



Peterhead CCS Project

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Executive Summary

Her Majesty's Government (HMG) Autumn Statement and Statement to Markets on 25 November 2015 regarding the Carbon Capture and Storage Competition confirmed that the £1 billion ring-fenced capital budget for the Carbon Capture and Storage Competition was no longer available. This meant that the Competition could not proceed on the basis previously set out. In accordance with the agreements with DECC, the Peterhead FEED was completed as planned in December 2015. The Government and Shell are committed to sharing the knowledge from UK CCS projects, and this Key Knowledge Deliverable represents the evolution and achievement of learning throughout the Peterhead FEED and Shell's intentions for the detailed design, construction and operating phases of the project at the time of HMG's Statement to Markets.

This Lessons Learned report provides a narrative of the financial, technical, commercial and general project learning generated from the Front End Engineering Design (FEED) phase of the Project with particular emphasis given to learnings related to Carbon Capture and Storage (CCS) specific aspects. Although the lessons learned detailed in this document have been generated with the primary aim of improving the quality of FEED delivery and supporting future phases of the Peterhead Project, the knowledge generated is also considered to be of use to the wider CCS Community as a whole.

The report consists of CCS specific learnings generated from:

- Across the CCS Chain during FEED captured from learnings generated by individual delivery work streams;
- Previous phases of the Peterhead CCS project;
- Applicable experience from analogous projects;
- Learnings as a result of novel design aspects associated with the Project;
- Lessons learned from arranging finance for the project including aspects such as debt financing and raising external equity; and
- Lessons learnt on open book accounting requirements delivering a CCS project to DECC's requirements.

This report documents the learning process undertaken by the Peterhead Carbon Capture and Storage (PCCS) Project during the FEED phase. Learnings have been captured in a variety of ways including:

- Identifying knowledge gaps;
- Capturing lessons both internal project and external project sources;
- Feedback of the identified learnings and associated recommendations and mitigations to the Project, where appropriate, to close knowledge gaps; and
- Review the effectiveness of any learnings applied during the FEED phase of the Project.

As part of Shell's standard lessons learned process, the lessons generated during FEED have been issued to the PCCS project team for their review and feedback to identify areas, if applicable, where these lessons could potentially add value to present and/or future phases of the PCCS project. Relevant learning and mitigation has been applied to the present phase and/or the preparation for subsequent project phase in terms of planning, contracts, management and any other relevant avenue as appropriate for each specific lesson learned.



The lessons generated during FEED will be taken forwards for consideration during the Execute phase of the PCCS project. Lessons generated from the PCCS FEED will also be reviewed to determine whether it might be appropriate to update Shell's Management System and/or technical DEPs based upon the identified learning.

The lessons learned presented in this report are a subset of those already generated by and disseminated to the PCCS project team. The focus of this document has been to present learnings which were identified as being particular to delivery of CCS projects and would be useful learning for the wider CCS community. It is hoped that the CCS specific learnings presented here for the FEED phase of the PCCS project will also be of benefit to subsequent Carbon Capture and Storage projects across the world.

PCCS FEED Study Overview

The PCCS FEED study scope had a duration from March 2014 to December 2015 and consisted of two phases. Within the overall PCCS FEED study scope, an engineering FEED study was undertaken by Shell and its engineering contractors between March 2014 and February 2015. Once the engineering FEED study phase was completed, the project team focused on developing the EPC tendering arrangements and undertaking other activities in readiness for the execution phase (Execution Preparation Phase) until the end of November 2015. A detailed package of engineering documents was produced during the engineering FEED study which is included in the appendices of the Basic Design & Engineering Package Key Knowledge Deliverable – KKD 11.003 [1].

The technical concepts of the PCCS design were developed in some areas after completion of the engineering FEED deliverables at the end of February 2015 – for example as a result of feedback from the EPC tendering process for the Execute phase. The detailed engineering FEED deliverables were not updated to reflect these concepts during the Execution Preparation Phase of FEED. As described in the Scope of Work for Execute Contracts – KKD 11.058 [2], after commencement of the Execute phase the intention was that the preferred EPC contractors would perform detailed design based on the PCCS technical design, as finalised at the end of the FEED, prior to commencing construction activities. Final technical deliverables which would have superseded the engineering FEED study deliverables would have been produced at the conclusion of that detailed design exercise.

An overview of the entire PCCS FEED study work can be obtained in the FEED Summary Report - KKD 11.133 [3]. The Basis of Design – KKD 11.001 [4] has been updated to reflect any design decisions taken up to December 2015, and reflects the project's technical status at the end of the PCCS FEED.

Detailed technical information on the technical aspects of the PCCS FEED study phase outcomes can be found in the Basic Design and Engineering Package (BDEP) – KKD 11.003 [1], which expands on the technical information provided in the Basis for Design and includes technical design documentation such as process flow diagrams, piping & instrumentation diagrams, heat and mass balance data and electrical single line diagrams as developed by the engineering FEED study. Key decisions which were made during FEED, including decisions related to the technical scope of work, are summarised in the FEED Decision Register – KKD 11.020 [5].

Some technical aspects of the PCCS FEED, such as the Project's approach to satisfying the CfD and EU ETS metering requirements were developed after the engineering FEED had finished in February 2015. As a result the engineering FEED design documentation contained in the Basic Design & Engineering Package - KKD 11.003 [1] does not fully reflect the project's technical status at the end of the PCCS FEED. Further information on the CfD and EU ETS metering requirements can be found in the Surveillance, Metering, Allocation Strategy and Design Package – KKD 11.077 [6].



Other aspects of the technical FEED study which are described in the suite of PCCS FEED Study Key Knowledge Deliverables include:

- The Technology Maturation Plan – KKD 11.064 [7], which describes the development of identified key technology aspects which were identified, investigated and/or progressed during FEED.
- The Risk Management Plan and Risk Register – KKD 11.023 [8], which described the top project risks, overall risk profile and risk management plan at the end of the FEED study including technical risks; and
- The FEED Lessons Learned Report – KKD 11.019 [9], which describes the lessons learned process undertaken during FEED and presents key learnings identified including CCS specific technical learnings



1. Introduction

The Peterhead CCS Project aims to capture around one million tonnes of CO₂ per annum, over a period of up to 15 years, from an existing Combined Cycle Gas Turbine (CCGT) located at SSE's Peterhead Power Station in Aberdeenshire, Scotland. This would be the world's first commercial-scale demonstration of post combustion CO₂ capture, transport and offshore geological storage from a gas-fired power station.

As the Goldeneye gas-condensate field has ceased production, the production facility will be modified to allow the injection of dense phase CO₂ captured from the post-combustion gases of Peterhead Power Station into the depleted Goldeneye reservoir.

The CO₂ will be captured from the flue gas produced by one of the gas turbines at Peterhead Power Station (GT13) using amine-based technology provided by Cansolv (a wholly-owned subsidiary of Shell). After capture the CO₂ will be routed to a compression facility, where it will be compressed, cooled and conditioned for water and oxygen removal to meet suitable transportation and storage specifications. The resulting dense phase CO₂ stream will be transported direct offshore to the wellhead platform via a new offshore pipeline which will tie in subsea to the existing Goldeneye pipeline.

Once at the platform the CO₂ will be injected into the Goldeneye CO₂ Store (a depleted hydrocarbon gas reservoir), more than 2 km under the seabed of the North Sea. The project layout is depicted in below:



Figure 1-1: Project Location



2. Lessons Learned Objectives

2.1. General Requirements

Shell employs a continuous improvement process which includes mandatory requirements for the retrieval, implementation and capture of learnings on projects. The aim of the process is to ensure that projects do not repeat errors of the past, but identify and repeat successes. Replication and standardization are proven enablers for the general improvement of project cost and schedule performance. The application of lessons learned processes enable the replication of concepts, designs, solutions, ways-of-working and execution strategies that have been proven to work successfully and safely on other projects.

This is of particular importance on First-Of-A-Kind (FOAK) projects such as Peterhead CCS where there is limited previous similar projects to provide relevant learning. It is useful to identify where it may be appropriate to apply learnings and processes from previous projects, but it is equally important to identify areas where a different approach is preferred and would be more suitable.

It is a requirement that every phase of a Shell project review and decide on opportunities for the replication and standardization of applied processes. By default, project delivery is pointed towards selection of standard solutions in equipment & design, supply chains and execution methods. Demonstrable justification is required for any deviations from previously developed Shell standard solutions.

The highest impact CCS specific learnings generating during FEED are presented in this report. It is important that the highest impact learnings are clearly presented so that they can readily be reviewed, and if applicable adopted and implemented by future projects and project phases. The clearer and higher impact the lessons are detailed the better, as future projects and project phases may be limited in the number of learnings they can assimilate and implement.

2.2. Knowledge Manger Role Description and Responsibilities

As part of the overall PCCS FEED project management structure, a Knowledge Transfer (KT) Manager was appointed, reporting to the project Integration Manager with responsible for managing the delivery of the Key Knowledge Deliverables (KKDs) to DECC which will ultimately be the information disseminated in the public domain from the PCCS project as well as supporting delivery of the project Key Knowledge Services to DECC.

The Knowledge Manager's responsibilities included the facilitation of lessons learned activities performed during the FEED phase of the PCCS project in conjunction with the Project team.

3. Lessons Learned Process

Planning of activities related to knowledge and lessons exchange was required at the outset of FEED including scheduled activities such as workshops, interviews and other means of collaboration.

A high level definition of Shell's lessons learned process flow is to:

- Identify.
- Ask.
- Learn.
- Share.

In implementing this process, individual Projects are required to:



- **Identify** learning needs;
- **Ask** previous analogous projects for their lessons learned (retrieval of historical learning) and **Evaluate** their applicability to the present project;
- Demonstrate that **Learning** has taken place based upon the experiences of others; and
- **Share** new lessons learned within the Shell's internal project community.

Lessons learned should include both positive and negative learnings.

3.1. Process summary

The lessons learned process detailed above is implemented anew at the beginning of each project phase. The process undertakes the following steps to generate and analyse and subsequently implement the lessons which have been learned:

1. **Identify:** **Lesson Generation**

Identified lessons are captured on an ongoing basis throughout each project phase. This involves applications of various complimentary methods including holding workshops to specifically identify and generate lessons to review of Shell's existing lessons learned database to identify lessons learned on previous projects which are also applicable to the present project.

