25°C, to a depth of circa 5000ft [1,500m] MD.

The very low temperature raises concerns with the current completion design relating to well bore freezing, material specification and tubing contraction. To overcome these issues the Goldeneye wells will be worked over and re-completed with small ID tubing. Re-completing the wells with small ID tubing will introduce sufficient pressure losses into the injection system to maintain the supplied CO₂ in the dense liquid phase. Working the wells over also provides the opportunity to change out surface equipment that will be subjected to extremely low temperatures during transient conditions such as opening up a well for injection, closing in a well, and TRSSSV testing.

Tubing

In general, 13Cr material is considered to be a suitable material for the completion tubing. Dry CO₂ is not considered to be corrosive to 13 Cr materials. Dry CO₂ is not corrosive even if oxygen is present in the feed gas. Even at wet conditions, 13Cr tubing is considered to be resistant to CO₂ corrosion if oxygen is not present, although it could be susceptible to corrosion at higher temperatures and salinity. However because certain transient operations can generate temperatures as low as –17°C, the upper completion down to a depth of circa 2,500 ft [762 m] MD will be completed with Super 13Cr tubing. Super 13Cr tubing has a Charpy brittle transition temperature at –50°C.

Wellhead

In general the Goldeneye Xmas tree / wellhead design is a robust system adopting primary metal to metal seals, which are field proven. The current Goldeneye Xmas tree is designed for temperature class U which is (-18 to 121°C); the limitation being the bonnet and the tree block, both being made from 410 stainless steel which has a very low Charpy impact value. The Xmas tree is planned to be changed during the workover operation and the tree selected for CO₂ injection operations will be made of F6NM, Material class FF which conforms to API-6A impact requirements. This material is suitable to cover the predicted temperature range during transient operations.

The wellhead will not be changed out during the workover. The wellhead is not in direct contact with the CO₂, but the transient operations will need to be carefully managed to stay within the temperature envelope of the equipment.

Lower Completion

Goldeneye lower completion consists of gravel pack including a slotted liner and premium screens. From the analysis to date, there is no reason to sidetrack the wells and to install a new lower completion. There are some operational restrictions related to the characteristics of CO₂ and some limitations related to the
particles in the CO\textsubscript{2} but these are considered to be manageable. The maximum particles size in the CO\textsubscript{2} stream should not exceed 17 microns to avoid erosion and plugging of the screens and gravel pack to avoid injectivity issues with time. The 17 microns particle size limitation related to the lower completion was selected considering the geometry of the gravel pack and the accepted rule of blockage of porous systems (1/3 will bridge). Note that to avoid formation plugging and hence injectivity reduction, particles over 6-7 microns need to be removed from the CO\textsubscript{2} stream.

**Monitoring, Measurement and Verification**

The Well Reservoir Management philosophy for the Golden Eye project is to ensure optimal CO\textsubscript{2} injection to meet the contractual agreement while maintaining well integrity. It is proposed that this will be achieved via a highly active programme of monitoring of the wells, part of a wider MMV (Monitoring, Measurement and Verification) Plan. It is planned to initially acquire baseline data during the well workover operations. Once injection commences there would be continuous acquisition of pressure, temperature and other required data in the wells and reservoirs. The acquired data will be used to calibrate the well and reservoir models for active well and reservoir monitoring.

Included in the proposals are:

- A Permanent downhole gauge to be installed in both the injection and monitoring wells for continuous measurement of the downhole injection pressure and reservoir pressure.

- The Distributed Temperature Sensor (DTS) to be run in the injector wells for tubing integrity monitoring. It is expected that a tubing leak will be picked up by the difference in temperature profile across the leak point. The Neon cable provides DTS temperature measurements at approximately 1.0m [3.3ft] intervals along the length of the fibre optic cable producing a profile of temperature effects along the injection tubing and across the mud line.

The overall MMV Plan is subject to approval by the Regulator, and is currently under review by the Regulator as part of ongoing discussions around Storage Licence and Permit.

**Well Operation**

The Goldeneye wells will be designed such that the well will be able to cope with the design case transient scenarios (low temperatures). The design case has been calculated for winter conditions and considers a pre-established steady state at different pressures and temperatures. The lowest temperature for the design case is -20°C for CO\textsubscript{2}, -15°C average for the tubing, -11°C in the A-annulus fluid and -10°C for the production casing.

**Well Intervention**

Routine intervention operations to carry out BHP surveys etc will occur during the lifecycle of the well. This is reflected in the completion design with the minimum restriction for access being 2.94”. In addition to considering routine intervention operations a worst case scenario was considered and modelled to confirm that the operation could be carried out. A Third Party carried out a detailed analysis into CT intervention operations on Goldeneye. The most challenging CT operation foreseen on Goldeneye was to clean up any debris or fill across the screens, which could severely impair injection rates. Each of the proposed
Goldeneye wells was modelled and in each case modelling shows that it is possible to access the Goldeneye wells and circulate out debris in a sub hydrostatic well.

The full report is available in Appendix C.8.4 under the following reference:
- UKCCS - KT - S7.17 - Shell - 002 Completion concept select

### 3.8.2 Well Reports

This section documents a description of the abandoned wells and hydrocarbon production wells present in the Goldeneye area, a suggested well proposal and programme for injection service and also the technical and functional specifications of the wells for use as CO₂ injectors. This section includes summaries of the following reports:
- Well Abandonment concept
- Well Proposal
- Well Programme
- Well Technical Specification
- Well Functional Specification

#### 3.8.2.1 Well Abandonment Concept

Drilled wells may create potential leak paths for reservoir fluids, as the cap-rock gets disturbed during the construction process of the well. The installed seal in and around the well-bore may not be as robust as the original cap-rock. In order to establish if the area around the Goldeneye field is suitable as a storage site for CO₂, potential well related leak paths associated with abandoned wells have been investigated.

The objective of the Well Abandonment Concept Study is twofold.
- Firstly, to review all abandoned wells in the proximity of the Goldeneye field for their suitability to cope with CO₂
- Secondly, to propose an abandonment concept for the five Goldeneye production wells post-CCS

For the first part of the study, an area of 25 x 17.5 km was selected with the Goldeneye field in the centre. In this area, 13 abandoned E&A wells are present. These abandoned wells have been assessed for the quality of abandonment and their suitability to cope with CO₂ conditions.

For the second part of the study, abandonment proposals for the five Goldeneye production wells have been prepared. The proposals take into account the current thinking that some of the Goldeneye wells will be worked-over prior to commencing CO₂ injection (three or four wells) and some wells will be left as monitoring wells without changing out the completions (one or two wells).

The current plan is to inject around 20 Million tonnes of CO₂ into the Captain reservoir in the Goldeneye field. It is therefore very likely that CO₂ will be contained within the original contours of the Goldeneye field.

Of the 13 reviewed E&A wells, there are a total of four wells that have no Captain reservoir. Even though the quality of the abandonment of these four wells has been assessed; these wells are in essence not applicable for the primary control of the CO₂ containment. These four wells are outside the Captain trough and are the two most northerly and two most southerly wells in the reviewed area.
One of the remaining nine wells poses a potential risk to containment of CO₂, but only if CO₂ would transmit out to this well. However, the well is situated about 10 km to the West of the Goldeneye field and is not expected to come into contact with CO₂ in its well-bore based on current injection volumes.

It is concluded that the abandoned E&A wells do not pose a serious risk related to CO₂ leaking through abandoned well bores, based on 20 million tonnes injection.

Abandonment proposals for the Goldeneye production wells have been prepared, based on the current well status (which will suit any wells used for monitoring purposes) and the well status after the proposed CCS workover activities.

The full report is available in Appendix C.9.1 under the following reference:
- UKCCS - KT - S7.16 - Shell - 002 Well Abandonment Concept

### 3.8.2.2 Well Proposal

The UKCCS Demonstration Competition requires the storage of 20 million tonnes of CO₂ in the Captain Sandstone reservoir of the Goldeneye field. A number of the five existing field production wells are to be worked over and re-completed in order to inject dense liquid phase CO₂ into the storage reservoir. Latest injection engineering studies suggest that three of the converted wells are required for full-time CO₂ injection. The remaining two wells can comprise injection maintenance contingency or monitoring functions if not in use for injection. CO₂ injection is planned to begin in 2016. The completion review report states that none of the field production wells have any known integrity issues. A workover is required to convert each production well from gas production to CO₂ injection/monitoring. A sidetrack option from a production well is also described in the event that it later becomes required.

The Well Proposal report provides an example of the sort of well work required to reconfigure production wells for CO₂ injection. This is not intended to be a definitive well proposal and it is expected that the document will be revised once the project has reached a suitable level of maturity. The document contains notional proposed details on the following:
- Completion/re-completion technical detail
- Risks, hazards and uncertainties
- Programme outline
- Geological prognosis
- Notional target locations
- Reservoir pressure
- Pore pressure and well engineering design

The full report is available in Appendix C.9.1 under the following reference:
- UKCCS - KT - S7.16 - Shell - 004 Well Proposal

### 3.8.2.3 Well Program

The Well Program Draft provides outline programmes, indicative costs and time estimates for the drilling and completion options currently being considered for Goldeneye CCS operations. Time and cost estimates, which are based on “outline” drilling and completion programmes are at this time purely indicative and may not reflect market forces immediately prior to injection operations commencing the year 2015.

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The options currently under consideration are:

- Workover the existing Goldeneye wells to make them suitable for CO₂ injection and long term monitoring, which is currently the base case
- Drill a new well from Goldeneye platform for monitoring and or CO₂ injection purposes
- Side track an existing well from the Goldeneye platform for monitoring and or CO₂ injection purposes

Goldeneye platform has five producing wells that can be used for CCS operations. The base case is that a number of the Goldeneye wells will be worked over to make them suitable for CO₂ injection. However, outline programs for drilling a new well from Goldeneye platform, and a sidetrack option from Goldeneye platform are also detailed in the Well Program Draft should final FEED studies indicate that one of these options are required.

Outline programs and time estimations for best case, mean average and worst case scenarios are summarised in this report.

The full report is available in Appendix C.9.1 under the following reference:
- UKCCS - KT - S7.16 - Shell - 003 Well Program - Draft.

3.8.2.4 Well Technical Specification

The Well Technical Specification (WTS) presents the planned workovers at Goldeneye for CO₂ injection. The WTS specifies the well technical requirements required to deliver the completion in accordance with the Well Functional Specifications. It specifies the workover activity in more detail than the Well Functional Specification.

The Well Technical Specification includes:

- Well Specification
- Reservoir Information
- Expected injection conditions: rate, pressure and temperature
- Material Selection
- Upper completion aspects
- Lower completion aspects
- Well Start Up requirements

The full report is available in Appendix C.9.5 under the following reference:
- UKCCS - KT - S7.16 - Shell - 006 Well Technical Specification

3.8.2.5 Well Functional Specification

For the purposes of CCS, the function of the Goldeneye production wells changes from hydrocarbon production to CO₂ injection. It is therefore necessary to ensure that the Goldeneye wells can accommodate the new conditions. Well workover is required in order to make the necessary adjustments. The well technical specification will detail the functional requirements, as defined from the well functional specification, for the Goldeneye wells.
The objective of this report is to provide all the details required for Goldeneye CO₂ injection well design in the existing production wells.

The specification provides a statement of requirements for Goldeneye Platform wells under CO₂ injection, which includes:

- Current well specification
- Expected reservoir characteristics
- Formation water characteristics
- Injected CO₂ composition
- Injection rate envelope
- Pressures and temperatures during injection
- Well constraints in terms of fracture gradient pore pressure
- Completion fluid requirement
- Downhole monitoring needs

Each of these specifications generates further requirements, which are discussed and specified. Examples include the injection rate envelope. This dictates tubing sizes and gas velocities down the tubing, during the life of the wells.

Transient conditions (well start-up and close-in) induce low temperatures near the top of the wells (Joule-Thomson effect), which is critical in terms of well integrity.

The wells operating envelope should have coherence with the transient operating envelope (which is operationally controlled).

In brief, the document specifies the requirements upon which the wells should be designed and will aid and inform the Well Technical Specification.

The full report is available in Appendix C.9.5 under the following reference:
- UKCCS - KT - S7.16 - Shell - 005 Well Functional Specification

### 3.8.3 Production Technology Reports

This section is concerned with the technical intricacies related to the proposed modes of operation of the injection wells. This section includes summaries of the following reports:

- Temperature & Pressure Modelling
- Operations support
- Injectivity Analysis Preparation
- Flowline Well Interactions
- Injection Fracturing Conditions

#### 3.8.3.1 Temperature and Pressure Modelling

The Temperature & Pressure Modelling report details the temperature and pressure modelling of the upper completion for the Goldeneye CCS wells.

The report includes the following:
- The operating envelope for different completion types and sizes

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- Calculation of pressure and temperature along the well at the different components
  - This information will be used later as the basis for the well design

- Modelling of the CO₂ properties

- Comparison between the results from Shell proprietary software and commercial software.

Given that CO₂ properties are very sensitive to Pressure and Temperature, it is necessary to accurately predict the change in properties with an equation of state. Heat exchange in the well and frictional pressure drop also needs to be accurately modelled.

Completion modifications are required in the existing Goldeneye wells to avoid very low temperatures in the shallow part of the wells during the initial stage of injection when reservoir pressure is relatively low. If we left the wells unchanged then the dense phase CO₂ would flash to vapour phase at the wellhead, and this would be accompanied by severe cooling as a result of the Joule-Thomson expansion effect. The resultant very low temperatures would create a number of concerns around well design and management such as material specification, well shrinkage, well bore freezing, annular fluid freezing and expansion, PBR contraction and hence vulnerability to failure, etc.

So to pre-empt these effects, the proposed solution is to workover the wells, replacing the existing large bore (7 inch) tubing with a smaller diameter. The resultant additional pressure drop from frictional effects will allow a gradual pressure decrease rather than sudden expansion, thereby avoiding the concerns outlined above.

With time – given the CO₂ injection and aquifer support – the reservoir pressure eventually increases to the point where the wells are not required to provide a large pressure drop in order to keep the CO₂ in single phase above the saturation line in the well.

The minimum wellhead pressure to avoid the CO₂ existing in two phases, has been calculated to be 45bar. The maximum available pressure for injection is about 100bar. This delineates the minimum and the maximum pressure at the wells during normal injection conditions.

Operating envelopes have been modelled for different tubing sizes. The operating range of the wells depends mainly on the size of the tubing and the injection bottom hole pressure. As the tubing size decreases, the operating range restricts and the capacity becomes smaller. The operating envelope for the tubing and the dual completion scenario is similar. There is some difference with respect to the insert string case.

The expected downhole temperature in the well is in the order of 20 to 35°C in most cases. There is little difference (2 to 5°C) between the CO₂ temperature and the temperature at the production casing.

The full report is available in Appendix C.8.4 under the following reference:
- UKCCS - KT - S7.18 - Shell - 001 Temperature and Pressure Modelling
### 3.8.3.2 Operations Support

Individual operating envelopes have been created for each well in the Operations Support report. The operating envelope for a given well is mainly driven by the philosophy of operating the CO₂ in single phase. As such, there will be a minimum wellhead pressure, which should be maintained under normal injection conditions. Other factors affecting the operating envelope are the maximum velocity in the tubing (12m/s currently accepted), maximum injection bottom hole pressure to avoid fracturing of the cap rock Rødby-Hidra and the maximum aperture velocity in the screens to avoid ‘hot spot’ erosion when injecting under fracturing conditions.

From the reservoir management perspective the order of preference to inject into the reservoir is as follows: GYA01, GYA04, GYA02S1 and GYA05. The preferred order determines the tubing size in the wells. The tubing of each well is also optimized considering the interactions of the different wells, the range of CO₂ rate to the platform and the change in conditions related to the life cycle of the project (inflation of reservoir pressure).

A single well will not be able to inject from the minimum to the maximum injection rate due to the limited injection envelope per well. A combination of available injector wells should be able to cover the supply injection rate ranges arriving to the platform. The completion sizing also considers overlapping of well envelopes to give flexibility and redundancy in the system for a given CO₂ arrival injection rate. At a given arrival rate different well combinations will add flexibility to the system.

The wells should be managed by wellhead pressure. Transient operations should be kept to a minimum in the wells due to generation of low temperatures in the CO₂ for a short period of time.

In the case of high CO₂ arrival rates to the platform, only changing the choke parameter will allow handling changes in the arriving CO₂ rates. However, at low arrival rates there will be requirements to carry out well closing-in / opening-up operations in order to accommodate the variable arriving rates due to the limited operating envelope of the wells.

The required number of wells to be worked over to cover the injection range and considering the initial and the final reservoir pressure is a minimum of four (and includes one back-up well). With the combination of wells and a spare well there will be no requirement to carry out a workover in a well at a later stage to change the tubing size.

Under normal circumstances, a back-up well will not be injecting, allowing monitoring of the reservoir in the area (reservoir pressure). It is envisaged that the redundant well will not always be the same well.

Well GYA03 is planned to be a monitor well. The well can be converted from monitor to injection once the CO₂ has arrived into the well or injection needs.

It is proposed to maintain annular pressure monitoring in the Goldeneye wells. The installation of DTS and PDGs will further aid identification of any leaks.

The testing of the SSSV will be a lengthy process, expected to take 20 to 40 hours. This time is needed to avoid generating low temperature during the CO₂ bleed-off operation especially at the gas-dense phase interface.
3.8.3.3 Injectivity Analysis Preparation

The objective of the Injectivity Analysis Preparation document is to analyse the expected injectivity of CO₂ in the Goldeneye reservoir. The maximum CO₂ injection rate in the reservoir will be in line with the capacity of the capture plant, which is estimated to be 2.2 million tonnes per year (114.4 million scf/day).

Preliminary calculations indicate that the initial phase of CO₂ injection at low reservoir pressure will be under matrix injection conditions. However, the late phase of injection, when the reservoir pressure increases, is uncertain in terms of injection condition. That is whether later injection will be matrix injection or fracturing conditions.

The Injectivity Analysis Preparation report assumes CO₂ injection under matrix condition, and is divided into three main sections: Initial injectivity; impairment; and mitigation options.

The initial CO₂ injectivity in Goldeneye is expected to be good. Injection pressure is well above the reservoir pressure for the expected injection rates (200 to 400psi [13.8 to 27.6 bar] greater). This conclusion is based on the rock properties and the hydrocarbon productivity. Corrections related to the different PVT properties between the hydrocarbon and the CO₂ are made to the hydrocarbon productivity to obtain the expected CO₂ injectivity.

The risk of not being able to inject the desired amount of CO₂ can be reduced by some proactive measures such as:

- **Pipeline commissioning**
  - Displacement of any pipeline content into the wells during the pipeline-commissioning phase must be avoided. This is to avoid the risk that pipeline debris could potentially be injected into the wells, causing damage or impairing downhole sand control.

- **Filtration of the CO₂ stream**
  - For the same reasons, during the life of the project CO₂ filtration is required to avoid blockage in the formation and blockage in the lower completion.

- **Hydrate inhibition**
  - This is required for a period of time until the water / hydrocarbon is displaced away from the wellbore.

There are other potential impairment mechanisms, which are considered of very low risk to CO₂ injectivity. These include Joule-Thomson cooling, Halite precipitation, and organic deposits such as wax and asphaltenes.

Flow reversal is the only mechanism without any mitigation option. However, based on production information the risk is considered low.

Apart from the proactive measures that can be taken, in the event of injectivity reducing with time there will be some reactive operations which might be carried out to re-gain injectivity performance (in a similar manner to any hydrocarbon development project). The number of wells converted to CO₂ injection can
mitigate the risk of insufficient injectivity due to well impairment or well failure. By using more injector wells the risk is spread and hence reduced.

The full report is available in Appendix C.10.3 under the following reference:
- UKCCS - KT - S7.18 - Shell - 002 Injectivity analysis Preparation

3.8.3.4 Flowline Well Interactions

The primary objective of the Flowline Well Interactions report is to understand the transient well behaviour due to CO₂ injection into Goldeneye wells and its potential implications to the well design. The report covers wells transient analysis for tapered tubing completion options using simulation software. Analysis of variations of Closed In Tubing Head Pressure (CITHP) with reservoir pressure is one of the objectives of this report. The analysed transient effects are:
- well close-in
- start-up operations
- SSSV testing

For the design case, for a short period of time, surface temperature drop in the CO₂ can be in the order of -20°C during well start-up. Due to heat capacity/storage, this low temperature is not observed in the other well components (tubing, annulus fluid, etc), which will see less severe temperature drops.

The reservoir pressure affects the temperature calculation during the transient calculations. The lower the reservoir pressure, the lower the surface temperature expected during transient operation and hence the higher the stresses/impact in terms of well design.

Strict operational procedures need to be implemented and adopted by the Goldeneye Well Operations Group to avoid extreme cooling of the well components due to temperature limitation of the well components.

The full report is available in Appendix C.8.4 under the following reference:
- UKCCS - KT - S7.18 - Shell - 003 Flowline well Interactions

3.8.3.5 Injection Fraccing Conditions

Injection fracturing conditions are obtained when the bottom hole injection pressure exceeds the fracture pressure of the formation. A propagating fracture is created.

The objectives of the Injection Fraccing Conditions document are to:
- Estimate the fracture length in the Captain sandstone which could be created in the formation in the event of CO₂ injection under fracturing conditions
- Highlight the sealing capacity of the Rødby under fracturing injection conditions in the reservoir
- Highlight any operational or well design limitation due to the creation of a propagating fracture in the well

Results of the simulation work indicate that any fractures will preferentially grow down toward the bottom of the Captain D reservoir.
Considering the minimum stress range in the formation and the injection pressure, the most likely scenario during the initial injection period, when the reservoir pressure is relatively low, is to have injection under matrix conditions. However, as the reservoir pressure increases, it is possible that the formation is fractured during the injection process.

In the event of injection under fracturing conditions, the CO\textsubscript{2} quality specification can be relaxed; however, there are limitations related to the erosion of the lower completions (screens / gravel) currently installed in the well. ‘Hot spot’ erosion of the screens is a potential problem for fracturing conditions, as the injected CO\textsubscript{2} is not uniformly distributed in the screens. If fracturing is suspected the recommendation is to limit the injection rate to 38 million scfd per well; however, this limitation can be relaxed with time assuming that the fracture will become wider with time.

A leak off or minifrac test can reduce the uncertainty on the minimum stress value. This information may be used to determine the natural conversion from matrix to fracturing conditions and the resulting consequences.

The full report is available in Appendix C.10.5 under the following reference:
- UKCCS - KT - S7.18 - Shell - 004 Injection Fraccing conditions

### 3.8.4 Geosciences, Reservoir Engineering, Production Chemistry, Monitoring and Reservoir Management Reports

This section is concerned with the seismic interpretation and petrophysical modelling which translates into the static and dynamic reservoir models used in design and through the injection period. The reports also deal with the other reservoir aspects such as reservoir pressure, temperature and volume, both in terms of CO\textsubscript{2} Storage and initial in-place hydrocarbons. Analysis and outcomes in terms of flow assurance, geomechanics, pore pressure, geochemistry, production chemistry and permeability measurement are also presented. Reservoir monitoring, well-reservoir management and the evolving technology associated with the suggested techniques are discussed. Finally, a summary of the storage development plan is presented. This section includes summaries of the following reports:
- (Wells) Fluid Flow Assurance & Technical Design
- Seismic Interpretation Report
- Petrophysical Modelling Report
- Static Model (Field)
- Static Model (aquifer)
- Static Model(overburden) report
- Full Field Model (FFM) Dynamic Modelling report
- Pressure, Volume, Temperature (PVT) Report
- Initially in Place (IIP) Volumes Estimate
- CO\textsubscript{2} Storage Estimate
- Geomechanics Summary Report
- Pore Pressure Prediction
- Geochemical Reactivity Report
- Special Core Analysis (SCAL) Report
- Production Chemistry Operability Review
- Asset Reference Plan
- Measurement Monitoring and Verification (MMV) Plan
- Monitoring Technology Feasibility Report
- Well and Reservoir Measurement (WRM) Plan

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3.8.4.1 (Wells) Fluid Flow Assurance & Technical Design

The objective of the (Wells) Fluid Flow & Technical Design document is to discuss the flow assurance aspects of the proposed UKCCS Demonstration Project.

No integrity concerns are discussed in this document as the injected CO₂ is assumed to be dry at the point of delivery such that wet corrosion is not an issue that requires consideration.

The technical design of the Goldeneye CCS scheme has been reviewed and the relevant flow assurance aspects of the scheme have been identified and considered. This flow assurance investigation has included:

- Hydrate formation
- Scale
- Wax
- Asphaltenes
- Corrosion
- Pipeline debris transport
- Halite precipitation

While most flow assurance considerations present no threat to project feasibility, there are still some important aspects of hydrate management that require characterisation before the current CCS scheme can be designated feasible.

The full report is available in Appendix C.10.2 under the following reference:
- UKCCS - KT - S7.19 - Shell - 001 Fluid Flow Assurance & Technical Design

3.8.4.2 Seismic Interpretation Report

The Seismic Interpretation report documents the geophysical work carried out to characterise the Goldeneye CCS storage complex. The current seismic work (based on data acquired in 1997 and reprocessed in 2001) is focused on the identification and interpretation of key seismic events (horizons) and discontinuities (faults) in the Upper Cretaceous to recent rocks over the Goldeneye Field and its adjacent aquifer.

The resulting seismic horizons and faults have been used as input data to create three static models covering:
- The Goldeneye Field itself
- The overburden above the Goldeneye Field
- The regional aquifer of the Captain Sandstone

The full report is available in Appendix C.10.2 under the following reference:
- UKCCS - KT - S7.19 - Shell - 006 Seismic Interpretation Report

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3.8.4.3 Petrophysical Modelling Report

The Petrophysical Modelling report compiles petrophysical input, the methods and the interpretation results, which were used to populate the reservoir properties in the Goldeneye Static and the Dynamic models:
- Full Field
- Overburden
- Aquifer.

The comprehensive evaluation is based on datasets which were acquired from exploration and development wells in the Goldeneye field, the location where routine and special core data are mainly concentrated.

For the aquifer model the scope of interpretation is extended to cover a wider area, including surrounding fields such as Atlantic, Hannay, Hoylake, and Cromarty. Key deliverables are porosity, permeability, net to gross, fluid contacts and the saturation height model for the FFM, and porosity, permeability, net to gross and Chalk capillary entry pressure for overburden and aquifer models. It is necessary to use analogue data to represent the properties, primarily permeability and capillary entry pressure, because of limited data acquisition in Goldeneye overburden formations and in the Fairway Trough Kopervik sand near the Goldeneye field.

The full report is available in Appendix C.10.2 under the following reference:
- UKCCS - KT - S7.19 - Shell - 007 Petrophysical Modelling Report

3.8.4.4 Static Model (Field) Report

A static reservoir model (SRM) was generated by the Shell Goldeneye Asset team, to support hydrocarbon volumetric assessment and dynamic simulation for history matching and field performance prediction. This model has been reproduced and is being used as a reference case (SRM1). It was discovered by the Asset that to achieve a reasonable match between predicted and observed performance during the production life-cycle of the field, some changes to the distribution of hydrocarbon volume in the dynamic simulation model were required. An attempt has been made to reproduce these dynamic model changes in SRM2.0, to provide geological foundations to the alterations made. Further models have been created to investigate other areas of geological uncertainty.

The overall objective of this work is to assess the suitability of this asset static reservoir model as a basis for the forward modelling of CO₂ injection and storage. Secondary objectives include:
- Create a static model realisation that matched (as close as geologically possible) the Asset’s dynamic simulation model
- Create a suite of models that allow the investigation of geological uncertainties important for CO₂ injection and storage. These models vary such things as reservoir layering, reservoir connectivity and overall connected hydrocarbon volume in order to assess the impact of these variables on the forward modelling of the CO₂ injection phase.

As a result of the work carried out in the ‘Static Model (Field)’ workstream, ‘end-member’ geological realisations have been passed to the dynamic simulator. The dynamic models are being historically
matched with known production performance in order to demonstrate that they provide a ‘robust’ model of the Goldeneye field that can be used to evaluate forward predictions of CO₂ injection.

The full report is available in Appendix C.11.4 under the following reference:
- UKCCS - KT - S7.21 - Shell - 002 Static Model (Field)

3.8.4.5 Static Model Aquifer

The Static Model Aquifer report documents the construction of a regional aquifer 3D static model for the Captain Sandstone in the South Halibut Basin.

The aquifer static model was constructed primarily for reservoir engineering purposes to enable the visualization and dynamic modelling of the Captain Sandstone aquifer in order to simulate any potential lateral discharge of CO₂ out of the Goldeneye containment structure. The coarsely gridded 3D static model captures the approximate dimensions and regional porosity and permeability trends present in the Captain Sandstone Fairway stretching from the Blake Field in the west through Cromarty, Atlantic, and Goldeneye Fields towards the Hannay Field in the east.

The resultant 3D model indicates the Captain Sandstone aquifer dimensions to be 5-10km wide and up to 100km long, with average porosities of 25-30% and Darcy range sands.

The full report is available in Appendix C.10.2 under the following reference:
- UKCCS - KT - S7.22 - Shell - 001 Static Model (Aquifer)

3.8.4.6 Static Model (overburden) Report

An overburden assessment has been conducted above and adjacent to the Goldeneye Field, to identify possible secondary containment horizons and potential migration pathways out of the Goldeneye storage complex, in the unlikely event of seal or fault leakage of the stored CO₂.

A 3D geological model was constructed which depicts the overburden and underburden lithologies, covering an area approximately 17km by 8km around the Goldeneye Field.

The model extends from the seafloor (~7874ft [~2400m] above the Captain reservoir) down to the Top Triassic Heron Group (~2953ft [~900m] below the Captain reservoir). By extending the model down to the top of the Triassic-aged Heron Group, we have included all of the underburden stratigraphy that is potentially in contact with the Captain Sandstone Unit within the area of our model. We are aware that fault juxtaposition in other parts of the trough may bring the Lower Cretaceous succession (including the Captain sandstone) into contact with Heron Group and Zechstein Group sediments but, as we feel that we have demonstrated the lack of pressure and fluid connection between the Captain and the underlying conductive formations, we deemed it unnecessary to reflect this possibility in our model.

The primary seal to stored CO₂ in the Goldeneye Field is provided by the calcareous and chalky mudstones of the Rødby Formation. CO₂ is not expected to leak through the top Rødby seal which has already trapped the Goldeneye gas over geological time, or via reservoir level faults which do not offset the sealing caprock. At least two different fault sets are present in the overburden, but these faults are considered to be decoupled from the Captain Reservoir faults.
The Lista Formation is identified as a secondary sealing interval in the overburden above the Goldeneye Field. The Lista mudstone comprises non-calcareous, bioturbated, non carbonaceous and non pyritic mudstones, and is a proven hydrocarbon seal in the central North Sea. CO₂ could also potentially be constrained by the Dornoch Mudstone. There are, however, no additional structural closures identified in the overburden stratigraphy.

Overall it is felt that migrating CO₂ from the Goldeneye Field is not likely to reach the surface via pathways originating in deeper parts of the overburden.

The full report is available in Appendix C.11.6 under the following reference:

- UKCCS - KT - S7.22 - Shell - 002 Static Model (Overburden)

### 3.8.4.7 FFM Dynamic Model Report

3D dynamic modelling of the injection of dense phase CO₂ into the Goldeneye depleted hydrocarbon reservoir has been performed with the following four aims:

- Showing that the system has sufficient capacity to store the required 20 Million Tonnes of CO₂
- Predicting the reservoir pressures to use in injection well design and geomechanical risk assessment
- Assessing the impact of the injection of CO₂ in Goldeneye on other users of the subsurface and their impact on Goldeneye
- Determining the effect of injection well selection on the plume development within the CO₂ store and on the risk of lateral migration

In order to address the above, a multiple scale modelling approach was adopted. This facilitated the assessment of the interaction of the complex static and dynamic factors which may coincide during CO₂ injection into the Goldeneye reservoir. Results from a three-dimensional, three-phase full field Goldeneye numerical simulation model, corroborated initial storage capacity estimations. Different injection scenarios were evaluated to map out the range of capacity available for CO₂ storage.

The effects of geochemical reactivity were tested in the models – by running coupled fluid flow and chemical reactive transport simulations. The results from the dynamic models were input into geomechanical models.

The full report is available in Appendix C.10.2 under the following reference:

- UKCCS - KT - S7.21 - Shell - 005 FFM Dynamic Model Report

### 3.8.4.8 Pressure, Volume & Temperature Report

The PVT report details the PVT characterisation that will be used to model the phase behaviour of CO₂ injection into the depleted Goldeneye Gas Condensate field.

The PVT report includes the following:

- Preparation of a consistent Equation of State (EOS) compositional model for Goldeneye Gas Condensate PVT. This involves the rationalisation of hydrocarbon single components (lumping) to achieve a representative but at the same time manageable fluid characterisation.
The Goldeneye hydrocarbon reservoir fluids have been extensively characterised during the hydrocarbon production phase of the fields. This PVT characterisation has been updated and extended to facilitate:

- An equation of state description in the reservoir simulation
- A good representation of the properties of CO₂ at storage conditions

The full report is available in Appendix C.11.8 under the following reference:

- UKCCS - KT - S7.21 - Shell - 001 PVT Report

### 3.8.4.9 Initially In-place Volumes Estimate

Initially In-place (IIP) hydrocarbon volumes have been calculated for the entire suite of static reservoir models (SRMs) created to investigate CO₂ injection performance in the Goldeneye reservoir. The gas initially in-place (GIIP) volumes derived from these models all fall within the P10-P90 expectation range from the field, as calculated by the Goldeneye field/asset production team in their most recent static modelling programme, suggesting that they are representative of the field.

Three sensitivities expected to have an impact on the behaviour of CO₂ in the full field simulation model (FFSM) have been investigated with this suite of models. Although only of secondary importance, the impact of these sensitivities on in-place volumes has been assessed. Of the three, the internal reservoir zonation has the greatest volumetric impact (-9.6% to +4.8%, when compared to the production teams model), the position of the northern stratigraphic pinchout the next largest impact (-5.3% to +1.2%) and the angle of dip of the western flank of the field has the least effect, leading to a maximum in-place volume reduction of only 1.5%.

The in-place volumes calculated from the entire static reservoir models under consideration have been compared to the stochastic volumetric assessment carried out by the production team during their most recent phase of modelling. The static reservoir models created for this project are in agreement with those calculated from three hundred and eighty-one stochastic modelling runs generated by the production team and so are believed to be a suitable representation of the Goldeneye Field.