2. **Ask / Evaluate:** **Lesson Analysis**

During and post structured lessons learned activities such as workshops, the identified lessons are evaluated using Shell's standard approach to validate and assign values to lessons so that they can be classified and ranked in terms of importance.

3. **Learn:** **Lesson Outcome**

It is the responsibility of the Project Manager and Knowledge Transfer Manager to ensure that relevant lessons generated during a project phase are disseminated to the project team and applied to the benefit of the project.

4. **Share:** **Lesson Dissemination**

Wider lessons dissemination takes place via generated lessons learned reports, update of Shell's internal lessons learned database and knowledge sharing events – such as supporting workshops undertaken by other future projects.

3.1.1. Lessons Generation

The lessons captured during the various methods employed during the lessons generation phase of the process reflect the expertise and skills of the contributors and details their learnings, observations and recommendations based on their interactions and experience during the course of working on the Peterhead CCS Project.

When undertaking lessons generation, the following aspects are considered:

- Lessons which can help current and future CCS projects (i.e. for use on similar projects and/or similar technologies);
- Lessons which can generally improve Shell's standards and ways of working; and
- Lessons which can help the next phase of the present project.



The generated lessons are classified as being either Lessons Learned (usually learning from experience which inform activities which should be avoided in future) or Best Practice Learning (i.e. identification from experience of methods which should be considered for adoption as best practice within this subject area).

Once generated, these initial lessons are captured and compiled in the form of a Lessons Learned Register which can then be evaluated in more formal lessons learned workshops. The headings are described below:

- **Lessons ID:** Reference Number.
- **Team:** Details the FEED team who generated the lesson.
- **Lesson Type:** Denotes whether it is a Lesson Learned or an identified Best Practice Learning.
- **Lesson Title:** A descriptive title of the learning.
- **Lesson Description and Impact on the Project:** The Cause and Impact on the Project, describing the issue (positive or negative).
- **Proposed Recommendation / Mitigation:** What changes can be made in future, to avoid a similar issue arising (where appropriate) or, if best practice, to repeat in future projects.

3.1.2. Lessons Evaluation

Lessons evaluation is carried out within the lessons learned workshops in order to identify the top ranked lessons which should be the focus of future dissemination activities. The evaluation activity should generally adhere to the following process:

1. **Lesson Validation:**
Identify if this is really an objective learning for inclusion in the register rather than a personal opinion or suggestion associated with a specific project issue which does not necessarily have a more universal application.
2. **Consider** whether the lesson:
 - Can help current and future CCS Projects?
 - Can improve standards and ways of working?
 - Can help the next phase of the Project?
3. **Apply a Value:**
In accordance with Shell's internal processes so that lessons which have the highest impact and value can be identified.
4. **Assign a Theme:**
A theme should be assigned to each lesson according to its scope and impact, i.e. a First-of-a-Kind (FOAK) Issue, Best Practice Replication, etc. Applied themes are generally consistent with those defined for use in Shell's normal business practice, although a CCS Specific theme has been created specifically for the PCCS project in order to identify captured lessons which are particularly relevant to future CCS projects.

The PCCS FEED learnings have been categorised according to the following themes:

- First Of A Kind (FOAK) Issues: including Technical, Non-Technical, Non Business as Usual;
- Oil and Gas Approach v Power sector approaches; and



- Demonstrable Benefit of Replication: maximising historically similar work.

3.2. Project Related Activities

3.2.1. Introduction

Following Shell's lessons learned processes, during the FEED phase lessons learned have been generated from:

- Previous phases of the Peterhead CCS project;
- Applicable experience and lessons learned from analogous projects;
- Lessons learned across the CCS Chain generated by individual delivery work streams;
- Learnings obtained as a result of identified novel design aspects associated with the Project;
- Lessons learned from arranging finance for the Project including aspects such as debt financing and raising external equity; and
- Lessons learned on open book accounting requirements delivering a CCS project to DECC's requirements.

The lessons learned generated during FEED covered all aspects of the Project including financial, technical, commercial and general project learnings. The internal focus for presentation of the learning achieved has been on identification and presentation of key learnings in order to maximise the benefit generated and likelihood that the learnings presented will be implemented by others in future. Those learnings which were considered to be particular to CCS and useful learning for the wider CCS community have been specifically identified under the PCCS lessons learned process and have been extracted for explicit inclusion in this document.

3.2.2. Key Learning Objectives

The following key learning objectives were specifically identified for and applied to the lessons learned activities undertaken for the FEED phase of the PCCS project:

- To identify any Knowledge Gaps, particularly in terms of areas requiring CCS specific knowledge, and then to plan for and implement their closure;
- To capture and apply relevant lessons and/or best practices from the FEED Phase teams experience to assist in the development and planning of future PCCS project phases;
- To capture and introduce relevant lessons and/or best practices generated by analogous projects as available, such as QUEST, Technology Centre Mongstad (TCM), Boundary Dam, Gorgon and also previous projects performed by SSE to assist in the development of the PCCS project; and
- To capture any learnings resulting from any novel design or construction techniques which might be developed during FEED to overcome specifically identified constraints.

3.2.3. Core Learning Activities

The core learning activities which were undertaken in order to achieve the FEED phase learning objectives detailed immediately above are presented below:

PCCS core Shell project team learnings were generated throughout the duration of FEED including:

- Performance of a lessons learned workshop on the commencement of FEED;



- Ongoing recording of lessons on the project's Continuous Learning Register during FEED; and
- Review of the lessons generated by the team at the end of FEED.

Workshops were held during FEED at suitable moments within the overall delivery schedule to gather learnings from the principal FEED teams delivering the individual CCS chain FEED scopes including the:

- The Onshore FEED team;
- The Subsea FEED team; and
- The Offshore FEED team

A lessons learned workshop was also held with the Project Management Office (PMO) FEED team which provided various support services including technical assurance, interface management, document management and key knowledge deliverable support during FEED.

Information on learning generated from analogous projects has been sourced throughout the FEED phase of the PCCS project including input from:

- QUEST Project;
- Saskpower CCS Boundary Dam Carbon Capture Project;
- Technology Centre Mongstad (TCM);
- Gorgon CO₂ Injection Project; and
- A portfolio of previous projects carried out by SSE.

Finally, a review was held towards the end of the FEED phase of the Project which focused specifically on novel learnings which had been generated during FEED. A description of the identified novel design and development to overcome a specific constraint is provided within this report.

The lessons captured as a result of applying the above processes have largely resulted in generation of lessons associated with technical, commercial and general delivery aspects of the project. As a result, two further lessons learned sessions were organised during FEED to specifically generate lessons associated with financial activities and open book accounting as follows:

- Financial learnings during FEED were generated including consideration of:
 - Arranging finance for the PCCS project;
 - Raising debt; and
 - Raising external equity.
- Lessons learned on open book accounting were generated with particular emphasis given to the consideration of the following:
 - Procedures for the management of invoices;
 - Appraisal of the value of work done; and
 - Experiences of dealing with subcontractors with respect to cost verification.



3.2.4. Learning Evaluation

Learnings generated within each of the various workshops and methods utilised during FEED were evaluated by the involved FEED teams as part of the process using a consistent ranking method throughout. This ranking process was performed to identify top learnings from FEED and also identify key CCS specific learnings for future dissemination.

4. Implementation – Application of Lessons

The lessons learned presented in this report are a subset of those already disseminated to the PCCS project team. Only those learnings which were considered to be particular to CCS and useful learning for the wider CCS community have been specifically identified under the PCCS lessons learned process and have been extracted for explicit inclusion in this document.

As part of Shell's standard lessons learned process, the lessons generated during FEED have been issued to the PCCS project team for their review and feedback to identify areas, if applicable, where these lessons could potentially add value to present and/or future phases of the PCCS project. Relevant learning and mitigation has been applied to the present phase and/or the preparation for subsequent project phase in terms of planning, contracts, management and any other relevant avenue as appropriate for each specific lesson learned.

There are several ways in which lessons can be implemented within and applied to the project:

1. Where any generated lessons are identified as having a risk element, these have been referred to the project risk management team. Lessons which were not already included in the project risk register and were subsequently deemed by the risk team to merit inclusion were added as an item in the project risk management system. Through the risk management system (using the Easy Risk tool), during FEED each risk was assigned a person responsible for following this up. This includes generation and implementation of a response plan.
2. Some learning experiences can be written directly into a Project's management system. Lessons generated at the outset of a project phase which have been retrieved from a similar project or previous phase with a strong recommendation relating to the organisation, and/or roles and responsibilities, for the coming project phase can be incorporated in the Project Execution Plan (PEP) for that project phase. Learnings generated during a project phase can either be incorporated into a revision of the PEP for that project phase, or taken forwards for inclusion in the PEP for the next project phase as appropriate.

Ultimately if a lesson is found to be generally applicable to project delivery or represents a significant and universal risk, then the information will be embedded in Shell's Management System, project standards and/or technical Design and Engineering Practices (DEPs) as appropriate.

5. Top Learnings

The Top Learning generated from the FEED Phase of the PCCS project which relate to the application of CCS are presented in this section of the report. These lessons have been derived from across all the learning activities undertaken during FEED as described above. Figure 5-1 shows the relationship between the learning activities and how they have been grouped for evaluation.