As an additional quality assurance/quality control step, one of the static reservoir models has been up-scaled into the dynamic simulator and IIP volumes from this full field simulation model have been compared with the source SRM. A comparison of these showed only small variations in hydrocarbon volumes in the two realisations of the model, due to differences in resolution between the two. The models are therefore deemed suitable for dynamic simulation and history matching to observed production data.
Note that none of the figures included in this report should be interpreted, in any way, as statements pertaining to Securities and Exchange Commission (SEC) compliant proved or expectation reserves or scope for recovery.

The full report is available in Appendix C.11.9 under the following reference:
- UKCCS - KT - S7.21 - Shell - 003 IIP Volumes Estimate

### 3.8.4.10 CO₂ Storage Estimate

Depleted oil and gas reservoirs are prime candidates for CO₂ storage for several reasons:
- Oil and gas that originally accumulated in structural and stratigraphic traps was contained (in some cases for many millions of years), demonstrating the long term integrity of such reservoirs.
- The geological structure and physical properties of most oil and gas fields have been extensively studied and characterised.
- Some of the infrastructure and wells already in place may be used for handling CO₂ storage operations.

Goldeneye has all of these elements, making it an excellent candidate for CO₂ storage. The geologic carbon storage capacity has been calculated for the Goldeneye reservoir.

The CO₂ storage capacity was initially estimated based on the pore space available for CO₂ injection from a standard volumetric assumption. The method used to estimate the CO₂ storage volume in Goldeneye, a depleted gas reservoir, was hydrocarbon production-based, corrected for CO₂ service. This resulted in a storage volume estimate of 47 million tonnes of CO₂ equivalent available for storage in Goldeneye.

This maximum initial estimate of storage volume was modified by storage efficiency factors, which account for the fact that CO₂ may not be able to completely refill this volume. An uncertainty analysis study was carried out, oriented towards the impact of CO₂ injection, which aimed to deliver a set of parameter ranges and subsurface realisations that need to be modelled (static and dynamic).

The conjunction of these static and dynamic uncertainties depicts the framework which is necessary for understanding the storage efficiency factors that discount the total theoretical capacity.

In addition to the storage capacity defined by the structural trap of Goldeneye, the water leg beneath the reservoir (that lies within the storage site) could potentially add 6 million tonnes of extra capacity, based on numerical simulation results.

Finally, the discounted analytical storage estimation was compared with the results from a three-dimensional, three-phase, full field Goldeneye numerical simulation model. The objective of this exercise was to corroborate the initial storage estimations and permit the evaluation of different injection scenarios, in order to map out the range of capacity available for CO₂ storage.

The complete suite of static reservoir models created to investigate CO₂ injection performance in the Goldeneye reservoir was tested. Injection scenarios ranged from:
- A reference case injecting in 4 of the 5 wells available in the field, with an even injection rate for 10 years
Extreme cases where all the available CO₂ was injected in a single well

Injection at double the predicted injection rate

All of these scenarios were investigated in order to demonstrate that Goldeneye has sufficient storage capacity to hold 20 million tonnes of CO₂, as mandated by the UKCCS Demonstration Competition. All the scenarios demonstrated the field can safely store the intended volume with respect to the uncertainties currently evaluated.

In order to gauge the maximum geologic carbon storage capacity for the Goldeneye reservoir the simulation models were run with continuous CO₂ injection until 2035 (20 years of injection). These “fill till spill” runs showed that over 30 million tonnes of CO₂ must be injected to reach the structural spill point and initiate lateral migration within the adjacent Captain Fairway. If CO₂ were to migrate in the Fairway it would undergo migration assisted storage and no leakage would be expected, however, a storage permit for a larger storage site would need to be applied for. The CO₂ was stored both in the Goldeneye hydrocarbon reservoir and also in the aquifer beneath the field. This analysis shows that there is at least a 50% storage capacity margin, giving confidence that Goldeneye can store the 20 million tonnes as mandated by the UKCCS Demonstration Competition and that extension of the site to include migration assisted storage is not required.

The full report is available in Appendix C.11.10 under the following reference:

UKCCS - KT - S7.21 - Shell - 004 CO₂ Storage Estimate

3.8.4.11 Geomechanics Summary Report

For safe storage of CO₂ in underground depleted gas reservoirs, it is of fundamental importance to understand and control the injection and trapping in the subsurface. During the CO₂ injection fluid pressure will increase, temperature (close to the wellhead) will change, and chemical reactions between the fluids and rocks will affect the rock strength and the stress state both inside and outside the reservoir. Therefore, the integrity of the reservoir itself and the overlying seal must be investigated with an emphasis on likelihood of leakage. Also the likelihood of fault slip needs to be investigated. This is investigated in the Geomechanics Summary Report.

The geomechanical analysis starts with the construction of a mechanical model of the structural geology of the Goldeneye reservoir and the formations around it. Therefore, seismic, drilling, logging, and core data is used. A reservoir model provides pressure data as well as porosity and net to gross from which mechanical properties can be derived. After initial equilibrium is achieved the mechanical model is then used to describe deformation and stress changes due to depletion (of the gas) and injection (of the CO₂). The re-equilibrium process allows for stress path predictions and mechanical stability of both cap-rock (integrity) and faults (slip). Special care was taken to define the different behaviour of the stresses between depletion and injection (hysteresis).

This mechanical model is used to investigate the limits of CO₂ injection operations such that containment is ensured during injection and trapping.

Relevant geomechanical threats as identified in other CCS studies are summarised in the report.
Note, that after a period ranging from 300 to tens of thousands of years (dependant on the connectivity in the aquifer, assuming no other injection into the connected volume), the aquifer re-pressurizes the field back to the initial pre-production pressure. This effect has not been taken into account in this assessment.

The full report is available in Appendix C.10.2 under the following reference:
- UKCCS - KT - S7.19 - Shell - 004 Geomechanics Summary Report

### 3.8.4.12 Pore Pressure Prediction

The key objectives of the Pore Pressure Prediction report are as follows;
- To provide the expected reservoir pressure of the Captain Sandstone for future well activity, be that a workover, sidetrack or new well.
- To review the expected pore pressure regime in the over- and under-burden which will provide an expected pore pressure in the overall CO₂ storage complex.

In order to discuss the relevant data and information for each of these objectives, the report is divided into two sections covering the over and under-burden and the reservoir, specifically.

A thorough review of 17 wells in the area of the Goldeneye Field indicated that the lowest mud weights used to drill the stratigraphic sequence from the seabed to TD (Total Depth) in the Permo-Triassic sequence ranged from 0.447-0.520 psi/ft, indicating a relatively low pore pressure regime compared to other parts of the North Sea.

The drilling data showed indications of pore pressure above hydrostatic pressure in the Tertiary mudstones (0.480 psi/ft), which is similar to the range of RFT (Repeat Formation Test) data from the AOI (Area of Interest) which ranged from 0.475-0.500 psi/ft. Both the Chalk Group and Cromer Knoll Group sequence appear hydrostatically pressured, supported for the latter by the consistency in Goldeneye well RFT data. The deeper Jurassic to Permian sediments encountered in the Goldeneye Field appear normally pressured based on drilling and RFT data, however, the Kimmeridge Clay Formation is under compacted relative to the general mudstone compaction trend, which indicates possible overpressure. This is supported by the kick that occurred in well 20/4b-4 from a sand unit within the Kimmeridge Clay Formation.

A depth trend of minimum principal stress (also termed the formation strength) for the Goldeneye Field and surrounding area has been calculated based on the available LOT (Leak-Off Test) and FIT (Formation Integrity Test) data from the well review.

The Goldeneye Captain reservoir has abundant pressure data, from both pre-production logging and testing through to the production wells which all had downhole gauges installed. The virgin pressure at the water contact was 3825 psi at 8592 ft [264 bar at 2619 m] TVDSS (True Vertical Depth Subsea), whilst the gas pressure at 8400 ft [2560 m] TVDSS was 3814-3818 psi [262.9-263.2 bar]. The well is expected to cease production in 2011. An extensive dynamic aquifer model for the Captain sand fairway has been constructed which covers adjacent fields including Hannay, Atlantic, Cromarty, Blake, as well as Goldeneye. The model predicts that by 2015 the reservoir pressure in the Captain Sand will be in the range 2830-2960 psi [195-204 bar]. Although the production and well test data indicate that the Goldeneye reservoir is well connected, isolated pockets of high and low pressures cannot be ruled out.

The full report is available in Appendix C.10.2 under the following reference:
The key subsurface selection criteria for a CO₂ storage reservoir are capacity (how much CO₂ can it store), injectivity (how many wells are required for storage, affecting the cost of storage) and containment (will the CO₂ stay underground).

There are many factors that influence these selection criteria. The factor addressed in the Geochemical Reactivity Report is the geochemical interactions between the (dissolved) CO₂ and the rock minerals. Each of the key criteria can be affected by these interactions:

- CO₂ can mineralise to form carbonate minerals, thus increasing the storage capacity and security of containment
- It can change (increase or decrease) the injectivity due to rock alterations around the well
- It can change (increase or decrease) the sealing capacity of the caprock.

In general the mineralological changes could impact each of the three key subsurface CO₂ storage selection criteria: capacity, injectivity and containment. To qualify and quantify this impact a reactive transport study was performed. The results are described in the Geochemical Reactivity report. The main results are summarised below:

- Caprock exposed to CO₂ plume
  - The CO₂ diffuses over a distance of 50-75m in 10,000 years. Caprock alterations possible within this distance. Alterations tend to decrease porosity. Therefore low risk of induced leakage.

- Caprock exposed to formation brine with dissolved CO₂
  - Similar outcome as caprock exposed to CO₂ plume. Some dissolution is possible in any calcite rich features running through the caprock, but only over a small distance at their base (less than 33cm in 10,000 years). Low risk of induced leakage.

- Reservoir within and close to CO₂ plume
  - Permeability decrease possible during injection period but unlikely to have significant impact on injectivity. Potential for a large CO₂ mineralisation in optimistic scenario. Dissolution storage relatively low (14% of injected CO₂ after 10,000 years).

The full report is available in Appendix C.10.2 under the following reference:
- UKCCS - KT - S7.19 - Shell - 003 Geochemical Reactivity Report

SCAL data is an important input to the assessment of the CO₂ storage capacity of the Goldeneye reservoir. Relative permeability and capillary pressure affect the mobility of the different fluid phases in the reservoir, and influence the overall volumetric sweep and the remaining water saturations in CO₂ invaded intervals. Trapped CO₂ saturations to brine imbibition post-injection provide long term storage of CO₂ as an immobile phase and limit the lateral movement of CO₂ in any aquifer egression.

The SCAL study has comprised three stages:
Development of a conceptual framework for the displacement mechanisms and identification of key uncertainties

Review of existing Goldeneye SCAL data

Specification and execution of a new SCAL programme to address uncertainties that have the largest impact on predictions of storage capacity.

The conceptual framework considered the full cycle of the Goldeneye reservoir:

- Production phase with the reservoir under depletion and subject to aquifer invasion in the hydrocarbon column
- Injection phase with the movement of the CO₂ plume, as highly mobile CO₂ displaces less mobile brine at trapped gas saturation in the original hydrocarbon column and potentially brine in the aquifer
- Post-injection phase with the fluid distribution equilibrating under gravity and the re-imbibition of brine trapping CO₂

The framework enabled the key aspects of the displacement mechanisms to be identified and the corresponding relative permeability data requirements. This focused subsequent modelling of uncertainty and laboratory measurements onto a high graded set of data from the otherwise wide range of displacement mechanisms occurring in the reservoir. The initial understanding of the displacement processes was confirmed by ongoing comparison with the dynamic modelling in the simulacrum box models and full field models of Goldeneye.

The existing SCAL data comprised of:

- Steady State imbibition gas/water relative permeability
- Steady State imbibition gas/oil, Steady State drainage gas/oil, Steady State imbibition water/oil

The data was reviewed and uncertainty ranges were developed for the trapped gas saturation to water and the brine endpoint relative permeability at trapped gas. This provided an input to the history matching of the existing Goldeneye performance.

The new SCAL programme was designed to reconfirm the ranges on trapped gas saturation and water mobility at trapped gas and to extend the data set to the key relative permeability data controlling CO₂ movement:

- CO₂ relative permeability at low water saturations, which influences Dietz stability and injectivity
- Trapped CO₂ saturation to water, which limits the possible movement of CO₂ in the aquifer
- Water primary drainage relative permeability, which controls the remaining water saturation within the CO₂ plume

The programme uses a series of ambient condition tests using centrifuge and unsteady state displacements, together with unsteady state reservoir condition measurements with CO₂. The reservoir condition tests are designed to minimise any laboratory artefacts by using pre-equilibrated CO₂ and brine in
a re-circulating system. Except for the centrifuge measurements, in-situ saturation monitoring is used throughout to allow better interpretation of the data.

The full report is available in Appendix C.11.14 under the following reference:
- UKCCS - KT - S7.19 - Shell - 002 SCAL Report

3.8.4.15 Production Chemistry Operability Review

The objective of the Production Chemistry Operability Review document is to identify and assess the significant production chemistry related operability issues associated with the proposed Goldeneye Carbon CCS scheme, and consider any necessary mitigation measures.

The production chemistry related operability issues have been identified and considered. No insurmountable operability issues were identified. The chemistry of hydrocarbon fluids is a significant focus in oil and gas production projects, with issues such as wax deposition, hydrate formation, and the breaking of emulsions all key determinants of project success. As this project is concerned with the injection of dense phase CO₂, an inherently less complex fluid, the production chemistry elements of this project are simpler. In summary, as long as the CO₂ is dry (essentially water free), and does not contain significant levels of contaminants such as H₂S, there are no significant operability issues until the CO₂ mixes in the injection well with the native Goldeneye reservoir fluids. At this point there is a small potential for hydrate formation, which can be controlled by the introduction of a suitable inhibitor. Inelastic compaction has been found to be insignificant and does not reduce the storage volume.

The full report is available in Appendix C.11.15 under the following reference:
- UKCCS - KT - S7.19 - Shell - 005 Production Chemistry Operability Review

3.8.4.16 Asset Reference Plan

The Asset Reference Plan (ARP) demonstrates that all activities, resources, threats and opportunities for improvement to a facility’s technical integrity have been fully evaluated and the impact on cash flow quantified over the life cycle. It is a living document, updated annually, and the first draft is typically drafted after the Storage Development Plan is written. It will contain the following elements:
- Discussion of the asset performance
- Current reservoir pressure
- Injection Forecasts
- Amount of CO₂ stored
- Remaining capacity
- Well and reservoir management plan

The scope for Shell, and therefore, of the ARP, is limited to the following:
- Transport of the CO₂ imported from St. Fergus Gas Plant to the Goldeneye Platform
- Injection and storage of the CO₂ into the Goldeneye reservoir.

An SDP has been written, but project execution is still at least three years away. As a consequence, the ARP describes the asset as it is currently constituted and uses headings and short descriptions as placeholders for the operational data and analysis that will be collected/undertaken when injection is underway.
The full report is available in Appendix C.11.16 under the following reference:
- UKCCS - KT - S7.23 - Shell - 003 Asset Reference Plan

3.8.4.17 Measurement, Monitoring & Verification Plan

The Goldeneye measurement, monitoring and verification (MMV) plan has been developed to address the following:
- Verify the volume and quality of CO₂ injected
- Show that the CO₂ is stored in the storage complex

The first activity, storage, is addressed from two angles: by showing conformance of monitoring results with 3D dynamic earth models; and by monitoring for indications of loss of containment or significant irregularities. The containment monitoring programme is based on two key tenets:

1. Monitoring is focussed on areas and features highlighted by the risk assessment as being of higher risk of potential leakage.
2. Monitoring is built on a staircase of increasing focus and cost; it starts by aiming to detect a potential irregularity then, if an irregularity is suspected, the programme focuses on delineation and confirmation that the suspect is an irregularity (contingency monitoring). The final step – performed in conjunction with the corrective measures plan – is to quantify or define the magnitude of any leak.

The MMV is divided into phases: pre-injection or baseline; during injection; and post-injection/closure. The baseline is key to ensuring that the project has a well defined starting point from which to measure any changes. This activity lays down both an environmental and a subsurface baseline. During injection a base plan is executed, informed by the risk assessment and aimed at detecting any irregularities. After injection has ceased another base line is taken to compare the before and after state of the system. This is complemented by additional monitoring over the subsequent years, again informed by the risk assessment.

A vital point to note is that the risk assessment and the monitoring plans are dynamic. They are updated as new information from conformance and containment monitoring is received.

After a significant set of screening and modelling exercises the following main monitoring techniques have been selected as suitable for use in the Goldeneye field specific situation:
- Environmental baseline monitoring using multi-beam echo sounding, seabed sampling and continuous injection tracer.
- Well integrity monitoring using pressure and temperature gauges, distributed temperature sensors, tubing integrity logging and seabed CO₂ detection below the platform.
- CO₂ injection conformance using pressure, saturation and flow monitoring
- Lateral and vertical irregularity and plume conformance using time lapse seismic

The timing and frequency of monitoring is informed by the risk assessment and varies from technique to technique. This is explained in detail in the MMV plan.
3.8.4.18 Monitoring Technology Feasibility Report

The Monitoring Technology Feasibility report documents the potential monitoring technologies that can be used to detect CO₂ migration/leakage and to validate injection conformance. The technologies are screened against CO₂ scenarios specific to the geology and dynamics of the Goldeneye system i.e. site-specific to CO₂ storage in the depleted Goldeneye hydrocarbon reservoir.

This screening results in a shortlist of technologies that are technically feasible for application at the Goldeneye storage complex. This list forms the basis for the development of the Monitoring, Measurement and Verification (MMV) plan.

The Monitoring Technology Feasibility report concentrates on technologies for monitoring CO₂ movement within the store (conformance) leakage or migration from the subsurface store, which includes both commercial and emerging (R&D) technologies. Proven/standard technologies related to the monitoring of CO₂ in facilities and pipelines are covered in the surface facilities design FEED activity.

The full report is available in Appendix C.10.2 under the following reference:
- UKCCS - KT - S7.20 - Shell - 003 Monitoring Technology Feasibility Report

3.8.4.19 Well and Reservoir Management Plan

The Well and Reservoir Management (WRM) plan for Goldeneye is an integral part of the MMV plan.

One of the main objectives of the MMV plan is the Verification and validation (or conformance) of dynamic earth models in the short term, to estimate the long-term behaviour of CO₂ plume, to inform the frequency and duration of the monitoring plan and to confirm secure containment.

Optimising the injection phase is the objective of the Well and Reservoir Management (WRM) team during the CCS project. Since reservoir behaviour is complex in a CO₂ injection project, WRM focuses on continuous performance monitoring, recognising issues/problems and acting upon these variances.

The frequency of monitoring and verification will change over time because the risk profile of the storage complex changes over time. An annual surveillance plan is issued to ensure the reservoir is adequately monitored.

WRM seeks to optimise injection and to improve the understanding of the reservoir. Data is collected to enable decisions to be taken: either on activities on the existing well stock or even on the requirement for new wells.

The full report is available in Appendix C.11.19 under the following reference:
- UKCCS - KT - S7.23 - Shell - 001 WRM Plan
3.8.4.20 Corrective Measures Plan

A number of scenarios have been identified whereby CO₂ could possibly migrate from the Goldeneye storage reservoir. The purpose of the Corrective Measures Plan is to identify and determine what corrective measures should be applied for each scenario.

Corrective measures do not necessarily mean direct and immediate intervention into an existing or abandoned well, the drilling of a relief well or even stopping of injection. It is explicit that determining the root cause, size and ultimate risk of an irregularity is essential in order to direct the appropriate course of action. Natural mitigation means that corrective measures involving increased monitoring along with pre-planning for a potential intervention are the most appropriate course of action in many circumstances. Notwithstanding, there are some circumstances whereby, although low probability of requirement, corrective measures involving active intervention are envisaged. This summary identifies, in outline, these measures.

The plan provides a summary of the contingent measures proposed for the various migration possibilities, which include:
- Active Injection Wells
- Decommissioned Exploration / Appraisal Wells
- Migration through Decommissioned Injection Wells
- Failure of the Primary Seal
- Failure of Primary and Secondary Seals
- Lateral Migration within the Captain Sands

The full report is available in Appendix C.10.2 under the following reference:
- UKCCS - KT - S7.20 - Shell - 001 Corrective Measures Plan

3.8.4.21 Technology Maturation Plan

Technology Maturation Definition

In a relatively new field of work it is to be expected that many of the technologies that are required to deliver the project have yet to be developed. To capture and monitor these, a technology maturation plan, specific to the Goldeneye CCS project, has been constructed. This lists those technologies selected at concept select phase as part of the base case scenario or identified as a ‘strong option’ where they are considered ‘key’ in order to deliver or enhance the value of project. The technology maturation plan will contain the procedure on how these technologies will be matured and made ready for application as per project timeline.

Project Concept Selection

Prior to FEED, the project underwent a concept select phase where a working case was determined from several options. Some of the decisions made require further study to either confirm the selection or to select an alternative option so it is important to include viable option/decisions in the scope as well as selected working case. The decisions/selection of working case and viable options from the surface and subsurface workstreams are listed in the plan.
Immature technologies will be specific to certain discipline(s) and require alignment with research projects (ongoing, planned or future), whether internally, within members of the Consortium or in conjunction with industry/university bodies. In the absence of aligned research projects, resources will have to be identified and allocated to ensure maturation is obtained within project timeline, based on necessity of the application to the success of the venture.

**Technology Enablers**

The immature technologies have been identified from the base case and the maturation plan for each technology is compiled in a data sheet contained in the technology maturation plan.

The full report is available in Appendix C.10.2 under the following reference:

- UKCCS - KT - S7.23 - Shell - 002 Technology Maturation Plan

### 3.8.4.22 Storage Development Plan

This Storage Development Plan has been prepared at the end of the FEED study of the UKCCS Demonstration Project. As such, it presents the current state of understanding of the storage of CO₂ in the Goldeneye system. Some key areas of uncertainty are outstanding at this time. These include:

- Regulatory uncertainty relating to the preparation for – and receipt of – a storage licence. This might require additional work to be performed.

- Additional technical assurance within the Shell group, planned for March 2011. This could identify areas that require further work or where results presented in this plan need to be revised.

- Continuing research into the field of geo-storage. These may lead to revision of the risk assessment and, ultimately, the recommendations of the plan.

The aim is to re-use as much existing infrastructure as possible. The current Goldeneye processing facilities at St. Fergus are no longer needed and will be bypassed with the installation of a new section of pipeline. However, the platform will still be operated remotely from the Shell St. Fergus (SEGAL) control room. The offshore pipeline will be cleaned and re-used, reversing the direction of flow. The platform will be modified with the addition of filtration and the replacement of much of the pipework. The vent system and all safety systems will also be upgraded for CO₂ operation.

A key challenge will be managing CO₂ as it flows into the field. If it is allowed to flow freely into the reservoir the ‘Joule-Thompson effect’ will refrigerate the CO₂ to, at worst, -30°C as it expands from the >100bara wellhead pressure on entry to the wells. This will be managed by working over the wells and installing slim tubing – constricting the flow and maintaining the CO₂ in the dense phase for the whole length of the well. The workovers require the use of a super-giant jack-up drilling rig. Transient effects are expected to occur at start-up and shut-down. Therefore, operational constraints have been placed on the rate of bean up/bean down and cycle frequency of the facility. Instrumentation will be added to the wells, in the form of distributed temperature sensors, to complement the existing surface and upgraded subsurface pressure and flow monitoring. This will also improve monitoring of well integrity.

The topside facilities will also be exposed to low temperatures in the event of a blown down. This will necessitate the replacement of existing pipework and wellheads with equipment fabricated from stainless steel capable of handling such temperatures. As the CO₂ will be de-hydrated at Longannet, corrosion of...
the pipeline and facilities is not a concern – as long as the system remains within specification. This is being assured by the implementation of quality monitoring systems at the compression stations.

Each injection well will have a unique tapered injection string in order to handle different ranges of flow and reservoir pressure while maintaining the CO₂ in dense phase. In order to match surface and bottom hole conditions and a specific flow rate, three out of a selection of four wells will be called upon. The fifth well will be re-completed as a spare in order to maintain injection if an integrity failure were to occur and will also be used as the main monitoring well. This technique has not been applied before on an industrial scale and therefore poses some risk owing to its novelty.

The wells have a non-cemented completion with gravel packs and sand screens. These are being re-used. The risk of plugging posed to these completions from fines in the offshore pipeline (residual after cleaning or from potential de-lamination of an internal coating) is being mitigated by the installation of a filtration package on the platform.

The CO₂ will be injected into the storage site at a depth >2516m below sea level into the high quality Captain Sandstone Member – a 130km long and <10km wide ribbon of Lower Cretaceous turbiditic sandstone fringing the southern margin of the South Halibut Shelf. At the Goldeneye field this sandstone has permeability of between 700 and 1500 MD.

Since 2004, the field has produced 568Bscf of gas. During production the field experienced moderate to strong aquifer support – which also served to end the production from the wells as each well sequentially watered out.

The primary CO₂ storage mechanism will be accommodation in the pore space voided by the production of gas and condensate from the Goldeneye field. A secondary mechanism will be immobile capillary trapping in the water-leg below the original hydrocarbon accumulation.

When CO₂ is injected into the field it has to push the invaded water back into the aquifer. This unstable displacement causes a phenomenon known as a Dietz tongue to form and push some of the injected CO₂ below the original oil-water contact. Once injection has stopped this CO₂ flows back up into the CO₂ leg, leaving between 20 and 30% behind, capillary trapped in the water-leg.

Analysis has shown that the field and water-leg have sufficient capacity to store over 30 million tonnes of CO₂ – more than sufficient for the 20 million tonnes proposed in the UK Demonstration Competition.

The Goldeneye field is hydraulically connected to the neighbouring fields in the east (Hannay, 14/29a-4 discovery – Hoylake – and, potentially, Rochelle) and the west (the soon to cease production Atlantic & Cromarty and, potentially, the still producing Blake). The pressure support from the Captain aquifer has limited the decline in Goldeneye pressure, from an original of 262bara to around ~152bara (at datum level of 2560m TVDSS). Injection of 20 million tonnes of CO₂ will raise the pressure to between ~241 and ~259bara at the end of injection. The pressure will then fall to between ~224 and ~245bara as it dissipates into the aquifer. The fall off will alter to no or a slow recharge, dependent on the activity of other fields in the Captain sandstone aquifer and also on the degree of connectivity 150km up dip where it is thought to ultimately crop out at seabed.
Other nearby fields have Upper Jurassic (Ettrick – 20km from Goldeneye; Tweedsmuir – 30km; Buzzard – 40km; Ross – 60km) or older (Buchan – 25km – is Devonian) reservoirs. Pressure and compositional data from these fields show that they are not in communication with the Captain Fairway fields.

Containment is provided by the 300m thick storage seal, a package including part of the Upper Valhall Formation, Rødby Formation, Hidra Formation and the Plenus Marl Bed. No gas chimneys are observed above Goldeneye. The sealing capacity of the Rødby formation is thought to be excellent as it acts as the primary seal for all for fields in the Captain fairway.

The complex seal is made up of two mudstone units that can be reliably correlated across the area of the Goldeneye field. These are the mudstone at the top of the Lista Formation (Lista mudstone) and the Dornoch mudstone. They are found at depths greater than 800m TVDSS across the entire area under investigation (meaning that any CO₂ that becomes captured beneath them will remain in the dense phase), dip upwards to the northwest at 1-1.5° and crop out at seabed at least 150km away from the storage site. The Lista mudstone is also a proven seal to hydrocarbons elsewhere in the Outer Moray Firth Basin.

Secondary storage is provided by the formations between the storage and complex seals (Chalk Group, Mey Sandstone Member and lower Dornoch sandstone). It is also recognised that there is a chance for CO₂ to escape the storage site laterally if the injection plume passes the structural spill point of the Goldeneye field. To account for this, it is proposed to include a lateral, up dip extension of the Captain sandstone as part of the secondary storage containment.

The site contains four exploration and appraisal wells within the Captain reservoir and one immediately to the north. All of these wells have good quality abandonment plugs isolating the reservoir.

Existing faults and fractures have been mapped and none have been identified that cross all seal systems. The key advantage of using a depleted hydrocarbon field is that the caprock integrity has been tested and proven by the very presence of a gas field containing highly mobile gas that is under pressure compared to the surrounding formations and will find any potential leak path. Even though no faults or fractures are observed that currently allow the migration of CO₂ two mechanisms exist that potentially allow for the formation of flow paths: the first is through geochemical interaction between the carbonic acid formed when CO₂ dissolves in water and the host rocks. These have been studied and found to be of a low magnitude and speed and so will not perforate the caprock or dissolve any cementation in the faults. The second is rock failure as a result of the pressure cycling. Current assessment of the shear capacity of the caprock at the planned maximum injection pressure indicates that this failure is unlikely to occur.

The complex seal is also crossed by exploration and appraisal wells. Only two of these crossings are plugged at the appropriate level, meaning that the rest may provide migration paths should CO₂ escape the primary containment and travel through the secondary storage and overburden buffers. This risk is being monitored in the MMV plan.

All the containment risks have been assessed using the bow-tie analysis technique. This identifies the barriers to, escalations factors for, controls of and consequences of CO₂ breaching the complex seal and (possibly) reaching the biosphere.

Bow-tie analysis is a risk assessment method which provides a readily understandable visualisation of the relationships between the causes of unwanted events, the escalation of such events to a range of possible outcomes, the controls preventing the event from occurring and the mitigation measures in place to limit the
consequences. Further information on this technique is provided as an appendix to the Storage Development Plan.

The key barriers in the Goldeneye system were the primary and complex seals, the well abandonment plugs and injection well design, and the fact that the system runs at a lower pressure than that in the surrounding formations. This means that – were a leak path to form – formation brine would flow into the store rather than CO\textsubscript{2} flow out - at least until the system re-pressurises. Modelling has shown that the rate of re-pressurisation depends on the connectivity along the Captain Fairway. If the Fairway is ultimately connected to the sea then the system could re-pressurise in a little as 300 years. If this connection is more tenuous then it can take many thousands of years to regain initial pressure. At this point there is insufficient evidence to constrain this forecast. Naturally if other operators also inject into the Fairway this could increase pressure faster.

A comprehensive monitoring programme has been designed tailored around the risk assessment. It consists of two plans:

- **Base case plan**: to enable prevention of CO\textsubscript{2} leakage by monitoring CO\textsubscript{2} migration (detect) within the storage complex, allowing action to be taken (if required) to ensure the integrity of storage before leakage occurs. The base case relates to the threats on the left hand side of the bow-tie.

- **Contingency plan**: in the event of CO\textsubscript{2} leakage outside the storage complex, the contingency plan is mobilised to locate the source of migration (delineate) and enable corrective measures to be implemented (including quantification or define). Activities in this plan relate right hand side of the bow-tie which link to consequences.

The **base case plan** includes environmental baselines before and after injection, injection well monitoring and monitoring of the seawater under the platform for traces of CO\textsubscript{2}. The key detection mechanism for non-injection well related leaks is 4D (timelapse) seismic. A baseline survey – using a hybrid of ocean bottom nodes and shipborne streamers – is planned before injection. A second, monitor survey will be acquired during injection to check conformance and identify any Dietz tongue. Another monitor survey will be shot one year post injection, to be used as the new baseline. The final surveys will be acquired at least six years after injection ceases, dependent on the pressure performance of the field. The seismic surveys are complemented by seabed surveying around exploration and appraisal wells to check for elevated levels of CO\textsubscript{2}.

The **contingency plan** ties closely to the corrective measures and includes focused application of the techniques/technologies used in the base case plan plus additional options.

Once the required volume of CO\textsubscript{2} has been injected it is currently planned to monitor the reservoir pressure buildup for three years while leaving the platform in place. After this the platform and wells will be decommissioned and, assuming that appropriate technology has been developed, continued monitoring of the reservoir pressure will take place. Handover to the UK Competent Authority is proposed to take place between six and twenty years post-closure. Exact timing will depend on the rate of pressure recharge, the dynamic performance of the reservoir and the acquisition of two timelapse surveys that show that no unplanned migration is taking place.

A corrective measures plan has been prepared outlining the actions that will be performed in the eventuality of a significant irregularity. The underlying principle is to identify the source/cause of the irregularity, assess its likely evolution and then plan remediation in consultation with the regulatory

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The response must always be proportional and the risk and impact associated with any corrective measure activity should be offset against the risk and impact of the irregularity being targetted.

The full report is available in Appendix C.10.2 under the following reference:
- UKCCS - KT - S7.23 - Shell - 004 SDP
4. End-to-End CCS Chain Operations

To ensure the UKCCS Demonstration Competition objectives are met, the End-to-End CCS chain must be considered as a system as well as separate elements. This section builds upon the description of the individual elements contained in Section 3 to capture the development of the End-to-End CCS Chain design completed during FEED.

Specifically, this section focuses on the following aspects:
- Commissioning the system in preparation for operations, as well as decommissioning at the end of the capture and storage period
- Operations and Maintenance activities
- Control
- Metering and monitoring
- Venting

This section also provides some selected information on the individual CCS chain elements and a summary of the RAM analysis completed during FEED of which one of the key outputs was the anticipated CO₂ injection profile for the project.
4.1 Summary of the End-to-End Philosophy Approach

Philosophy documents were developed for various aspects of the End-to-End CCS chain design during FEED. These documents have been built upon the individual philosophies for the component parts of the chain. The philosophies which have been developed give an indication of the Consortium’s vision of how the CCS chain will operate taking account of technical limitations within each element of the chain and the specific properties of CO₂. Development of these documents was an iterative process with learning from development of the End-to-End documents fed back into the final version of the component philosophies as required.

Development of the End-to-End CCS chain design philosophies during FEED has been a means of achieving an appropriate level of harmony between the individual design philosophies. As result, this exercise has enabled the identification of some design inconsistencies and has had some influence the design of the final FEED design for the individual chain elements.

The following End-to-End documents will be described in this section and are included in Appendix D.1:
- UKCCS - KT - S7.24 - E2E - 001 End-to-End Operations and Maintenance Philosophy
- UKCCS - KT - S7.24 - E2E - 002 End-to-End Control Philosophy
- UKCCS - KT - S7.24 - E2E - 003 End-to-End CO₂ Venting Philosophy
- UKCCS - KT - S7.24 - E2E - 004 End-to-End Metering and Monitoring Philosophy
- UKCCS - KT - S7.24 - E2E - 005 End-to-End Commissioning, Start-up, Decommissioning and Demobilisation Philosophy

An extract from the executive summaries of each of these documents is provided in this section. Detailed procedures will developed during the implementation stage for each these philosophies. Detailed procedures for each for each chain section will be developed during the implementation phase of the project when the design will be finalised and equipment vendors selected.

Although written specifically for the Longannet CCS Project, these documents are anticipated to be of benefit to designers of future CCS plants who are looking to understand and develop the basic operating principles of their own CCS projects.

4.1.1 End-to-End Operations and Maintenance Philosophy

The high level End-to-End Operations and Maintenance Philosophy document which was developed for the CCS chain during FEED is included in Appendix D.1.1 and is summarised below.

Operations

The Consortium’s outline operating philosophy for the UKCCS Demonstration Competition is based on proven, safe and reliable practices for the transportation of natural gas and the arrangements made in this analogous industry between producer, transporter and consumer.

It is proposed that National Grid will coordinate the operation of CCS chain as it has a central function within the End-to-End chain. Under this arrangement, the National Grid Control Centre would have the responsibility for managing the transportation of CO₂ from export at Longannet Power Station into the onshore and offshore transportation systems for permanent storage in a depleted hydrocarbon reservoir.

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The assets and expertise required to operate the Onshore Transportation System for CO₂ are similar to those required for the operation of a natural gas transportation system. The basic model of input, transportation and offtake is fundamentally the same, with essentially the same assets (e.g. pipelines, valves, compressors, telemetry, etc.) being utilised, although it should be noted that the duty will be different (i.e. CO₂ instead of natural gas).

The role of ‘System Operator’ is a familiar one to National Grid. They have a proven track record in this field of operating safely, reliably and efficiently for many years. It is envisaged that National Grid will facilitate the processes employed by the Consortium in managing system inputs and outputs (i.e. system balancing) and that this is likely to be managed along similar lines to the notification system currently employed for the natural gas transportation system.

One notable difference from the natural gas transportation system is the configuration of the End-to-End CCS chain, as there is only one input source (i.e. Longannet Power Station) and one offtake (i.e. Goldeneye storage site). This is likely to allow less dynamic operation of the Onshore Transportation System than the current natural gas transportation system. Further work will be undertaken during detailed design to progress the understanding of how this affects system operation and what policies, processes and procedures will be required to facilitate safe, reliable and efficient operations.

To meet the UKCCS Demonstration Competition target of capturing 20 million tonnes of CO₂ within 10 to 15 years of operation, it will be necessary to mostly operate the CCS chain at rated output for the demonstration period, although some allowance has been made for flexible operation and system downtime.

Base load for the CCS chain involves capturing, transporting and injecting 250 t/h of CO₂. There is some degree of flexibility in the operation of the CCS chain elements: the CCP at Longannet is designed to operate over a CO₂ production rate range of 75 t/h to 250 t/h and the injection wells can be turned down to approximately 60% of peak flow.

The combination of different injection wells will allow the platform to handle the predicted receiving CO₂ rates (75 – 250 t/h) during the life cycle of the project without performing work-overs. The minimum total rate has been taken to be 60% of the capacity of one train of the CCP.

Line-pack in the Onshore Transportation System will be utilised, wherever practicable, to manage abnormal conditions (such as temporary equipment trips) and small transients due to time lags between supply and demand balancing. Dynamic analysis completed during FEED indicated that the available line-pack in the transportation system could be in the order of 10 hours. However, line-pack is a function of many variables including:
- The selected operating pressure of the pipeline
- The system management philosophy

Therefore it is not possible to develop a definitive volume of line-pack for the End-to-End CCS chain.

Since the proposed system comprises only one source of CO₂ (LPS) and requires to mostly operate at rated output for the demonstration period, a minimum generation level of 363 MW has been defined for the unit supplying flue gas to the CCP. This is approximately equivalent to the CCP’s maximum flue gas abstraction plus 10% - to prevent air being drawn down the stack into the CCP. Provided that the existing unit is generating in excess of 363MW, the CCP can be operated independently to the unit supplying flue gas.

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gases. This will greatly simplify operations at LPS and avoid LPS being significantly and adversely impacted by the operations of the CCP or the CCS chain. It also provides the flexibility to investigate the performance and operation of the CCP and the CCS chain during the demonstration period without having to also modify the operation of the generating unit.

**Maintenance**

Maintenance activities will be planned and coordinated with the objectives of maximising End-to-End CCS chain availability, minimising disturbances to operation and minimising consequential well shutdowns. Planned major maintenance activities for each installation will be scheduled in advance (and coordinated) as far as practically possible around the longest or most constrained outage(s) within the overall chain.

Not all maintenance activities require that the system be shutdown. Some maintenance activities for the pipeline system such as the In Line Inspections (ILI) will require a specific, even constant flow rate of CO$_2$ within the system.

As the offshore facility is a Normally Unattended Installation (NUI), only infrequent planned visits to the facility are expected to take place. Maintenance activities must be rigorously planned and prepared to align with both the CCS chain’s outage schedule and also local logistical constraints. Preparation of plans to minimise the time taken to perform unplanned maintenance is also important to the availability of the overall CCS chain system.

**4.1.2 End-to-End Control Philosophy**

The high level End-to-End Control Philosophy document which was developed for the CCS chain during FEED is included in Appendix D.1.2 and is summarised below.

The control philosophy has been based upon the existing successful UK natural gas operating practice. Each Consortium Partner will be responsible for the control of their respective element of the CCS chain – capture, onshore transportation, and offshore transport and storage. In addition to management of the Onshore Transportation System, National Grid will also be responsible for co-ordination of the flow of CO$_2$ across the End-to-End chain.

Including LPS, the chain will rely on four main control systems. The proposed strategy allows the Consortium Partners to use the most appropriate technologies and design practices for their industry sector. Interface signals are required between each of the elements of the CCS chain. As well as controlling their own element, it is intended that the operators of all the control systems will have the ability to view real time information on the End-to-End process.

The interface signals between the control systems fall into two categories. Signals that are deemed essential for efficient operations will be passed directly between the control systems concerned. Non essential signals will be transmitted between the systems using a centralised database, located at the CCP. The database will include a data historian which will be primarily used to support chain operations and optimisation but may provide data to facilitate the knowledge transfer function, as required.
4.1.3 End-to-End CO₂ Venting Philosophy

The high level End-to-End CO₂ Venting Philosophy document which was developed for the CCS chain during FEED is included in Appendix D.1.3 and is summarised below.

The venting philosophy describes the venting requirements considered necessary to support commissioning, operation and maintenance of the End-to-End CCS chain. It identifies factors which require consideration when designing the venting system such that venting CO₂ to atmosphere can be carried out in a controlled manner without posing a risk to health, safety, environment or equipment.

Venting is required in a number of scenarios to support the operation of the End-to-End CCS chain. A permanent vent is required at the exit point of each of the CCP trains to support CCP start-up. The CCP venting system must be capable of discharging the full CCP design mass flow. The CCP vent may also be used to maintain operation of the CCP in the event that one or all of the downstream system are shutdown. The CCP venting system will be connected to a new common plant stack which will also discharge flue gas from the dedicated Steam and Power Supply (SPS) plant which provides heat and electricity to the CCP. This allows the vented CO₂ to benefit from the buoyancy of the flue gas from the operation of the SPS, resulting in improved efficiency of CO₂ dispersion into the atmosphere.

The requirement for permanent vents at other locations along the CCS chain was also identified during FEED, e.g. venting from equipment, such as at the Blackhill Compressor Station or at the Goldeneye Platform. These vents will be sized for the required duty but will be minor in comparison to the venting system at the Longannet site.

Abnormal operating scenarios including pipeline depressurisation may require venting at other locations. This will be an infrequent occurrence and will be carried out using temporary vents.

4.1.4 End-to-End Metering and Monitoring Philosophy

The high level End-to-End Metering and Monitoring Philosophy document which was developed for the CCS chain during FEED is included in Appendix D.1.4 and is summarised below.

The philosophy identifies the primary requirements to be satisfied by the proposed metering and monitoring arrangements across the chain. These requirements include compliance with relevant legislation such as the greenhouse gas emissions permits, other environmental permits and the requirements of the European Directive on geological storage of CO₂. Other requirements include demonstration of safe operations, and demonstration to DECC that the CCS Competition requirements to capture and store CO₂ are met. Metering will also be required to substantiate the consumables component of the cost of operation.

In the context of greenhouse gas emissions, the entire project (from CO₂ capture to storage) is required to be operated under the European Union Emissions Trading Scheme (EU ETS) and the philosophy generally follows the European Commission’s published guidelines on monitoring and reporting. The guidelines imply reporting boundaries, requiring the elements of the CCS chain be reported separately. This has resulted in an increase in metering points across the chain when compared with the pre FEED design.

Monitoring for potential CO₂ leakage from the geological storage site will be carried out using various methods. A combination of techniques is required to fully document the storage site. Seismic survey has
been identified as one of the most valuable techniques available – since it can be used to monitor the movement of CO2 within the reservoir and identify potential leak paths.

The integrity of the transportation and injection system pressure parts and therefore the safety of much of the CCS Chain will rely on avoiding the increased risk of corrosion and other adverse conditions which can result from out-of-specification CO2. The CO2 composition analysers will play a significant safety role in providing the reliable continuous measurement required to ensure the correct CO2 specification is maintained.

### 4.1.5 End-to-End Commissioning, Start-up, Decommissioning and Demobilisation Philosophy

The high level End-to-End Commissioning, Start-up, Decommissioning and Demobilisation Philosophy document which was developed for the CCS chain during FEED is included in Appendix D.1.5 and is summarised below.

The commissioning philosophy presents a high-level strategy for putting the CCS chain into operation in accordance with the present project implementation programme. The commissioning strategy envisages that the CCS chain will be progressively filled with CO2, starting with the Longannet site, and when complete the CO2 transportation system will be raised to the normal operating pressures so that CO2 injection into the storage site can commence.

As a result of comparisons to the process of commissioning similar projects on the UK natural gas network, where there is an abundant secure supply of gas, it has been identified that there is a risk of interruption of supply when commissioning the End-to-End CCS chain. Supply interruption could create serious problems to the initial purging of the onshore and offshore pipelines. Additionally supply interruptions during commissioning can potentially cause damage to the injection wells. This requires further evaluation by the Consortium from a risk perspective.

This risk can be partly mitigated by maximising the plant available for operation before commissioning is undertaken and defining minimum reliability criteria for key CCS chain components. Once minimum reliability criteria have been defined, they must be demonstrated to allow each stage of the CO2 commissioning process to progress. This may require that both CCP trains are available to provide supply security for commissioning of the Onshore Transportation System and similarly that two compressors are available at the Blackhill Compressor Station prior to well commissioning taking place.

The proposed commissioning philosophy assumes that activities will not take place during winter months when low pressure operation of the offshore pipeline is precluded to maintain pipeline integrity. Whilst the current project programme is unaffected, alternative solutions to this issue are being investigated, in case the programme becomes subject to change.

Commissioning will require a coordinated effort across the Consortium in order to be achieved in a safe and efficient manner. These activities will need to be managed at the implementation stage to ensure that all relevant issues are addressed.

In addition to commissioning, the document also considers the decommissioning and demobilisation of the End-to-End CCS chain. However, a detailed understanding of these activities will not be developed until the implementation stage of the project.
4.2 Carbon Capture Plant Operations

Outline philosophies for the operation and maintenance of the Carbon Capture Plant have been prepared. They give high level descriptions of how the designers expect these activities to be undertaken and are at a level commensurate with the degree of design detail produced during a FEED study. The documents are as follows:

- UKCCS - KT - S7.24 - ACC - 001 Outline Operating Manual
- UKCCS - KT - S7.24 - ACC - 002 Maintenance and Intervention Philosophy

Copies of these documents can be found in Appendix D.2.
4.3 Onshore Transportation Operations

During FEED, National Grid developed a number of operational philosophies covering the Onshore Transportation System. The development work covered aspects including first fill of the system, start-up and shutdown, operating and control philosophies, the pipeline protection system and the alarm and trip philosophy.

The scope of the National Grid development work included both the pipeline and Blackhill Compressor Station but also extended to provide an overview of the operation, control and monitoring of the End-to-End CCS chain.

As with all the other philosophy documents they present how the designers perceive these activities should be undertaken and are at a level commensurate with the detail produced during a FEED study.

The National Grid development work has been summarised in the following documents entitled:
- UKCCS - KT - S7.24 - NG - 001 Operations Report
- UKCCS - KT - S7.14 - NG - 001 Philosophy Statement for Vent Stacks

Copies of these documents can be found in Appendix D.2.
4.4 **Offshore Transport and Storage Operations**

An Offshore Operating Philosophy document has been developed for the offshore transportation system and the permanent storage activities. It outlines the operations objectives, strategies and work processes that will ensure the safe operation and sustained delivery of injection targets during the operational phase of the project.

A copy of the Shell report can be found in Appendix D.2 under the following reference:
- UKCCS - KT - S7.24 - Shell - 001 Operations Philosophy
4.5 End-to-End RAM Analysis

An End-to-End Reliability, Availability and Maintainability (RAM) Analysis was performed to develop an accurate prediction of the availability of the CCS chain based upon the proposed design taking into account the redundancy built into each aspect of the overall system. As a result, it was also possible to forecast the CO₂ injection and storage rate over the project lifetime, based upon an anticipated normal injection rate of 250 t/h CO₂ at the offshore storage site.

The RAM model which was developed during FEED was based upon the earlier Outline Solution model and covers the CCS chain system from source to sink. The model was developed based upon the process information produced during FEED and determined the availability of the overall CCS chain based upon the availability of the component parts and the level of in-built redundancy for each part of the chain.

The CCS chain availability figures included in the model were obtained from industry standard datasets such as OREDA as well as in-house historical reliability data held by the Consortium Partners. The availability of the flue gas provided to the CCP was developed based upon the forecast availability of the two units which will be connected the CCP.

This FEED analysis will be developed further during the implementation phase once equipment orders have been placed and specific availability data is available.

The RAM analysis involved consideration of the following factors:

- The frequency and duration of planned maintenance outages for all equipment
- The approach to CCS chain maintenance activities as defined in the End-to-End Maintenance Philosophy – i.e. with individual planned outages co-ordinated to take place at the same time as the longest maintenance outages in the CCS chain
- The frequency and duration of unplanned outages based on historical failure rates for each type of equipment. Repair times were based upon historical repair time information and estimated mobilisation times for the present CCS project application.

The RAM model was used to identify the areas of lowest and highest availability across the chain and determine whether there were areas where cost savings could be made with minimal impact on overall system availability, or where the overall availability might be improved for little additional cost. However, no significant changes were proposed to the CCS chain design as a result of this review.

The RAM analysis highlighted the following:

- The CCP provides the greatest contribution of any element of the chain to lost days of operation of the overall End-to-End CCS chain. This is because the CCP is the most complex part of the system and has the most equipment connected in series.
- The Goldeneye platform also had a significant impact on the availability of the CCS chain operations. Since it is a Normally Unattended Installation (NUI), unplanned maintenance must consider mobilisation time in addition to the active repair time to remedy the situation. This information has been incorporated into the RAM study work.
The CCS chain was found to be relatively insensitive to doubling the rates of failure included in the base RAM model which utilised historical data.

The most effective way of increasing the overall availability of the End-to-End CCS chain is to install redundancy in some of the sub-systems of the CCP. This was not pursued further during FEED since increased availability was not required to achieve the CO₂ storage target.

The RAM analysis is an ongoing process and will be revisited during the implementation phase of the project.

### 4.5.1 CO₂ Injection Profile

One of the requirements of the UKCCS Demonstration Competition is that the project captures and permanently stores 20 million tonnes of CO₂ over a minimum of 10 years and a maximum of 15 years. The projected CO₂ injection profile for the project is shown in Figure 4.5-1 below.

![CO₂ Injection Profile](image)

The Carbon Capture Plant is designed to capture a maximum of 2 million tonnes of CO₂ per year. To achieve this, the generating unit supplying flue gas to the carbon capture process must be operating at base load (a rated output of 600MWe gross) whenever the Carbon Capture Plant is operating. Although the capture plant, is theoretically capable of producing 2 million tonnes of CO₂ per year, the total availability...
of the CCS chain must also be taken into account to determine the length of time it would take the Consortium to store the target amount of 20 million tonnes of CO₂.

The results of the RAM Analysis indicate that the target storage of 20 million tonnes of CO₂ can be achieved within 11 years from the commencement of CCS chain operations as is shown in Figure 4.5.1 above.

No allowance has been made for reduced availability during the initial operational period and both carbon capture trains have been assumed to be available and producing a total of 250 tonnes/hour of CO₂ from the commencement of CCS chain operations. However, with a forecast injection duration of 11 years, this is considered to leave sufficient time margin to store the target amount of CO₂ within the maximum 15 year UKCCS Demonstration Competition period should the project experience technical problems due to the application and operation of new technology. This time margin also provides some allowance for flexible operation of the CCS chain or LPS units providing flue gas.

The CCS chain has the capacity to allow flexible operation in each element of the system and it will be possible to operate the CCP with the LPS unit generating between 363MWe and base load. However, below 600 MWe, the flue gas stream will have a lower CO₂ content. Therefore, if operating below 600MWe for extended periods there is a risk that it may not be possible to capture 20 million tonnes of CO₂ within the specified time period.

During the implementation phase of the project, the CO₂ profile will be revisited to identify the limits of flexible operation.
5. Key FEED Decisions

This section of the report provides a summary of key decisions and design changes made during FEED that have resulted from the development of the End-to-End solution and the design works conducted by each of the Consortium Partners. The information described in this section captures the design decisions and changes that have had the most prominent impact on the End-to-End Basis of Design.

For each key design change/decision, the background, options considered and the final outcome is described.

The ScottishPower CCS Consortium decision register can be found in Appendix E.1 under the following reference:

- UKCCS - KT - S4.0 - FEED - 001 Consortium Decisions Register
5.1 End-to-End CCS Chain

Key design changes and decisions taken which impact on the End-to-End CCS chain are given below with an explanation of the change or decision.

5.1.1 Operating pressure of the Onshore Transportation System

To achieve the most efficient design, the pipeline transportation system should be operated at the highest pressure possible. The pre-FEED solution proposed a Maximum Allowable Operating Pressure (MAOP) for the onshore pipeline system of 37 barg. However, transportation conditions for CO₂ in the existing Onshore Transportation System are constrained to avoid phase changes within the pipeline. This resulted in a decision to operate the pipeline at the lower MAOP of 34 barg.

CO₂ phase behaviour is a function of pressure, temperature and composition. Impurities in the CO₂ influence the phase boundaries and alter the thermodynamic characteristics. Based on the pressure / temperature phase diagram for CO₂, the worst case winter ground temperature gives a transition between the gaseous and liquid/dense phases occurring at a pressure approaching 38 barg. Therefore the pipeline system Maximum Incidental Pressure (MIP) was set at 37.5 barg to provide some design and operating margin. Hence, following accepted pipeline design practice, the pipeline system MIP is set at 10% above MAOP at 34 barg.

Analysis during FEED confirmed that operation of the onshore pipeline in the gaseous phase at 34 barg could provide the design flow requirement of 2 million tonnes of CO₂ per year.

A decision to operate at a lower pressure than initially proposed has certain impacts, namely:

- A reduction in CO₂ line-pack within the Onshore Transportation System. CO₂ line-pack is an important property for operation of the End-to-End CCS chain as it acts as a buffer which allows the chain to continue to operate for a limited period should certain elements of the chain fail or trip. A reduction of line-pack means that should operation of the CCS chain experience a loss of CO₂ supply from Longannet there is reduced capacity for maintaining flow to the wells which potentially results in increased cycling of individual injection wells.

- The compressors sited at Longannet required an element of redesign to allow for operating at a lower discharge pressure. The compressors always need to operate within a defined envelope (now clarified to be 34 – 31 barg for this application). The range of the envelope has a large impact on compressor selection.

While the impacts on the design are undesirable, they reflect constraints which are related to the properties of CO₂. To achieve a higher operating pressure consistent with dense phase flow, a new pipeline or major rework to the existing infrastructure would be required. The project complexities involved with developing a dense phase pipeline for this project, in terms of financial and environmental costs, resources, programme and design, far outweigh the benefits. Therefore, the most appropriate solution is re-using the existing pipeline system with gaseous phase CO₂.
5.1.2 CO₂ Composition

The composition of the CO₂ exported from Longannet has a significant impact on the transportation pipelines and the injection wells. Consequently the purity of the CO₂ produced and therefore the type and quantity of contaminants therein are very important for the success of the project.

The Outline Solution Basis of Design contained inconsistent specifications for CO₂ and its contaminants. This is because this data was based on the individual requirements of the Consortium Partners using best available information at the time and the inconsistencies were deliberately recorded to identify that this required future resolution. During the FEED study, various work streams and research activities gave greater insight into the CO₂ composition specification which could be achieved and was necessary to protect the CCS chain infrastructure. Consequently, the Post-FEED Basis of Design records the final agreed CO₂ specification. The key decisions that influenced the FEED CO₂ specification are discussed below:

1. Aker Clean Carbon expects to obtain a high purity CO₂ stream from the CCP. However for the End-to-End Basis of Design, a conservative approach was preferred and the minimum purity level was reduced from 99.4% to 99%.

2. CO₂ and water combine when pressurised to form carbonic acid which is highly corrosive to the carbon steel from which the transportation pipelines will be fabricated. Studies indicated that if the original limit of 50 ppmw was adopted, free water could be released from the CO₂ stream under the worst combinations of pressures and temperatures anticipated in both the gaseous and dense phases of the process. Consequently the limit on water content was reduced to 50 ppmv (i.e. being defined by volume rather than by weight) which decreases the possible water content in the CO₂ and minimises the potential for future operational issues. This required a modification to the proposed de-hydration equipment at Longannet.

3. To ensure that water cannot be formed in the pipeline by the chemical reaction of free oxygen and free hydrogen, oxygen is controlled to a maximum of 1ppmv by injecting a slight excess of hydrogen into the CO₂ stream upstream of a catalyst unit which combines the oxygen and hydrogen to form water and which is in turn located upstream of the CO₂ dryer package at Longannet. This required that an additional de-oxygenation package be provided at Longannet for transport conditioning.

4. The presence of volatile impurities in CO₂ can exacerbate the consequences of a pipeline crack. This can lead to a running ductile fracture due to the failure to relieve the stress on a crack in the pipeline wall during the consequent decompression of the pipeline. This is caused by the dense phase fluid entering the two-phase region at a higher pressure than for pure CO₂ leading to a sharp reduction in the speed of the decompression wave to a level where it is less than the propagation speed of the crack tip. The crack does not arrest and the pipeline unzips. To eliminate the risk of running ductile fracture in the dense phase pipeline the total of (nitrogen + hydrogen + methane + argon) in the CO₂ is specified to have a maximum level of 1% with a limit on hydrogen alone of 0.3%. The specification imposes a design temperature limitation on the Goldeneye pipeline of 29 ºC. This required that additional cooling equipment be considered prior to exporting CO₂ into the offshore pipeline.
In doing this work, the prime consideration was the safety of the End-to-End CCS chain assets. The development of the CO₂ composition and specification will continue post-FEED.

5.1.3 Pipeline Protection

Pipework and equipment downstream of the CO₂ compressors at Longannet and Blackhill are likely to be protected against overpressure with High Integrity Pipeline Protection Systems (HIPPS) rather than using full flow relief valves. This is to prevent the discharge of large quantities of CO₂ from relief systems. Additionally, the reliability of standard pressure relief valves on CO₂ duty may be reduced due to the nature of CO₂ and the risk of solids formation at the throat or in the tailpipe of the relief valve. A HIPPS will sense a high-pressure condition and take appropriate action to prevent overpressure of a system, using dedicated hardware devices including pressure transmitters (initiators) and shutdown valves (final elements). The HIPPS will isolate the lower-pressure system from the high pressure source, either by closing valves and/or by shutting down the source of pressure (i.e. the CO₂ compressors).

It is proposed that a HIPPS will be installed at Longannet for the protection of the compression equipment at the Carbon Capture Plant from overpressure from the onshore transportation pipeline and for the protection of the onshore transportation pipeline from overpressure from the Longannet CO₂ compression plant. A further HIPPS system will be installed at Blackhill which will protect the equipment within National Grid’s Blackhill Compressor Station and also the downstream pipework and equipment owned by Shell.

5.1.4 CO₂ Metering

The present CO₂ metering provisions for the ScottishPower Consortium are based on satisfying the requirements of the EU Emissions Trading Scheme (ETS). There remains some debate about the state of metering technology and its ability to provide adequate real time, in-line measurements upon which suitable payment and indemnity provisions may be based. At this stage, metering provisions are expected to satisfy basic commercial requirements. The ScottishPower Consortium will seek to address the technical adequacy question in subsequent design stages.
5.2 **ScottishPower**

Key design changes and decisions taken which impact solely on the ScottishPower scope of supply are given below with an explanation of the change or decision.

### 5.2.1 Revision of the Steam and Power Supply Electrical Connection

The steam and power supply (SPS) provides both process steam, used during the carbon capture process to release CO₂ from the amine to which it is bonded, and electrical energy to power the Carbon Capture Plant, compressors and associated auxiliary plant. The technical and economic merits of different steam and power systems were investigated in order to determine the optimum SPS solution. Due to the nature of each of the energy streams, the system has a higher process steam demand than electrical demand. The optimum solution identified was to size the SPS based upon the CCP steam demand. As a result the excess electricity produced must be exported; in this case via a tie-in with the existing electrical infrastructure at Longannet Power Station. In addition there is a requirement to import electrical power to the SPS and Carbon Capture Plant both to supply minor auxiliaries during standby conditions and also to start-up the SPS.

The Outline Solution for electrical tie-in between the SPS and Longannet Power Station proposed an interconnection from the SPS to the Longannet Power Station 11 kV distribution system. Further analysis of the solution during FEED identified that this solution would impose unacceptable operational constraints on the existing LPS operations but that a tie-in to Longannet’s 275 kV substation would be a possible alternative. ScottishPower will also provide a power supply to National Grid’s Longannet AGI.

The impacts of changing the connection from 11 kV to 275 kV were assessed. It was found that the 275 kV connection was likely to be more expensive than the 11 kV connection but this was countered by a number of positive aspects, including:

1. A simpler technical design. The risk associated with the 275 kV design was lower as more of the design parameters were known, compared with the 11 kV Outline Solution design, which, as a result of the completed study identified that unacceptable operational constraints would need to be imposed upon the existing system operations and reduce the reliability and security of station supplies.

2. More clearly defined interfaces which would make the management of the design, construction, and operation of the assets more straightforward.

3. Limited or minimal modifications would be required to the operating procedures at Longannet Power Station.

After consideration of the impacts, a decision to interconnect the steam and power supply with the 275 kV substation was taken by the Consortium.

### 5.2.2 The Future Supercritical Power Plant

The supercritical power plant was subject to two key decisions during the FEED study as follows.
The first decision was on the CO₂ capture rate from the supercritical power plant.

The Outline Solution proposed a CO₂ capture rate of 250 t/h for the existing subcritical power plant which would be increased to 285 t/h for the proposed supercritical unit.

The ability to capture more CO₂ from the supercritical unit compared with the subcritical unit stems from the fact that there is a higher concentration of CO₂ in the flue gas of the supercritical plant compared with subcritical flue gas; thus for the same flue gas flow rate and the same absorber column design a higher capture rate is possible, assuming that the amine flow is increased.

However there are a number of impacts on the Carbon Capture Plant should the capture rate be increased, including:

1. An increase in steam demand for the capture process and an increase in electricity demand for the compressors and Carbon Capture Plant auxiliaries. This would require a larger steam and power supply system which would be more costly to build and operate and would not be optimally designed for the existing sub-critical unit application.

2. A redesign of the injection well strings at Goldeneye.

Given the complexities already involved due to the size of the SPS plant and its integration with the existing electrical network at Longannet Power Station plus the additional costs associated with a redesign of the well strings at Goldeneye, the Consortium decided to limit the maximum CO₂ capture rate to 250t/h for all operating cases.

There is no case for investing in supercritical power plant in the UK under current market conditions. Given this, it was agreed that the FEED study would limit consideration of supercritical integration to an analysis of the site plan, potential location of any new supercritical plant and the revisions required to duct runs to accommodate it.

5.2.3 Refinement of the Carbon Capture Plant Design and Operation

In parallel to FEED, research work has been undertaken to enhance the overall recovery efficiency of the capture process, particularly in terms of energy consumption and general operating consumables.

A number of changes/ refinements were made to the Carbon Capture Plant Design and Operation plan in order to improve the capture process efficiency and overall Project cost:

1. An improved Amine became available during FEED (but not as a result of the FEED study) that provided higher energy efficiencies for the overall plant and so the Amine choice was amended.

2. The original design to integrate a Heat Recovery Unit (heat exchanger) was put through a Cost Benefit analysis during FEED and the results indicated that the higher capital costs associated with this equipment were not justified by the energy savings achieved. As such the decision was taken to remove this item from the final FEED design.
3. An optimisation of the Water Washes process to assist in the reduction of environmental emissions was undertaken during FEED. The results from these tests are still under consideration and will be progressed during implementation phase.
5.3 **National Grid**

Key design changes and decisions taken which impact principally on the National Grid scope of supply are given below with an explanation of the change or decision.

5.3.1 **Onshore Pipeline Block Valve Bypass Bridles**

Following HAZID and HAZOP studies, it was decided that the bypass would be 450 mm and the bridle 200 mm for the pipeline block valves. The bypass is required to maintain full flow if the mainline valve is shut, with the bridle required for commissioning and venting. This would improve flexibility by meeting the following requirements:

- It allows the main pipeline valve to be operated (exercised) whilst maintaining adequate flow through the bridle pipework
- It permits pressurising of the downstream pipeline during commissioning
- It permits throttling of the flow to the vent valves

5.3.2 **No.10 Feeder Pipeline Block Valves**

Investigations were undertaken into whether single or double isolation was required at the No.10 Feeder pipeline block valves. HAZID and HAZOP studies were performed together with risk assessments and it was concluded that the existing single valve isolation is acceptable arrangement is acceptable for the revised CO2 transportation duty. The secondary impact of this decision is that it minimised the cost of re-engineering to design double isolation.

5.3.3 **Additional Above Ground Installation at Longannet**

An Above Ground Installation (AGI) is required at each end of a buried pipeline. The Outline Solution assumed that an onshore transportation pipeline AGI would be located adjacent to the CCP at Longannet. The AGI consists of remote operated isolation valves, pig trap, filtration, and flow metering and gas quality measurement facilities. The site adjacent to the CCP was found to be unsuitable due to space limitations and hazardous area encroachment and also the existing ground conditions and significant costs for civil works that would be required for piling the ground. As a result, the AGI was relocated to a green field site to the north of the power station site. An additional small AGI with limited facilities consisting of a pig trap, remote operated isolation valves and gas quality monitoring is located adjacent to the CCP. There is a 3.3 km long pipeline between the two AGIs.

This arrangement has two additional benefits.

- Firstly, in the unlikely event of out of specification CO2 inadvertently entering the pipeline it can be held in the pipeline between the two AGIs while detailed analyses are performed and a decision made whether this CO2 should be vented or exported

- Secondly, it gives the opportunity for the short length of pipeline between the two AGIs to be inspected by an intelligent pig more frequently than the rest of the system to monitor the impact of CO2 on the pipeline materials and give guidance on the required inspection frequency for the rest of the pipeline system.
5.3.4 Pipeline Route Selection

Safety considerations formed an integral part of the route selection for the new pipeline. There were also numerous studies undertaken during FEED as part of the Formal Process Safety Assessment and these are detailed in the National Grid HSE Summary Report in Appendix F – Health, Safety and Environment.

The safety-related considerations and outcomes outlined in the Route Corridor Investigation Study (RCIS) influenced the selection of the final route and were as follows:

- Avoidance of population centres was one of the principle factors
- The building proximity requirements of BSI PD 8010-1:2004 will be adhered to
- Safe access for construction and any future maintenance activities was considered
- Potentially difficult construction areas such as side slopes, solid rock strata, complex river crossings, etc. were avoided wherever possible
- Steep slopes will be traversed directly since construction on severe side slopes is undesirable
- All crossing points such as rivers, major roads and railways will be crossed at right angles as far as possible
- Unexploded ordnance from aircraft crashes during WWII poses a potential constraint
- The identification of the possible requirement to, and available methods for, crossing the Firth of Forth river

The safety considerations identified during the RCIS, and developed further as part of the FEED Formal Process Safety Assessment, will be taken into consideration and explored further during the implementation phase of the project.

5.3.5 Transference of the pipeline asset (No. 10 Feeder) between commercial entities

The End-to-End CCS chain design will require National Grid to transfer the No. 10 Feeder pipeline asset from its natural gas business to its carbon business.

National Grid Gas (NGG) has submitted a Formal Notice of Intent to Dispose to Ofgem that outlines the proposed principles for asset disposal. Access to the pipeline from a commercial perspective remains subject to approval from the Gas and Electricity Markets Authority (GEMA) and potentially the Secretary of State. At the time of writing, Ofgem are currently undertaking a due diligence exercise and have 60 days to object to the proposal. NGG are providing additional information to assist with this process.

National Grid (both Carbon and Gas entities) sought business compliance advice to ensure that all asset acquisition negotiations between National Grid Carbon (NGC - otherwise referred to as National Grid in other sections of the report) and NGG were conducted on an ‘arms length’ basis. To achieve separation and comply with this advice, NGC and NGG established their own negotiating teams, each with separate legal representation. Negotiations followed an established process, with offers and counter-offers being
submitted to and from the respective teams, and meetings arranged to negotiate detailed points as required.

Each party represented the interests of their own stakeholder group, with NGC focused on achieving objectives aligned to the requirements of the UKCCS Demonstration Competition, whilst NGG pursued the interests of gas consumers and acted as an advocate for Ofgem.

Each party continues to have a separate reporting lines and an associated governance process through which they seek respective Board approvals. NGC and NGG have done, and will continue to, manage communications with their respective external stakeholders (DECC and Ofgem).