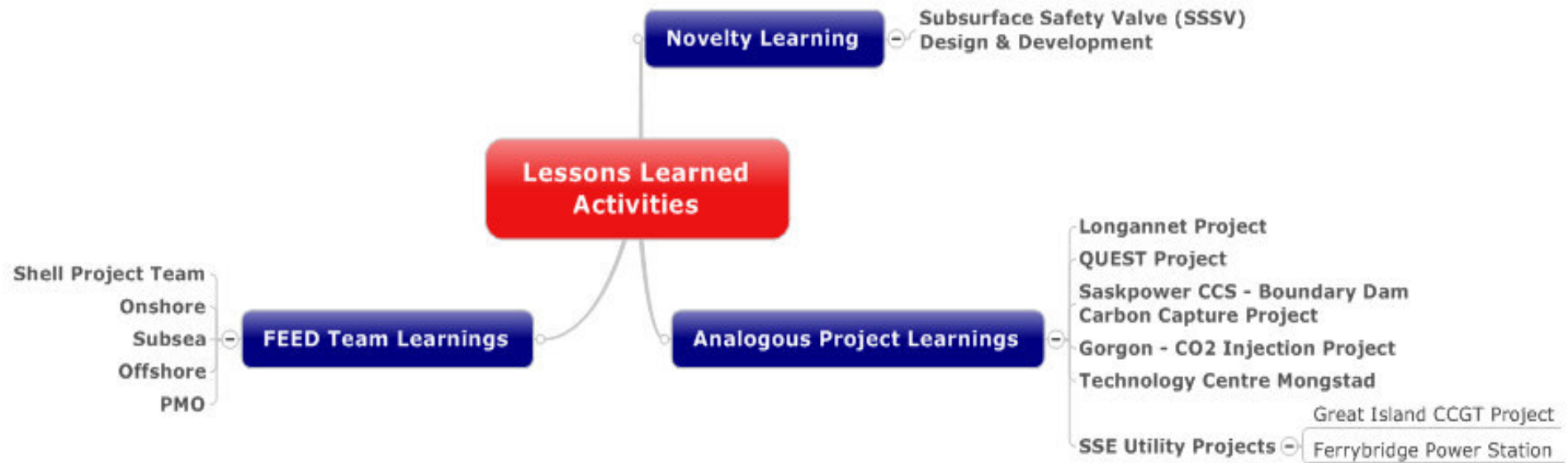


Figure 5-1: Mind Map Showing the Relationship of the Core Learning Activities to Lessons Learned.



5.1. FEED Teams' Learnings

In the FEED phase, a number of lessons learned workshops were held with each FEED team. This commenced with the Shell core team at the beginning of FEED. Workshops were held with the individual Onshore, Offshore and Subsea FEED teams during and at the end of delivery of their work stream activities in FEED. A final wrap up lessons learned review was also held at the end of FEED. These activities generated a number of evaluated lessons from each team. The identified highest impact CCS specific learnings output from this process are presented in Table 5-1 below.

Table 5-1: FEED Team Lessons Summary

ID	Key Theme	FEED Team	Discipline	Lesson Type	Lesson Title	Lesson Description & Impact on the project	Proposed Recommendation / Mitigation
1	FOAK	PMO	Project Management	Lesson Learned	FEED management processes needed to evolve from existing O&G and Power sector processes to meet the needs of a FOAK CCS FEED.	Where processes are based on existing practices, it is beneficial to identify FOAK aspects & issues, monitor how they are progressed and then update and incorporate revised processes into the Project's governance procedures.	Sufficient time should be allowed to develop, disseminate and establish processes and procedures on commencing each Project phase of a FOAK project. The time to develop and identify such processes and procedures should not be underestimated.
2	O&G v Power Sector Approach	Shell / PMO	Engineering	Lesson Learned	The Onshore FEED design should be based on appropriate standards and technical principles.	Pre-FEED, PCCS recognised that there may be design and cost benefits from not applying Shell O&G standards to the Onshore FEED since the duty required to support Power Plant operations is less onerous than would typically be applied to an Oil & Gas installation.	The Onshore FEED contractor was only required to apply the process safety aspects of Shell's O&G standards to their FEED design. The learnings from this first FEED study require to be developed further in order for Shell to produce CCS specific standards for use on future projects.
3	FOAK	PMO	Engineering	Lesson Learned	FEED should focus on identifying and resolving FOAK CCS issues prior to commencing Execute.	During FEED priority should be given to resolving as far as possible FOAK CCS issues to reduce the level of uncertainty and de-risk the Project scope taken forward into the future Execute phase.	Consider making additional time / cost contingency allowance in FEED to address potential FOAK CCS issues on top of the usual activities necessary to achieve the standard FEED cost and technical outputs. Ensure that FOAK CCS issues which need addressed in FEED are clearly defined and the process to resolution is monitored (and communicated to the Project team) during FEED.
4	FOAK	PMO / Onshore FEED	Project Management	Lesson Learned	Developing new technology and designs for a FOAK CCS project is likely to take longer than expected and result in knock-on delays / impacts to other activities.	The Process Design Package (PDP) issued to the Onshore FEED team from the capture technology provider (Cansolv) and Process Safety extract from Shell's Design & Engineering Standards issued to the PMO were released later in FEED than originally planned. This impacted on progress on related Onshore FEED activities.	An increased likelihood of delivery delays should be expected on FOAK projects due to increased uncertainty in the development of new technology and processes. Such risks could be mitigated by making increased contingency allowance in the scheduling of these activities.
5	FOAK	All FEED Teams	Engineering	Lesson Learned	Increased likelihood that assumptions made on a FOAK project will need to be revised and/or revisited.	Due to the FOAK nature of CCS projects and lack of operational CCS project data, assumptions made at the start of the FEED subsequently had to be revisited which meant that some redesign work was required.	Consider working flexibly and deviating from normal FEED practice to maintain the overall schedule on a FOAK CCS project. For example, detail of the constituent effluent streams was not available until late on in FEED meaning the water treatment design could not finalised without extending the Onshore FEED schedule. Instead, a separate exercise was performed to identify the preferred solution to use as the basis for commencing the Execute phase.
6	Replication	Offshore	Engineering	Best Practice	Good use of historically similar work	The PCCS project made use of knowledge gained and work previously carried out on the Longannet CCS Project. This provided benefits, not least in terms of the Offshore and Subsurface FEED scopes, since it was not necessary for the Shell team to validate or replicate much of the work which had been performed previously on the Longannet CCS project.	Use of experience gained from previous similar projects reduced the required PCCS FEED scope. For example, the Offshore FEED was able to reuse much of the structural integrity and life extension study work performed previously for the Goldeneye platform.
7	FOAK	Subsea	Process Engineering	Lessons Learned	Process Engineering Philosophy	Changes to the industry approach for handling hydrocarbons is ultimately required for working with CO ₂ . Until CCS specific engineering processes mature then this will result in increased uncertainty in the produced FEED outputs when compared with performance of FEED on more mature technologies and sectors.	Due to the FOAK nature of the Project, existing Shell FEED processes were not comprehensively rewritten to cover the required CO ₂ duty. Collation of learnings generated during the PCCS FEED, and from other future FEED studies across the world can be used as inputs to update Shell's Process Engineering Philosophy and Flow Assurance requirements and ultimately mature to become a CCS specific set of standards for use on N th of a Kind (NOAK) CCS projects.



ID	Key Theme	FEED Team	Discipline	Lesson Type	Lesson Title	Lesson Description & Impact on the project	Proposed Recommendation / Mitigation
8	FOAK	Onshore	Design HSE	Lessons Learned	Impact of COMAH legislation requirements on the design.	Evolution of definition of the Project technical requirements during FEED in terms of application of HSE's COMAH legislation in conjunction with a lack of maturity in terms of the application of CO ₂ within COMAH impacted upon the delivery schedule. This was further compounded by a change in COMAH regulations in 2015.	Performance of a review at the start of FEED covering the potential project options which needed to be considered during FEED and their COMAH implications would have been beneficial to set expectations and better mitigate impact on the FEED delivery schedule.
9	FOAK	Onshore	Shell/ Cansolv	Lessons Learned	Unresolved Pre-FEED Concept Selection Issues	Going into FEED with too many open items due to novel technology caused additional work and rework in some areas during FEED. For example, delay in FEED activities due to late receipt of biodegradability and absorber lining data.	Concept selection issues should be resolved as early as possible. If some FOAK items remain unresolved, they should be clearly identified and tackled first in the next project phase to maintain the overall delivery schedule.
10	FOAK	Onshore	HSE	Lessons Learned	Waste Water Treatment Plant (WWTP)	Due to the FOAK nature of CCS projects and lack of operational CCS project data, assumptions made at the start of the FEED subsequently had to be revisited which meant that some redesign work was required. One example was the Waste Water Treatment Plant (WWTP) where detail of the constituent effluent streams was not available until relatively late on in FEED and different from what had been assumed. As a result, it was not possible to finalise the WWTP design during FEED without extending the Onshore FEED schedule.	Monitoring of assumptions as well as decisions is important in a FOAK CCS FEED to provide early identification where assumptions are unlikely to be accurate and/or where there is a delay in generating data to confirm the assumptions made. A review of the options for waste stream disposal was undertaken after completion of the Onshore FEED identifying that it may be cost effective for off-site treatment of selected waste streams.
11	Best Practice	FEED TEAM Kick Off	Best Practice	Demonstrates Good Practice	Development and Identification Best Practice on Technical Issues was supported by good communications between the FEED team and across the CCS community.	Good interaction and support was provided to the FEED subsurface team from storage and containment research groups. Engagement with DECC EDU led to close alignment. Further areas such as specialist modelling covering refrigeration, and dense phase change were identified and best practice shared.	Best Practice identified by the FEED subsurface team was shared within the associated CCS community to help develop and identify best practice. Confirming the PCCS FEED findings and also supporting future CCS projects.
12	Best Practice	FEED TEAM Kick Off	Best Practice	Demonstrates Good Practice	Risk management, Opportunity Identification	Varied & complex risks on the project have required a robust approach to risk management within the project. As well as managing risks, it is important to identify opportunities. A successful Opportunities workshop was held in FEED which generated over 100 potential opportunities for the risk register.	The Risk Management function should keep the Risk Management plan up to date during each Project phase holding regular workshops to review existing risks and also stimulate new ideas. The "Health" of the Risk Register should be monitored with regards to Opportunities v Threats.
13	Learning from Others	FEED TEAM Kick Off	Best Practice	Identify Learning from others – Analogue projects	Learning From Other Projects	At the start of FEED a number of opportunities to gain technical and financial Learnings from other analogous projects were identified. The learning plan was implemented with useful knowledge gained. Some of which was incorporate into the FEED work. Other learning has been taken forwards into the plan for Execute.	Plan to learn from other analogous projects. Identify Knowledge Gaps and seek to fill them from analogous experience gained by others. Develop relationships with other parties to help gain insights from other projects and assess their applicability to the PCCS project.
14	FOAK	FEED TEAM Kick Off	Lesson Learned	Lessons Learned	Contracts Management	The non-standard nature of project, time to become familiar with DECC terms and requirements and lack of contracts definition for a FOAK CCS project meant increased time was required to get contracts in place for FEED.	Allow more time to negotiate and put contracts in place where there is a FOAK aspect. Involve the technical team early to assist in defining contract scope.
15	Educate	FEED TEAM Kick Off	Lessons Learned	Education – Raise Awareness	Requirement to educate FEED team and raise awareness of CO ₂ specific hazards	In the previous phase of the PCCS Project, it was identified that there were significant differences between designing for, handling and operating a process system based upon CO ₂ rather than hydrocarbons – which is the present Oil & Gas industry standard. As a result, significant research into the properties of CO ₂ and their	A detailed on-boarding presentation was prepared by Shell's Technical Safety Engineer which summarised the results of the research performed and the specific application to CCS projects in general, and the PCCS project in particular. This presentation was given to each of the FEED teams, including the PMO on commencement of FEED – applying the lessons generated from the previous project phase.