The priority for NGG regarding the sale of the pipeline was compliance with the published GEMA principles of disposal. These principles were designed to ensure that gas consumers benefited from the disposal of the asset, and were also not exposed to undue risks as a result. This meant consideration of any potential and peripheral adverse affects of the disposal (e.g. assured pressures, line-pack operation, incremental buyback costs, additional maintenance and compressor utilisation costs, etc.).

NGC’s objective was to agree favourable terms for the UKCCS Demonstration Competition by reducing risk, improving cost certainty, demonstrating value for money and fundamentally securing the asset for re-use by following due process to allow the release.
5.4 Shell

Key design changes and decisions taken which impact principally on the Shell scope of supply are given below with an explanation of the change or decision.

5.4.1 CO₂ Phase for Offshore Transportation

At the commencement of the FEED study, an investigation was undertaken to verify that transportation of CO₂ in dense phase through the offshore pipeline as proposed in the Outline Solution was indeed the optimum option.

The investigation assessed four flow options, namely:
- dense phase above the mixture cricondenbar
- multiphase
- gaseous phase
- dense phase liquid

Following assessment of the pipeline hydraulics, hydraulic simulations, assessment of topsides equipment, materials selection and health, safety and environmental considerations it was confirmed that offshore pipeline transportation of CO₂ in dense phase above the mixture cricondenbar was the preferred solution.

5.4.2 Temperature of CO₂ at the Inlet to the Offshore Transportation Pipeline

There is a pipeline code requirement that operation of the pipeline in the ductile fracture regime be avoided. Parts of the Goldeneye offshore pipeline could be operated in this regime if in a corroded state in dense phase CO₂ service.

Three options were considered to resolve this problem, namely:
- To control the CO₂ properties at the inlet to the offshore pipeline
- To retrofit crack arrestors to the relevant sections of the offshore pipeline, or
- To replace the relevant sections of pipeline by thicker walled piping.

For a fixed operating pressure range, the CO₂ properties that influence running ductile fracture are the gas composition and temperature. With the composition of the CO₂ produced by the CCP determined as detailed above, the only available option is to reduce the maximum CO₂ inlet temperature to the offshore pipeline from 30°C to 29°C. This requires the installation of a propane chiller at Blackhill Compressor Station for high ambient temperature conditions.

The section of pipeline susceptible to running ductile fracture is located sub-sea. Hence options for installing crack arrestors or replacing the relevant section of pipe would both very expensive to implement.

A cost/benefit analysis was performed and the option of installing a propane chiller to limit the CO₂ temperature at the inlet to the offshore pipeline to 29°C was selected as the preferred lowest cost option.
5.4.3 **Installation of Offshore Filtration of CO₂**

There is a risk that solid contaminants in the CO₂ could block or compromise the injectivity of the injection wells. A well work-over due to blockage is a very expensive operation.

A cost benefit analysis and various other assessments were performed to compare various options for solid contaminant removal offshore with no solid removal. It was concluded that installing a new filtration package on the Goldeneye platform is the best cost solution and hence this option was adopted.

5.4.4 **Retention of the Goldeneye Platform Sub-Sea Isolation Valve**

The existing Sub-Sea Isolation Valve (SSIV) is located in the offshore transportation pipeline on the sea bed 150 m from the Goldeneye pipeline riser base and oriented for production operations to shore i.e. in the reverse direction to that needed for CO₂ injection.

Various options were considered. It was decided to install a new actuated pigable ball valve as the offshore transportation pipeline has a very large inventory which needs to be isolated in the event of loss of containment close to the platform, and the existing valve is not suitable for modification. This decision was based on health, safety and environmental considerations which took precedence over the significant cost impact.

Installing the SSIV requires the replacement of pipe spools between the SSIV and the riser base with spools with a higher design pressure. This is to accommodate pressures generated by the thermal expansion of the blocked-in inventory of dense phase CO₂ in the event of the SSIV and ESD valve being closed.

5.4.5 **Workovers to Replace Upper Completions in Existing Wells**

The completions in the 5 existing Goldeneye wells are considered unsuitable for CO₂ injection operations. Pressure and Temperature modelling suggests that injecting CO₂ into the current Goldeneye completions below the saturation point would cause a Joule-Thomson expansion effect that would cool the wellhead and upper section of tubing to around –25°C, to a depth of circa 2,500 ft [762m] MD (Measure Depth).

This very low temperature would create a number of concerns around well design and management such as material specification, well shrinkage, well bore freezing, annular fluid freezing and expansion, PBR contraction and hence vulnerability to failure, etc.

So to pre-empt these effects, the proposed solution is to workover the wells, replacing the existing large bore (7 inch) tubing with a smaller diameter. The resultant additional pressure drop from frictional effects will allow a gradual pressure decrease rather than sudden expansion, thereby avoiding the concerns outlined above.
6. Health, Safety and Environment

This section provides information on how the ScottishPower CCS Consortium approaches the health, safety and environmental aspects of the End-to-End CCS chain.

The key components of the Health and Safety (H&S) Policies already in place for each Consortium Partner include:

- Commitment from top level management
- Systematic approach to ensure legal compliance
- Provision of training to develop H&S awareness and competence
- Providing a safe and healthy work environment
- Identify, assess and control hazards and risks
- Set targets and objectives for improvement
- Monitor, measure and review H&S performance
- Report on H&S performance, both internally and externally
- Extend the policy to contractors and monitor their compliance
- Include H&S performance in staff appraisal and reward accordingly
- Achieve continuous improvement

This section gives some background and the key drivers to health safety and environmental aspects of carbon capture.

The narrative describes the Consortium’s method of integrating process safety activities with the overall design process.

In the appendices, the full End-to-End CCS safety report is provided, followed by detailed summaries of all the CCS chain specific HSE work undertaken during FEED.
6.1 Background

Health, safety and environmental considerations are the most important factors influencing the design of the End-to-End CCS chain. CCS, like all industrial processes, must meet strict health and safety regulations as controlled by UK regulatory agencies. UK agencies will not permit a project unless these regulations are met.

CO₂ is currently not a named substance under the Seveso II Directive. Although proposals have been put forward to classify CO₂ as a named substance in the revision of the Directive it is currently not clear whether or not this proposal will be accepted. Nonetheless, it was agreed with the UK Health and Safety Executive (HSE) that for the FEED study CO₂ will be treated as though it were classified under this directive.

There is much experience of the industrial handling and uses of CO₂, but these applications generally have limited inventory of up to a few hundred tonnes maximum in either gaseous or liquid phase. By comparison this project is proposing to capture, transport and put into permanent geological storage 250t/h of CO₂. The transportation system will have many thousands of tonnes of inventory in both gaseous and dense phases and future projects can expect to handle even larger quantities. Consequently the ScottishPower CCS Consortium, in close consultation with the HSE and the Scottish Environmental Agency (SEPA), has taken a cautious approach to the identification and mitigation of the specific risks pertaining to CO₂ in both gaseous and dense phases.

In addition, since the End-to-End CCS chain traverses the power generation, onshore transportation pipeline and oil and gas sectors, each with its own regulations, procedures and cultures, special attention was paid to health, safety and environmental issues at interfaces and across the CCS chain.

Other health, safety and environmental issues in the project are related to common substances and activities whose risks are known and well understood and hence are addressed in the normal manner following well established procedures.

The Consortium Partners each have a strong safety culture and have followed their own established procedures for identifying and mitigating HSE risks within their scope of responsibility. Hence the presentation of the documents differs between different sections of the End-to-End CCS chain. This was considered to be the best approach due to the different sectors in which each Partner operates.
6.2 Health, Safety and Environment Full Chain Reports

During FEED, each Consortium Partner has followed their own internal methodologies for performance of hazard studies on their respective element of the CCS chain.

In addition, National Grid carried out interface hazard studies with Shell and ScottishPower, ensuring that the review has covered the entire End-to-End CCS chain.

Since some health, safety and environmental matters can potentially affect all the Consortium Partners, or even impact both ends of the CCS chain without being identified when considering the intermediate interfaces, an End-to-End system safety review workshop was held. The aim of this workshop was to communicate, examine and resolve any End-to-End actions identified from the individual or interface hazard studies carried out during FEED and also seek to identify any potential system issues which had not been previously determined by the earlier hazard reviews.

The results of this workshop are summarised in the End-to-End System Safety Review which can be found in Appendix F.1.1:

- UKCCS - KT - S3.1 - E2E - 001 End-to-End Safety Review
6.3 Generation and Capture

A series of formal health, safety and environmental studies have been performed for Longannet site and the Carbon Capture Plant including the steam and power supply and the interface to Longannet Power Station.

In addition, we are aware of the concern raised in Norway over the potential health and safety effects of amine capture technology and the small amounts of amines and degradation products that are released as part of the process. The levels of amines and degradation products will be reviewed throughout the permitting process and the Scottish Environmental Protection Agency will not permit the project unless the strict UK health and safety regulations are met. Technological solutions will be developed should it be discovered that further controls are required in order to meet these strict regulations.

These documents can be found in Appendix F.2 under the following references:
- UKCCS - KT - S3.2 - SP - 001 MAH Report
- UKCCS - KT - S3.2 - ACC - 001 Project HSE Report
- UKCCS - KT - S3.2 - ACC - 002 HAZID and Hazards Analysis Report
6.4 **Onshore Transportation System**

A series of formal health, safety and environmental studies have been performed for the Onshore Transportation System. This covers both the pipeline and the compressor station. The results of these studies are summarised in one report entitled “Health, Safety and Environmental Onshore Transportation Reports”. This report describes the formal studies performed and summarises the main issues identified.

The Health, Safety and Environmental Onshore Transportation document can be found in Appendix F.3.1 under the following reference:
- UKCCS - KT - S3.3 - NG - 001 National Grid HSE Report
6.5 Offshore Transport and Storage

A series of formal health, safety and environmental studies have been performed for the offshore transportation pipeline (including the onshore pipeline from the compressor station to the beach emergency shut-down valve at St. Fergus), the offshore injection facilities and the permanent geological storage. A summary of these activities is provided in the Shell HSE summary report. This document includes descriptions of the hazards and effects management process and the hazard identification studies. It also includes discussions of major hazards, risk reduction in design, safety critical elements, the environmental impact assessment and a summary of the results of full scale dense phase CO₂ release and dispersion tests conducted at the Spadeadam Test Centre. Finally it includes a table of safety critical elements and the key major accident hazard summary sheets.

The Health, Safety and Environmental Offshore Transport and Storage report can be found in Appendix F.3.1 under the following reference:
- UKCCS - KT - S3.4/3.5 - Shell - 001 Design HSE Case
7. Risk Management

This section of the report aims to inform potential developers of CCS of the impact of risks on the design of large-scale CCS. It discusses the ScottishPower CCS Consortium approach to risk management looking particularly at the identification and mitigation of specific areas of risks during FEED and the mitigating actions required for the major residual risks.

The section will cover five key areas:
- Overview of the risk assessment process through FEED, including mitigation measures, major movement of the Top 50 risks, and current active risks
- Mitigation strategies for major project risks
- Mitigation strategies for those risks with the potential to cause significant delay to the Overall Project Programme
- Allocation and insurability of risks
- Integrity and risk assessment of existing plant to be integrated

From the outset of FEED, risk management was co-ordinated by the Risk Workstream. The Risk Workstream included representatives of each of the Consortium Partners and Aker Clean Carbon. The Risk Workstream had a remit to capture, codify and report on progress with risk management throughout the study. The management of the risks themselves remained with the risk owners.

The Consortium’s risk management strategy was based on the provision of a cross-Consortium, overarching risk management framework. This was developed to:
- provide visibility of the Consortium’s risk exposure
- make best use of the Consortium Partners’ risk management experience
- facilitate the assessment of the impact of changes within the scope of one Partner’s risk profile to the others
- encourage the identification of risks at Partner interfaces
- provide consistent risk reporting across the Consortium in line with agreed requirements

Each Consortium Partner was responsible for reporting monthly on their risks to the Consortium risk lead, who in turn collated the Consortium Partner updates and reported the overall Consortium risk status to the Consortium Management Office and DECC.
7.1 Risk Assessment during FEED

The proposal for CCS carries considerable risks in its development, execution and legacy. It is accepted that risks are integral to the proposition of CCS, and it has been one of the purposes of FEED to establish if the potential benefits of CCS merit exposure to these risks, and to assess how these risks can be managed.

Risk management is being applied to the End-to-End CCS chain to raise awareness of the potential hazards in the proposal, and to reduce the residual risk exposure. At this stage, risk management has:

- Focused attention on the key risks to be addressed
- Proactively identified potential risks
- Allowed early linkage of cause with possible effects
- Allowed active management of those risks that could be addressed during FEED and longer term strategies for the remainder of the project
- Supported the design process to reduce and remove risk
- Improved understanding of individual and shared risks, risk allocation, as well as the overall risk exposure
- Identified the risks that are applicable to each phase of the overall project
- Improved Cross Consortium awareness of risks
- Allowed clustering of risks to raise awareness of key themes, such as Consents, H&S, storage longevity
- Provided an initial estimate of risk cost, schedule and reputational impact
- Allowed development of the risk response strategies
- Helped inform stakeholder engagement & understanding
- Provided key information for the Commercial workstream

As such, Risk Management is an integral component of both FEED, and with an appropriate change in emphasis, to the implementation phase which lies ahead.

The risk management approach taken by the SP CCS Consortium during FEED has been to follow industry standard principles. There is no one specific standard for the application of risk management to the energy, petro-chemical, oil & gas or indeed government sectors. However, the same general principles and concepts are generally applied and adopted across all these sectors.

7.1.1 Background

During the Outline Solution phase of the project, risks were generated in a series of workshops, utilising established practices for Risk Management (as defined in the HM Treasury ‘Orange Book’, ‘PRAM’). A register was developed to capture these risks. During the Outline Solution stage of the project, the Consortium Risk Register captured only a single value of probability and a single assessment of impact.

7.1.2 Development of the Risk Register

As understanding of the risks and of the reporting process increased, the Consortium Risk Register was further developed. Firstly the single measure of ‘impact’ was differentiated into cost impact, schedule impact and reputation impact. A three by three matrix was developed with calibrated scoring to allow scoring of each risk on a nine point scale, on the basis of its likelihood and its impact. Thus a score was
generated for cost impact, schedule impact and reputation impact, with nine points available for each. Each risk could have a total score of between three (1 + 1 + 1) and twenty seven points (9 + 9 + 9).

This process was then further refined to provide greater granularity in the scoring, moving to a five by five matrix thereby allowing 25 points for cost, 25 points for schedule and 25 points for reputation. Risks could now score up to seventy five points.

As FEED progressed the Consortium Risk Register was further developed to include additional information on the following aspects:
- project phase
  - From FEED through to detailed design, procurement, construction, commissioning and operation
- Scores at four project milestones
  - (Outline Solution, Current Score, end of FEED score, after final mitigation)
- Whether the risk is mitigated within the FEED study
- Whether the risk is a ‘Demonstration risk’
  - Either specific to Carbon Capture or novel demonstration aspects of the project

As calibration of the scoring system was refined, the concept of ‘Parent’ risks to cover several similar risks also improved focus and understanding or key risk themes. ‘Parent Risks’ are compilations of related risks into a single entry. They greatly assist with de-cluttering the Risk Register and presenting scale and impact of themes in a more informative way. The history of the individual ‘Child’ risks was still retained, with the ‘Child’ risks monitored for any changes during the FEED which would impact on the ‘Parent’. The concept of ‘Parent’ risks helped to provide a more complete and coherent picture of risks inherent to the CCS chain.

As an example, within the Outline Solution a number of risks were identified relating to obtaining the necessary consents and licences for construction of new assets of the CCS chain, with award of these consents and licences being out of the direct control of the Consortium. The ScottishPower CCS Consortium opted to group these risks under a ‘Parent’ risk of “not obtaining key project construction consents to programme or in line with expectations”, and transfer the risk to a third party (see description below). A consolidated score for the new ‘Parent’ risk was outlined based on an assessment of the ‘Child’ risks, giving a realistic view of the risk of not obtaining these consents. The current Consortium risk register has over 350 risks that are actively reviewed by the Partners.

### 7.1.3 Mitigation Measures Carried Out During FEED

Over the course of the FEED study, risk response strategies have been developed on the following four themes:
- Tolerate
- Treat
- Transfer
- Terminate
7.1.3.1 Tolerate

Early in the FEED process, the Consortium discussed what level of risk could be tolerated. An assessment was made on the basis of the probability / impact matrix, from which a risk could score between five and seventy five points depending on its likelihood combined with its cost, schedule and reputational impact potential.

From this assessment, a tolerable threshold of fifteen points, or twenty percent of the maximum risk score, was set by the Consortium.

Risks assessed as being fifteen points or less did not then require a further response strategy, as the assessment is that these risks could be accepted without further redress. Nonetheless, all risks were reassessed towards the end of the FEED study to ensure that their scoring had not substantially increased from the original assessment.

7.1.3.2 Treat

Where a risk was assessed as being above the tolerance threshold, a further risk response strategy was required. In the majority of cases, this response was to treat the risk, to reduce its value to the tolerance threshold. This was done by reducing either the risk event likelihood and / or its impact. This was done in the majority of cases through developing the design, but also through consultation with third parties.

7.1.3.3 Transfer

In instances where a risk could not be treated sufficiently by the Consortium, where the subject matter was not under the control of the Consortium, the risk response strategy was to ‘transfer’ that risk to a third party.

7.1.3.4 Terminate

The fourth risk response strategy within the Treasury Guidance is to ‘terminate’. This means to end the project or at least a component of the project where a risk is not treatable, transferable or tolerable. This risk response strategy was not selected for any of the Consortium risks.

7.1.3.5 Other Responses

In addition to these four risk response strategies, risks could also be closed because they materialised into events during the FEED study and became issues (i.e. risks that have been realised), or because the circumstances that could cause the risk to materialise were no longer apparent (perhaps due to design work or investigation).

Certain commercial risks will be addressed by placement of terms and assumptions within the bid. Other risks that increased in likelihood to near certainty were transferred to the ‘issues log’ for attention. The issues log compiles circumstances that, in most instances, required a design solution to be addressed by the appropriate workstream.
7.1.4 Major Movement of Top 50 risks

Over the course of FEED, the Consortium reported to DECC on the risk management aspects of the project. Within this monthly report was a progress update on the Outline Solution Top 50 project risks as well as the live Top 50 risks. In the appendices of this is an extract of the Consortium risk register detailing the post-FEED status of both sets of risks. These are included within Appendix G.1.1 and Appendix G.2.1 under the following references:

- UKCCS - KT - S10.1 - OS - 001 Outline Solution Top 50 Risks
- UKCCS - KT - S10.2 - FEED - 001 Post-FEED Top 50 Risks

7.1.4.1 Outline Solution Top 50 risks

Of the Outline Solution Top 50 risks, 34 have been closed over the course of FEED. These risks are summarised in Table 7.1.4-1 along with the reason for closure and current score and the score when the risk was closed. The current status of each risk provided in the table can be defined as follows:

- **Active**
  - This risk is live and is relevant to the achievement of the project objectives.

- **Closed (resolved)**
  - This risk can no longer be realised or is no longer relevant to achievement of the project objectives.

- **Closed (merged)**
  - This risk is sufficiently similar to other risks that it does not require a separate entry in the register.

- **Closed (Child)**
  - To assist recognition of key risk themes, this risk is being reported in the Register under a ‘Parent’ risk that summarises a set of related risks. The owner continues to actively manage this child risk.

- **Closed (Commercial)**
  - This risk is a commercial consideration that will be addressed via the assumptions, terms and conditions of the contract with the UK Government.

- **Closed (Issues)**
  - This risk is considered sufficiently probable that it is being addressed as an ‘issue’ requiring design or management attention. The risk transfers to the Consortium issues log.

<table>
<thead>
<tr>
<th>Risk No</th>
<th>Risk Description</th>
<th>Current Status</th>
<th>Current score / Score when risk closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Onshore pipelines and compressors fail to comply with a future CO₂ specification.</td>
<td>Active</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Construction risks with unidentified adverse ground conditions along pipeline route.</td>
<td>Active</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>Damage to onshore pipeline system due to transportation of CO₂.</td>
<td>Active</td>
<td>22</td>
</tr>
<tr>
<td>4</td>
<td>Problems encountered during River Forth pipeline crossing.</td>
<td>Active</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>Loss of dense phase CO₂ from offshore pipeline.</td>
<td>Closed (Child)</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>Offshore pipeline unsuitable for CCS use.</td>
<td>Closed (Child)</td>
<td>26</td>
</tr>
<tr>
<td>7</td>
<td>CO₂ specification is not achieved and out-of-specification CO₂ is</td>
<td>Active</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 7.1.4-1: Outline Solution Top 50 Risks

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## Risk Close Out Report

<table>
<thead>
<tr>
<th>Risk No</th>
<th>Risk Description</th>
<th>Current Status</th>
<th>Current score / Score when risk closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Onerous government regulations due to offshore CO₂ storage being novel.</td>
<td>Closed (Child)</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>Offshore platform unable to support construction workforce.</td>
<td>Closed (Child)</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>CO₂ leakage through abandoned exploration well bores.</td>
<td>Closed (Child)</td>
<td>28</td>
</tr>
<tr>
<td>11</td>
<td>Integrity of wells poor and cannot support CO₂ injection.</td>
<td>Closed (Child)</td>
<td>26</td>
</tr>
<tr>
<td>12</td>
<td>Unstable injection flow into wells and reservoirs.</td>
<td>Closed (Child)</td>
<td>28</td>
</tr>
<tr>
<td>13</td>
<td>Availability of suitable jack-up for offshore work.</td>
<td>Closed (Child)</td>
<td>52</td>
</tr>
<tr>
<td>14</td>
<td>Migration of CO₂ beyond original hydrocarbon boundary.</td>
<td>Closed (resolved)</td>
<td>25</td>
</tr>
<tr>
<td>15</td>
<td>Leakage of CO₂ into secondary containment.</td>
<td>Closed (Child)</td>
<td>24</td>
</tr>
<tr>
<td>16</td>
<td>Caprock fails to contain CO₂.</td>
<td>Closed (Child)</td>
<td>28</td>
</tr>
<tr>
<td>17</td>
<td>Offshore platform must be left in place post-closure.</td>
<td>Closed (Child)</td>
<td>44</td>
</tr>
<tr>
<td>18</td>
<td>Subsea CO₂ plume cannot be modelled effectively.</td>
<td>Closed (Child)</td>
<td>24</td>
</tr>
<tr>
<td>19</td>
<td>Compaction of the offshore storage site.</td>
<td>Closed (Child)</td>
<td>18</td>
</tr>
<tr>
<td>20</td>
<td>Injectable into storage site gradually reduces over time.</td>
<td>Closed (Child)</td>
<td>24</td>
</tr>
<tr>
<td>21</td>
<td>Vented CO₂ plumes beyond the safe concentrations outside of the designated zones.</td>
<td>Closed (to issues)</td>
<td>22</td>
</tr>
<tr>
<td>22</td>
<td>Working on/around live plant and associated permits and approvals.</td>
<td>Closed (merged)</td>
<td>15</td>
</tr>
<tr>
<td>23</td>
<td>Approvals for onshore construction delayed.</td>
<td>Closed (Child)</td>
<td>45</td>
</tr>
<tr>
<td>24</td>
<td>Safety related accident.</td>
<td>Active</td>
<td>14</td>
</tr>
<tr>
<td>25</td>
<td>Insufficient suitably qualified and experienced resources to deliver CCS project.</td>
<td>Active</td>
<td>20</td>
</tr>
<tr>
<td>26</td>
<td>Delivery schedules impacted (plant, materials, etc.).</td>
<td>Closed (to issues)</td>
<td>45</td>
</tr>
<tr>
<td>27</td>
<td>Uncertainties in Consultee body requirements.</td>
<td>Closed (Child)</td>
<td>18</td>
</tr>
<tr>
<td>28</td>
<td>Sensitive detailed design / commercial information becomes publicly available.</td>
<td>Closed (to issues)</td>
<td>16</td>
</tr>
<tr>
<td>29</td>
<td>Delays in obtaining onshore pipeline construction consents and licences.</td>
<td>Closed (Child)</td>
<td>48</td>
</tr>
<tr>
<td>30</td>
<td>Changes made to Planning / Energy Legislation.</td>
<td>Closed (Child)</td>
<td>32</td>
</tr>
<tr>
<td>31</td>
<td>Adverse public reaction to CCS.</td>
<td>Active</td>
<td>36</td>
</tr>
<tr>
<td>32</td>
<td>Low availability of flue gas to CCP due to aged power plant assets.</td>
<td>Active</td>
<td>18</td>
</tr>
<tr>
<td>33</td>
<td>Low CCP operating efficiency due to flexible power plant operation.</td>
<td>Active</td>
<td>24</td>
</tr>
<tr>
<td>34</td>
<td>Items of novel plant have shorter life than predicted.</td>
<td>Active</td>
<td>27</td>
</tr>
<tr>
<td>35</td>
<td>Scale-up of CCP incorrect.</td>
<td>Closed (merged)</td>
<td>18</td>
</tr>
<tr>
<td>36</td>
<td>Operations staff unfamiliar with CO₂.</td>
<td>Active</td>
<td>36</td>
</tr>
<tr>
<td>37</td>
<td>CCP output is out of specification.</td>
<td>Closed (Child)</td>
<td>24</td>
</tr>
<tr>
<td>38</td>
<td>Problematic tie-ins for CCP.</td>
<td>Closed (merged)</td>
<td>24</td>
</tr>
<tr>
<td>39</td>
<td>Approvals not given for increase in water abstraction at CCP.</td>
<td>Closed (Child)</td>
<td>16</td>
</tr>
<tr>
<td>40</td>
<td>Further ground contamination at proposed CCP site.</td>
<td>Active</td>
<td>21</td>
</tr>
<tr>
<td>41</td>
<td>Laydown areas required for CCP construction are not sufficient.</td>
<td>Active</td>
<td>3</td>
</tr>
<tr>
<td>42</td>
<td>Freedom of Information Act request is made for commercially sensitive information.</td>
<td>Closed (to issues)</td>
<td>21</td>
</tr>
<tr>
<td>43</td>
<td>Power station unit which supplies flue gas is not dispatched.</td>
<td>Closed (resolved)</td>
<td>9</td>
</tr>
<tr>
<td>44</td>
<td>Changes in government policy impact commitment to and sponsorship of project.</td>
<td>Closed (resolved)</td>
<td>16</td>
</tr>
</tbody>
</table>

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### 7.1.4.2 Post-FEED Top 50 risks

As the FEED progressed and assessments of the Outline Solution risks were conducted, risk scores changed, risks were closed, and new risks were identified. This altered the positions of the Outline Solution Top 50 risks, meaning that other and new risks appeared within the Top 50 rankings.

These risks are summarised in Table 7.1.4-2 in descending score order.
<table>
<thead>
<tr>
<th>Risk No</th>
<th>Risk Description</th>
<th>Current score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Key project onshore <strong>construction</strong> consents not obtained to programme</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>- to be managed by third parties outside the Consortium</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Key project onshore <strong>operational</strong> consents not obtained to programme</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>- to be managed by third parties outside the Consortium</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Key project onshore <strong>construction</strong> consents not obtained to programme</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>- to be managed by the Consortium</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Offshore decommissioning and post-closure consent uncertainties.</td>
<td>52</td>
</tr>
<tr>
<td>5</td>
<td>Offshore construction and operation consent uncertainties.</td>
<td>52</td>
</tr>
<tr>
<td>6</td>
<td>Project team disbanded due to significant gap between FEED and contract award.</td>
<td>40</td>
</tr>
<tr>
<td>7</td>
<td>Key project onshore <strong>operational</strong> consents not obtained to programme</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>- to be managed by the Consortium</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Complications due to scaling-up CCS technology.</td>
<td>36</td>
</tr>
<tr>
<td>9</td>
<td>Adverse public reaction to CCS.</td>
<td>36</td>
</tr>
<tr>
<td>10</td>
<td>Operations staff unfamiliar with CO₂.</td>
<td>36</td>
</tr>
<tr>
<td>11</td>
<td>Offshore system sensitive to variable flow rates.</td>
<td>36</td>
</tr>
<tr>
<td>12</td>
<td>Offshore construction and operation risks.</td>
<td>36</td>
</tr>
<tr>
<td>13</td>
<td>Macroeconomic volatilities impacting project economics.</td>
<td>35</td>
</tr>
<tr>
<td>14</td>
<td>CCS levy fails to be adopted.</td>
<td>30</td>
</tr>
<tr>
<td>15</td>
<td>Uncertainties with mineworkings along the new onshore pipeline route.</td>
<td>30</td>
</tr>
<tr>
<td>16</td>
<td>Integrity of existing offshore equipment found to be poor.</td>
<td>28</td>
</tr>
<tr>
<td>17</td>
<td>Migration of CO₂ from the storage site.</td>
<td>28</td>
</tr>
<tr>
<td>18</td>
<td>Other construction works at power station impact on CCS programme.</td>
<td>27</td>
</tr>
<tr>
<td>19</td>
<td>Items of novel plant have shorter life than predicted.</td>
<td>27</td>
</tr>
<tr>
<td>20</td>
<td>Failure to agree offshore asset transfer terms.</td>
<td>27</td>
</tr>
<tr>
<td>21</td>
<td>Archaeological finds along new onshore pipeline route.</td>
<td>25</td>
</tr>
<tr>
<td>22</td>
<td>Unit supplying flue gases to CCP not operating at required load factor.</td>
<td>24</td>
</tr>
<tr>
<td>23</td>
<td>Low CCP operating efficiency due to flexible power plant operation.</td>
<td>24</td>
</tr>
<tr>
<td>24</td>
<td>Inability to agree flue gas composition specification.</td>
<td>24</td>
</tr>
<tr>
<td>25</td>
<td>Problems encountered during River Forth pipeline crossing.</td>
<td>24</td>
</tr>
<tr>
<td>26</td>
<td>Disruption on online assets during disconnection of onshore pipeline.</td>
<td>24</td>
</tr>
<tr>
<td>27</td>
<td>Changes to proposed new pipeline crossing methodologies.</td>
<td>24</td>
</tr>
<tr>
<td>28</td>
<td>Damage to onshore pipeline system due to transportation of CO₂.</td>
<td>22</td>
</tr>
<tr>
<td>29</td>
<td>Industrial disputes and relationship issues.</td>
<td>21</td>
</tr>
<tr>
<td>30</td>
<td>Further ground contamination at proposed CCP site.</td>
<td>21</td>
</tr>
<tr>
<td>31</td>
<td>Uncertainty in the level of change instigated by stakeholders.</td>
<td>21</td>
</tr>
<tr>
<td>32</td>
<td>Depressurisation of CO₂ cause low temperature embrittlement of onshore plant.</td>
<td>20</td>
</tr>
<tr>
<td>33</td>
<td>Third Party Access to CCS infrastructure is required.</td>
<td>20</td>
</tr>
<tr>
<td>34</td>
<td>Insufficient suitably qualified and experienced resources to deliver CCS project.</td>
<td>20</td>
</tr>
<tr>
<td>35</td>
<td>Two-shift operation introduced at the power station.</td>
<td>20</td>
</tr>
<tr>
<td>36</td>
<td>Construction risks with unidentified adverse ground conditions along pipeline route.</td>
<td>20</td>
</tr>
<tr>
<td>37</td>
<td>Further intrusive civil works required along onshore pipeline route.</td>
<td>20</td>
</tr>
<tr>
<td>38</td>
<td>Further ground contamination along CO₂ pipeline route (power station boundaries).</td>
<td>20</td>
</tr>
<tr>
<td>39</td>
<td>Further ground contamination along CO₂ pipeline route.</td>
<td>20</td>
</tr>
<tr>
<td>40</td>
<td>Onshore pipeline commissioning delays due to switch from natural gas to CO₂.</td>
<td>18</td>
</tr>
</tbody>
</table>
41  CCP is below required performance acceptance criteria.  
42  CCP degrades more readily due to amine degradation.  
43  Failure to address applicable safety legislation.  
44  Low availability of flue gas to CCP due to aged power plant assets.  
45  Political changes result in withdrawal of CCS funding / interest.  
46  Legal challenge is made against state aid / funding.  
47  Inadequate control of project due to scale of project.  
48  Intellectual property infringement.  
49  Regulator unwilling to licence aquifer.  
50  Additional compressor requirements for onshore pipeline due to friction in pipe.  

### 7.1.5 Risk Score

An objective of the FEED was to reduce the value of the identified risks as their associated management controls were actioned and completed. In May 2010, the Outline Solution risks were baselined (valued or scored, taking no account of their proposed management controls), and then on a monthly basis all risks values were assessed as their associated management controls were developed and completed.

Figure 7.1.5-1 below shows how the total risk values have changed over the course of FEED, from the baseline value to the final reported value, taking into account the calibration of ‘Parent’ scoring (introduced in November 2010) for all FEED reporting months. The reduction in the total risk value over the course of FEED shows that the above objective has been achieved.

**Figure 7.1.5-1: Risk Score**
7.2 Mitigation Strategies for Major Project Risks

During the FEED study, the risk workstream differentiated between risks that are generic to major construction / transmission / offshore practices and those risks that are distinct to Carbon Capture and Storage or related to the novel/demonstration aspects of the project.

The five highest scoring demonstration risks specific to CCS are:
- 1 Key project consents are not obtained to programme or in line with expectations
- =2 Technology scale-up challenge
- =2 Adverse public reaction to project
- =2 Challenges of operating with CO₂
- =2 Offshore transportation system sensitivities to variable flow rates of CO₂

This section of the report will discuss the mitigation strategies of these high scoring risks.

It should be noted that the first three risks listed are also considered to be the three greatest risks of delay to programme discussed in section 7.2.

7.2.1 Key project consents are not obtained to programme or in line with expectations

7.2.1.1 Background

Throughout the project, the Consortium has identified the full suite of consents and licences that are required in order for a full chain CCS project to be fully consented. The required consents and licences were identified by the consents and regulation experts within each Consortium Partner, and refined through discussions with the relevant consenting and regulating authorities. Progress towards gaining these consents and licences has been recorded and managed through the Consortium Consents and Licences register. The consents and licences cover the full chain of CCS; those required for the CCP at Longannet, the Onshore Transportation System, the offshore transportation system from St. Fergus to Goldeneye, and the offshore consenting of Goldeneye as the storage site.