ID	Key Theme	FEED Team	Discipline	Lesson Type	Lesson Title	Lesson Description & Impact on the project	Proposed Recommendation / Mitigation
						application to the PCCS project was undertaken by Shell prior to commencing FEED since the need to educate the contractor teams who would support delivery of the FEED study was a key learning identified for FEED.	



These FEED Team learnings have been categorised according to the following themes and sub-divisions:

- First Of A Kind Issues:
 - Technical;
 - Non-Technical;
 - Non Business as Usual; and
 - All CCS Related.

- Oil & Gas Approach v Power sector approaches
- Demonstrable Benefit of Replication (maximising historically similar work)

5.1.1. First of a Kind Issues

PCCS is novel project in terms of concept and execution. It requires collaboration across multiple disciplines and stakeholders who may not be initially familiar with CCS project requirements. As a result, learnings on First Of A Kind (FOAK) issues were identified by all FEED teams and these issues had an impact across multiple project disciplines:

1. **The Project Management Office team** identified FOAK impacts on the development and delivery of processes and procedures during FEED. Where processes are based on existing practices, it is beneficial to identify FOAK issues, monitor how they are progressed and then update and incorporate revised processes into the Project's governance procedures. It was also identified that the time to develop and identify such processes and procedures should not be underestimated and that sufficient time allowance be made to develop, disseminate and establish these processes and procedures on commencing each Project phase.
2. **The Subsea FEED team** identified issues around the application of standard Oil & Gas sector process engineering and flow assurance procedures to a CCS project. Changes to the industry approach for handling hydrocarbons is required for working with CO₂. Shell's standard process engineering philosophy and flow assurance practices were reviewed during FEED, but due to the FOAK nature of the Project were not comprehensively rewritten prior to FEED to cover the required CO₂ duty. Collation of learnings generated during the PCCS FEED, and from other similar FEED studies across the world can be used as inputs to an update to Shell's Process Engineering Philosophy and Flow Assurance requirements which could ultimately mature to become a CCS specific set of standards for use on Nth of a Kind (NOAK) projects.
3. **The Onshore FEED team** identified several FOAK issues including:
 - The application of the UK Health and Safety Executive (HSE) Control Of Major Accidents Hazards (COMAH) legislation to CCS projects (revised in 2015 during FEED). Evolution of definition of the Project technical requirements during FEED in conjunction lack of maturity in terms of the application of CO₂ within COMAH impacted upon the delivery schedule. It was recognised that performance of a review at the start of FEED covering the potential project options which needed to be considered during FEED and their COMAH implications would have been beneficial to set expectations and better mitigate impact on the FEED delivery schedule.
 - The Process Design Package (PDP) issued to the Onshore FEED team from the capture technology provider (Cansolv) was released later in FEED than originally planned. This caused an associated delay in starting related Onshore FEED activities.



Due to increased uncertainty in the development of new technology and the need to mature the process design package, such risks could be mitigated by making increased contingency in the scheduling of these activities. Alternatively not to start FEED until the PDP is finalised. The FOAK nature of this risk will be reduced as CCS technology matures and contractors gain increased understanding of NOAK process requirements.

- Due to the FOAK nature of CCS projects and lack of operational CCS project data, assumptions made at the start of the FEED subsequently had to be revisited which meant that some redesign work was required. An example with the Waste Water Treatment Plant (WWTP) where detail of the constituent effluent streams was not available until relatively late on in FEED. As a result, it was not possible to finalise the WWTP design during FEED without extending the Onshore FEED schedule. Instead, a review of the WWTP options was subsequently performed to identify a preferred solution to use as the basis for commencing the Execute phase.

These lessons demonstrate that FOAK issues arose during FEED as a result of the lack of previous industry track record in delivering CCS FEED studies. The general lack of previous industry experience in performing CCS FEED studies made it difficult to both anticipate the issues likely to arise and also the amount of time and effort necessary to resolve them. Such activities are outside the typical scope of a FEED study and although some allowance had been made for this in the FEED schedule, the issues arising were found to be more complex than originally anticipated which impacted on the FEED delivery.

The lessons highlight the issues involved with maturation and transition of CCS from a FOAK to NOAK technology and the need to mature existing processes and procedures to reflect specific requirements of dealing with CO₂. This learning is applicable across the whole project team, including the onshore, subsea and offshore scopes.

In addition to the above learnings, information on FOAK aspects of the technical design is described in the Basic Design and Engineering Package (BDEP) – KKD 11.003 [1].

5.1.2. Oil & Gas vs Power Sector Approach

It was identified in the pre-FEED phase of the PCCS project that there are fundamental differences between the approach to project development and delivery in the Oil & Gas and Power sectors. As a result, an opportunity was identified to depart from Shell's standard practice in the development of the Onshore FEED design scope for the Carbon Capture, Compression and Conditioning plant and potentially simplify the technical scope of this project element and also achieve cost reductions.

Shell's approach to developing the project is in alignment with the standard Oil & Gas sector approach which is to take responsibility for performance in-house of the design and/or design assurance activities. This position has evolved in the sector since the large Oil & Gas companies are best placed to manage design risks including risks relating to health and safety. Therefore, Shell, as well as other similar large Oil & Gas companies has developed a suite of technical standards known as Design & Engineering Practice documents (DEPs) to manage these risks, and standardise the design approach on projects in accordance with their commercial risk management practices. There is a high cost of unavailability associated with hydrocarbon extraction projects so Oil & Gas sector design generally focus on achieving a high availability for a project, specifying high levels of availability for equipment as well as installation of redundant equipment in order to maximise operations.

In contrast, the Power sector's standard approach for the development of large power plant projects is to outsource the majority of the project design and design responsibility. This involves



approaching the market for the purchase of proven, mature technology using standard designs developed by OEMs (Original Equipment Manufacturers) who have standardised their design offerings over many years to minimise their costs. Such OEM equipment is typically offered to comply with British and/or International Standards and minimum functional specification requirements which are defined for the project. There are regular planned outages for maintenance of the major power plant equipment items. Therefore, it was identified pre-FEED that maintenance of key CCCC plant equipment could be scheduled to align with major power plant outages. As a result, it is possible to consider relaxation of the specification for this equipment since a less onerous duty is required. Lower levels of redundancy can also therefore be considered.

Although it would have been Shell's normal practice to apply the DEP requirements to the onshore FEED study scope, which includes the Carbon Capture, Compression and Conditioning (CCCC) plant scope, it was identified prior to commencing FEED that there would potentially be benefit in not applying the Shell DEP requirements to the Onshore FEED study scope.

The starting point for the PCCS FEED was to apply Shell standards to the Offshore and Subsea FEED scopes. It was recognised that there may be design and cost benefits from not applying these standards to the Onshore FEED and development of the CCCC plant design since the duty required to support Power Plant operations is less onerous than would typically be applied for an Oil & Gas installation. This difference in requirements is because it is necessary to perform regular scheduled maintenance on power plant units. Therefore regular maintenance of CCCC equipment can be performed during these power plant outage periods reducing the reliability requirements for this equipment when compared to Oil & Gas installations. Also oil and gas standards and design practices have been developed over time taking into considerations the hazards associated with hydrocarbons. It was not considered necessary to apply similar standards and practices to a CO₂ duty for CCS.

Driven by the desire to promote replication that power generation will lead the installation of carbon capture in future power plants and the reduced risk associated with CO₂ relative to hydrocarbons it was recognised prior to commencing FEED there was potential benefit in applying a power sector approach to the development of the CCCC plant scope with the Onshore FEED contractor only required to apply the process safety aspects of Shell's standards to their design.

The learnings from this first FEED study require to be developed based upon learnings from subsequent CCS projects in order for Shell to produce CCS specific standards for general use on future projects.

5.1.3. Replication in Action

The project identified the benefit of learning from previous projects and used good practice through applying historically similar work and using the experience gained from similar projects. The PCCS project made use of knowledge gained and work previously carried out on the Longannet CCS Project performed by the ScottishPower CCS Consortium which included Shell. This provided benefits to the PCCS FEED, not least in terms of the Offshore and Subsurface FEED scopes, since it was not necessary for the Shell team to validate or replicate much of the work which had been performed previously on the Longannet CCS project.

However, the PCCS project considers use of the gas fired Peterhead Power Station instead of Longannet Power Station. Therefore, a new Onshore FEED study was required and some of the Offshore and Subsurface work needed revisited.

For example, the Offshore FEED considering reuse of the Goldeneye platform was able to reuse much of the structural integrity and life extension study work performed previously which greatly reduced the PCCS FEED scope requirement.



In addition, a number of the subsurface reports produced during the PCCS FEED were an evolution of the earlier ScottishPower CCS Consortium work. The reports were updated incorporating any new findings or requirement to undertake further modelling work. Examples include:

- 11.108 – Static Model Reports [10]
- 11.112 – Special Core Analysis (SCAL) Report and Geomech / Reactive Transport Modelling (RTM) Core Analysis Reports [11]

5.1.4. Learning from Others

The PCCS project identified that learning from analogous and previous projects would provide tangible benefit to the Peterhead CCS Project through FEED and beyond. The following similar projects were identified as being the most appropriate to provide useful knowledge and learnings to the PCCS project:

- Gorgon – CO₂ Injection Project
- Technology Centre Mongstad (TCM)
- Saskpower CCS – Boundary Dam Carbon Capture Project
- QUEST project, Saskatuin, Canada
- SSE power sector projects

As a result, a learning plan was developed for implementation during FEED to determine where knowledge gaps existed and what learnings could be leveraged from the analogous projects identified as having specific relevance. Section 5.2 describes the Analogous Learnings obtained.

5.1.5. Education

In the previous phase of the PCCS Project, it was identified that there were significant differences between designing for, handling and operating a process system based upon CO₂ rather than hydrocarbons – which is the present Oil & Gas industry standard. As a result, significant research into the properties of CO₂ and their application to the PCCS project was undertaken by Shell prior to commencing FEED since the need to educate the contractor teams who would support delivery of the FEED study was a key learning identified for FEED.

As a result, a detailed on-boarding presentation was prepared by Shell's Technical Safety Engineer which summarised the results of the research performed and the specific application to CCS projects in general and the PCCS project in particular. This presentation was given to each of the FEED teams, including the PMO on commencement of FEED – applying the lessons generated from the previous project phase.

Established Shell practice is to have more experienced engineers supervise, review and sign-off on the technical assurance activities performed by the discipline engineers working on a FEED project. Due to the novel nature of the PCCS project, the outcome of some project learnings was to recommend deviation from Shell's standard processes – which have been developed to support the hydrocarbon based business. These deviations required to be justified to Shell's senior discipline assurance team and can be used to form the basis of a technical standard which can be applied to future Shell CCS projects.

Examples of such learnings include the requirement to use alternative materials in the recompleted wells due to the lower temperatures anticipated as a result of CO₂ injection and the decision to use methanol rather than Mono Ethylene Glycol (MEG) to inhibit hydrate formation. Although MEG is



generally preferred to methanol in the oil industry as an inhibitor for well injection, methanol has been preferred to MEG for PCCS operations to minimise the reaction with the injected CO₂.

5.2. Analogous Project Learning

The PCCS project identified that learning from analogous and previous projects would provide tangible benefit to the Peterhead CCS Project through FEED and beyond. Specific examples of such projects included the QUEST and Boundary Dam projects which have already completed their FEED studies and have been commissioned. Outside the scope of the PCCS project, Shell has an ongoing involvement with the work at Technology Centre Mongstad (TCM) and the PCCS team engaged with TCM during FEED to maximise applicable learnings from the TCM programme.

It was also identified that it may be beneficial in FEED to review learnings obtained by SSE with respect to brownfield modifications to existing power stations. Several site visits to SSE locations were made (Great Island CCGT Project, Ferrybridge Project) and the learnings obtained were disseminated to the project team and integrated into the development of the Onshore FEED work stream.

The mind map presented in Figure 5-2 shows the Analogous Learning from the other projects demonstrating:

- Which projects were approached and involved in sharing lessons learned from their experiences;
- The form of interaction and learning between PCCS and other projects: including site visits and knowledge sharing workshops; and
- The areas of specific focus identified within each analogous project.

The learnings obtained from engagement with these analogous projects are presented in Figure 5-2 below.

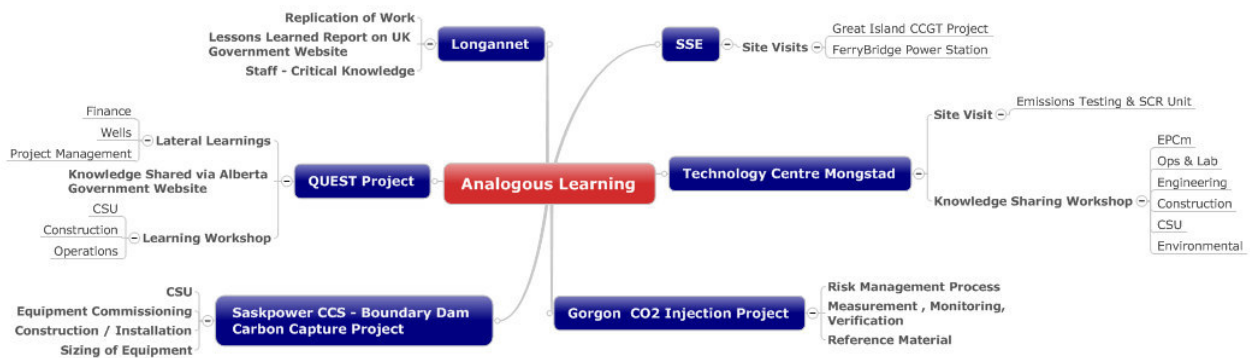


Figure 5-2: Analogous Project Learning Matrix

5.2.1. Longannet CCS Project

The Longannet CCS Project undertook an extensive FEED Study in 2010. The project was developed by a consortium consisting of ScottishPower, National Grid and Shell. This project also proposed to utilise the Goldeneye reservoir and storage facility. Further details can be found online in the UK National Archives (12):

http://webarchive.nationalarchives.gov.uk/20121217150422/http://decc.gov.uk/en/content/cms/missions/ccs/ukccscomm_prog/feed/scottish_power/lessons/lessons.aspx



The Lessons Learned Reports and project documentation which was produced by this earlier FEED study was reviewed by the PCCS team at the commencement of FEED to discern any applicable lessons to the Peterhead CCS Project.

In addition, since Shell was part of the project Consortium, some key staff who were involved in the offshore and subsurface aspects of the earlier project were available to the present FEED team and able to discuss lateral learnings. In this way lessons were incorporated into the PCCS project processes and management systems. Examples of this are covered in Section 5.1.3 where reports and documentation were identified which could be used to minimise rework, specifically work associated with subsurface modelling and the Offshore scope for the PCCS FEED.

5.2.2. QUEST Project

The QUEST project will capture the CO₂ produced at the Scotford Upgrader and transport, compress and inject the CO₂ for permanent storage in a saline formation near Thorhild, Alberta in Canada. The project has a designed capacity to capture up to 1.2 MT of CO₂ per year. The QUEST Project is a part of the Athabasca Oil Sands Project (AOSP), an oil sands joint venture operated by Shell and owned by Shell Canada, Chevron Canada and Marathon Oil.

QUEST Knowledge Sharing Reports can be found on the Government of Alberta website at [13]: <http://www.energy.alberta.ca/CCS/3848.asp>

QUEST was identified at the start of FEED as a key project for knowledge sharing activities. This is because the project is at a more advanced stage in development than PCCS and therefore is an ideal candidate to provide beneficial learnings. Shell's involvement in both projects has helped facilitate knowledge transfer between the two projects.

During the Peterhead CCS FEED phase a positive relationship was developed which resulted in the PCCS FEED leadership team being given access to the QUEST Project documentation for review across all disciplines and project phases. The team were also able to approach the QUEST project members to obtain further insight as required.

Regular communications took place during the PCCS between the Finance, Wells, and Project Management disciplines for the two projects.

Towards the end of FEED a knowledge sharing workshop was held in Shell's offices in Aberdeen which was attended by the PCCS and QUEST leadership teams. The focus of the meeting was to generate on learnings which the PCCS project team could apply to the Execute project phase. This included QUEST's experience regarding construction, commissioning, start up and operational aspects, which the PCCS team found to be beneficial for incorporation into Execute phase processes. The learnings obtained from the QUEST project will be reviewed during the Execute phase of the PCCS project to determine the relevance and effectiveness of the proposals developed during FEED for Execute phase delivery.

5.2.3. Technology Centre Mongstad

Technology Centre Mongstad (TCM) is the world's largest facility for testing and improving CO₂ capture technologies. It is a joint venture between Gassnova, Statoil, Shell and Sasol. The Technology Centre operates testing programmes for CO₂ capture technology.

Further information on TCM can be found here [14]: <http://www.tcnda.com/en/>

Learnings were taken from TCM through their experience with CCS technology testing as a whole and also from their particular experience testing the Cansolv technology which is proposed for the PCCS project. Learnings were collected and shared through site visits (e.g. December 2013, March 2015). The March 2015 visit focussed on Emissions Testing and the Selective Catalytic Reduction (SCR) Unit. Learnings were shared on the following aspects:



- Monitoring air quality;
- Online monitoring & measurement of amines;
- Emissions testing to refine the dispersion modelling; and
- Monitor performance of the stripper.

Further knowledge sharing took place via a workshop which was held in May 2015. This workshop covered the following aspects:

- EPCm project delivery method
- Engineering aspects:
 - Viscosity Issues
 - Monitoring Instrumentation
 - Specialist Water Treatment Plant
 - University of Oslo study and techniques
 - Operational Learnings
- Construction methods
- Commissioning and Start-Up (CSU) activities including:
 - TCM Operations and Training Plans
 - TCM Start Up audit information
 - TCM Operators Organisation Chart
 - Warm Stack Learnings
- Environmental
 - Analyser Learnings
 - Baseline Challenges

The learnings taken from the above aspects were integrated into the PCCS project where appropriate. For example the CSU learnings helped the PCCS project to improve the project's CSU plan.

5.2.4. Gorgon CO₂ Injection Project

The Gorgon project is a huge hydrocarbon development located on North West Australia and as a part of its hydrocarbon production commitments is the largest planned CO₂ storage project in the world. It plans to store around 100 Mt at a rate of over 3 Mtpa onshore at Barrow Island. The storage project consists of injection wells, monitoring wells, water extraction wells and water disposal wells. The CO₂ will be sourced from gas treatment at the nearby Liquefied Natural Gas (LNG) plant. Shell is a partner in this project.

Shell was involved in the design stages of the CCS part of the project and much of the knowledge obtained informed the design of the risk management process used in earlier stages of the Goldeneye storage evaluation. The storage review for the PCCS project was led by one of the key participants in the review of the Gorgon CO₂ Injection Project review. This provided an independent review and validation of Shell's work for PCCS.



The PCCS storage manager has participated in technical meetings in Perth for the Gorgon project, with particular focus on Measurement, Monitoring and Verification (MMV) activities. The PCCS Project has access to the technical material that the Gorgon operator has shared with Shell Australia. Reference to this material shows that the PCCS project is following a similar approach as the Gorgon project with regards to the CO₂ storage philosophy. However, the PCCS project has developed a more streamlined approach employing a smaller team of subsurface professionals which are required to do less modelling work. This stems partially from the key differences between the two projects:

Table 5-2: Gorgon vs PCCS Comparison Table

Gorgon CO ₂ Injection Project	vs	Peterhead CCS
Gorgon is aquifer storage is a potentially confined system, it therefore employs water extraction to manage pressure build up		PCCS is depleted field storage and benefits from the pressure sink caused by the production of 568 Bscf [16 billion Sm ³] of gas plus associated condensate. The system is also open to a large regional aquifer.
Gorgon is planning to inject into an “unknown” saline formation. As a result they have done multiple iterations of subsurface modelling – just like QUEST – and their models change each time they get appraisal data.		PCCS is planning to inject into a known formation that is extensively appraised by exploration and appraisal wells, plus five production wells with six years of production history and now over two years of regional pressure build up. As such PCCS did not have to go through multiple iterations of subsurface modelling (this was done, but over a decade ago when the gas field was developed)
A key uncertainty for Gorgon is the connectivity between the injection wells and the water extraction wells. Too close and early breakthrough will occur, too far and there will be limited benefit from the pressure relief.		PCCS has a proven well connected system and does not have this challenge.