Not gaining one of these consents could result in the whole project failing, while delays in securing any consent could add significant time and/or cost to the project which may also impact on the reputation of the developer. Consenting different parts of the process represents different levels of risk to the developer. This is because some parts of the chain can be consented through existing processes that are well understood by both the regulators and developers (for example, consenting of a power station in Scotland through the existing Section 36 process), while others have required new legislation to be drafted and enacted (for example, the offshore storage permit).

Developers are well placed to manage the risks of consenting through existing processes as each of the Partners has vast experience of securing consents through those processes, and the project teams have experience of managing the risks that these consents present the developers with. Where legislation is new or not in place, there is little control for the developer and therefore the risk to the developer and the project is higher. In these situations, such risks are expected to be transferred to the Authority.
7.2.1.2 Mitigation Strategy

Risk mitigating actions taken by the Consortium include:
- Ongoing engagement with both the policy developers and the regulating and consenting authorities to support the definition of legislation where there is none in place to ensure that legislation is developed that facilitates CCS Demonstration
- Simple presentation of a complex project to ensure key stakeholders have a clear understanding of the project and their role in the consenting process, including a joined up Consortium approach to all consultation activities
- Developing and implementing a stakeholder engagement plan that includes:
  - Using existing positive relationships with key stakeholders within the Consortium to gain support for the project (for example, DECC Oil and Gas team and Scottish Government)
  - Continued consultation and interaction with all consenting bodies (for example DECC and the Scottish Government) as well as other statutory and non-statutory stakeholders (SEPA, SNH and HSE) to consult on the project requirements and the requirements of those stakeholders so that these can be addressed as early as possible
  - A series of public engagement events with communities local to the project to gain buy-in to the project from those communities and ensure any issues are identified and addressed early
- Early development of a consenting programme, and integration of that consenting programme with the Overall Project Programme, to allow identification and visibility of critical path items in relation to timely receipt of required consents

7.2.2 Technology scale-up challenge

7.2.2.1 Background

Although technology to capture CO₂ from the flue gases of power plant is already in operation at various establishments worldwide, including the pilot carbon capture unit at Longannet and the Mongstad carbon capture research centre, this technology has only taken the first steps from the laboratory in the journey towards being implemented at commercial scale. Furthermore, notwithstanding the fact that CO₂ is transported through pipeline systems in various parts of the world and CO₂ injection into offshore wells is carried out for Enhanced Hydrocarbon Recovery (EHR) activities, to date no one project has demonstrated all of the elements of a CCS system at full scale. The UKCCS Demonstration Competition will therefore involve CCS technology being implemented on a scale which has not yet been undertaken. Consequently, there is a risk that a failure to scale-up correctly from existing CCS pilot projects and unforeseen scale related problems will lead to complications, particularly during the construction, commissioning and operation phases of the Longannet CCS project.

CCS on this scale is a novel concept and if not scaled-up correctly, the realisation of this risk could lead to major project delays plus the associated costs with re-design and re-work activities being undertaken, as well as the reputational impacts to the Consortium due to this risk being realised.
7.2.2.2 Mitigation Strategy

During FEED, the following mitigation strategies have been developed to address the risks associated with the use of novel technology and also the application of known technology at either a larger scale or for a novel application:

- In addition to the FEED design work being undertaken, significant additional R&D effort is being undertaken in parallel by all three Consortium Partners to improve their understanding of CO₂ behaviour with respect to its application for CCS.

- ScottishPower has now been operating the Mobile Test Unit (MTU) at Longannet for 18 months and have built up an extensive understanding of the interaction of the amine solvents proposed for use in the demonstration capture plant with the actual Longannet Power Station flue gases. The learning’s from the MTU work have been fed back into the FEED study work.

- National Grid and Shell have been undertaking independent research into CO₂ behaviour including CO₂ testing at the Spadeadam Test Centre. Again the learning’s from the research undertaken have been used to inform the present FEED study activities.

- Early experience transfer is and will continue to be taken from other CCS demonstration projects, although having completed the FEED study work, the Consortium Partners’ personnel working on the Longannet CCS project are becoming the key experts on CCS within their own companies.

- Aker Clean Carbon, the proposed carbon capture technology provider has extensive experience in CO₂ capture dating back to 1996 when their first amine pilot rig was established together with the Sintef Research Institute in Trondheim. In 1998 a larger pilot plant was put into operation at the gas Terminal Karsto. Aker Clean Carbon has since joined the CASTOR/CESAR EU project in Denmark and different solvents have been tested in a larger pilot plant at a coal-fired power station in Esbjerg since 2006. In 2008 ACC was awarded the contract to build the larger amine test facility at TCM (capacity of 78,000 tCO₂/year). The plant is presently under construction and will be commissioned in 2011. In 2009 a MTU was installed at Longannet. This unit includes some new process solutions and improved amines are now being tested under various conditions. A new amine rig was completed in Trondheim in 2010 as part of the SOLVit R&D programme. Therefore, realising the Longannet demonstration plant will, to large extent, become the culmination of ACC’s stepped process to develop capture plant technology at a commercial scale.

7.2.3 Adverse public reaction to project

7.2.3.1 Background

Each of the Consortium Partners are experienced in stakeholder engagement for major engineering works and have greatly benefited from the established local community and environmental NGO support and interest in the Longannet demonstration project. The Longannet demonstration project involves an offshore storage option and retrofitting CCS onto an existing coal station, minimising the case for opposition to the project, however, as with all high profile construction projects there is a risk that adverse public reaction could stall the project by forcing public enquiries or judicial reviews, making investment decisions and or government backing difficult to maintain.
Over the course of FEED, the Consortium have been closely monitoring public reaction to both the UK demonstration project and other CCS schemes hoping to learn from the mistakes and best practices of others.

### 7.2.3.2 Mitigation Strategy

During FEED the following has been developed:

- A clear and proactive engagement strategy with local communities and key stakeholders which has been underway during FEED and will continue as the project progresses. These take the form of public meetings, speaking events and invitations to the visitor centre at LPS.

- Solid relationships with 3rd party advocates of CCS such as environmental non-governmental organisations (NGOs) and academics.

- A messaging grid that focuses on jobs, skills and opportunities for growth for the local community, the region and the UK as a whole.

- Active engagement with the media at a local and regional level to ensure positive transmission of project to wider community.

- Close analysis and continuous feedback on comments from communities.

### 7.2.4 Challenges of operating with CO₂

#### 7.2.4.1 Background

Transportation, storage and handling of CO₂ is common practice in industry, and procedures have been developed in these industries to ensure that operations staff are familiar with handling CO₂. However the CCS chain being developed is a novel concept, with each element of the chain having different operational requirements and operating conditions with large inventories of CO₂, therefore there is a risk that operations staff throughout the CCS chain will be unfamiliar with the associated operating and maintenance requirements associated with CO₂ to assure that safety is maintained throughout the chain.

If realised, this risk may cause safety related incidents to personnel, the public and the environment, as well as the implications of further developing training procedures through the life of the project.

#### 7.2.4.2 Mitigation Strategy

During FEED the following mitigation strategies have been developed:

- Training of CCS project staff (particularly designers and operators) is underway, building on experience gained from the FEED study, wider industry knowledge and other CCS demonstration projects. Specific training on CO₂ and its particular properties is proposed for all new members of the project team.

- In general, CO₂ is a less hazardous substance than the natural gas which was previously transported in the existing National Grid pipeline. However, technical modelling has been undertaken during FEED to better understand the impact a release of CO₂ and allow comparison with the arrangements which were previously put in place for natural gas.
- National Grid and Shell have been undertaking independent research into CO₂ behaviour including CO₂ dispersion testing at the Spadeadam Test Centre. Knowledge gained from the research undertaken has been used to inform the present FEED activities.

- Specific operating procedures and maintenance manuals will be developed for each element of the CCS chain based upon the knowledge developed during FEED and at the implementation stage of the project.

**7.2.5 Offshore transportation system sensitivities to variable flow rates of CO₂**

**7.2.5.1 Background**

The offshore transportation system utilises existing assets to transport CO₂ to the storage reservoir. Over the course of the project it has been highlighted that there is a risk that the system downstream of the onshore Blackhill Compressor Station will be sensitive to variable flows and injection rates. The primary concern, with regard to variable flow rates, is the resulting pressure changes and the corresponding Joule-Thomson effect which could reduce the operating temperature to below the existing equipment’s lower material temperature limits. This could also have serious consequence to the reservoir as well as the wells.

The realisation of this risk would affect project cost, project schedule and may also have high reputational impacts, particularly if there is a resulting loss of containment or damage to the reservoir and/or wells.

**7.2.5.2 Mitigation Strategy**

During FEED the following has been developed/confirmed, which will mitigate realisation of this risk and improve system flexibility:

- The Onshore Transportation System allows for several hours of line pack. The extent of this will depend on the allowable margin between the inlet MAOP of the National Grid pipeline and the range of suction pressures that can be accommodated by the compressor station at Blackhill.

- A decision has been taken to operate the offshore pipeline in the dense phase region where pressure fluctuations do not correspond to a large Joule-Thomson effect, except for when the phase changes from dense phase to gas. The Offshore pipeline will be operated with an inlet pressure of 120 barg; this will also allow some additional line pack for further flexibility.

- The CCS transportation system was dynamically modelled during FEED to predict system performance for a number of defined operating scenarios. The results obtained indicate that line-pack will allow sufficient time for operator intervention to prevent well trips on low temperature.

- The wells will be designed and re-completed with small tapered tubing so that they can operate in the dense liquid phase and operate above 0°C apart from brief excursions during start-up and shut-down.

- The well designs and use of multiple wells will allow operation over the full range of flow rates from 75 tonnes per hour to 250 tonnes per hour over project life without need for re-completion.

- The wells will be designed so that during start-up and shutdown, material low temperature limits will not be exceeded. This will involve change-out of the ‘Christmas’ trees and upper completions. The limiting
factors are existing casings hangers and some elements of the wellhead, not in contact with CO₂. Simulations currently indicate that the temperature limits of the casing will not be exceeded. Further work must be done during detailed design with regard to temperature limits of the wellhead.

- Steady state throughput from the Carbon Capture Plant will not be less than 75 tonnes per hour.
- The impact on well integrity of thermally cycling the well remains a risk that needs to be understood so that limits to well start-up and shutdown, if any, can be quantified.
- Filtration of CO₂ will reduce the risk of fines entering well/lower completion.
- A hydrate inhibitor will be used initially and for start-up.
7.3 Mitigation strategies for risks of delay to Programme

Given the time sensitivity on CCS demonstration delivery, any factor that causes delay to the Overall Project Programme is considered to be a major issue. Therefore, risks of delay to the Overall Project Programme were actively identified, monitored and managed. Schedule, or programme risk, was calibrated at five levels; the highest level being the potential of delays exceeding sixteen weeks.

Below are the five risks to the project that have the greatest potential to cause the highest level of project programme delay, these risks have been categorised as having a 'Very High' schedule impact:

- 1 Key project consents are not obtained to programme or in line with expectations
- =2 Technology scale-up challenge
- =2 Adverse public reaction to project
- =2 Delays with offshore construction and operation activities
- 5 Operational reliability of CCS Chain (CO₂ transportation and storage)

It should be noted that the first three risks listed are also considered to be the three greatest demonstration risks discussed in section 7.2.

For comparison, the assessment of the greatest risks of delay to programme as understood at the Outline Solution stage is included in Appendix G.3.1 under the following reference:

- UKCCS - KT – S6.4 - OS - 001 Outline Solution risks of delay to Programme

7.3.1 Key project consents are not obtained to programme or in line with expectations

This risk represents the highest programme and CCS demonstration risk, and is discussed in section 7.2.1.

7.3.2 Technology scale-up challenge

This risk represents the joint second highest programme and CCS demonstration risk, and is discussed in section 7.2.2.

7.3.3 Adverse public reaction to project

This risk represents the joint second highest programme and CCS demonstration risk, and is discussed in section 7.2.3.

7.3.4 Delays with offshore construction and operation activities

7.3.4.1 Background

The UKCCS Demonstration Project will involve a number of offshore construction and operation activities. Work will be conducted at the existing platform but the FEED has also identified the requirement to work over the wells for which a jack-up drilling rig has been identified as being the most effective means of performing this task.
Due to the lack of availability of rigs which can operate in the required water depth and the lack of synergies with other Shell work there is a concern that contracting a rig will not be possible or will cause a schedule delay. There is also the concern that there will not be a lot of market interest or that they will charge a premium due to the scope of work being relatively small.

Additional risks to the offshore work include the lack of available welfare spaces on the Goldeneye platform causing a delay to the completion of the topsides work scope, as well as the risk of adverse weather conditions preventing progress on both well or topsides scopes.

7.3.4.2 Mitigation Strategy

During FEED the following has been developed / identified:

- During the course of FEED three additional suitable rigs have entered the market in the North Sea, all of which currently have availability on the drilling sequence for 2014 operations.
- The scope of work for the wells has been developed to sufficient detail to understand the amount of offshore work required.
- During FEED a "rigless" study was conducted in order to assess the suitability of rigless operations for Goldeneye. As part of this study, a HAZID was performed. The results strongly pushed in the direction of a Jack-up rig for the Goldeneye well operations, mainly because of the requirement for a floating support vessel. Furthermore, contracting of a rig will provide additional bed space for the topsides facilities construction workforce.
- A recommendation has been given to DECC to pre-book a suitable rig, currently this has not been progressed. At a minimum this will be done immediately after contract award.
- Modifications to a medium duty rig (e.g. leg extensions) have been investigated and potential candidates have been identified.

7.3.5 Operational reliability of CCS chain (CO₂ transportation and storage)

7.3.5.1 Background

The operational events which represent a very high risk of delay to the programme, post-FEED, are:

- Onshore Transportation System: Corrosion or damage to internal coatings or assets due to CO₂ transportation.
- Offshore Transportation System: Integrity of existing equipment is found to be poor or it is discovered that elements are not compatible with CO₂.
- Offshore Storage System: Reservoir fails to contain the CO₂ or is found to be unsuitable.

The realisation of any of these events will cause technical complications, further re-design and re-work and health, safety and environmental impacts, resulting in severe project delays.

Realisation of the final two events listed could result in an inability to continue the storage of CO₂.
7.3.5.2 Mitigation strategy

The likelihood of this risk has reduced during FEED due to progression of the risk control measures, which include the following:

Onshore Transportation System:
- The compatibility of the existing pipeline internal coating for operation with CO₂ has been assessed.
- Extensive seal endurance and environmental cycling testing on selected seal materials has been performed, and the use and performance of seals in existing CO₂ systems has been investigated.
- Incoming CO₂ will be monitored precisely (with sufficient redundancy and availability) with effective shutdown procedures in place.

Offshore Transportation System:
- Existing equipment has been checked for the new process conditions.
- Inspection records have been checked, along with material compatibility, current corrosion rates and calculated expected corrosion rates.
- Components will be replaced where needed or where high risk areas exist.
- Intelligent pigging runs will be undertaken at the earliest opportunity after contract award to verify the pipeline and platform riser have sufficient wall thickness.
- Remotely Operated Vehicle (ROV) inspection of the pipeline will be undertaken at the earliest opportunity after contract award to verify external condition of the pipeline.
- PEC (Pulse Eddy Current) tests have been completed on the well conductor/surface casing which indicate that there is sufficient strength in the surface casing to operate until 2035.
- The well completions and trees will be replaced as part of proposed design for CCS.
- Modelling has been undertaken to establish the potential for corrosion on well materials.
- Multiple wells are available for injection if a problem with one well is encountered.

Offshore Storage:
- A baseline survey will be undertaken to confirm that the reservoir is not currently leaking after contract award.
- A regulatory process will be implemented for dispute resolution in case of greater than expected impact on adjacent reservoirs.
- Injection of a tracer to mark CO₂ may be possible.
- The shoe strength has been studied to determine if safety margins are sufficient in order to contain CO₂.
A desktop integrity check of 3rd party abandoned exploration wells has been done to identify any integrity concerns.

The size and direction of the CO₂ plume will be directed away from expected troublesome abandoned wells.

Seismic and geological studies will be undertaken.

Baseline seismic survey will be performed.

Modelling and geochemical lab experiments have been undertaken.

Secondary containment has been found to be present.

System has been found to be sub-hydrostatic and likely to remain that way for a significant period of time. Therefore driving force tends to force formation water into the reservoir rather than CO₂ out.

The monitoring plan will be designed to detect potential leaks and migrations.

If required to side track or drill a new well, it has been confirmed that the depleted reservoir can be drilled if appropriate contingency measures are employed.

Compaction of the reservoir has been confirmed to have negligible effect on storage capacity.
7.4 Allocation and Insurability of risks

During FEED, a detailed investigation of the insurance market for CCS was undertaken. This research sought to establish the status of the following requirements for the insurance of CCS:

- Insurance funds are readily accessible if and when they are needed and adequate to pay for the worst-case losses
- The financial community (Lenders) is comfortable with the protection afforded
- That insurance is available and if necessary transferable upon change in ownership(s)
- That the cost of insurance does not make commercial development and operation of CO₂ capture and sequestration facilities economically impractical

Appendix G.4.1 contain the following reports:

- UKCCS - KT - S10.5 - FEED - 001 Insurance Strategy Report
- UKCCS - KT - S10.5 - Shell - 001 Insurance Report

The Insurance Strategy Report considers the risks and insurance associated with the important stages of CO₂ capture and storage from drilling and construction, operation, monitoring, testing and closure and the associated impact on the electricity producing plant. The report considers 5 distinct phases of the CCS operation lifecycle to establish the extent and nature of the risks and available insurance solutions.
7.5  **Integrity and risk assessment of existing plant to be integrated**

7.5.1  **Outline**

For the End-to-End CCS chain to function, it requires a source of CO₂, a means of transporting the CO₂ from its extraction site to its storage site, and a permanent storage site. As the UKCCS Demonstration Project has developed from its initial concept, there has been consideration of which assets are currently available that could potentially perform these functions, and during FEED this plant has been analysed in further detail to determine its integrity and suitability for operation within the CCS chain.

The benefits of utilising existing plant will, in general, hugely outweigh the construction of new plant, with the key factors in this being the high cost of new construction works, environmental aspects of installing new plant, the planning and other consents required for new-build projects, and the demonstration value of retrofitting CCS technology onto existing infrastructure.

The three main existing assets which are to be integrated with the CCS chain are:

- ScottishPower’s LPS
- A significant length of the onshore transportation pipeline system (previous service being natural gas)
- The offshore Shell pipeline, wells and reservoirs (previous service being natural gas)

The FEED has reduced the level of uncertainty associated with re-using these existing assets, and has also determined which assets cannot be used and where new plant is required.

This section of the report looks at how the existing plant has been assessed for its suitability within the CCS chain, with consideration of its integrity and also how the risks of re-using this existing plant have been assessed.

It also considers what impact the operation of existing plant may have on future CCS chain operation and what impact operation of the CCS chain may have on existing plant, including operations at LPS.

This section also includes a summary of the control systems philosophy for the Carbon Capture System at LPS, and a statement regarding the effect on the monitoring and auditing requirements for participation in the EU ETS for LPS.

7.5.2  **Longannet Power Station**

7.5.2.1  **Decision to Tie-In to Existing Systems**

The CCP and its associated SPS Plant require various utilities to operate, as well as a source of CO₂. In general the operation philosophy of the CCP is that it will be operated separately from the main station. However, due to the CCP being sited in the vicinity of the source of CO₂ (at LPS) it is beneficial to ‘share’ utility supplies (where possible) rather than create or source new ones.

The utilities required by the CCP for operation are:

- Natural gas supply
- Flue gas supply (source of CO₂)
- Cooling water supply
Potable water supply
Demineralised water supply
Electrical supply
Fire fighting water supply

The FEED has assessed the option of tying in to the current supplies of these utilities to LPS where possible, including if this approach is suitable, feasible, and allows a tolerable risk.

Tie-in locations have been outlined in principle, and one important aspect of this has been ongoing discussion with LPS site operations staff throughout the FEED to ensure that potential interface issues are identified early.

The FEED has considered the physical conditions at tie-in locations and capacities available as well as the routes required to take utility supplies from the tie-in locations to the CCP. The outcomes from these assessments have been important factors in the decision whether to tie-in or not tie-in to the existing LPS systems. The assessment of the individual tie-ins which have been undertaken for LPS are discussed in this section.

### 7.5.2.2 Management of Tie-Ins

As well as the assessments conducted during the FEED, there are risks associated with physically tying-in to any live systems at a working power station. These include poor interface management during the construction phase, damage to existing assets and problems with tie-in locations including poor accessibility, poor condition of existing assets and contamination (e.g. asbestos and lead paint and the timing of tie-ins to live systems).

A number of mitigation measures have been outlined for these risks, which include the following:

- The CCS project will involve working closely with LPS operations to ensure that programme milestones and the consequences of delays are understood by all parties
- A coordinated tie-in and interface plan will be developed
- The programme will be developed to integrate tie-ins and permitting to minimise disruption to both construction activities and plant operations; key dates will be agreed by the relevant parties
- Seek to include sufficient float within the programme to accommodate some slippage in the tie-in events with the live plant
- All construction work will be managed in a coordinated and safe way in accordance with defined processes and the agreed programme
- Day to day permitting will be coordinated with the station operating team to minimise delays.
- The use of appropriately qualified and experienced contractors is key, working to defined safe systems of work
- Contactor works will be managed to reduce the likelihood of accidents / unplanned incidents
Float will be included within the programme for addressing contamination at tie-in locations, and specialist asbestos contractors will be employed as required to safely remove asbestos.

7.5.2.3 Natural Gas tie-in (supply to CCP)

Natural gas is currently supplied to LPS through a National Grid feeder line, for the purposes of warm-up, ignition, combustion support and as a supplementary fuel for the existing sub-critical coal fired units. A natural gas supply is required by the SPS plant at the CCP. Aker Solutions and Aker Clean Carbon confirmed through the FEED that there is sufficient capacity for a supply of natural gas to the CCP as well as the maximum demand of LPS. Therefore, tying-in to the existing natural gas supply will not impact either LPS or CCP operation.

7.5.2.4 Flue Gas tie-ins (supply to CCP)

A portion of the flue gas from either existing sub-critical Unit 2 or Unit 3 will be supplied to the CCP with the remaining portion exiting via the existing stack. To run both capture plant trains at 100% load and ensure an excess amount of flue gas up the existing stack the load on the unit supplying the flue gas is to be greater than 363MWe. The CCP connected unit will be 'first on' and 'last off', with the Minimum Stable Generation (MSG) figure for the CCP connected unit to be 363MWe to reduce the risk that the forecast CO₂ capture profile will not be achieved.

Shutdown of part or all of the CCS chain will not force an outage of LPS as the units can continue to operate as they currently do, with flue gas exiting via the existing stack and the CCP isolated through a damper arrangement.

To mitigate the risk of the low availability of flue gas from LPS due to forced outages (aged assets), it is proposed to connect multiple units to the CCP (i.e. unit 2 and unit 3), introduce a station longevity works package including preventative maintenance to allow the operation of the existing units beyond their normal design life, and bringing forward CAPEX spend to do this.

Two items particular to LPS which have been outlined during the FEED are the use of Flue Gas Desulphurisation (FGD) and NOₓ reduction technology (NRT) flue gas treatment systems at LPS, upstream of the CCP. These systems are not yet commissioned and so the full operation of these and any associated affects on CCP operation are not yet fully understood. However, the following mitigation measures have been outlined:

- **FGD**: Performance of FGD will be monitored once commissioned, and if necessary the flue gas pre-treatment section (the DCC) at the CCP will be adjusted accordingly.
- **NRT**: The influence of nitrogen oxide (NOₓ) levels on the CCP will be investigated, and performance of NRT will be monitored once commissioned.

7.5.2.5 Cooling Water tie-ins (supply to CCP and discharge from CCP)

The CCP requires a cooling water (CW) supply for the SPS plant. As LPS is a coastal power station it uses a seawater cooling method. The existing system comprises of four intake bays which are separated from the Firth of Forth using stoplogs. Various configurations for CW abstraction to the CCP at the same location as the LPS CW supply have been modelled, and the optimum configuration has been chosen.
which is unlikely to have any effect in on the supply to the existing LPS pumps and therefore normal operation of LPS.

Following the cooling process the CCP will discharge CW into the existing LPS flume. The existing flume currently handles the CW discharge from the four LPS unit condensers and the seawater FGD intake and discharge flows. The layout for this interface has been modelled so that discharging into the existing flume will not impact the existing processes.

7.5.2.6 Potable Water tie-in (supply to CCP)

A potable water supply is required by the CCP, and it is proposed to take this supply from the existing LPS townswater supply downstream of the townswater pumping station. Aker Clean Carbon has determined during the FEED that there is sufficient capacity for a supply of potable water to the CCP as well as the maximum demand of LPS. Therefore, tying-in to the existing potable water system will not impact either LPS or CCP operation.

7.5.2.7 Demineralised Water tie-in (supply to CCP)

The existing demineralised water system has been assessed by Aker Clean Carbon, and it has been determined that there is insufficient capacity within the system to supply the CCP during the case of a boiler-fill. Hence, a holding tank arrangement has been designed into the CCP which will enable a continuous supply of demineralised water to be provided to the CCP. Therefore, tying-in to the existing demineralised water system will not impact either LPS or CCP operation.

7.5.2.8 Electrical tie-in (supply to and from CCP)

The CCP will interface with LPS in the form of a local electrical supply from the existing LPS 11kV ringmain and a 275kV connection at the 275kV substation (which is owned and operated by SP Energy Networks). Through the FEED the approach has been to undertake power systems studies to determine the feasibility of tying-in to the existing electrical systems.

7.5.2.9 Fire Fighting Water Supply

During FEED, the decision was made that the CCP would have a stand-alone fire protection and fighting system, rather than tie-in to the existing LPS system.

7.5.3 Onshore National Grid Pipeline

Re-using an existing pipeline as a means of transporting the CO₂ from its extraction site to its storage site differs to interfacing with a power station, in that an existing asset will now transport a different working fluid under different conditions.

During FEED the following risks of re-using the existing onshore pipeline have been assessed:

- There is a risk that depressurisation of CO₂ may result in low temperature embrittlement of plant materials. The FEED has determined sources of significant pressure changes within the pipeline and the consequential effects of low temperatures.
There is a risk that unintended changes in temperature and pressure may cause the CO\textsubscript{2} to enter the liquid or supercritical phases. The pipeline has been modelled to identify ‘upset conditions’, and during operation there will be active monitoring and control of pressure and temperature at the boundaries of the Onshore Transportation System.

There are concerns around the commissioning of a CO\textsubscript{2} pipeline, including removal of hydrostatic test medium, CO\textsubscript{2} sectional filling duration and cleaning/removal of contaminants. The required commissioning procedures have been developed and contingency will be allowed within the construction programme.

The minimum CO\textsubscript{2} specification/purity parameters have been agreed between the Consortium Partners. There does remain a residual risk that the CO\textsubscript{2} specification is not met during operations. Mitigation measures for this include implementing an effective monitoring system for the CO\textsubscript{2} ensuring that there is sufficient redundancy in the control of this to ensure availability, developing a drying procedure, and assessing the period of off-specification CO\textsubscript{2} transport that would be required to impair containment within the Onshore Transportation System.

There is a risk that transportation of CO\textsubscript{2} will cause damage to or corrosion of the pipeline internal coatings. The incoming CO\textsubscript{2} stream is to be precisely monitored and effective shutdown measures put in place.

To mitigate the risk of failure of existing seals, extensive seal endurance and environmental cycling testing on selected seal materials has been performed, and the use and performance of seals in existing CO\textsubscript{2} systems has been investigated.

The compatibility of the existing pipeline internal coating for operation with CO\textsubscript{2} has been assessed to understand if additional drag is created from transporting the new working fluid.

Control of the onshore CO\textsubscript{2} pipeline will be by National Grid and will be independent of other National Grid operations, hence operation of CCS is not foreseen to impact other existing National Grid operations.

### Offshore Shell Pipeline, Wells and Reservoirs

Similar to the onshore pipeline, there are risks associated with utilising the existing offshore assets for the new duty of CO\textsubscript{2} transportation and storage.

During FEED, the following risks of re-using the existing offshore assets have been assessed:

- There is a risk of loss of system containment due to operation with CO\textsubscript{2} within the pipelines and wells. This could be caused by the presence of water and oxygen in the plant, blistering of internal linings, leakage from topsides system and loss of containment due to corrosion or low temperature (due to depressurisation). Mitigation measures for this include implementing an effective monitoring system for the CO\textsubscript{2} ensuring that there is sufficient redundancy in the control of this to ensure availability, developing a drying procedure, and assessing the period of off-specification CO\textsubscript{2} transport that would be required to impair containment within the offshore transportation system. Material studies include verification of coating qualities for the new duty, along with process depressurisation studies.
There is a risk that the integrity of the existing offshore assets is found to be poor or not compatible with CO₂, and these assets are therefore unsuitable for use within the CCS chain. A number of the mitigation measures that have been undertaken to explore this include checking the current condition of these assets, outlining the proposed new design conditions, specifying new equipment where necessary, and establishing the potential for corrosion including assessing the chemistry between CO₂ and existing materials.

### 7.5.5 Summary of the Control Systems Philosophy for the Carbon Capture System at LPS

Station systems will be modified to monitor the use of services provided by LPS for the required operation of the SPS plant and CCP. The monitoring will take place using the existing systems, reporting to the common systems control console in the power station central control room. The console will additionally display status information relating to SPS plant/CCP operation.

The unit control systems of Unit 2 and Unit 3 will each provide a small number of signals required for the operation of the CCP. These are derived from the unit status, without operator involvement.

### 7.5.6 Effect on the monitoring and auditing requirements for participation in the EU ETS for LPS

The principal of the EU ETS is that each installation will have a greenhouse gas emissions permit with the requirement to quantify the net CO₂ emitted from the installation, to the satisfaction of the competent authority (in the case of LPS, the Scottish Environmental Protection Agency). In the case of CCS, the CO₂ emitted will incorporate CO₂ that is transferred in and/or out of an installation. ScottishPower’s emissions permit will be modified to show that CO₂ is being transferred to another entity rather than emitted.
8. Consents and Permitting

This section of the report will provide details of the regulatory work carried out during FEED for the purposes of assisting potential developers of CCS projects in assessing the work necessary to achieve the legal requirements of constructing and operating an End-to-End CCS system.

During the development of the Outline Solution for the UKCCS Demonstration Competition, the ScottishPower CCS Consortium developed a comprehensive Consents Register that tracks month by month progress and captures all relevant Consents, permits and licenses required by the End-to-End CCS chain. A summary of the Consortium progress will be provided.

Written against a backdrop of significant regulatory change and uncertainty, this report also outlines the process undertaken in identifying consenting risk and provides commentary on the key risks identified, as contained within the project Risk Register.
8.1 Background

On the 23rd January 2008, the European Union (EU) released its proposal for Directive 2009/31/EC on the geological storage of CO₂ (CCS Directive). It covers all CO₂ storage in geological formations in the EU both onshore and offshore and lays down requirements covering the entire lifetime of a storage site.

The Directive was adopted on 23rd April 2009, and Member States have until 25th June 2011 to adopt its provisions.

There are existing EU Directives that would regulate the capture and transportation components of the CCS Chain:

- 85/337/EEC (Environmental Impact Assessment)
- 96/61/EC (Integrated Pollution Prevention and Control)
- 2000/60/EC (Water Framework Directive)
- 2001/80/EC (Large Combustion Plant Directive)
- 2004/35/EC (Environmental Liability)
- 2006/12/EC (Waste Framework Directive)
- Regulation (EC) No. 1013/2006 (Shipment of Waste)

These Directives had not previously considered the capture, transportation and storage of CO₂ and were prohibitive and inhibiting to CCS as a process. They are therefore undergoing consultation and amendment, with Consortium understanding of the current position set out within the following sections of this report.

Figure 8.1-1 below provides an overview of the key consenting requirements for CCS.

Figure 8.1-1: CCS Key Consenting Requirements

Source: ScottishPower CCS Consortium
8.2 Consents Register

8.2.1 Overview

The Consents Register is very detailed and addresses each stage of the process separately (capture, transportation, and storage). The register then draws each of the key consents into an End-to-End consolidated register.

For each of the consents identified, the Consents Register has captured:
- The title of the consent
- A description of the consent
- A description of the work needed to meet the requirements for granting the consent, including, where relevant, references to published documents
- The area of the project covered by the consent
- The granting authority or commercial entity
- Date of application/ anticipated date of application
- Date of award/ anticipated date of award
- Current status of application
- Any amendments to the existing terms of the consent that will be required for the project, and the process for obtaining these
- A month on month summary of any work (including dialogue with the relevant authorities) undertaken in achieving Consents and a summary of work still to be undertaken at the close of FEED

On a monthly basis during FEED the Consents Register has been reviewed and updated. The following sections summarise, for the key consents, the current status, the process undertaken to date and any future activities required to secure the necessary permissions. It is recognised that the register will be a collection of live documents that will continue to be reviewed and evolve as the regulatory framework for CCS emerges and evolves.

8.2.1.1 Supporting Documentation

The Consortium Consents Register in provided in Appendix H.1 under the following reference:
- UKCCS - KT - S11.1 - E2E - 001 Consents and Licenses Register

8.2.2 Carbon Capture Plant and Steam and Power Supply

8.2.2.1 Relevant Consents and Legislation

The following consents and legislation have been identified as key for the Carbon Capture Plant (CCP) and the associated Steam and Power Supply (SPS) plant
- Section 36 Electricity Act 1989
- Electricity Works (Environmental Impact Assessment (Scotland)) Regulations 2000
- Electricity (Applications for Consent) Regulations 1990
- Town and Country Planning (Scotland) Act 1997 as amended by the Planning etc (Scotland) Act 2006
- Pollution Prevention and Control (Scotland) Regulations 2000
- S.14 (1) Energy Act 1976
- Planning (Hazardous Substances) (Scotland) Act 1997
The areas of the CCP and SPS to which these consents and legislation apply, as well as details of work carried out to date in obtaining these permits and complying with the relevant legislation, is incorporated into the Consents Register.

Section 8.2.2.2 provides a summary of the current consenting position for the CCP and the SPS.

8.2.2.2 Summary of Progress to Date

The following sub-section outlines the activities undertaken during FEED with regards progressing the relevant consents and legislation for the CCP.

Section 36 Consent (and Deemed Planning Permission)

a) Overview

Following consultation with Scottish Government it was ascertained that an application under Section 36 of the Electricity Act 1989 would be required for the CCP and associated SPS. This results from the change of operations at Longannet Power Station (LPS) through the installation of the CCP and the associated requirement for additional steam and power.

b) Summary of Progress

ScottishPower appointed a Planning Consultant to oversee the Section 36 Application and has been undertaking discussions with the Energy Consents Unit (ECU) within the Scottish Government's Energy Division, in association with the Planning Consultant, since the very early stages of the project.

The Planning Consultant has been involved in all consultation with both statutory and non-statutory stakeholders and has coordinated the scoping process with Scottish Government. No major issues have arisen from this process.

An approach that has proven to be beneficial is the conducting of two, and programming of a third, Key Decision Maker (KDM) meetings. These were held jointly between ScottishPower and National Grid and were initially organised to introduce the CCS project and to outline the topics and issues to be covered by the Environmental Impact Assessment (EIA). In addition, Shell and National Grid jointly held a KDM meeting for the Aberdeen regulators in August 2010. Subsequent meetings have given the KDMs an opportunity to be involved in project development and to offer their views on approach and methodology as well as raising any concerns they may have. This serves to ensure there are no surprises further down the line and that the EIA is conducted in a manner that is acceptable to the KDMs.

The Scottish Government proposed that a Programme Monitoring Board be set up and the desired outcomes of the board are being progressed in collaboration with the ScottishPower Consortium.

A series of working parameters have been agreed between the Scottish Government, relevant participating agencies and the Consortium. This is essentially designed to identify any blockages in consenting processes and to work together to rectify them.
Attendees include the various local authorities that may be involved in consenting processes, as well as Scottish Natural Heritage (SNH), Scottish Environment Protection Agency (SEPA), Health and Safety Executive (HSE), Department for Energy and Climate Change (DECC) and the Scottish Government.

The first of these meetings was held in January 2011.

c) Current Position

A draft of the Section 36 Application documents was submitted to DECC on the 31st January 2011. Submission of the regulatory Section 36 Application is planned for early 2012. Providing no Public Inquiry is triggered and no Section 75 Agreement (a legal agreement made under Section 75 of the Town and Country Planning (Scotland) Act 1997 and regulating the future use of the land) is required, it is hoped that Section 36 Consent (and Deemed Planning Permission) will be granted by October 2012. There is however no statutory time limit for issue of a Section 36 Consent.

Environmental Impact Assessment (EIA) Regulations

a) Overview

These regulations determine the requirement for conducting an EIA. The Environmental Statement (ES) prepared as a result of the EIA forms part of the Section 36 Application submission (outlined above).

An EIA is an assessment of the possible positive or negative impacts that a proposed project may have on the environment, considering also the natural, social and economic aspects.

b) Summary of Progress

At a very early stage of the process, and following initial consultation discussions, ScottishPower received letters of support from SEPA and Fife Regional Council (the local planning authority).

Early consultation has proved invaluable as the project has evolved and close communication with key stakeholders has been maintained throughout.

ScottishPower and National Grid consulted jointly with SNH regarding the Conservation Regulations 1994. Following this consultation, a Report to Inform a Habitat Regulation Appraisal (HRA, formally known as an Appropriate Assessment) is being prepared. The HRA will address the UKCCS Demonstration Project’s onshore area (i.e. from LPS to Blackhill Compressor Station).

As a result of the area to be assessed, it was agreed within the ScottishPower CCS Consortium that National Grid would lead the HRA with input from ScottishPower for the Firth of Forth Special Protection Area (SPA) and River Teith Special Area of Conservation (SAC). The HRA will be appended to the CCP project ES and submitted with the regulatory Section 36 Application and the Pipeline Construction Authorisation (PCA) application.

The EIA Scoping Report was submitted to Scottish Government and some 40 relevant consultees on the 8th September 2010. Scottish Government provided the formal Scoping Opinion on the 5th November 2010 and there were a few headline items but nothing unexpected and all issues can be addressed satisfactorily.
There has been a strong interface with National Grid given the local proximity of their new pipeline and above ground installations (AGIs) and the likelihood of common areas. Baseline information and results of assessments have been shared to support the respective EIAs and ensure a consistent approach and this has been useful in determining locations and layout of key plant, laydown and contractors’ areas.

c) Current Position

An ES was delivered to DECC on the 31st January 2011 and this will be revisited and updated with any design conformation that becomes available during March to June 2011. It is planned to submit the regulatory Section 36 Application with the full ES documents in early summer 2011, with a view to obtaining planning permission in time for construction to commence early 2012.

Pollution Prevention and Control (PPC) Permit

a) Overview

The PPC regime employs an integrated approach to regulating certain industrial activities and installations that may cause pollution or have other environmental effects. PPC also considers further types of environmental impacts, such as resource consumption as well as pollution. LPS is subject to PPC as a Part A installation and holds a PPC Permit for the existing operations. This Permit is regulated by SEPA.

b) Summary of Progress

There were two scenarios considered in consultation with SEPA, in particular the SEPA Inspector for LPS and the SEPA Policy Specialist for CCS, as follows:
- Applying for a variation to the existing PPC Permit for LPS involving a “substantial change” that would extend to the CCP and SPS plant.
- Applying for a new PPC Permit for the CCP and associated SPS plant.

These ongoing discussions between ScottishPower and SEPA have resulted in SEPA recommending that a single PPC Permit be pursued covering both the existing LPS and the new CCP and SPS plant.

c) Current Position

An application will be made to SEPA for a variation in the permit conditions of the PPC Permit for LPS. The proposed variation would likely involve a "substantial change" and be subject to the same consultation and advertising procedure as an application for a new permit.

SEPA will issue a variation notice under Regulation 13. This will specify the variations and the date(s) on which they will take effect. SEPA may decide that some parts of the variation requested by the Operator may be reflected in new permit conditions, but others may not be permitted. SEPA may also need to impose conditions that are stricter than, or additional to, the Operator's proposals.

There is a need to determine whether or not LPS is to become a COMAH site and how this will affect the PPC Permit variation and LPS as a whole. This is further discussed in the subsequent COMAH sub-section.
Preparation of the PPC Permit variation application will commence post-FEED and will feed into the more
detailed design process with particular attention to Best Available Techniques (BAT).

Control of Major Accident Hazards Regulations 1999

a) Overview

The UK COMAH Regulations 1999 are a Statutory Instrument (SI 1999/743) under the Health and Safety at
Work Act (1974), which has been amended by the COMAH Regulations 2005 (SI 2005/1088).

The substances to which the COMAH Regulations apply are detailed in Schedule 1 of the amended
regulations. In determining application of the COMAH Regulations the maximum quantity of a regulated
substance, including storage and any quantities in use in the process, must be considered.

The CO₂ stripping process uses chemicals such as amines that, depending upon the characteristics and
the volumes stored and used in process, may be a qualifying substance under COMAH.

Presently CO₂ is not listed as a regulated substance under COMAH, although this is presently under review
by the European Union (EU). DECC has advised that any revision to the COMAH Regulations associated
with CO₂ will not be determined until 2015, which supersedes the proposed project programme. The
project will therefore progress on the assumption that COMAH will not apply and DECC will carry the
regulatory risk for any subsequent requirements that could arise for the project.

b) Summary of Progress

The HSE has been consulted from the early feasibility stage of the project with a view to understanding the
potential for the CCP project to bring LPS under the COMAH Regulations.

The two substances that require consideration are the CO₂ itself and the amines used in the scrubbing
process.

With respect to the amines, although the composition of the amine solution is not yet known, work is
progressing to design out any risk (i.e. through the use of specific concentrations/ dilutions) to retain the
installation below the COMAH thresholds.

CO₂ is not presently a listed substance under COMAH although it is possible that by 2015 that the Seveso
Directive (the COMAH Regulations implement the Seveso Directive in the UK) will be updated to include
CO₂. The EU has been reviewing the Seveso Directive and the HSE has put forward their considered view
of the CO₂ thresholds that should apply (50-100 tonnes). In light of the anticipated volumes of CO₂
contained within the CCP process (five tonnes per 100 metres of pipeline), it appears unlikely that LPS
would fall under COMAH for CO₂.

c) Current Position

A Major Accident Hazards (MAH) review has been prepared by ScottishPower to address the potential for
major accidents and to inform the design process from a safety perspective (the MAH review is
summarised in Appendix F.2.1). The potential requirement to upgrade this into a full COMAH report has
been discussed with the HSE and SEPA. This would be a ‘worst case scenario’ and may not be

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necessary, particularly as a decision on classification of CO₂ will not now be made until 2015. Consultation on this matter is ongoing.

Planning (Hazardous Substances) (Scotland) Act 1997

a) Overview

An application for a Hazardous Substance Certificate (HSC) would authorise the storage and use of certain hazardous substances on site. The application to the local planning authority must list the substances to be stored or used on site, the processes within which they would be used, the quantities concerned and the manner in which the substances will be stored. This may be applicable for CO₂ and/or the use of amine (depending on the composition).

b) Summary of Progress

As described above on COMAH, discussions have been ongoing with the HSE relating to the categorisation of CO₂ as a hazardous substance. It is generally considered that a HSC will not be relevant to LPS as the pipeline option negates storage of CO₂ on site. Ongoing discussions are progressing with HSE over the classification of CO₂ as a hazardous substance and the associated storage thresholds that will be applied.

Similarly, the amine solution used in the scrubbing process could instigate a requirement for a HSC. The composition of the final project amine solution is not yet known, therefore at this stage, it is not possible to assess the likelihood of it being determined a hazardous substance. It is however intended that the composition of the amine solution will be designed to avoid the requirement for an HSC.

c) Current Position

Ongoing discussions are progressing with HSE over the classification of CO₂ as a hazardous substance and the associated storage thresholds that will be applied.

The intention and current expectation is that the CCP at LPS will not require a HSC.

8.2.3 CO₂ Transportation

8.2.3.1 Relevant Consents and Legislation

The following consents and legislation have been identified as key for the proposed new pipelines from Longannet to Dunipace, the existing No. 10 Feeder pipeline from Dunipace to Blackhill, modifications to new and existing AGIs, and the new compressor station at Blackhill:

- Pipe-Lines Act 1962 Section 1(1) / Pipeline Works (Environmental Impact Assessment) Regulations 2000
- Pipeline Works (Environmental Impact Assessment) Regulations 2000
- The Conservation (Natural Habitats, &c.) Regulations, 1994
- Food and Environment Protection Act (FEPA) 1985 / Coastal Protection Act (CPA) 1949 (To be superseded by the Marine (Scotland) Act 2010 and Marine and Coastal Access Act 2009)
- Town and Country Planning (Scotland) Act 1997 as amended by the Planning etc. (Scotland) Act 2006
- Environmental Impact Assessment (Scotland) Regulations 1999
The pipeline and associated infrastructure areas to which these consents and legislation apply, as well as details of work carried out to date in obtaining these permits and complying with the relevant legislation, is incorporated into the Consents Register.

Section 8.2.3.2 provides a summary of the current consenting position for the onshore transportation element of the project.

**8.2.3.2 Summary of Progress to Date**

The following sub-section outlines the activities undertaken during FEED to progress the relevant consents and legislation for CO$_2$ transportation.

**Pipe-Lines Act 1962 Section 1(1) and Pipeline Works (Environmental Impact Assessment) Regulations 2000**

* a) Overview

The Scottish Government ECU has confirmed that the new pipeline for the transportation of gaseous CO$_2$ from Longannet to Dunipace will require Pipeline Construction Authorisation (PCA) under the Pipe-Lines Act 1962 and an EIA under the Pipeline Works (EIA) Regulations 2000. It has also been agreed that the pipeline running from the Longannet AGI to the Valleyfield AGI (within the LPS site) and the pipeline running from the Valleyfield AGI to the Dunipace AGI will be included in one PCA. Consent under the Town & Country Planning (Scotland) Act 1997 for pipelines of 16.093 km or less is therefore not required.

* b) Summary of Progress

National Grid held Public Information Days in Kincardine and Plean in July 2010 on the proposed route corridor for the new pipeline and feedback was generally positive. National Grid prepared a briefing note and submitted this along with a draft EIA Scoping Report to the KDMs in August 2010. The EIA Scoping Report was formally submitted on the 3rd December 2010 to Scottish Government and over 85 consultees. The formal consultation period ended on the 31st January 2011, a Scoping Opinion is awaited.

Following feedback from the KDMs, a single ES was to be prepared for the whole of the onshore transportation element of the project.

* c) Current Position

Preparation of the ES for regulatory submission is ongoing. A draft ES has been prepared for the UKCCS Demonstration Project and was delivered to DECC on 31st January 2011. The ES will be revisited and updated with any subsequent design and survey (such as wintering birds) information that becomes
The Conservation (Natural Habitats, &c.) Regulations 1994

a) Overview

Regulation 48 of the Conservation (Natural Habitats, &c.) Regulations 1994 states that a competent authority, before deciding to grant any consent, permission or other authorisation for a project which is likely to have a significant effect on a European site, either alone or in combination with other projects shall make an 'Appropriate Assessment' of the implications for the site in terms of the site's conservation objectives. The person applying for any such consent, permission or other authorisation must provide 'such information as the competent authority may reasonably require for the purposes of the assessment'.


The Scottish Government as the competent authority (in relation to the PCS), in conjunction with SNH, is required to make an 'Appropriate Assessment' of the implications of the project on the site, and the Applicant is required to provide the necessary information to allow for this assessment.

b) Summary of Progress

The requirement for an Appropriate Assessment will be determined by the crossing method proposed and the likely impact on the qualifying interests of the Firth of Forth SPA.

National Grid and ScottishPower consulted jointly with SNH regarding the Conservation Regulations 1994. National Grid is taking the lead in conducting and preparing the Report to Inform a HRA for the CCS project onshore area (i.e. LPS to Blackhill Compressor Station) with input from ScottishPower on the CCP and SPS. This means that all sites and species of international interest within that area will be considered. Following screening it is expected that the need for detailed consideration will be reduced to just a few specific areas i.e. the Forth Valley with implications for Firth of Forth SPA and River Teith SAC if found relevant.

c) Current Position

Preparation of the Report to inform the Habitats Regulation Assessment (HRA) is ongoing. The Report will be submitted along with the PCA application.
Food Environment Protection Act (FEPA) 1985 / CPA 1949 (To be superseded by the Marine (Scotland) Act 2010 and Marine and Coastal Access Act 2009)

a) Overview

A FEPA Licence regulates for the deposit of substances or articles within UK waters and a CPA Consent is required for activities affecting marine navigation. This has been considered for the new CO₂ transportation pipeline crossing of the River Forth.

b) Summary of Progress

Marine Scotland has been consulted on the consenting requirements for a pipeline crossing of the River Forth. Marine Scotland has confirmed that tunnelling is exempt from FEPA under Deposits in the Sea (Exemptions) Order 1985, Section 3.25. Tunnelling is the optimum method likely to be selected for crossing the River Forth. A Coastal Protection Act (CPA) consent may be required if there is an issue relating to marine navigation / traffic.

FEPA Licence and CPA Consent will be replaced by Marine Licensing from April 2011. According to the Marine Scotland consultation document Consultation on Marine Licensing for Scotland under the Marine (Scotland) Act 2010 and the Marine and Coastal Access Act 2000, a similar exemption is proposed to that under FEPA for bored tunnels under the seabed. The new exemption will only apply if the licensing authority is notified in advance of the intention to carry on the activity. The exemption includes a condition that the construction of the tunnel does not adversely affect the environment of the UK marine area or the living resources that it supports.

c) Current Position

For this project, the condition would be demonstrated by the results of the EIA and HRA being prepared under the Pipeline Works (EIA) Regulations 2000 and The Conservation (Natural Habitats &c.) Regulations 1994.

Consultation will continue with Marine Scotland to ensure that activities required during the design and construction of the CO₂ transportation elements of the project are carried out in compliance with Marine Licensing requirements.

Town and Country Planning Act (TCPA) 1997 as amended by the Planning etc. (Scotland) Act 2006

a) Overview

The TCPA applies to the development of several transportation stages:
- New pipeline from LPS to Dunipace (if 16.093 km or less)
- New AGIs associated with the new pipeline
- Change of use of the existing No.10 Feeder pipeline from Dunipace to Blackhill
- Modifications to existing AGIs and associated sections of new pipeline required to separate the existing pipeline from the natural gas National Transmission System and accommodate the change of use
- New AGIs associated with the conversion of the existing pipeline;
- New compressor station at Blackhill
- New pipeline connecting existing No.10 Feeder pipeline with the new compressor station at Blackhill

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The Scottish Government has confirmed that the Pipe-Lines Act applies to the new pipeline from LPS to Dunipace and agreed that only one PCA application is required for the new pipeline from Longannet to Valleyfield and the Valleyfield to Dunipace AGIs. Consent under the TCPA 1997 for pipelines of 16.093 km or less is therefore not required.

b) Summary of Progress

Site selection for the new AGIs at Longannet, Valleyfield and Dunipace has been carried out and the sites have been included within the EIA. Drawings are being prepared for the purposes of progressing planning applications.

The No.10 Feeder was constructed under the Gas Act and therefore has deemed planning consent for the transportation of natural gas by a gas supplier (General Permitted Development (Scotland) Order 1992 Schedule 1 Part 13 Class 39). The proposed works require a change of use of the pipeline from the conveyance of natural gas by a statutory undertaker (gas supplier) to conveyance of CO2 and therefore development for which planning permission would be required. This would require applications for planning permission for change of use of the pipeline to five Local Planning Authorities (LPAs).

The conversion of the No.10 Feeder from natural gas to CO2 will require modifications to existing AGIs including the installation of short sections of new pipeline to allow the separation of the existing pipeline from the National Transmission System for natural gas. Modifications will also be required to existing block valves to adapt them for CO2. Planning applications for these "development" works (and those of new AGIs on the No. 10 Feeder) can be used to seek the necessary consent to permit the change of use of the pipeline for CO2 transportation. These sites have been included within the EIA. Drawings are being prepared for the purposes of progressing planning applications.

In addition, two new AGIs will be required at Murthill (Kirriemuir) and Fordtown (Kintore). Site selection has been carried out and the sites have been included within the EIA. National Grid held a Public Information Day at Kintore in November 2010 regarding the proposed Fordtown AGI and feedback was positive. Drawings are being prepared for the purposes of progressing planning applications.

Planning consent will also be required for the new compressor station at Blackhill and the new section of pipeline connecting the No.10 Feeder to the Compressor site. Site/ route selections have been carried out and the sites have been included within the EIA. Drawings are being prepared for the purposes of progressing planning applications.

Consultation with the Scottish Government Planning Department has confirmed that the pipelines and works which make up the onshore transportation element of the project are not national development in terms of the Planning etc. (Scotland) Act 2006, but should be treated as a major development. The requirements for processing planning applications as set out in Town and Country Planning (Development Management Procedures) (Scotland) Regulations 2008 and Circular 4/2009 would therefore apply.

KDM meetings have been held in conjunction with ScottishPower at Longannet and with Shell at Aberdeen to discuss the project. Constructive feedback has been received.

The issues are as follows:
1. The process of gaining planning consent for the change of use of the No.10 Feeder and associated works via the TCPA would be very complex and involve five separate Local Planning Authorities (LPAs). However initial consultations with the LPAs has been encouraging and supportive, Scottish Government has also indicated that the Scottish Ministers would consider exercising powers under Section 46 of the TCPA to call in the various applications so that they are all considered by the Scottish Ministers, this would aid speed and consistency of decision making.

2. As part of the transfer of the existing No.10 Feeder pipeline from natural gas transmission by a gas supplier to CO2 conveyance, Scottish law will require new land rights to be negotiated with landowners and tenants to enable National Grid to transport CO2. The powers of compulsory purchase provided under the TCPA are not sufficient to enable National Grid to acquire all necessary land rights in the event of a refusal. National Grid has therefore looked at a number of options to resolve this issue. This includes new legislation through the Scottish Parliament to cover compulsory purchase of land rights (deeds of servitude). In parallel, an amendment to legislation through the Westminster Parliament to allow transfer of land rights / consents for pipelines constructed under the Gas Act has been pursued.

**Pipeline Safety Regulations (PSR) 1996**

a) **Overview**

The PSR 1996 were developed under the Health and Safety at Work Act 1974 and are the principal health and safety legislation in the UK concerning the safety of pipelines.

b) **Summary of Progress**

CO2 does not presently fall within the "dangerous fluid" category under Schedule 2 of the Regulations.

c) **Current Position**

Preliminary information has been submitted to the HSE for information as part of the UKCCS Demonstration FEED work.

**Gas Act 1986 / Energy Act 2008**

a) **Overview**

National Grid Gas is a licensed Gas Transporter, regulated by the Office of Gas and Electricity Markets (Ofgem) and both the licensing framework and regulator are established by the Gas Act (1986) (as amended). Ofgem’s primary interest is to protect gas consumers, and they in turn are governed by the Gas and Electricity Markets Authority (GEMA). In order to protect gas consumers and ensure a breadth of views are considered, most Ofgem approvals require consultation with industry which once concluded is presented to GEMA with a recommendation, to achieve consent.

National Grid Gas requires consent from Ofgem and GEMA for the disposal of assets which are defined under National Grid Gas’ Licence as “transportation assets”. Under National Grid Gas Licence Standard Special Condition A27 (SSC – A27), consent may also be required from the Secretary of State, as the assets for disposal could be considered a significant part of the natural gas transmission network. If
disposal is granted, the assets will be transferred to, operated and maintained by National Grid (note: ‘National Grid’ refers explicitly to the carbon business registered as ‘National Grid Carbon’). The pipeline will cease to be used to transport natural gas and will instead transport CO₂.

b) Summary of Progress

National Grid Gas engaged with Ofgem in November 2008, ahead of the FEED programme, in a bid to reduce the risk of not securing asset disposal within the DECC timescales to allow sufficient time for all parties’ due diligence. It seemed prudent to explore this proposal at the earliest opportunity to increase project certainty, primarily for National Grid, DECC and Consortium Partners.

Disposal and re-use of assets of this magnitude is innovative and unique to NGG, with no previous process or precedent to follow. It is recognised that whilst a different process may be preferable for any subsequent disposal, it is unlikely these same circumstances would be repeated. A key learning from this process is a belief that any future disposals would likely require a case-by-case approach.

For this proposal, Ofgem’s process to date has included an initial consultation on the principle of asset disposal (April 2009) followed by a second consultation on commercial terms (May 2010). The second consultation contained revisions that reflected previous industry feedback from the first consultation, with the initial Regulatory Impact Assessment (including external verification) used as the basis for further exploration.

National Grid held an industry day alongside each consultation to further explain the proposal and encourage industry discussion, given the importance and breadth of the proposal to both gas and CCS industries. These were vital to understanding and discussing gas industry participants' concerns and both generated an unprecedented number of formal responses to Ofgem. The primary concerns raised by industry were around the perceived impact to supply capability at St. Fergus and increased likelihood of system constraints. These were explored by National Grid and National Grid Gas through network analysis and external verification, with the results presented and discussed at the second industry day. The findings supported initial views on the feasibility of disposal, and provided some level of reassurance to industry. The remaining complexity also requiring industry consultation is on methodologies for identifying and funding residual liabilities that arise from the asset disposal, such that gas consumers are not unduly exposed to incremental costs.

c) Current Position

There has not been a decision to date on the release of assets to National Grid, however Ofgem released a set of principles (September 2010) as guidelines to National Grid when negotiating asset disposal terms. The principles were approved by GEMA, who raised no objections to a disposal that is aligned to these. The principles are in keeping with GEMA’s principal objective and general duties, including GEMA’s duty to protect existing and future gas consumers. The principles are also in keeping with the fact that GEMA may, in carrying out any function under Part I of the Gas Act 1986, have regard to the interests of existing and future electricity consumers. GEMA recognise the importance of the UK CCS Demonstration project, and particularly the need to deliver a transport solution for 2014.

The conclusion of asset disposal negotiations will be captured as Heads of Terms. These will be submitted to Ofgem when finalised and, if acceptable, National Grid Gas will then make a formal application to GEMA and the Secretary of State for consent to dispose of the assets (as per SSC - A27). National Grid will
submit the Heads of Terms to DECC and need to ensure these are accommodated within the project Contract discussions with DECC and the Consortium Partners.

Until formal approval by the relevant authorities is granted, there remains a risk (albeit reduced by work to date) that the assets will not be acquired for the project, or that the terms of release will not be acceptable to Ofgem and/or GEMA. The acquisition remains a condition of National Grid’s progression in the UKCCS Demonstration Competition. Similarly, progression in the UKCCS Demonstration Project remains a condition of the acquisition. The complexity, uniqueness and dynamic nature of the two elements (UKCCS Demonstration Competition and Ofgem process) has created a number of challenges and uncertainties when trying to achieve project certainty. Early and continued engagement with Ofgem has been a key factor in progressing this to date.

Environmental Impact Assessment (Scotland) Regulations 1999

a) Overview

The EIA (Scotland) Regulations apply to developments requiring consent under the TCPA. Although each individual element of the project requiring planning consent may not in themselves be classed as an EIA development, following feedback from the KDMs a single ES is being prepared for the whole of the onshore transportation element of the project.

b) Summary of Progress

National Grid prepared a briefing note on consenting and submitted this along with a draft EIA Scoping Report to the KDMs in August 2010. KDM meetings were held in August, in conjunction with ScottishPower and Shell, where feedback was received from the KDMs regarding the draft EIA Scoping Report that a screening opinion should be sought for the new Blackhill Compressor Station, the modified St. Fergus compressor and interconnecting pipeline. The EIA Scoping Report was formally submitted on the 3rd December 2010 to LPAs and over 85 consultees.

c) Current Position

Preparation of the ES is ongoing. A draft ES has been prepared for the UKCCS Demonstration Project and was delivered to DECC on 31st January 2011. The ES will be revisited and updated with any subsequent design and survey (such as wintering birds) information that becomes available post-FEED. The intention is to submit the full ES documents with planning applications in Autumn/Winter 2011 following a 12 week consultation period.

Control of Pollution (Amendment) Act 1989/ The Controlled Waste (Registration of Carriers and Seizure of Vehicles) Regulations 1991

a) Overview

The revised Waste Framework Directive (WFD) 2008, due to be transposed into UK / Scottish legislation and laid before parliament in January 2011, does not exclude CO₂ from its scope.
b) Summary of Progress

If CO₂ is confirmed to be a waste, National Grid may need to register as a waste carrier under the Waste (Registration of Carriers and Seizure of Vehicles) Regulations 1991. Confirmation is therefore required from the DECC Regulatory Team that captured CO₂ transported for storage is not waste.

The CCS Directive (2009/31/EC) states that the WFD should be amended to provide that CO₂ captured and transported for the purposes of geological storage should be excluded from the scope of the WFD. However, the CCS Directive only amends the 2006 WFD and not the 2008 revised WFD.

c) Current Position

This is an area for ongoing discussion with the Programme Monitoring Board set up by Scottish Government for the UKCCS Demonstration Competition.

8.2.4 CO₂ Offshore Transportation and Storage

8.2.4.1 Relevant Consents and Legislation

The following consents and legislation have been identified as mandatory and/or key for the St. Fergus compressor site, the subsequent on and offshore pipelines and the Goldeneye storage facility:

- s.34 Coast Protection Act 1949 (CPA), as amended - Consent to locate platform (CPA2)
- Offshore Chemicals Regulations 2002 (SI 2002/1355) - Chemical Permit (PON15D Approval)
- Offshore Chemicals Regulations 2002 (SI 2002/1355) - Chemical Permit (PON15C Approval)
- Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005 (SI2005.2055), as amended - OPPC Permit
- Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005 (SI2005.2055) - OPPC Permit
- Section 34 Coast Protection Act 1949 - CPA 1
- s.17 Petroleum Act 1998 - Consent for connecting to existing offshore pipelines
- Town and Country Planning (Hazardous Substances) (Scotland) Regulations 1993, as amended
- Planning (Hazardous Substances) (Scotland) Act 1997 - Consent for storage of hazardous substances (CO₂) at the onshore gas plant at Blackhill
- Regulation6(4) Control of Major Accident Hazards Regulations 1999 (SI 1999/743) - Approval of updated COMAH Safety Report
- Energy Act 2008 - Consent to cease injection and storage operations
- s 29 Petroleum Act 1988 - Approval of Decommissioning Programme
- Energy Act 2008 - Consent to handover storage facilities

The areas of the Blackhill Compressor Station, on and offshore pipelines, and Goldeneye storage facility to which these consents and legislation apply, as well as details of work carried out to date in obtaining these permits and complying with the relevant legislation, is incorporated into the Consents Register.

Figure 8.2.4.1-1 below provides a schematic of the key elements of the UK’s CO₂ storage licensing regime.

Section 8.2.4.2 summarises the current consenting position for the consents and legislation mentioned above for the offshore transportation and storage of the CO₂.

Figure 8.2.4.1-1: CO₂ Storage Licensing Framework

8.2.4.2 Summary of Progress to Date

a) Overview

Meetings with the DECC Licensing and Consents Group took place on the 23rd October 2009 and 30th April 2010 in order to describe the high-level project plans, establish the likely licences and consents required and to clarify the timing associated with the proposed changes to the licence and consenting regimes. Further to these meetings DECC EDU (the licensing team) and Shell agreed to establish separate parallel workstreams in order to progress discussions on the various requirements for securing a Storage Permit and Shell's plans for meeting these.
From September 2010, the Terms of Reference agreed with DECC for the different elements of the Carbon Storage Licence / Storage Permit were launched with participation from The Crown Estate.

Regulations providing for the licensing of offshore CO₂ storage came into force on 1st October 2010. Regulations regarding Transfer of Responsibility are to be consulted upon and Shell will respond when the draft Regulations are published.

In order to issue a Carbon Storage License, a Strategic Environmental Assessment (SEA) needs to be completed, this is presently programmed for February 2011.

A draft Carbon Storage Permit award decision cannot be submitted to the EU Scientific Panel (which has yet to be set up) for review until the ES has been approved. Subject to the timing of the ES, it seems unlikely that referral to the EU Scientific Panel will occur until at least the end of quarter 3 of 2011. Full approval of the Storage Permit is therefore not expected until at least quarter 4 of 2011. The European Commission (EC) has commenced discussion with the EU Member States in order to set up the EU Scientific Panel.

Negotiations continue with The Crown Estate for the Lease and Agreement for Lease documents. In addition, discussions with DECC have commenced regarding how the storage Joint Venture (JV) Partners will meet the Financial Security requirements of the CCS Directive and UK regulations.

Shell have been requested by DECC to submit a draft Storage Development Plan to assist them in developing appropriate guidance.

The Environmental Amendment Order, which extends existing oil and gas environmental Regulations to offshore CO₂ storage, came in to effect on the 1st July 2010.

**Approval of updated COMAH Safety Report**

A direct interface meeting was undertaken by the Shell with the HSE team at their Liverpool office in June 2010. At this meeting it was established that it is likely to take at least a few years before the existing COMAH Regulations are revised in congruence with the Seveso directive. It has subsequently been announced by DECC that any revision will not be announced until 2015. The understanding shared with the HSE was that Shell will be required to submit and seek approval of a revised COMAH safety report.

**Approval of Decommissioning Programme**

Discussions have been undertaken with DECC to clarify Cessation of Production requirements under the current Production Licence.

No discussions have taken place yet regarding the Final Field Development Plan or the Decommissioning Plan or the decommissioning obligations following carbon storage operations. However, it is expected that an outline plan will be required as part of the application for a Carbon Storage Permit, discussions on which ongoing.
8.2.4.3  **Key Consents and Legislation - Not Yet Progressed**

Those permits, consents and legislation identified as key that have not yet progressed as they are not required at this stage of the project are listed below. These will all be pursued in due course and secured in advance of CO₂ capture, transportation and subsequent storage. Other relevant permits and consents are included within the Consents Register in Appendix H.1.

- SI 1996/825 The PSR 1996 - Approval of updated Major Accident Prevention Document for the Goldeneye export pipeline
- S1 1996/825 PSR 1996 Reg 21 - Notification before use / re-use of a major accident hazard pipeline for the Goldeneye export pipeline
- SI 1996/825 The PSR 1996 Reg 22 - Notification in other cases for the Goldeneye export pipeline
- SI 2005/3117 Offshore Installations (Safety Case) Regulations 2005 (SCR05), as amended - Revised Goldeneye Installation Safety Case (14.2 Material Change) Approval for the operation of the mobile drilling rig adjacent to existing, fixed installation
- S1 1996/825 PSR 1996 Reg 20:L82 - Notification before construction of a major accident hazard pipeline for the new pipeline at St. Fergus connecting the National Grid pipeline to the Goldeneye pipeline
- S1 1996/825 PR 1996 Reg 21 - Notification before use / re-use of a major accident hazard pipeline for the new pipeline at St. Fergus connecting the National Grid pipeline to the Goldeneye pipeline
- The Environmental Impact Assessment (Scotland) Regulations 1999 (SSI 1999/1), as amended - ES approval for modifications to the St. Fergus plant
- Town & Country Planning (Scotland) Act 1997; The Planning etc (Scotland) Act 2006 - Planning Consent for modifications to the St. Fergus plant
- Reg 13 of The Pollution Prevention and Control (Scotland) Regulations 2000 (SSI 2000/323) - Variation to PPC Permit for modifications to the St. Fergus plant
- SI 2005/3117 Offshore Installations (Safety Case) Regulations 2005 (SCR05) - Revised Goldeneye Safety Case (14.2 Material Change (CO₂ introduction) for the Goldeneye platform

8.2.4.4  **Summary of Progress to Date**

With regards the modifications to the St. Fergus plant, initial meetings have been undertaken with Aberdeenshire Council to discuss any requirements for undertaking EIA to support the planning application. Aberdeenshire Council (Planning and Environmental Services) has confirmed support for Shell’s proposed submission of a Screening Assessment under Schedule 3 of the Environmental Impact Assessment (Scotland) Regulations 1999 (as amended) to determine the EIA requirements for the Shell scope of work at St. Fergus. Screening will be issued by the end of 2010 and, should an EIA be required, Shell will liaise with National Grid in the preparation of a joint ES to support the Planning Application.

There is regular consultation with DECC and statutory advisors, including Joint Nature Conservation Committee (JNCC) and Marine Scotland, on the EIA assessing offshore works. Consultation with Central North Sea stakeholders (e.g. Scottish Fisherman’s Federation, Marine Conservation Society and Defence Estates) has also been undertaken.