5.2.5. SSE Learning

With respect to the onshore construction activities for PCCS, the Project sought to understand how construction and operations activities had been achieved of other similar power station sites to enhance project knowledge and learnings in this area. Two site visits were made to SSE sites to review previous brownfield modification projects:

5.2.5.1. Site Visit to Great Island CCGT Project – October 2014

The PCCS project team visited SSE’s Great Island CCGT project which was under construction at a time when Shell was preparing its Execution Contracts. The visit’s primary objective was to take learning’s from Great Island for inclusion into the PCCS Onshore EPC tender documents and support Shell’s discussions on the PCCS onshore delivery scope with SSE.

Learnings from the visit included the following aspects:

- Contracts structure;
- Solutions to develop site with limited space;



- Electrical zoning requirements;
- High number of commissioning staff required on site; and
- An onsite batching plant used for concrete production.

The visit helped the PCCS project team better understand implementation and operation of brownfield site modification projects in the power sector and SSEs working practices. The visit helped improve alignment between Shell and SSE and several of the lateral learnings subsequently helped to inform the contents of the Onshore EPC tender documents for Execute.

5.2.5.2. Site Visit to Ferrybridge Power Station – February 2014

The PCCS project Team visited SSE's Ferrybridge site. The objective of the visit was to take construction learnings from SSEs Multifuel Power Plant and Coal Fired Power Station which was under construction.

Learnings from the visit included the following aspects:

- Multifuel Power Plant.
 - Construction of new plant.
 - Site Management and HSSE.
- Coal Fired Power Station.
 - New Flue Gas Desulphurization (FGD) Absorber Construction.
 - Gas/Gas Heat Exchanger design.
 - Booster Fan requirements.
 - Dampers and Ducting requirements.

This visit built on the learnings obtained from an earlier SSE site visit, and helped the PCCS project team better understand the implementation and operation of brownfield site modification projects in the power sector and also improve understanding of SSEs working practices. Key learnings from the visits were identified for incorporation into the execution phase of the PCCS project.

5.2.6. Saskpower CCS – Boundary Dam Carbon Capture Project

The Boundary Dam CCS Project rebuilt a coal fired generation unit carbon capture technology, resulting in low emission power generation. In the latter half of 2014, the project came online as the world's first operational post-combustion coal fired CCS project.

This project had matured through development before PCCS and was approached to identify if useful learnings could be obtained and applied to PCCS. As a result, it was identified that commissioning and start up lessons could be learned from Boundary Dam for implementation in the FEED phase of the PCCS project.

A Commissioning and Start-Up (CSU) lessons learned workshop was held between the PCCS and Saskpower in late 2014.

Lessons obtained by PCCS from the Boundary Dam project covered aspects such as:

- Equipment commissioning;
- Construction/Installation; and
- Sizing of equipment.



These lessons were provided to the Onshore FEED contractor for incorporation into their FEED design.

6. Financial Learnings

Under the Project's contract strategy for Execute, an incorporated joint venture company called Peterhead Carbon Capture Storage Limited (PCCS Ltd) was incorporated with responsibility as the developer for the delivery of the Execute phase of the PCCS Project. PCCS Ltd will be the counterparty to DECC, on behalf of the UK government, to the Project Contract which will set out the basis on which PCCS Ltd would deliver the Execute phase of the Project. PCCS Ltd will engage Shell U.K. Limited to manage delivery of the Project on their behalf. Further information on the Project's contract strategy for Execute can be found in Scope of Work for Execute Contracts – KKD 11.058 [2].

The Financial Learnings from the FEED phase are presented in this chapter. This includes the lessons learned from arranging finance for the Project, lessons learned on the experience of raising debt and the lessons learned on the experience of raising additional external equity.

6.1. Lessons Learned from arranging finance for the project.

6.1.1. The approach to establishing optimum gearing ratios for the Peterhead Project

Shell has reviewed different scenarios to decide on an optimal gearing ratio, considering a 100% equity case, an 80%:20% Equity/Debt case and a 60%:40% Equity/Debt case. Based on the base case Internal Rate of Return (IRR) definition in the Project Contract between DECC and PCCS Ltd and the blended nature of this IRR calculation, Shell considers that the base case IRR would be independent of the funding route chosen. Hence no benefits from a return perspective were identified of choosing a debt funding instrument. After evaluating the tax impact of the different funding structures, Shell formed a view that an interest bearing instrument would create tax deductions for PCCS Ltd and therefore could potentially reduce the strike price without necessarily affecting the return to the shareholders. This however was not seen as a decision driver given the very limited reduction in strike price that the two debt funded scenarios presented. Therefore, Shell considers that a 100% equity solution as the optimal funding structure for the project as it avoids the unnecessary complexity from debt funding and this additional complexity would not be outweighed by any potential benefits arising from debt funding.

6.1.2. Experience of engaging with credit support facilities such as Export Credit Agency ECA's or policy lenders

This section is not applicable to the project at this stage. Based on the consideration for a 100% equity solution to finance the project, no discussions have taken place with Export Credit Agencies (ECA) or policy lenders in relation to this project.

6.1.3. Risk allocations to various classes of finance providers

This section is not applicable in relation to the project at this stage. Based on the consideration for a 100% equity solution to finance the project, no discussions have taken place with external finance providers with a view to allocation of risk.



6.2. Lessons Learned on experience of raising debt, including (but not limited to) the competition process, securing of terms, refinancing expectations, size and capacity of the market

Shell's financial strategy is to manage Shell's assets and liabilities with the aim that, across the business cycle, "cash in" at least equals "cash out" while maintaining a strong balance sheet.

Gearing, calculated as net debt (total debt less cash and cash equivalents) as a percentage of total capital (net debt plus total equity), is a key measure of Shell's capital structure. Across the business cycle, Shell aims to manage gearing within a range acceptable to its executive management committee.

With respect to the objective of maintaining a strong balance sheet, management prioritises the application of cash to the servicing of debt commitments, paying dividends, investing for organic and inorganic growth and returning surplus cash to shareholders. Shell has access to international debt capital markets via two Commercial Paper (CP) programmes, a Euro Medium-Term Note (EMTN) programme and a US universal shelf (US shelf) registration. Issuances under the CP programmes are supported by a committed credit facility and cash. All CP, EMTN and US shelf issuances have been undertaken by Shell International Finance B.V., the issuance company for Shell, with its debt being guaranteed by Royal Dutch Shell plc.

In relation to the Peterhead CCS project, Shell considered at an early stage that a 100% equity solution is the optimal funding structure for the project as it avoids the unnecessary complexity from debt funding and this additional complexity would not be outweighed by any potential benefits arising from debt funding. No discussions have taken place with external finance providers to provide debt funding for the project, and therefore no lessons have been learned in relation to this requirement.

6.3. A report on the experience of raising additional external equity (if required), including (but not limited to) the source of funds, rewards, expectations, size and capacity of the market

From a Shell Group perspective, Shell plans to finance the Peterhead CCS project with cash flow from corporate resources. This may include, but is not limited to, cash flow from operations and investing via the mechanisms discussed in previous paragraphs. Shell satisfies its funding and working capital requirements from the cash generated by its businesses and through the issuance of external debt. Shell's external debt is principally financed from the international debt capital markets through central debt programmes.

A cross-functional review was undertaken within the Peterhead CCS Project to determine the most appropriate legal structure, both for the Project as it stands with Shell acting as a single Developer and also in the context of potential future equity dilution. On the basis of this review, the Project team proposed that a Special Purpose Vehicle (SPV) be utilised and formed as soon as possible, with a view to using this SPV as the legal entity for a fully incorporated Joint Venture in the event that an appropriate Joint Venture partner be identified and agreements executed. As a result, Shell incorporated a new company at Companies House on 10th August 2015, called Peterhead Carbon Capture and Storage Limited (PCCS Ltd). Establishment of the SPV isolates the Project from the rest of Shell U.K. Limited, fulfils DECC's own preference for a legal entity which is able to stand alone, protected from any wider financial exposure of the business and provides a convenient model for seeking potential equity dilution. Shell undertook an engagement process during the Execution Preparation Phase of the PCCS FEED to seek external equity to support the Project. This engagement process had not been finalised by the end of November 2015.



7. Lessons Learned on Open Book Accounting

This section presents the lessons learned generated on Open Book Accounting during the PCCS FEED. It provides an outline of the principles and processes agreed between the parties in relation to Open Book cost verification and practical experience of the working of these processes during FEED.

The learnings are presented with respect to:

1. Management of invoices.
2. Appraisal of the Value Of Work Done (VOWD).
3. Experiences of dealing with sub-contractors with respect to cost verification.

7.1. Management of invoices

7.1.1. Payments made in advance under the Technip Onshore FEED Agreement

During the negotiation of the Onshore FEED Agreement between Technip and Shell, Technip requested that the invoicing be based on payments in advance rather than in arrears. In return agreement on this issue, Technip's bid reflected lower financing requirements. Shell accepted these terms and was willing to take the risk in return for a lower contract value.

However, during the early part of the onshore FEED work, it was noted that the monthly variability between the estimated advance payment and the actual value of work done by Technip was unexpectedly high. This was primarily due to the later mobilisation of Technip resources than planned. Various meetings were convened with the Contractor to discuss this issue and an agreed action plan was put in place to improve the quality of the monthly forecasting to better reflect the value of work done. It was noted that the difference between estimate and actual work done was much smaller after Shell's intervention with the Contractor. The lesson learned is to more critically review any request for advance payments prior to signing contracts, and also to ensure the Contractor's cost reporting controls are fit for purpose to ensure no significant deviations on a monthly basis. In future the Project Finance Manager will be asked to formally approve requests for advance payment terms in advance of the agreements being signed.

7.1.2. Advance Agreement on Cash versus Accruals Basis for Cost Recovery

During the negotiation of the FEED Agreement between DECC and Shell, the cost recovery mechanism was never fully described in terms of cash versus accruals basis for recovery. During the course of preparing the Payment Period 1 invoice report, DECC advised Shell its expectations were that the invoices were to be submitted on a cash basis. Shell subsequently had to revise its Payment Period 1 invoice report to satisfy DECC's requirements, which DECC settled within the agreed timeframe in the FEED Agreement.

The lesson learned from these experiences is, to ensure that the cost recovery methodology is discussed and agreed in advance of the agreement being signed, and that Shell's cost recovery budget provisions reflect the agreed cost recovery methodology (i.e. cash vs accruals for cost recovery). This also affected the cost forecasting, whereby Shell had to provide cash based forecasts to DECC in addition to its standard VOWD based forecasting used for internal planning. The Shell project team also had to place extra emphasis on ensuring sub-contractors submitted their invoices on a timely basis to ensure no material discrepancy between Shell VOWD and Shell cost recovery calculations.



7.2. Learnings on Appraisal of the Value of Work Done

7.2.1. Differences between Contractor VOWD and Shell VOWD on Sub Contracts

During the course of reviewing the Payment Period 2 invoice report, DECC noted that there was a discrepancy between the contractor calculated VOWD for Technip and SSE as compared to the Shell VOWD for payments and accruals under both of these sub-contracts. The Shell VOWD which formed the basis of Shell's cost recovery claim to DECC, was based on actual payments due by Shell to the sub-contractors under the terms of those contracts, and therefore Shell were liable for those costs at that point in time despite the Contractors not recording the same VOWD in their own ledgers. DECC advised Shell that it would only pay for incurred/actual costs as these were the costs of work done.

The lesson learned from this example is, to ensure that the cost recovery methodology is discussed and agreed in advance of the agreement being signed, and that Shell's cost recovery budget provisions reflect the agreed cost recovery methodology (i.e. cash vs accruals for cost recovery). This also affected the cost forecasting, whereby Shell had to provide cash based forecasts to DECC in addition to its standard VOWD based forecasting used for internal planning. Ideally the Shell project team should have also ensured that any stipulations from DECC on cost recovery rule on sub-contractor costs should have flowed down into the agreements with the sub-contractors, whereby the sub-contractor also felt the effect of not being able to recover costs until such time the costs were actually incurred.

7.3. Experiences of Dealing with Sub-Contractors with respect to Cost Verification

Shell has robust processes in place to provide accurate cost verification of sub-contractor work scopes and to ensure any invoice queries and disputes are resolved in a timely manner.

The following section describes the processes required for verification of sub-contractor costs:

7.3.1. Personnel Authorisation Form (PAF)

In cases where the contractual agreement stated that all reimbursable personnel should be authorised to work on the project via the Personnel Authorisation Form (PAF) process, sub-contractors are required to submit a PAF for each member of personnel who will bill to the project, the PAF has to be physically signed off by the Contract Holder after a review of the employees skills and competencies, details on the role they would fill within the project and agreement on the hourly rate to be billed to the project.

7.3.2. Invoice Verification

All invoices submitted with a reimbursable time component had to include a breakdown of hours billed per person per week to the project, regardless of whether a PAF process was in place for the contract. On receipt of the invoice all hours are verified by the Contract Holder, and the hourly rates by the Project Services Team.

Where CTRs were defined for the scope of work the sub-contractors were expected to provide invoice backup information which referenced the CTR and any hours billed against it. In addition to this, as part of the monthly cost verification process sub-contractors were required to provide a detailed cost, man-hour and progress information per CTR.

All sub-contractor expense claims must be evidenced by receipts and verified by the Budget Holder before payment.

In addition to checks on man hours and rates, a comparison is made against progress vs cost to date with a view to identifying in advance any potential risks to the delivery of work within the expected timeframe & cost estimate.



Due to the significance of the Technip Onshore FEED (in terms of schedule critical path and contract value), two deep dive cost verification audits were performed by the Shell contract management team in the Technip premises. Neither audit, resulted in significant monetary or procedural findings, and the actual process audited was deemed to be consistent with that described in the tender document by Technip prior to contract award.

7.4. Conclusion on Open Book Accounting

Based on the lessons learned described above and Shell's view of the relationship with DECC during the FEED phase on issues relating to cost, including VOWD and invoicing, the conclusion is that the standard Shell controls and procedures are effective and fit for purpose. No material financial loss occurred as a result of the issues described in the lessons learned.

8. Novel Learnings

Where novel learning was generated within the FEED teams, this was solicited via the individual project team lessons learned workshops which are reported separately within Section 5 of the report. However, during FEED, it was identified that a specific workshop was required to determine the approach for FEED to address the SSSV design as a result of the subsurface discipline identifying the requirement for a novel design to overcome a specific constraint in the wells. The development of this novel design is presented here. This constraint and need for this novel design was identified in the Technology Maturation Plan –KKD 11.064 [7].

Although a SSSV concept design was developed during the Execution Preparation Stage of the FEED study, the intention was for this issue to have been addressed to conclusion by the appointed EPC Contractor during the Execute phase of the project post Project Contract award.

8.1. Novel Design – Subsurface Safety Valve

8.1.1. Background to SSSVs:

Subsurface Safety valves (SSSVs) are required in many platform wells around the world. They are designed to limit the flow from the reservoir should a catastrophic failure take place at surface (e.g. the loss of a Christmas tree). As such they are required to work at the temperature of the formation fluids – normally above 50°C. Over the past 20 years as High Pressure High Temperature (HPHT) developments have become more common the trend has been to develop SSSVs for higher and higher temperatures.



8.1.2. SSSVs in a CO₂ Well:

In the highly unlikely event of an uncontrolled CO₂ release from a well, there will be a rapid expansion of CO₂ in the top of the well. This expansion will be accompanied by a reduction in the temperature due to the Joule-Thomson (JT) effect in the CO₂ as the CO₂ travels down the saturation and possibly the sublimation lines as shown in Figure 8-1. This pressure and temperature reduction propagates down the well until equilibrium. The top part of the well will be exposed to these low temperatures. The CO₂ liquid/gas interface drops and its position will depend on reservoir properties (reservoir pressure, productivity index) and the release size.

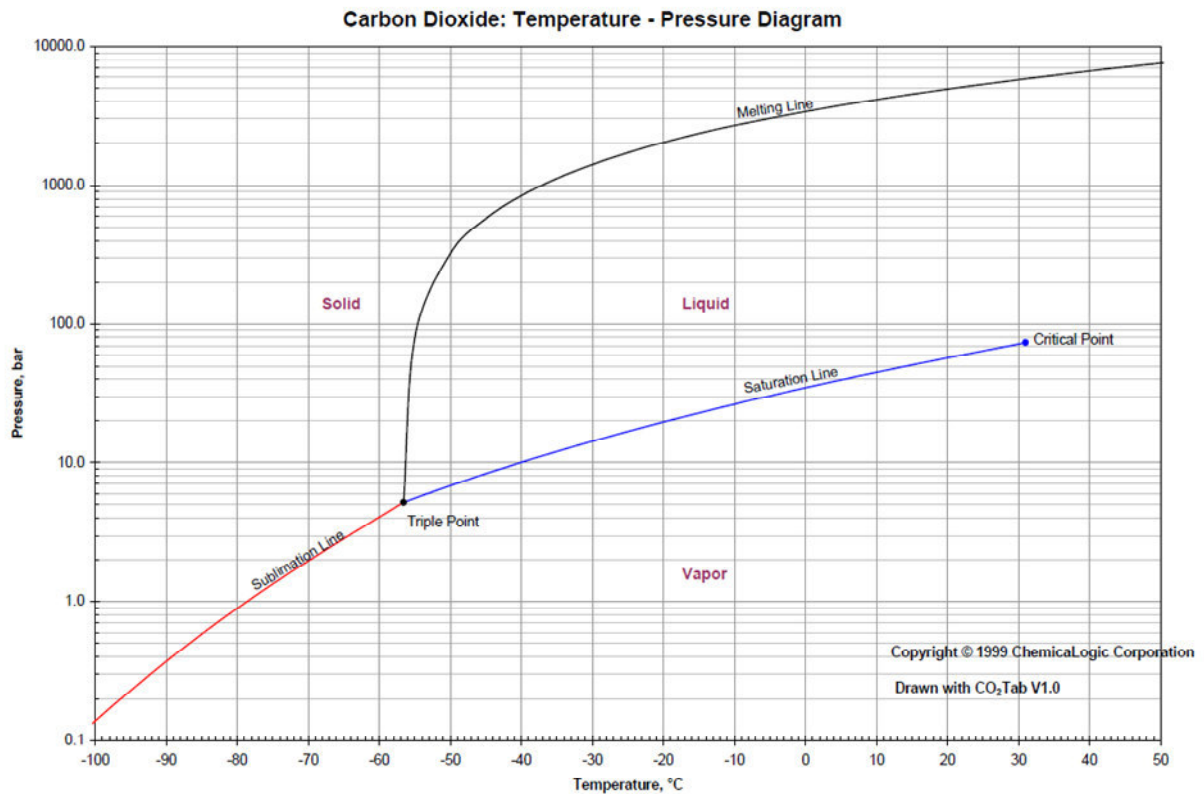


Figure 8-1: CO₂ Phase Behaviour

In such a scenario closing of the Subsurface Safety Valve (SSSV) will prevent further escalation. The size of the release will dictate how fast the tubing above the closed SSSV is emptied. The CO₂ liquid/gas interface will travel down in the well until it reaches the SSSV and will stay there until all liquid CO₂ boils off into gas at low pressure.