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During engagement with the HSE on 21st January 2011, the HSE stated its understanding that CO₂ is not currently going to be explicitly included under the update to Seveso II and that COMAH and PSR legislation is unlikely to be updated in the CCS project timeframe.

8.2.4.5 Shell Regulatory Permits and Approval Plan

The Shell Regulatory Permits and Approval Schedule/Plan is found within Appendix H.3 under the following reference:
- UKCCS - KT - S11.2 - Shell - 001 Regulatory Permits and Approval Plan
8.3 Consents: Risks, Issues and Uncertainties

8.3.1 Overview

As set out in the introduction, the CCS Directive has been adopted to regulate the geological storage of CO₂. There are existing EU Directives to regulate the capture and transportation components of the CCS Chain and these have been subject to ongoing consultation and amendment.

The key risks and issues for the UKCCS Demonstration Project relate to the uncertainties surrounding emerging and changing legislation, what the regulatory requirements might be and when the regulatory framework will be implemented. Of particular concern is whether or not the regulatory framework will be suitably established to facilitate delivery of the UKCCS Demonstration Project within the required timeframes.

In recognition of the risk the regulatory uncertainty has upon the project, at a very early stage of FEED consenting risk was identified as one of the top 10 project risks. This has been included in the project Risk Register.

An extract of the risk register is provided in Appendix H.2 under the reference:

- UKCCS - KT - S11.2 - FEED - 001 Key Consents Risks

8.3.2 Carbon Capture Plant and Steam and Power Supply

8.3.2.1 Section 36 Consent (and Deemed Planning Permission)

a) Issues and Uncertainties

The most critical issue is the potential for objections from Statutory Agencies (i.e. SEPA & SNH) and/or Local Authorities in response to vociferous local opposition to the proposals.

b) Potential Impacts on project

Such objections could trigger a Public Inquiry which will result in extensive project delays and additional cost.

c) Level of Uncertainty

The outcome of the Section 36 Consent application is already time constrained if the UKCCS Demonstration Project is to achieve the programmed construction and operation milestones.

d) Mitigation Approach and Rationale

A programme to achieve effective stakeholder engagement has been undertaken that will identify and address / respond to issues in advance of any application being made.
Dialogue with Government bodies, statutory agencies and Local Authorities is already indicating their general satisfaction with the approaches being taken for the constituent elements and this is helping to reduce the potential for objection.

However, where a significant level of construction activity may be undertaken over the same period as the CCP and pipeline construction, this could prompt increased objection from the local communities. These areas are being specifically targeted for engagement and ongoing dialogue.

e) Residual Uncertainty

Following adoption of mitigation, the residual likelihood of the risk occurring has been reduced from likely to possible.

8.3.2.2 Pollution Prevention and Control (PPC) Permit

a) Issues and Uncertainties

Presently a variation of the existing PPC Permit for LPS involving a "substantial change" will be pursued post-FEED. This will exclude the pipeline connecting the CCP to the AGI and discussions on this issue are ongoing.

However, there may be issues in determining emission limits for the cumulative plants (i.e. the existing LPS, the CCP and SPS). In addition, the CCP and SPS plant may be operated by a different operator under the ScottishPower Consortium which would impact issue of a PPC Permit variation to the appropriate operator.

There is also a need to determine whether or not LPS is to become a COMAH site and how this will affect the PPC Permit variation and LPS as a whole.

b) Potential Impacts on project

There may be unacceptable impacts for the exiting LPS as a result of permit conditions imposed by SEPA resulting from the cumulative emissions and discharges.

The application will be to seek an amalgamation of the existing PPC permits that cover LPS as per a SEPA suggestion and subject to being able to achieve reasonable standards for discharges etc a single LPS PPC Permit should be achievable.

In addition, the current uncertainty regarding the regulatory requirements for CO₂ could result in inadequate design or assessment.

c) Level of Uncertainty

It is too early in the project to establish the potential impacts of the cumulative plant. As the design iterates to a more detailed stage, assessment and modelling of discharges and emissions will be conducted. At the moment the impact remains uncertain although early indications are that issues for LPS can be designed out.
The ongoing question of classification of CO₂ remains and is not expected to be resolved until 2015, which will supersede the PPC Permit application. It is therefore assumed that, should CO₂ become classified under COMAH, any impact on the PPC Permit can be subsequently varied.

Alterations to the regulatory regime to accommodate CO₂ are subject to a high degree of uncertainty and the likelihood of project risk realisation is also considered high.

d) Mitigation Approach and Rationale

The PPC Permit application will seek an amalgamation of the existing PPC Permit that covers LPS, as suggested by SEPA. Subject to being able to achieve reasonable standards for emissions and discharges, a single LPS PPC Permit should be achievable.

SEPA will be regularly consulted to ensure the PPC Permit application does not contain any surprises and that SEPA are on board with the techniques put forward.

e) Residual Uncertainty

Following mitigation, the likelihood of potential impacts on the project remains possible.

8.3.2.3 COMAH

a) Issues and Uncertainties

The HSE has delayed making a decision on the inclusion of CO₂ as a hazardous substance under the COMAH Regulations until 2015. Consequently it is not known whether LPS will fall under COMAH and require licensing. Given the timescale for the HSE decision there is potential that additional legislation could be introduced on health and safety consents and licenses.

b) Potential Impacts on project

Current uncertainty regarding the regulatory requirements for CO₂ could result in inadequate design or assessment. project scheduling could be affected through associated delays in consent approval or through any delay by the statutory authorities in establishing safety protocols for CO₂.

The ongoing question of classification of CO₂ remains and is not expected to be resolved until 2015. Until such time, the scale of potential risk (related to the level of hazard deemed to be associated with CO₂) will be unclear.

c) Level of Uncertainty

Alterations to the regulatory regime to accommodate CO₂ are subject to a high degree of uncertainty and the likelihood of project risk realisation is also considered high.

d) Mitigation Approach and Rationale

The Consortium has been involved in continued dialogue with Government bodies, including HSE and DECC, to understand additional requirements and provide analysis as necessary.
e) Residual Uncertainty

Ongoing dialogue with the HSE is helping to clarify where they view the likely CO₂ thresholds will be set. However there remains a risk that major changes to the current unofficial position could occur with little warning. Following mitigation the likelihood of the risk occurring is therefore considered to remain high.

8.3.3 Onshore Transportation System

8.3.3.1 PCA and Planning Consents (new pipeline, new AGIs and new Blackhill Compressor Station).

a) Issues and Uncertainties

EIA and HRA are required to accompany the application for PCA and Planning Consents. EIA and HRA will be subject to statutory and public consultation. The outcome of the consultation process cannot be foreseen and there remains the possibility that irreconcilable objections are raised by the Statutory Agencies (including SEPA and SNH) or the LPAs.

b) Potential Impacts on project

Objections to the project from the Statutory Agencies or LPAs may trigger the need for a Public Inquiry. A Public Inquiry would result in project scheduling delay and increased project costs.

It would also carry risk of PCA/Planning Consent refusal and, in this event, further scheduling delay and cost would be incurred through the need for redesign, a pipeline re-route or alternative site location or utilisation of different construction methods.

c) Level of Uncertainty/Risk

The outcome of the PCA and planning applications are subject to a high degree of uncertainty and risk.

d) Mitigation Approach and Rationale

The mitigation strategy employed is primarily focussed on early and ongoing dialogue with key stakeholders, including SNH, SEPA, HSE, LPAs, DECC, the Scottish Government and affected land owners and occupiers. The purpose of this approach is to develop an early understanding of requirements and potential issues, and to inform options and provision of further analysis. As discussions have progressed, potential issues have been identified (for example, the pipeline crossing at the River Forth and these areas have been specifically targeted for engagement and ongoing dialogue).

A public consultation strategy has been implemented to inform local communities about the project and address any concerns.

At the same time work has taken place to identify contingency options for some construction consent risks, including re-routing. These mitigations measures will reduce the risk of objections.
e)  Residual Uncertainty/Risk

Following adoption of mitigation the residual likelihood of the risk occurring has been reduced from likely to possible.

8.3.3.2  Compulsory Purchase Provisions – New Pipeline

a)  Issues and Uncertainties

In relation to the construction of new pipeline, National Grid will need to negotiate a Deed of Servitude with landowners and tenants for access initially to survey and then to construct the pipeline, and for ongoing access to the pipeline for monitoring and maintenance. It is not always possible to reach a negotiated agreement on land rights and in this case it may be necessary to apply for a Compulsory Purchase Order (CPO) under the Pipe Lines Act 1962 Section 11 and Land Compensation (Scotland) Act 1963 for the acquisition of land for pipeline construction.

An application for a CPO may be subject to Public Inquiry in the event of objection, the outcome of which is inherently uncertain.

b)  Potential Impacts on project

Failure to reach a negotiated settlement on land rights and requirement for CPO application would result in a substantial cost increase.

project scheduling delays could also be experienced in the event of Local Inquiry and, should the application be refused, further scheduling delay and cost would be incurred through the need for redesign or re-routeing of the pipeline.

c)  Level of Uncertainty

The outcome of land rights negotiation and CPO is subject to a high degree of uncertainty and risk.

d)  Mitigation Approach and Rationale

A programme of consultation with key stakeholders including landowners, occupiers, and the Scottish Government was implemented early in the process and is ongoing. Work has also taken place to identify contingency options.

e)  Residual Uncertainty

Following adoption of mitigation the residual likelihood of the risk occurring has been reduced from likely to possible.

8.3.3.3  Planning Consent for Pipeline Change of Use – Existing Pipeline

a)  Issues and Uncertainties
National Grid has been advised that Consent will be required under the Town & Country Planning (Scotland) Act 1997 for change of use of the existing pipeline from the conveyance of natural gas to conveyance of CO₂. This will also cover associated modification works and new AGIs. Consent for change of use will require applications to five separate LPAs. The possibility remains that irreconcilable objections are raised by the LPAs.

b) Potential Impacts on project

Objections to the project from the LPAs may trigger the need for a Public Inquiry. A Public Inquiry would result in project scheduling delay and increased project costs. It would also carry risk of PCA/Planning Consent refusal and, in this event, further scheduling delay and cost would be incurred through the need for redesign or design and construction of a new pipeline.

c) Level of Uncertainty

The outcome of the consent application is subject to a high degree of uncertainty and risk due to the number of LPAs involved.

d) Mitigation Approach and Rationale

With regard to applications for planning consent for Pipeline change of use, early consultation with the Scottish Government and affected LPAs was undertaken. Public information days have been carried out to keep local communities informed and address any concerns. Initial feedback indicating their general satisfaction with the approaches being taken and this is helping to reduce the potential for objections.

Work will continue through consultation with the LPAs and the Scottish Government to facilitate a consistent approach to processing these applications. A strategy is being prepared for further public consultation.

e) Residual Uncertainty

Following adoption of mitigation the residual likelihood of the risk occurring has been reduced from likely to possible.

8.3.3.4 Change of Commodity on Deed of Servitude – Existing Pipeline

a) Issues and Uncertainties

In terms of land rights for the existing pipeline, there is currently no mechanism in place under Scottish law to enable the existing land rights for natural gas transmission to be used for CO₂ transmission. (note: Provisions for Deed of Variation under the Gas Act 1986 do not apply).

New wayleave agreements (Deed of Servitude) will therefore need to be negotiated with landowners and tenants for the transportation of CO₂.

If problems are experienced in obtaining wayleave and landowner / tenant consent, it may be necessary to undertake compulsory purchase proceedings. The powers of compulsory purchase provided under the
Town and Country Planning (Scotland) Act 1997 are not sufficient to enable National Grid to acquire all necessary land rights in the event of a refusal.

**b) Potential Impacts on project**

Failure to establish a suitable legislative framework for the transfer of land rights or for compulsory purchase could result in project scheduling delays in the event of a failure to reach a negotiated settlement on land rights with the potential for substantial cost increase incurred through the need for redesign or re-routing of the pipeline and delays in establishing appropriate infrastructure.

**c) Level of Uncertainty**

There is currently a high degree of uncertainty surrounding the ability to obtain wayleave agreements and the establishment of a suitable compulsory purchase mechanism. The likelihood of potential impacts occurring is considered likely.

**d) Mitigation Approach and Rationale**

National Grid has examined a number of options to resolve the issue of land rights. This includes new legislation through the Scottish Parliament to cover compulsory purchase of land rights (Deeds of Servitude). In parallel, National Grid has pursued an amendment to legislation through the Westminster Parliament to allow transfer of land rights for pipelines constructed under the Gas Acts by extending the existing Deeds of Servitude for gas transportation to include CO₂.

National Grid is undertaking an ongoing process of consultation with all landowners / tenants along the existing pipeline on consent for this potential change in land rights.

**e) Residual Uncertainty**

Following mitigation the likelihood of potential impacts on the project remains possible.

**8.3.3.5 Consent for the Disposal of a Regulatory Asset / Change of Use of Existing Pipeline**

**a) Issues and Uncertainties**

Consent is required from Ofgem and GEMA for the disposal of the existing pipeline which forms part of the regulatory asset base (the natural gas National Transmission System). Consent may also be required from the Secretary of State because the pipeline is considered to be a significant part of the gas transmission network.

Until formal approval by the relevant authorities is granted for asset transfer, there is a risk that the assets will not be acquired for the project, or that the terms of release will not be acceptable to Ofgem and / or GEMA. The acquisition remains a condition of National Grid’s progression in the UKCCS Demonstration Competition. Similarly, progression in the UKCCS Demonstration Competition remains a condition of the acquisition. The complexity, uniqueness and dynamic nature of the two elements (UKCCS Demonstration Competition and Ofgem process) has created a number of challenges and uncertainties when trying to achieve project certainty.
b) Potential Impacts on project

Failure to obtain consent to transfer the NTS asset from National Grid Gas to National Grid, would result in substantial project scheduling delays and a requirement to utilise an alternative sub-optimal transportation option. Both of these outcomes would incur significant additional costs and jeopardise the viability of the project proposal.

c) Level of Uncertainty

The likelihood of potential impacts occurring is considered high.

d) Mitigation Approach and Rationale

Early and ongoing consultation with Ofgem, GEMA, DECC and the Scottish Government.

As part of the standard regulatory process, consultation has also been undertaken with gas shippers, suppliers and generators to ascertain whether the transfer of the pipeline would have any detrimental effect on the NTS capacity to meet future demand for gas transmission.

e) Residual Uncertainty

Mitigation carried out to date has reduced the identified risks but not sufficiently to alter the risk assessment outcome detailed above. It is envisaged that full implementation of mitigation will reduce the likelihood of impacts occurring to possible.

8.3.3.6 Notifications under the Pipeline Safety Regulations (PSR) 1996

a) Issues and Uncertainties

The PSR require the following notifications:

- Notification of Commencement of Construction (Reg 20)
- Change of use notification for an Existing Pipeline (Reg 22 (2))
- De-notification of Existing Onshore Pipeline (Reg 22 (2))
- Revalidation notification of Existing Onshore Pipeline (Reg 21)

The HSE is currently progressing amendments to the PSR to include reclassification of CO₂ as a “dangerous fluid” under Schedule 2 of the Regulations. The amendments are expected to be published in April 2011. In the meantime, work is progressing on the assumption that CO₂ will fall under the PSR.

A consultation exercise conducted by the HSE will identify thresholds and allowable proximity of the pipeline (these distances will also likely have risk profiles associated with them in the same way that natural gas pipelines do). Any pipeline application will be required to be supported by the relevant safety case (disaster management) and mitigation measures to address safety considerations.

b) Potential Impacts on project
Current uncertainty regarding the regulatory requirements for CO₂ could result in inadequate design or assessment. Project scheduling could be affected through associated delays in consent approval or through any delay by the statutory authorities in establishing safety protocols for CO₂.

c) Level of Uncertainty

Alterations to the regulatory regime to accommodate CO₂ are subject to a high degree of uncertainty and the likelihood of project risk realisation is also considered high.

d) Mitigation Approach and Rationale

The Consortium has been involved in continued dialogue with Government bodies, including HSE and DECC, to understand additional requirements and provide analysis as necessary.

e) Residual Uncertainty

Ongoing dialogue with HSE is helping to clarify where they view the likely CO₂ thresholds to be set. However, there remains a risk that major changes to the current unofficial position could occur with little warning. Following mitigation the likelihood of the risk occurring is therefore considered to remain high.

8.3.3.7 COMAH

a) Issues and Uncertainties

The HSE has delayed making a decision on the inclusion of CO₂ as a hazardous substance within the COMAH Regulations until 2015. Consequently it is not known whether the Blackhill Compressor Station will fall under COMAH and require licensing. Given the timescale for the HSE decision, there is the potential that additional legislation could be introduced on health and safety consents and licenses.

b) Potential Impacts on project

Current uncertainty regarding the regulatory requirements for CO₂ could result in inadequate design or assessment. Project scheduling could be affected through associated delays in consent approval or through any delay by the statutory authorities in establishing safety protocols for CO₂.

c) Level of Uncertainty

Alterations to the regulatory regime to accommodate CO₂ are subject to a high degree of uncertainty and the likelihood of project risk realisation is also considered high.

d) Mitigation Approach and Rationale

The Consortium has been involved in continued dialogue with Government bodies, including HSE and DECC, to understand additional requirements and provide analysis as necessary.

In the meantime, work is progressing on the assumption that the Blackhill Compressor Station will fall under COMAH.
e) Residual Uncertainty

Ongoing dialogue with HSE is helping to clarify where they view the likely CO2 thresholds will be set. However, there remains a risk that major changes to the current unofficial position could occur with little warning. Following mitigation the likelihood of the risk occurring is therefore considered to remain high.

8.3.4 Offshore Transportation and Storage

8.3.4.1 Carbon Storage License (CSL)

a) Issues and Uncertainties

A CSL will be required in order to undertake storage site appraisal activities, and to prepare and submit to DECC an application for consent for storage operations.

A CSL cannot be issued by DECC until the Government has completed its update to the Strategic Environmental Assessment (SEA) to include offshore CO2 storage activities. This process is out with the control of Shell and significant slippage experienced in delivery has implications for the scheduling of the full project.

In order to undertake appraisal activities consented under the CSL, Shell is required to have in place an Agreement for Lease from The Crown Estate. This process is circular as receipt of an Agreement for Lease from The Crown Estate is dependent upon award of a CSL.

The environmental impact of activities to be licensed under a CSL will require prior assessment under the Offshore Petroleum Production and Pipe-lines (Assessment of Environmental Effects) Regulations 1999 (as amended to include carbon storage). The outcome and approval of these assessments is subject to a public and statutory consultation process. The possibility of onerous mitigation requirements cannot be discounted and the level of information that will require disclosure is uncertain. This is a particular concern given the confidentiality surrounding some project processes.

b) Potential Impacts on project

The issues associated with the CSL application could result in scheduling delays with associated cost implications. Reliance on completion of the Government’s SEA is particularly problematic as any further material delay in this process risks compromising the Consortium’s ability to secure a storage permit prior to executing the project contract, whilst also prolonging the uncertainty of knowing exactly what rights and obligations will be conferred by the regulations.

The ES approval process also requires a minimum 28 day public consultation period, requiring a significant disclosure of project detail to the public domain. Uncertainty remains surrounding the level of disclosure required and the possibility of onerous mitigation requirements cannot be discounted.

c) Level of Uncertainty / Risk

The likelihood of offshore permitting risks materialising has been assessed as likely.

d) Mitigation Approach and Rationale

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Early and extensive contact has been made with both DECC and The Crown Estate during the FEED study to discuss the proposals for storing CO₂ in the Goldeneye Field, to establish the likely licences and consents required, and to clarify the processes for securing these. This consultation process is ongoing.

Shell has written to DECC to request guidance on the level of disclosure required for public consultation on the ES.

e) Residual Uncertainty

As a result of the extensive consultation process, the likelihood of potential impacts occurring that can be resolved through dialogue has been assessed as possible. However, the timescale for the production of the SEA is out with the control of Shell and it remains a significant risk to the project schedule.

8.3.4.2 Carbon Storage Permit (CSP)

a) Issues and Uncertainties

DECC consent for storage operations will initiate the operational phase of the licence. The issue of a CSP will allow the construction of the storage facilities and the commencement of storage injection, though operations will be subject to certain thresholds on aspects such as the permissible injection rate and the purity of the injected CO₂ stream.

Award of a CSP will be conditional upon DECC approval of the following from the applicant:
- Storage Development Plan
- EIA
- Monitoring Plan
- Corrective Measures Plan
- Financial security
- Site closure / post-closure plan
- In addition, DECC will need to approve the proposed Operator and will need to be satisfied that the applicant(s) have secured a seabed Lease from The Crown Estate.

Before granting a CSP, DECC is also required to forward a draft of the proposed permit to the EC. The EC’s Scientific Panel has up to 4 months to provide an opinion on the draft permit award decision. This non-binding opinion is required to be taken into account by DECC prior to granting the permit.

The major uncertainties and risks associated with these aspects of the CSP are discussed below.

Environmental Statement / Habitat Regulations Appraisal

A CSP cannot be issued by DECC until the ES has been approved and a HRA undertaken. Other environmental regulations may also apply as for offshore oil and gas developments.

Approval of the ES for the CSP cannot take place until the Government has concluded a SEA to incorporate offshore CO₂ storage activities. The SEA process is out with the control of Shell and significant slippage experienced in delivery has implications for the scheduling of the full project.
The ES approval process also requires a minimum 28 day public consultation period, requiring a significant disclosure of project detail to the public domain. Uncertainty remains surrounding the level of disclosure required and the possibility of onerous mitigation requirements cannot be discounted.

The Crown Estate Lease

Shell will need to enter into an agreement with The Crown Estate for a lease that will run in parallel with the CO₂ storage site until the site is closed and handover to the State has been achieved. The process for achieving this is currently under discussion.

EC Scientific Panel Opinion on Draft Carbon Storage Permit

Delays have been experienced in establishing the EC Panel and, owing to the primacy of the technology, a lengthy process and significant degree of scrutiny are expected that could extend the review period beyond the scheduled four months.

Further, it is considered unlikely that the Panel will be able to review outline project proposals or conditional award decisions from inception. Rather it will only be able to review draft permits awarded by DECC. This is potentially problematic as, if a draft CSP cannot be secured from DECC, regulatory uncertainty will remain at the time of execution of the project contract.

The lack of directly comparable precedent is likely to create considerable uncertainty over the outcome of the Panel's deliberations. Whilst the opinion will not be legally binding, consideration of aspects such as public acceptance and future Storage Permit award decisions suggest that it would be unlikely for DECC to ignore the Commission's advice.

‘First of a Kind’ Uncertainties and Risks

The project is exposed to a number of important ‘first of a kind’ regulatory risks reflecting a potential tendency towards a conservative interpretation of the rules. These include, but are not limited to:

- Possible limits on the size of the licensable volume;
- Constraints on the permissible injection rate or total stored volume;
- Onerous site characterisation requirements;
- Limits on the purity of the CO₂ stream intended for injection; and/or
- Onerous operational and/or post-closure monitoring obligations.

It is also possible that DECC will fail to re-issue the CSP in the event of a leakage from storage site.

Revisions to the CCS Directive

Article 38 of the CCS Directive provides for a review of the Directive by March 2015. Insofar as such a review could impose retrospective changes or introduce new obligations in connection with the operation, monitoring, closure and handover of a storage site, then it will represent a source of significant regulatory uncertainty for prospective developers.
Oslo Paris (OSPAR) Convention

In 2006, the contracting parties to the 1992 OSPAR Convention agreed an amendment removing the prohibition against the sub-seabed storage of CO₂. However, this amendment can only take legal effect once ratified by a minimum of seven contacting parties. To date 6 countries have ratified the amended convention including the UK, but it could be summer 2011 at the earliest before the minimum seven can be achieved, with a real risk that this minimum may not be achieved in time for commencement of project operations. Failure to ratify the OSPAR amendment would mean that the sub-seabed injection of non-indigenous CO₂ for storage purposes would be illegal under the Convention, and so far DECC have not been able to provide a fallback plan for this eventuality.

b) Potential Impacts on project

The identified issues, risks and uncertainties could alone, or in combination, result in the following:
- An inability to execute the project
- Limitations placed on injection and storage and/or compensation to be paid to others
- Delay in obtaining approval with resultant delay to the project and increased costs
- Premature termination of the project
- Additional cost and design changes post FID to meet new requirements
- Threat to project handover after completion of injection

c) Level of Uncertainty / Risk

The likelihood of the identified risks arising prior to mitigation is considered high.

d) Mitigation Approach and Rationale

Environmental Statement / Habitat Regulations Appraisal

Shell has undertaken consultation with the DECC environmental unit and the Joint Nature Conservation Committee (JNCC). An introduction to the project has been provided and the offshore transportation and storage elements of the project described. The timeline and requirements for the EIA have also been discussed. This consultation process is ongoing with DECC and statutory advisors, including JNCC and Marine Scotland, along with Central North Sea stakeholders (e.g. Scottish Fisherman’s Federation, Marine Conservation Society, Defence Estates).

Shell has written to DECC to request guidance on the level of disclosure required for public consultation on the ES.

The Crown Estate Lease

Early and extensive consultation has taken place with the The Crown Estate and DECC regarding procedures for obtaining all necessary consents and permits. This consultation process is ongoing.

EC Scientific Panel Opinion on Draft Carbon Storage Permit

Shell has engaged in dialogue with DECC to encourage the timely involvement of the EC in order to identify issues at an early stage. Future mitigation has been identified that includes timely response to EC
information or data requests, and support for DECC in challenging EC advice in the event that the panel fails to ratify the draft CSP.

‘First of a Kind’ Uncertainties and Risks

Shell is working closely with the DECC regulatory team to narrow down the uncertainties in pursuing approval of its Storage Development Plan and award of a CSP. However, all risks will remain under observation and included in the project risk matrix until the exact licensing requirements for the storage of CO₂ become clear.

Revisions to CCS Directive

As the CCS Directive is out with UK jurisdiction, Shell will continue to highlight its importance to DECC and to monitor the situation.

OSPAR Convention

As the OSPAR Convention is out with UK jurisdiction, Shell will continue to highlight its importance to DECC and to monitor the situation.

e) Residual Uncertainty

The identified mitigation measures are anticipated to reduce the likelihood of the event occurring to possible.

8.3.4.3 Consent to Handover Storage Facilities

a) Issues and Uncertainties

DECC has recently concluded a public consultation on a proposed new draft Regulation (The Storage of Carbon Dioxide (Termination of Licences) Regulations 2011) intended to define arrangements for the transfer of responsibility for a CO₂ storage site at the end of operations.

Shell has no significant concerns with DECC’s proposals. However, incremental to the requirements of the Directive the Regulation does make provision for open-ended powers for the Secretary of State to impose additional obligations on storage site operators at will.

It is also foreseen that achievement of an agreement with DECC and The Crown Estate on the transfer of responsibility will be protracted as a result of difficulties in proving CO₂ is "completely and permanently contained", as required by the Regulations.

Under Article 18(4) of the CCS Directive the transfer of responsibility is also subject to non-binding support from the EC. The EC can issue advice to DECC stating it does not support a proposed transfer of responsibility.

b) Potential Impacts on project

Impacts on the project could include:
c) Level of Uncertainty

The likelihood of the identified impacts occurring has been assessed as possible.

d) Mitigation Approach and Rationale

Shell has challenged those aspects of the draft regulations that present the greatest risk through submission to the public consultation. Shell also provided input to separate responses by the CCS Association (CCSA) and by Oil & Gas UK (OGUK).

In addition, the following mitigation measures have been identified:

- Ensure complete clarity at the time of the licence award on criteria that will need to be met in order to achieve transfer of responsibility
- Secure undertaking from DECC that there will be no ‘creep’ in these requirements with time
- Ensure DECC appraised of all activities during injection and post-closure phases, and regular reporting includes full description of behaviour of CO₂ versus prognosis
- Work on liabilities with Joint Venture Partners

Mitigation identified to limit risks associated with obtaining EC approval includes:

- Press DECC for timely involvement of EU Commission so any issues are identified early
- Ensure timely response to any requests for data/information
- Support any DECC challenge to EU Commission advice

e) Residual Uncertainty

Whilst mitigation is anticipated to reduce the level of risk there remains a high degree of uncertainty and the likelihood of impacts occurring has been assessed as remaining possible following implementation of mitigation.

8.3.4.4 Agreement for Lease for Carbon Storage / Lease for Carbon Storage

a) Issues and Uncertainties

An Agreement for Lease for Carbon Storage and a Lease for Carbon Storage will be required to coincide with the issuing of the CSL and CSP respectively. Issues have been identified on the schedule for obtaining these permits and these are discussed in sections 8.3.3.2 and 8.3.3.3. A number of additional risks have been identified in obtaining leases from The Crown Estate.

In the event that a small volume of CO₂ leaks from reservoir, The Crown Estate may be unwilling or unable to licence the aquifer (outside the original hydrocarbon boundary or outside FDA) in view of concerns over managing liabilities.
It is also possible that the lease will be refused on the grounds that the site risk assessment has identified, in the view of The Crown Estate, a "significant risk of leakage" or that the site presents a "significant environmental or health risk" as prescribed under Article 4(4) of the CCS Directive.

The terms of the lease are also unknown at this stage and there remains the possibility that The Crown Estate will insist on unacceptable or onerous terms.

b) Potential Impacts on project

If The Crown Estate refuse to licence the aquifer outside the original boundary it is possible the project will be unable to expand beyond the base case value proposition. Additional expense or delay to the project could be incurred during the process of negotiating onerous lease terms, and in the event of The Crown Estate identifying significant leakage or health issues the project may not be executed.

c) Level of Uncertainty

The likelihood of potential impacts as a result of prevention of expansion, leakage and health issues, and onerous lease terms have been assessed as unlikely, possible, and likely respectively.

d) Mitigation Approach and Rationale

The following control measures have been proposed to mitigate the identified risks:

Prevention of Expansion:
- Ensure The Crown Estate understands the likely egress/ migration of CO₂ outside the hydrocarbon boundary or outside FDA to impact the aquifer. Modelling shows that this will occur. Localised migration assists in the monitoring of conformance
- Work proactively with The Crown Estate to shape regulatory requirements
- Take out insurance against loss of containment
- Ensure The Crown Estate is willing to licence the required volume

Leakage and Health Issues:
- Undertake site characterisation and risk assessment (Technical Evidence Supported Logic Assessment - TESLA)
- Careful design of monitoring programme and operational envelope
- Ensure a shared understanding of what represents "significant risk", through comprehensive dialogue with Regulator and The Crown Estate ahead of licence and lease award
- Present storage development plan to DECC early in process

Onerous Lease Terms:
- Obtain a draft copy of The Crown Estate lease and review
- Ensure sufficient time is allocated to negotiate terms
- Consider routes for escalation in order to achieve resolution before the issue becomes a 'critical path'

e) Residual Uncertainty

Following implementation of mitigation, the likelihood of all risks occurring has been assessed as unlikely.
8.3.4.5 Notifications and Approvals Required under the Pipeline Safety Regulations and COMAH Regulations

a) Issues and Uncertainties

The PSRs and COMAH Regulations are being revised in light of the SEVESO Directive. It is possible that these revisions will result in additional HSE obligations although at this stage the nature of those obligations is not known.

b) Potential Impacts on project

It may be necessary to revise the project design depending on the safe distance required between the pipeline and centres of population. This could result in additional costs and design changes post-FEED to meet new requirements. It is also possible that design alterations would result in delays in obtaining approvals and impact on the project schedule.

c) Level of Uncertainty

The likelihood of the identified impacts occurring has been assessed as high.

d) Mitigation Approach and Rationale

Shell is undertaking early and expansive communication with the regulator to identify potential regulatory changes and assess potential impacts.

e) Residual Uncertainty

Following implementation of mitigation the likelihood of all risks occurring has been assessed as possible.
9. Stakeholder Profiling

The UK Government’s basic premise for financially supporting CCS demonstration is to facilitate further commercial scale CCS projects in the UK and internationally. To ensure that learning from CCS demonstration is shared, DECC have made knowledge transfer activities a key requirement of the UKCCS demonstration. The ScottishPower Consortium is creating a comprehensive knowledge transfer programme to meet the UK Government’s two stated knowledge transfer objectives:

- To allow subsequent projects in the UK and overseas to be able to learn from the experience of the first UK demonstration project.
- To demonstrate the full chain of CCS at a commercial scale to show other governments that it can be achieved.

Identifying key stakeholders and understanding their CCS knowledge requirements, is a fundamental first step to establishing a CCS knowledge transfer programme capable of helping facilitate future CCS development. During FEED, the ScottishPower Consortium Knowledge Transfer team built on existing stakeholder relationships to identify stakeholder groups particularly relevant for knowledge transfer activities. Stakeholders were categorised in terms of:

- Knowledge needs
- Potential to influence CCS deployment
- Experience/ expertise they can bring to demonstration knowledge
- Potential to disseminate demonstration knowledge

The assessment identified six priority audience groups, due to their potential to collaborate, influence, share existing CCS knowledge and disseminate knowledge through their network profile. They are Academics, Environmental NGOs, Finance and Insurance, Industry, Initiatives and Developers and Regulatory and Policy.

In order to gain a better understanding of the specific knowledge requirements of these six priority groups, this section of the FEED Close Out Report combines over 30 stakeholder interviews, with examples of knowledge transfer leading practice. The Stakeholder Profiling Interviews sought to answer the following questions:

- Who are the key CCS stakeholders?
- What information are these stakeholders interested in from a CCS demonstration?
- What are the preferred methods for key stakeholders to receive and access information?
- Are the key stakeholders interested in interacting with CCS demonstrations, and if so, what is the preferred method to facilitate this interaction?

Throughout FEED, other workstreams considered wider stakeholder engagement, for example, local community engagement and public communication. This section focus only on stakeholder groups specifically identified as knowledge transfer stakeholders.

Please refer to the following documents in Appendix I.1:

- UKCCS - KT - S8.0 - SP - 001 Stakeholder Profiling Report
- UKCCS - KT - S8.0 - SP - 002 Interviewee List
- UKCCS - KT - S8.0 - SP - 003 Stakeholder Interview Approach
- UKCCS - KT - S8.0 - SP - 004 Stakeholder Interview Framework
- UKCCS - KT - S8.0 - SP - 005 Stakeholder Interview Transcripts
10. CCS project Costs

This section of the report contains the cost estimate for the End-to-End CCS Chain for the purposes of providing potential developers of CCS projects with refined cost information.

One of the key objectives of the FEED phase of the UKCCS Demonstration Competition was to increase the cost certainty for the overall project.

During the Outline Solution development, costs were estimated to an accuracy of -30% to +50%. Through the design and project development across the various Consortium workstreams (as outlined in the previous sections of this report), it has been possible to refine this accuracy and increase the cost certainty of the core capital costs to approximately -12%/+15% accuracy.

The cost schedules at the Outline Solution and post-FEED stage are provided in Appendix J under the following references:

- UKCCS - KT - S5.2 - OS - 001 Outline Solution project Cost Schedule
- UKCCS - KT - S5.1 - E2E - 001 Post-FEED project Cost Schedule
10.1 Overview

10.1.1 Costing Methodology

The ScottishPower Consortium Partners have well established and robust cost estimating methodologies. These methodologies are individual to each organisation and must be followed in order to comply with their internal governance procedures. As such, it is inevitable that the total cost of the CCS project is made up of three underlying cost estimates.

The Consortium has adopted the following key principles in compiling the cost estimate:
- A coherent end-to-end cost submission
- Value for money test to ensure best value
- A transparent and fully auditable approach

10.1.2 Capital Costs

The core cost estimates from the FEED scope are the majority, but not the entirety, of the full capital cost picture. Figure 10.1-1 illustrates the main components of the estimate.

Figure 10.1-1: Main Components of the Cost Estimate
The main components of the cost estimate are:

- **Core Costs**
  - Those directly identifiable elements of cost which make up the majority of the capital costs, and comprise equipment, civil works, pipework, electrical, etc. These costs are based on a combination of external quotes, external estimates (which may be factored to the required volumes), and internal estimates. These are based on the technical specifications developed through the FEED programme of work.

- **Scope Development**
  - An estimate, based on the technical drawings and drafters expertise, of the additional requirements which are likely when moving from FEED to the implementation phase of the project. This typically accounts for the additional ‘nuts and bolts’ which are not specifically drawn and identified at the FEED stage, but are known omissions at the time of drafting.

- **Contingency & Risk**
  - An additional amount to cover the expected value of risks facing the project, calculated using the Consortium Partners internal risk pricing approach and is based on a P50 (ie midpoint) probability estimate. The calculation of the contingency amount depends critically on the contracting approach adopted, and the final risk/reward allocation of the project, and as such is indicative at this stage of the commercial negotiations.

- **Fees**
  - The developer fees associated with managing the project. As per the contingency calculations, these numbers are indicative, pending further commercial discussions.

### 10.1.2.1 Breakdown of Capital costs

The capital cost estimates are produced in discrete segments which cover the following elements of the CCS chain. When combined, they cover the full End-to-End CCS chain:

**ScottishPower (with Aker Clean Carbon as a key contractor):**
- SPS – Steam & Power Supply
- CCP – Carbon Capture Plant
- Comp – Compression
- BoP – Balance of Plant and Utilities
- Site/Other – additional items required at Longannet Power Station over and above the Aker cost estimate
- OE/Mgt. – Owners Engineer (Technical Assurance) / Project Delivery

**National Grid:**
- New Pipeline – New link-line from Longannet Power Station to Dunipace
- No. 10 Feeder – Existing pipeline from Dunipace to St. Fergus Terminal
- Compressor Station – Works at Blackhill Compressor Station in the vicinity of St. Fergus Terminal

**Shell:**
- Advance works – advance works scope
- Surveys – offshore surveys around the platform and well location
- St Fergus – onshore modification works to St Fergus

Access to and use of the information in this document is subject to the terms of the disclaimer at the front of the document
Pipeline Prep – including pigging
Topsides/Platform – infrastructure required above the seabed at the Goldeneye site
Subsea – components required at the wellhead/seabed
Wells – injection and/or monitoring well work at the Goldeneye site
Pre-injection – preparation works

The costs are summarised for each segment of the CCS chain (see above) and presented for consolidation using the following categories:
- Mobilisation & Enabling
- Land
- Equipment
- Civil works
- Mechanical
- Electrical
- Buildings
- Testing & Commissioning
- Strategic Spares
- First-fill chemicals
- Insurance
- Legal, Permits, Licence fees
- Interconnections
- Other
- Contractors fees

In order to achieve the principles outlined above, the following assumptions have been applied across the full CCS cost chain:
- All prices are in 2010 terms.
- Real costs, with no inflation applied.
- The operating life is 15 years and there will be zero residual value – unless otherwise specified.

For each item of cost, the following information was assessed:
- Basis of cost – e.g. Estimate/Budget/Tendered/Quote.
- Accuracy of cost – e.g. +/- 10%.
- Inflation profile which costs are linked to – e.g. link to CPI, RPI, etc.
- Spend profile – % p.a. (either for individual items, or summarised at a higher level).
- Any element of foreign currency.

Contingency is separately identified, and the calculation basis noted.

10.1.3 Operating Costs

Operating costs have been estimated using the internal cost estimating process for each of the Consortium Partners. The key principle is to separate the underlying unit cost and volume drivers, in order that the Pricing Model can reflect estimated operating costs based on changes in those underlying volume drivers.

The costs have been summarised for each segment of the CCS chain and presented for consolidation using the following categories:
- Fuel / Power / Energy
10.1.4 Decommissioning Costs

On the basis that the project has a defined operating period of 10-15 years, a provision has been calculated for decommissioning costs for each element of the End-to-End CCS chain where applicable.

10.1.5 Post-injection monitoring and well closure costs

These additional costs have currently been excluded from the operating cash-flows of the project, due to the uncertainty on the final treatment and liability for those costs. However, it should be noted that they will be an integral part of the full project cash-flow.
10.2 Outline Solution project Cost Estimates

Appendix J.2 contains the cost schedule prepared for the entire project at the Outline Solution stage of development. The capital, abandonment and operating costs are summarised in Table 10.2-1, Table 10.2-2 and Table 10.2-3 respectively.

Table 10.2-1: Summary of Estimated Project Capital Costs at the Outline Solution stage

<table>
<thead>
<tr>
<th>Chain Segment</th>
<th>Total CAPEX (£m)</th>
<th>Cost estimate range (+/-%)</th>
<th>Cost estimate range (£m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam and Power Supply</td>
<td>153.6</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>Carbon Capture Process</td>
<td>241.8</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>Compression &amp; Conditioning</td>
<td>43.5</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>Balance of Plant and Utilities</td>
<td>54.0</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>Owner’s Engineer (Technical Assurance)</td>
<td>58.7</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>Knowledge Share</td>
<td>8.2</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>Link-line between Longannet and Dunipace</td>
<td>43.6</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>No. 10 Feeder (Existing pipe)</td>
<td>54.7</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>Compression and facilities at St Fergus (Blackhill)</td>
<td>100.5</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>Offshore pipe</td>
<td>114.4</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>Infrastructure at the Goldeneye field</td>
<td>32.4</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td>Wells at the Goldeneye field</td>
<td>171.9</td>
<td>-30% to +50%</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,077.2</strong></td>
<td><strong>-30% to +50%</strong></td>
<td><strong>754 to 1,616</strong></td>
</tr>
<tr>
<td><strong>Risk &amp; Contingency</strong></td>
<td><strong>102.8</strong></td>
<td>n/a</td>
<td><strong>103</strong></td>
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<tr>
<td><strong>Total Project Capex</strong></td>
<td><strong>1,180.1</strong></td>
<td></td>
<td><strong>857 to 1,719</strong></td>
</tr>
</tbody>
</table>

1 Indicative subject to final agreement of the risk/reward balance and procurement strategy

Table 10.2-2: Summary of Estimated Project Abandonment Costs at pre-FEED stage

<table>
<thead>
<tr>
<th>Chain Segment</th>
<th>Total ABEX (£m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam and Power Supply</td>
<td>47.5</td>
</tr>
<tr>
<td>Carbon Capture Process</td>
<td>70.2</td>
</tr>
<tr>
<td>Compression &amp; Conditioning</td>
<td>12.8</td>
</tr>
<tr>
<td>Balance of Plant and Utilities</td>
<td>14.7</td>
</tr>
<tr>
<td>Owner’s Engineer</td>
<td>-</td>
</tr>
<tr>
<td>Knowledge Share</td>
<td>-</td>
</tr>
<tr>
<td>Link-line between Longannet and Dunipace</td>
<td>10.8</td>
</tr>
<tr>
<td>No. 10 Feeder (Existing pipe)</td>
<td>8.0</td>
</tr>
<tr>
<td>Compression and facilities at St Fergus (Blackhill)</td>
<td>10.4</td>
</tr>
<tr>
<td>Offshore pipe</td>
<td>-</td>
</tr>
<tr>
<td>Infrastructure at the Goldeneye field</td>
<td>9.3</td>
</tr>
<tr>
<td>Wells at the Goldeneye field</td>
<td>16.9</td>
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</table>
### Table 10.2-3: Summary of Estimated Project Operating Costs at pre-FEED stage

<table>
<thead>
<tr>
<th>Chain Segment</th>
<th>Annual Fixed OPEX (£m)</th>
<th>Annual Variable OPEX (£m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam and Power Supply</td>
<td>2.4</td>
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<tr>
<td>Carbon Capture Process</td>
<td>5.0</td>
<td>8.7</td>
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<td>4.2</td>
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<tr>
<td>Balance of Plant and Utilities</td>
<td>16.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Owner’s Engineer / Management</td>
<td>3.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Knowledge Share</td>
<td>2.9</td>
<td>0.0</td>
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<tr>
<td>Link-line between Longannet and Dunipace</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>No. 10 Feeder (Existing pipe)</td>
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<td>0.0</td>
</tr>
<tr>
<td>Compression and facilities at St Fergus (Blackhill)</td>
<td>1.2</td>
<td>10.5</td>
</tr>
<tr>
<td>Offshore pipe</td>
<td>15.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Infrastructure at the Goldeneye field</td>
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<td>0.0</td>
</tr>
<tr>
<td>Wells at the Goldeneye field</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>51.0</strong></td>
<td><strong>81.4</strong></td>
</tr>
</tbody>
</table>
### 10.3 Post-FEED project Cost Estimate

#### 10.3.1 FEED Cost Estimate

Appendix J.1 contains the cost estimate prepared for the entire project at the post-FEED stage. The capital, abandonment and operating costs are summarised in Table 10.3-1, Table 10.3-2 and Table 10.3-3 respectively.

<table>
<thead>
<tr>
<th>Chain Segment</th>
<th>Total CAPEX (£m)</th>
<th>Cost estimate range (+/- %)</th>
<th>Cost estimate range (£m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam and Power Supply</td>
<td>114.8</td>
<td>-20% to +20%</td>
<td>-</td>
</tr>
<tr>
<td>Carbon Capture Process</td>
<td>228.1</td>
<td>-10% to +10%</td>
<td>-</td>
</tr>
<tr>
<td>Compression &amp; Conditioning</td>
<td>47.2</td>
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<td>-</td>
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<tr>
<td>Balance of Plant and Utilities</td>
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<td>Site - Other(^1)</td>
<td>146.7</td>
<td>-10% to +10%</td>
<td>-</td>
</tr>
<tr>
<td>Link-line between Longannet and Dunipace</td>
<td>81.3</td>
<td>-10% to +15%</td>
<td>-</td>
</tr>
<tr>
<td>No. 10 Feeder (Existing pipe)</td>
<td>78.9</td>
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</tr>
<tr>
<td>Compression and facilities at St Fergus (Blackhill)</td>
<td>121.0</td>
<td>-10% to +15%</td>
<td>-</td>
</tr>
<tr>
<td>FEED Extension</td>
<td>12.5</td>
<td>-25% to +30%</td>
<td>-</td>
</tr>
<tr>
<td>Surveys/Licenses</td>
<td>22.1</td>
<td>-25% to +30%</td>
<td>-</td>
</tr>
<tr>
<td>St Fergus</td>
<td>14.9</td>
<td>-15% to +25%</td>
<td>-</td>
</tr>
<tr>
<td>Pipeline preparation</td>
<td>4.6</td>
<td>-25% to +30%</td>
<td>-</td>
</tr>
<tr>
<td>Topsides / Platform</td>
<td>91.3</td>
<td>-15% to +30%</td>
<td>-</td>
</tr>
<tr>
<td>Subsea</td>
<td>8.9</td>
<td>-15% to +30%</td>
<td>-</td>
</tr>
<tr>
<td>Wells</td>
<td>37.5</td>
<td>-15% to +25%</td>
<td>-</td>
</tr>
<tr>
<td>Pre-injection</td>
<td>16.0</td>
<td>-15% to +25%</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,145.5</strong></td>
<td><strong>-12.3% to +15.6%</strong></td>
<td><strong>1,005 to 1,324</strong></td>
</tr>
<tr>
<td><strong>Risk &amp; Contingency(^2)</strong></td>
<td><strong>194.8</strong></td>
<td>n/a</td>
<td><strong>195</strong></td>
</tr>
<tr>
<td><strong>Total Project Capex</strong></td>
<td><strong>1,340.3</strong></td>
<td>-</td>
<td><strong>1,200 to 1,519</strong></td>
</tr>
</tbody>
</table>

\(^1\) Includes technical assurance, management and knowledge transfer

\(^2\) Indicative subject to final agreement of the risk/reward balance and procurement strategy
Table 10.3-2: Summary of Estimated Project Abandonment Costs at post-FEED stage

<table>
<thead>
<tr>
<th>Chain Segment</th>
<th>Total ABEX (£m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam and Power Supply</td>
<td>23.0</td>
</tr>
<tr>
<td>Carbon Capture Process</td>
<td>45.6</td>
</tr>
<tr>
<td>Compression &amp; Conditioning</td>
<td>9.4</td>
</tr>
<tr>
<td>Balance of Plant and Utilities</td>
<td>23.9</td>
</tr>
<tr>
<td>Site - Other</td>
<td>-</td>
</tr>
<tr>
<td>Link-line between Longannet and Dunipace</td>
<td>16.3</td>
</tr>
<tr>
<td>No. 10 Feeder (Existing pipe)</td>
<td>15.8</td>
</tr>
<tr>
<td>Compression and facilities at St Fergus (Blackhill)</td>
<td>24.2</td>
</tr>
<tr>
<td>Offshore Topsides &amp; Subsurface</td>
<td>25.7</td>
</tr>
<tr>
<td>Wells</td>
<td>39.3</td>
</tr>
<tr>
<td>Pipelines</td>
<td>31.4</td>
</tr>
<tr>
<td>Onshore Facilities</td>
<td>1.5</td>
</tr>
<tr>
<td>Post C.O.P.</td>
<td>25.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>281.3</strong></td>
</tr>
</tbody>
</table>

Table 10.3-3: Summary of Estimated Project Operating Costs at post-FEED stage

<table>
<thead>
<tr>
<th>Item</th>
<th>Longannet Site</th>
<th>Transport</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel / Power / Energy</td>
<td>Calculated based on volume and energy price profiles</td>
<td>0.04533MWh/t CO₂</td>
<td>£4k/month</td>
</tr>
<tr>
<td>Consumables</td>
<td>£4.86/t CO₂</td>
<td>-</td>
<td>£8k/month</td>
</tr>
<tr>
<td>Waste disposal</td>
<td>£0.31/t CO₂</td>
<td>-</td>
<td>£2k/month</td>
</tr>
<tr>
<td>Maintenance</td>
<td>£505k/month</td>
<td>£58k/month</td>
<td>Annual profile, averaging £284k/month</td>
</tr>
<tr>
<td>Staff</td>
<td>£421k/month</td>
<td>£350k/month</td>
<td>£202k/month</td>
</tr>
<tr>
<td>Rates</td>
<td>£425k/month</td>
<td>£4k/month</td>
<td>-</td>
</tr>
<tr>
<td>Insurance</td>
<td>£425k/month</td>
<td>£33k/month</td>
<td>Annual profile, averaging £19k/month</td>
</tr>
<tr>
<td>Overheads</td>
<td>£325k/month</td>
<td>£602k/month</td>
<td>£178k/month</td>
</tr>
<tr>
<td>Lease Costs</td>
<td>-</td>
<td>-</td>
<td>£8k/month</td>
</tr>
<tr>
<td>Other Fixed Costs</td>
<td>£238k/month</td>
<td>-</td>
<td>£96k/month + Annual profile, averaging £267k/month</td>
</tr>
</tbody>
</table>

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10.4 Summary

10.4.1 Capital Costs

Table 10.4-1 displays a summary comparison of the capital cost estimates at the Outline Solution stage and post-FEED for the capture, transport and storage sections of the scheme.

Table 10.4-1: Summary of Estimated Project Capital Costs at pre- and post-FEED

<table>
<thead>
<tr>
<th>Section</th>
<th>Outline Solution (£m)</th>
<th>Post-FEED (£m)</th>
<th>Change (£m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture</td>
<td>559.8 (47%)</td>
<td>656.5 (49%)</td>
<td>+96.7</td>
</tr>
<tr>
<td>Transport</td>
<td>198.7 (17%)</td>
<td>281.2 (21%)</td>
<td>+82.5</td>
</tr>
<tr>
<td>Storage</td>
<td>318.7 (27%)</td>
<td>207.8 (16%)</td>
<td>-110.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,077.2 (91%)</td>
<td>1,145.5 (85%)</td>
<td>+68.3</td>
</tr>
<tr>
<td>Risk &amp; Contingency</td>
<td>102.8 (9%)</td>
<td>194.8 (15%)</td>
<td>+92.0</td>
</tr>
<tr>
<td><strong>Total Project Capex</strong></td>
<td>1,180.1 (100%)</td>
<td>1,340.3 (100%)</td>
<td>+160.2</td>
</tr>
<tr>
<td>Estimated Range</td>
<td>857 to 1,719</td>
<td>1,200 to 1,519</td>
<td>n/a</td>
</tr>
</tbody>
</table>

1 Includes technical assurance, management and knowledge transfer

The central case capital cost estimate for the capture and transport sections rose following FEED by £96.7m (+17%) and £82.5m (+42%) respectively whereas the estimate for the storage section fell by £110.9m (-35%).

The variations to the overall capital costs can be attributed to the following:

- The rise in the capture section estimate was principally due to refined estimates of the balance of plant and utilities costs. These include enabling works, buildings including the control room and a larger electrical substation, a greater definition of the water intake works and steelwork required for the ductwork combined with other site costs which were only apparent as a result of the FEED.

- The increase in the estimate for the transport section was due primarily to increases in the estimates of the work required for the new pipeline connecting Longannet Power Station to the No. 10 Feeder pipeline. FEED has enabled closer identification of river crossing risks and therefore better understanding of costs in respect to ground conditions along the pipeline route - specifically the requirement for tunnelling under the Firth of Forth river instead of Horizontal Directional Drilling (HDD) as was originally proposed in the Outline Solution. The FEED study has enabled a greater understanding of the work required and consequently a more accurate estimate to be compiled.

- The decrease in the storage section cost estimate was due to a better understanding of the work required as a result of the FEED and in particular the scope and costs of work to be undertaken at the wells.

- The risk and contingency costs increased by £92m (82%) as a result of FEED reflecting the better identification and quantification of risks as outlined in Section 7. This value is indicative and is subject to final identification of the risk/reward balance of the project, and the procurement strategy adopted.

The capital costs at the Outline Solution and post-FEED stage are summarised in Figure 10.4-1.
All these changes to the cost estimate reflect the uncertainty present at the Outline Solution stage and the refinements that the FEED study brought to the cost estimate. Whilst the midpoint cost estimate has increased by £160m, it should be noted that the costs accuracy has improved significantly with the result that the maximum estimated costs have fallen by £200m as a result of the FEED work undertaken.

### 10.4.2 Decommissioning/Abandonment Costs

Table 10.4-2 shows a summary comparison of abandonment cost estimates pre- and post-FEED for the capture, transport and storage sections of the scheme.

<table>
<thead>
<tr>
<th>Section</th>
<th>Pre-FEED (£m)</th>
<th>Post-FEED (£m)</th>
<th>Change (£m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capture</td>
<td>145.2 (72%)</td>
<td>102.0 (36%)</td>
<td>-43.2</td>
</tr>
<tr>
<td>Transport</td>
<td>29.1 (15%)</td>
<td>56.2 (20%)</td>
<td>+27.1</td>
</tr>
<tr>
<td>Storage</td>
<td>26.2 (13%)</td>
<td>123.1 (44%)</td>
<td>+96.9</td>
</tr>
<tr>
<td>Total Project AbEx</td>
<td>200.6 (100%)</td>
<td>281.3 (100%)</td>
<td>+80.7 (+40%)</td>
</tr>
</tbody>
</table>

Abandonment costs were only estimated using rough approximations at the Outline Solution stage so the changes to the estimates reflect the greater level of understanding and work undertaken on this topic during FEED.

### 10.4.3 Operating Costs

The methods for estimating the operating costs changed from pre-FEED (annual fixed and variable cost estimates) to post-FEED (price per tonne of CO₂ or per month) so a direct comparison of the cost estimates is not possible.
This final section of the report is designed to be read as a support document to all the tangible learning and documentation contained within the FEED Close Out Report and accompanying appendices.

Using two sets of data collection workshops at different points during FEED, the Consortium Knowledge Transfer team attempted to capture the experiential learning of the teams working across key functions of the FEED study:
- project Governance
- Commercial
- Technical
- Consortium Management Office
- Consents, Licensing and Regulation
- Communication

Each of the FEED workstreams took part in guided discussions halfway through FEED to establish the specific challenges, successes and learning from that workstream. Representatives from all the workstreams were then brought together in December 2010 for a Consortium-wide Lessons Learned Workshop to reflect on the Consortium’s performance during FEED and try to capture specific, discrete lessons that could benefit future CCS FEED studies in the UK and abroad.

Analysis of all the cross-Consortium learning showed strong agreement on the important lessons learned during FEED, with five key themes emerging consistently across workstreams:
- **Mobilisation**: Ensuring an appropriate mobilisation period to establish Consortium relationships, processes and systems prior to the start of FEED
- **Early Engagement**: Facilitating early engagement with key decision makers, internal stakeholders, local communities, regulators and potential Partners
- **Communication and Collaboration**: Strong leadership, planning and cross-Consortium communication required to create and present an integrated Consortium
- **Competitive Procurement**: Recognising restrictions imposed by trying to develop a demonstration project within the bounds of a competitive procurement
- **Adapting to Uncertainty**: Working with uncertainty across regulation, scope, budget and political will

These key themes are considered in some detail in the report together with specific learning regarding novel approaches developed to deal with challenges or methods to improve performance in future. Workstream specific learning outcomes are summarised in the main report, with detailed examples included in the appendices.

The technical and communication workstream appendices both contain examples of actual documents used during the ScottishPower Consortium FEED (National Grid CCS staff training material and the ScottishPower Consortium Communications Strategy) that were considered useful for future CCS project Developers.

Please refer to Appendix K.1, where the following documents are contained:
- UKCCS - KT - S12.0 - FEED - 001 Lessons Learned report
- UKCCS - KT - S12.0 - FEED - 002 National Grid Training Material
- UKCCS - KT - S12.0 - FEED - 003 ScottishPower Consortium Communications Strategy

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UK Carbon Capture and Storage Demonstration Competition
FEED Close Out Report

# Appendices

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</thead>
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</tr>
</tbody>
</table>
Appendix A. Programme

A.1. FEED Programme
A.1.1. UKCCS - KT - S2.0 - CMO - 001 Outline Solution FEED Programme
A.1.2. UKCCS - KT - S2.0 - CMO - 002 Post-FEED Level 3 FEED Programme

A.2. Overall Project Programme
A.2.1. UKCCS - KT - S6.1 - E2E - 001 Post-FEED Overall Project Programme
A.2.2. UKCCS - KT - S6.2 - OS - 001 Outline Solution Overall Project Programme
A.2.3. UKCCS - KT - S6.2 - OS - 002 Outline Solution Overall Project Programme Report
Appendix B. FEED Cost

B.1. UKCCS - KT - S1.0 - SP - 001 ScottishPower CTR Summary

B.2. UKCCS - KT - S1.0 - ACC - 001 Aker Clean Carbon CTR Summary

B.3. UKCCS - KT - S1.0 - NG - 001 National Grid CTR Summary

B.4. UKCCS - KT - S1.0 - Shell - 001 Shell CTR Summary
Appendix C. Design

C.1. End-to-End Basis of Design
C.1.1. UKCCS - KT - S7.2 – E2E -001 Outline Solution End-to-End Basis of Design
C.1.2. UKCCS - KT - S7.1 - E2E -001 Post-FEED End-to-End Basis of Design

C.2. Process Flow Diagrams (PFDs)
C.2.1. UKCCS - KT - S7.8 - E2E - 001 End-to-End Process Flow Diagram
C.2.2. UKCCS - KT - S7.8 - ACC - 001 Aker Clean Carbon Process Flow Diagrams
C.2.3. UKCCS - KT - S7.8 - NG - 001 National Grid Process Flow Diagrams
C.2.4. UKCCS - KT - S7.8 - Shell - 001 Shell Process Flow Diagrams
C.2.5. UKCCS - KT - S7.9 - OS - 001 Outline Solution Process Flow Diagrams

C.3. Heat and Mass Balances (HMBs)
C.3.1. UKCCS - KT - S7.10 - E2E - 001 End-to-End Heat and Mass Balance
C.3.2. UKCCS - KT - S7.10 - ACC - 001 Aker Clean Carbon Heat and Mass Balance
C.3.3. UKCCS - KT - S7.10 - NG - 001 National Grid Heat and Mass Balance
C.3.4. UKCCS - KT - S7.10 - Shell - 001 Shell Heat and Mass Balance
C.3.5. UKCCS - KT - S7.11 - OS - 001 Outline Solution Heat and Mass Balance

C.4. Piping and Instrumentation Diagrams (P&IDs)
C.4.1. UKCCS - KT - S7.12 - ACC - 001 Aker Clean Carbon P&IDs
C.4.2. UKCCS - KT - S7.12 - NG - 001 National Grid P&IDs
C.4.3. UKCCS - KT - S7.12 - Shell - 001 Shell P&IDs
C.5. Layout and Construction

C.5.1. UKCCS - KT - S7.14 - E2E - 001 End-to-End Plant and Site Layout Drawings

C.5.2. UKCCS - KT - S7.14 - ACC - 001 Modularisation Study

C.6. UKCCS - KT - S7.13 - E2E - 001 End-to-End Major Equipment List

C.7. Plant and Equipment Specifications

C.7.1. UKCCS - KT - S7.15 - ACC - 001 Aker Clean Carbon Datasheets

C.7.2. UKCCS - KT - S7.15 - NG - 001 National Grid Datasheets

C.7.3. UKCCS - KT - S7.15 - Shell - 001 Shell Datasheets

C.8. Subsurface Engineering – Material and Concept Select Reports

C.8.1. UKCCS - KT - S7.16 - Shell - 001 Material Selection Report

C.8.2. UKCCS - KT - S7.16 - Shell - 007 Cement Concept Selection

C.8.3. UKCCS - KT - S7.17 - Shell - 001 Component Concept Select

C.8.4. UKCCS - KT - S7.17 - Shell - 002 Completion concept select


C.9.1. UKCCS - KT - S7.16 - Shell - 002 Well Abandonment Concept

C.9.2. UKCCS - KT - S7.16 - Shell - 004 Well Proposal

C.9.3. UKCCS - KT - S7.16 - Shell - 003 Well Program – Draft

C.9.4. UKCCS - KT - S7.16 - Shell - 006 Well Technical Specification

C.9.5. UKCCS - KT - S7.16 - Shell - 005 Well Functional Specification
C.10. Subsurface Engineering – Production Technology Reports

C.10.1. UKCCS - KT - S7.18 - Shell - 001 Temperature and Pressure Modelling

C.10.2. UKCCS - KT - S7.18 - Shell - 005 Operations Support

C.10.3. UKCCS - KT - S7.18 - Shell - 002 Injectivity Analysis Preparation

C.10.4. UKCCS - KT - S7.18 - Shell - 003 Flowline Well Interactions

C.10.5. UKCCS - KT - S7.18 - Shell - 004 Injection Fraccing Conditions

C.11. Subsurface Engineering – Geosciences, Reservoir Engineering, Production Chemistry, Monitoring and Reservoir Management Reports


C.11.2. UKCCS - KT - S7.19 - Shell - 006 Seismic Interpretation Report

C.11.3. UKCCS - KT - S7.19 - Shell - 007 Petrophysical Modelling Report

C.11.4. UKCCS - KT - S7.21 - Shell - 002 Static Model (Field)

C.11.5. UKCCS - KT - S7.22 - Shell - 001 Static Model (Aquifer)

C.11.6. UKCCS - KT - S7.22 - Shell - 002 Static Model (Overburden)

C.11.7. UKCCS - KT - S7.21 - Shell - 005 FFM Dynamic Model Report

C.11.8. UKCCS - KT - S7.21 - Shell - 001 PVT Report

C.11.9. UKCCS - KT - S7.21 - Shell - 003 IIP Volumes Estimate

C.11.10. UKCCS - KT - S7.21 - Shell - 004 CO₂ Storage Estimate

C.11.11. UKCCS - KT - S7.19 - Shell - 004 Geomechanics Summary Report

C.11.12. UKCCS - KT - S7.21 - Shell - 006 Pore Pressure Prediction

C.11.15. UKCCS - KT - S7.19 - Shell - 005 Production Chemistry Operability Review
C.11.16. UKCCS - KT - S7.23 - Shell - 003 Asset Reference Plan
C.11.17. UKCCS - KT - S7.20 - Shell - 002 MMV Plan
C.11.18. UKCCS - KT - S7.20 - Shell - 003 Monitoring Technology Feasibility Report
C.11.19. UKCCS - KT - S7.23 - Shell - 001 WRM Plan
C.11.20. UKCCS - KT - S7.20 - Shell - 001 Corrective Measures Plan
C.11.21. UKCCS - KT - S7.23 - Shell - 002 Technology Maturation Plan
C.11.22. UKCCS - KT - S7.23 - Shell - 004 SDP
Appendix D.  End-to-End CCS Chain Operation

D.1.  End-to-End Reports

D.1.1.  UKCCS - KT - S7.24 - E2E - 001 End-to-End Operations and Maintenance Philosophy

D.1.2.  UKCCS - KT - S7.24 - E2E - 002 End-to-End Control Philosophy

D.1.3.  UKCCS - KT - S7.24 - E2E - 003 CO₂ Venting Philosophy

D.1.4.  UKCCS - KT - S7.24 - E2E - 004 Metering and Monitoring Philosophy

D.1.5.  UKCCS - KT - S7.24 - E2E - 005 Commissioning, Start-up, Decommissioning and Demobilisation Philosophy

D.2.  Consortium Partner Operations Reports

D.2.1.  UKCCS - KT - S7.24 - ACC - 001 Outline Operating Manual

D.2.2.  UKCCS - KT - S7.24 - ACC - 002 Maintenance and Intervention Philosophy

D.2.3.  UKCCS - KT - S7.24 - NG - 001 Operations Report

D.2.4.  UKCCS - KT - S7.14 - NG - 001 Philosophy Statement for Vent Stacks

D.2.5.  UKCCS - KT - S7.24 - Shell - 001 Operations Philosophy
Appendix E. Key FEED Decisions

E.1. UKCCS - KT – S4.0 - FEED - 001 Consortium Decisions Register
Appendix F. Health, Safety and Environment

F.1. Full Chain
F.1.1. UKCCS - KT - S3.1 - E2E - 001 End-to-End Safety Review

F.2. Generation and Capture
F.2.1. UKCCS - KT - S3.2 - SP - 001 MAH Report
F.2.2. UKCCS - KT - S3.2 - ACC - 001 Project HSE Report
F.2.3. UKCCS - KT - S3.2 - ACC - 002 HAZID and Hazards Analysis Report

F.3. Onshore Transportation System
F.3.1. UKCCS - KT - S3.3 - NG - 001 National Grid HSE Summary Report

F.4. Offshore Transport and Storage (inc CO₂ Dispersion)
F.4.1. UKCCS - KT - S3.4/3.5 - Shell - 001 Design HSE Case
Appendix G. Risk Management

G.1. Outline Solution Risk Assessment
G.1.1. UKCCS - KT - S10.1 - OS - 001 Outline Solution Top 50 Risks

G.2. Post-FEED Risk Assessment
G.2.1. UKCCS - KT - S10.2 - FEED - 001 Post-FEED Top 50 Risks

G.3. Outline Solution Risks of Delay to programme
G.3.1. UKCCS - KT – S6.4 - OS - 001 Outline Solution Risks of Delay to Programme

G.4. Allocation and Insurability of Risks
G.4.1. UKCCS - KT - S10.5 - FEED - 001 Insurance Strategy Report
G.4.2. UKCCS - KT - S10.5 - Shell - 001 Insurance Report
Appendix H.  Consents and Permitting

H.1.  UKCCS - KT - S11.1 - E2E - 001 Consents and Licenses Register

H.2.  UKCCS - KT - S11.2 - FEED - 001 Key Consents Risks

H.3.  UKCCS - KT - S11.2 - Shell - 001 Regulatory Permits and Approvals Plan
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I.1. Stakeholder Profiling Report and Appendices

I.1.1. UKCCS - KT - S8.0 - SP - 001 Stakeholder Profiling Report

I.1.2. UKCCS - KT - S8.0 - SP - 002 Stakeholder Interviewee List

I.1.3. UKCCS - KT - S8.0 - SP - 003 Stakeholder Interview Approach

I.1.4. UKCCS - KT - S8.0 - SP - 004 Stakeholder Interview Framework

I.1.5. UKCCS - KT - S8.0 - SP - 005 Stakeholder Interview Transcripts
Appendix J. CCS Project Costs

J.1. UKCCS - KT - S5.1 - E2E - 001 Post-FEED Project Cost Schedule

J.2. UKCCS - KT - S5.2 - OS - 001 Outline Solution Project Cost Schedule
Appendix K. Lessons Learned

K.1. Lessons Learned Report

K.1.1. UKCCS - KT - S12.0 - FEED - 001 Lessons Learned Report

K.1.2. UKCCS - KT - S12.0 - FEED - 002 National Grid Training Material

K.1.3. UKCCS - KT - S12.0 - FEED - 003 ScottishPower Consortium Communications Strategy
# Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>AGI</td>
<td>Above Ground Installation</td>
</tr>
<tr>
<td>AOI</td>
<td>Areas of Interest</td>
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