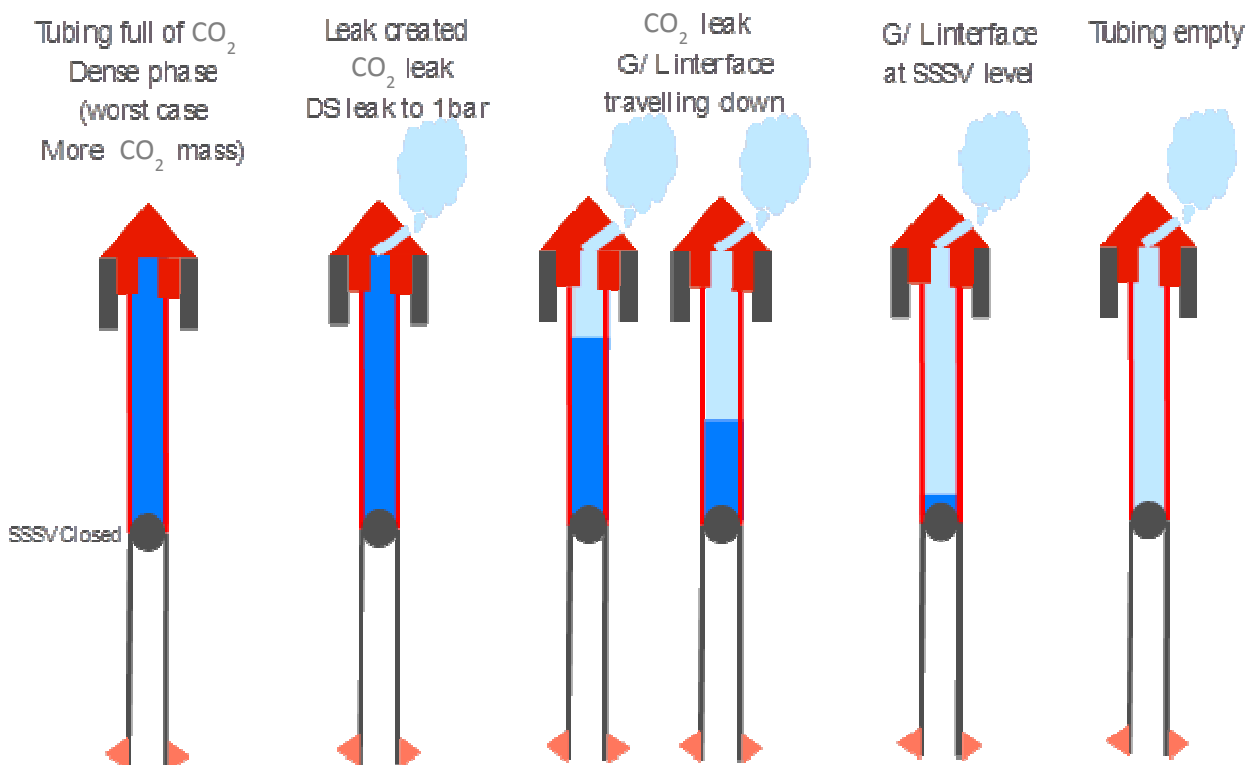


Figure 8-2: Process of Emptying the Tubing in a Release to Atmospheric Conditions

8.1.3. SSSV Design Constraint:

When the interface reaches the SSSV, it can create localised low temperatures at the valve for a couple of hours. Modelling indicates that even for small releases the CO₂ temperature at the valve can reach -78.5°C for approximately 1 hour with the metal temperature falling to -60°C.

SSSVs currently available in the market are designed and qualified for temperatures down to -7°C. It is not certain whether these SSSVs will be capable of maintaining integrity under extreme cold conditions.

The specification requirements for this Subsurface Safety Valve do not currently exist in the market place but are required for this project and for future similar CCS projects.

There are a limited number of suppliers able to potentially provide the SSSVs required, some suppliers have CO₂ experience but in a different CO₂ market i.e. for enhanced oil recovery.

Barriers to entry for these suppliers include:

- Valves being deemed a small value item in terms of their portfolio; and
- R&D being invested in warmer environments.

The dedicating of resources to R&D for CCS project may not be considered a viable cost solution by manufacturers unless the number of prospective CCS projects undergoing FEED and subsequently entering operations increases worldwide.

8.1.4. Novel SSSV Design:

After technical assurance of the modelling and understanding the well integrity escalation potential, a proposal for SSSV development was presented to the PCCS project's Management of Change (MoC)



panel. After approval through the MoC process work was commenced on the detailed design and assessment of SSSVs with the view to qualify a valve suitable for CCS applications. A number of engagement sessions were held with vendors of SSSVs and their engineering and manufacturing centres. Vendors were then allowed a period to respond to the statement of requirements based on which they were selected to participate in the SSSV development during FEED.

8.1.5. SSSV Development:

The overall delivery of the novel SSSV design has been split into 3 stages, detailed design, prototype testing & qualification and finally manufacturing.

The first stage (detail design) allows the vendors to select the most suitable technologies from their portfolio of valve designs. It also involves carrying out theoretical analysis and modelling of the effects of cold temperatures on the existing design allowing the vendors to then make suitable modifications and material selection. The detailed design drawings for the SSSV and test apparatus are required to be completed and a Gantt chart for the subsequent stage development is to be provided. Another important design consideration at this stage is the selection of the power fluid (hydraulic oil) to operate the valve.

At the end of Stage 1 there is a short period of time for evaluation and clarifications prior to progressing to Stage 2 of the development after a final investment decision has been taken.

Stage 2 of the SSSV development will see successful vendors undergoing the manufacturing process for the prototype valve and putting it through rigorous testing and qualification criterion at low temperatures. For this all the standard testing apparatus will require modification to suit the low temperature facilities.

Stage 3 is the final stage in the SSSV delivery process where a successful vendor will be awarded the contract for manufacturing and supplying the SSSVs for Goldeneye wells for the PCCS project during Execute.

9. Conclusions

The lessons learned process applied during the FEED phase of the PCCS project was undertaken in accordance with Shell's standard processes which were tailored to meet the particular needs of a novel carbon capture and storage project.

Lessons which were generated in previous projects were reviewed at the commencement of the present FEED phase and where applicable were implemented in the FEED process – e.g. in the performance of CO₂ awareness presentations to the FEED contractor teams.

A number of core lessons learned activities were undertaken during the FEED phase of the Project including performance of lessons learned workshops, site visits and maintenance of a Continuous Learning Register. The lessons gained from these core learning activities demonstrate the value of a Lessons Learned approach and how the learnings can contribute to the development of PCCS throughout the project's lifecycle from concept development to construction and operations. As part of Shell's standard lessons learned process, the lessons generated during FEED have been issued to the PCCS project team for their review and feedback to identify areas, if applicable, where these lessons could potentially add value to present and/or future phases of the PCCS project.

In addition to the core learning activities, useful learning for other analogous projects was also obtained during FEED. This provided valuable lessons across all disciplines from the wider CCS industry. Where relevant, learnings from analogous project were implemented into the PCCS FEED work scope and/or have been taken forwards for consideration in the Execute project phase.



There are several ways in which lessons can and have been implemented to the PCCS FEED activities including:

- Direct application to the PCCS FEED study activities;
- Inclusion in the PCCS project risk register; and/or
- Inclusion in the Project Execution Plan for the Execute phase of the project.

In addition, the lessons generated during FEED will be taken forwards for consideration during the Execute phase of the PCCS project. Lessons generated from the PCCS FEED will also be reviewed to determine whether it might be appropriate to update Shell's Management System and/or technical DEPs based upon the identified learning.

The lessons learned presented in this report are a subset of those already disseminated to the PCCS project team. The focus of this document has been to present learnings which were identified as being particular to delivery of CCS projects and would be useful learning for the wider CCS community. It is hoped that the CCS specific learnings presented here for the FEED phase of the PCCS project will also be of benefit to subsequent Carbon Capture and Storage projects across the world.



10. References – Bibliography

1. Basic Design and Engineering Package – KKD 11.003
2. Scope of Work for Execute Contracts – KKD 11.058
3. FEED Summary Report - KKD 11.133
4. Basis of Design – KKD 11.001
5. FEED Decision Register – KKD 11.020
6. Surveillance, Metering, Allocation Strategy and Design Package – KKD 11.077
7. Technology Maturation Plan – KKD 11.064
8. Risk Management Plan and Risk Register – KKD 11.023
9. FEED Lessons Learned Report – KKD 11.019
10. Static Model reports – KKD 11.108
11. Special Core Analysis (SCAL) Report and Geomech / Reactive Transport Modelling (RTM) Core Analysis Reports – KKD 11.112
12. UK National Archives:
http://webarchive.nationalarchives.gov.uk/20121217150422/http://decc.gov.uk/en/content/cms/emissions/ccs/ukccscomm_prog/feed/scottish_power/lessons/lessons.aspx
13. QUEST Knowledge Sharing Reports, Government of Alberta,
<http://www.energy.alberta.ca/CCS/3848.asp>
14. Technology Centre Mongstad (TCM), <http://www.tcmda.com/en/>



11. Glossary of Terms

Term	Definition
AOSP	Athabasca Oil Sands Project
BDEP	Basic Design and Engineering Package
Bscf	Billion Standard Cubic Feet
CCCC	Carbon, Capture, Compress & Conditioning
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CfD	Contract for Difference
CO ₂	Carbon Dioxide
COMAH	Control of Major Accident Hazards
CP	Commercial Paper
CSU	Commissioning and Start-Up
CTR	Cost Time Resource
DCAF	Discipline Controls Assurance Framework
DECC	Department of Energy and Climate Change
DEP	Design Engineering Practice
ECA	Export Credit Agency
EDU	Energy Development Unit
EMTN	Euro Medium Term Note
EPC	Engineering, Procurement and Construction
EPCm	Engineering, Procurement and Construction Management
EU ETS	European Union Emissions Trading Scheme
FEED	Front End Engineering Design
FGD	Flue-Gas Desulphurisation
FOAK	First of a Kind
GT13	Gas Turbine 13
HPHT	High Pressure High Temperature
HSE	Health, Safety and Environment
HSSE	Health, Safety, Security and Environment
ID	Identification
IRR	Internal Rate of Return
JT	Joule-Thomson
KKD	Key Knowledge Deliverable
KT	Knowledge Transfer
LNG	Liquefied Natural gas
MEG	Mono-Ethylene Glycol
MMV	Measurement, Monitoring & Verification
MOC	Management Of Change
NOAK	N th of a Kind
O&G	Oil & Gas
OEM	Original Equipment Manufacturers
PAF	Personnel Authorisation Form
PCCS	Peterhead Carbon Capture and Storage
PDP	Process Design Package



Term	Definition
PEP	Project Execution Plan
PMO	Project Management Organisation
R&D	Research & Development
RTM	Reactive Transport Modelling
SCAL	Special Core Analysis
SCR	Selective Catalytic Reduction
SPV	Special Purpose Vehicle
SSE	SSE Generation Ltd.
SSSV	Subsurface Safety Valve
TA	Technical Authority
TCM	Technology Centre Mongstad
US Shelf	US Universal Shelf
VOWD	Value of Work Done
WWTP	Waste Water Treatment Plant

12. Glossary of Unit Conversions

Table 12-1: Unit Conversion Table

Function	Unit - Imperial to Metric conversion Factor
Volume	1 scf = 0.028 Sm ³