Peterhead CCS Project

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Executive Summary

This document; Well & Reservoir Management (WRM) Plan is a Key Knowledge Deliverable and defines activities that need to be undertaken in order to implement the Well, Reservoir and Facilities Management (WRFM) strategy.

This document complements Measurement, Monitoring and Verification (MMV) Plan (1) by detailing the operational activities for effective management of the coupled wells and injection system.

The MMV objectives are the verification of the CO_2 containment in the storage complex and the validation (conformance) of the long term behaviour of the CO_2 injection. The MMV activities only touch lightly on the facilities and injection system.

This document is designed according to the principles of regulatory-compliance; it is risk-based, site-specific and adaptive. Its scope does not cover the capture plant and power station.

The WRM plan philosophy for the Peterhead Carbon Capture and Storage (CCS) project is to ensure optimal CO_2 injection to meet the contractual agreements while maintaining overall system integrity (wells, reservoir and facilities). This will be done through very active surveillance of the wells, reservoir and facilities from start up. Acquisition of baseline data during the pre-injection phase and continuous acquisition of pressure, temperature and other required data from the wells and reservoir is also required. The acquired data will be used to calibrate the well and reservoir models for active well and reservoir management/optimisation.

The WRM plan should be updated before the start of injection. Thereafter, it is usually updated on a yearly basis after injection starts.

1. Introduction

A strategy for Well, Reservoir and Facilities Management (WRFM) was produced pre-Front End Engineering Design (FEED) i.e. Select phase, which outlines the framework for effective management of an asset. It sets out how the asset should be managed in order to accomplish the business objectives.

This document defines the Well & Reservoir Management (WRM) plan that needs to be followed in order to implement the WRFM strategy. Specifically it covers actions that will contribute to the surveillance of the Goldeneye wells, reservoir and the Peterhead/Goldeneye surface facilities (excluding the capture plant and power station).

The plan for Measurement, Monitoring and Verification (MMV) is agreed with the UK authorities as part of the storage permit. Its main objectives are the verification of the CO_2 containment in the storage complex and the validation (conformance) of the long term behaviour of the CO_2 injection.

The WRM plan complements the MMV activities by detailing the operational tasks for effective management. The WRM plan focuses on the operation of the injection systems and wells.

This WRM plan should be updated post-FEED and Final Investment Decision (FID) when final project definition will exist, yet pre-operation (Operations phase) i.e. Execute phase.

WRM activities will be adapted through time to meet the different requirements of the plan for MMV and to reflect any operational issues that may arise during the injection period. The surveillance and WRM plans are normally updated every year after CO_2 injection starts.

2. Asset description & storage development

A summary of The Storage Development Plan (Key Knowledge Deliverable 11.128) (2) is presented in this section for easy reference and to illustrate the main elements of the CCS system.

The Peterhead Carbon Capture and Storage (CCS) project proposes to separate, capture and permanently store CO_2, thereby reducing greenhouse gas emissions from the Peterhead power plant. Around 1 million tonnes per annum, of 99% purity CO_2, will be injected over a period of up to 15 years for storage in the UK Continental Shelf within the depleted Goldeneye hydrocarbon field. The Storage Development Plan (2) details the main parts of the development.

The three main components of the Peterhead CCS project are:

- Post-combustion removal of CO_2 from a portion of the flue gases from Peterhead power station by retrofitting the power station with a Carbon Capture & Conditioning Plant (CCCP). This part of the project falls out with the scope covered by this document.
- The captured CO_2 will be conditioned, compressed and transported in a dense phase via a portion of new build offshore pipeline and then the majority of the re-tasked 102 km Goldeneye gas export pipeline to the Goldeneye platform (Figure 2-1) in the North Sea.
- The CO_2 arrives at the platform where it is filtered before injection into the reservoir. The CO_2 flows to an injection manifold where the flow will be directed to one or more wells. Reusing existing hydrocarbon production wells, the CO_2 will be injected into the depleted Goldeneye gas field for geological storage, at a rate of approximately one million tonnes per annum.

The injection target is the upper part of the Captain 'D' sub-unit where the CO_2 will displace and mix with the remaining reservoir hydrocarbon and the aquifer water that has swept the reservoir during production. The CO_2 will refill the voided hydrocarbon structure. As the refilling takes place there will be a front of CO_2 moving though the original hydrocarbon volume, displacing the invaded water.

The reservoir pressure will increase due to the CO_2 injection and the aquifer recharge.

Figure 2-1: Goldeneye Platform

The Storage Development Plan (2) also highlights the plan for the Peterhead CCS, in summary:

- Following capture, compression and conditioning at the Peterhead Power Station the dense phase CO_2 will be metered prior to transfer into a pipeline system.
- It will be transported from the power station in a short new build pipeline tied into the existing undersea Goldeneye pipeline.
- The current Goldeneye hydrocarbon processing facilities at St Fergus will not be required but the MEG (Mono Ethylene Glycol) system will be converted to methanol and reused.
- The 20" [508 mm] offshore pipeline will be cleaned and reused after testing for integrity. Some valves and spool pieces will need to be replaced. The CO_2 will be transported in dense phase at a pressure of around 1740 psia [120 bara].
- In addition to the 20" CO_2 export pipeline, the existing 4" pipeline from St Fergus will be reused to enable injection of methanol into the wells.
- The Goldeneye platform will be reused. The installation is normally unmanned which is suitable for CO_2 operations. Hydrocarbon producing facilities will be decommissioned. Vent and safety systems will be modified for CO_2 service and much of the pipework will be replaced with low temperature rated pipework. Filtration equipment will be installed in the platform.
- Goldeneye production wells will be reused for CO_2 injection. The completions will be replaced to accommodate the phase behaviour of the CO_2.
- The system is required to handle varying CO_2 rates from the capture plant, ranging from 89 to 137 tonnes per hour.

- Five existing wells are available for injection. Three wells will be recompleted as injectors, the fourth well will be used for monitoring and the fifth well will feature a subsurface abandonment with downhole cement plugs at the primary seal level.
- At any specific flow rate, one or two out of a selection of three injector wells will be called upon to provide the desired surface and subsurface pressures.
- Transient well operations (closing-in, starting-up and subsurface safety valve (SSSV) testing) are operations which require attention and monitoring.
- Late in injection life as the CO_2 plume grows the value of information from well monitoring will reduce allowing the monitor well to be used as a spare late-life injector.
- The fifth well will be a subsurface abandonment with downhole cement plugs at the primary seal level. Monitoring of this partially abandoned well would be performed during the project injection period. Information will be gained for assessing the final abandonment of this well and the rest of the injectors at the end of the life of the project.
- CO_2 injection rates will be metered at the platform and at the wells and integrity monitoring will take place. Conformance monitoring of the CO_2 injection will be executed as will containment and environmental monitoring.
- The wells each have a non-cemented completion with gravel pack and sand screens. These are to be re-used. The risk of plugging posed to these completions from fines in the offshore pipeline (residual after cleaning or from potential de-lamination of an internal coating) is being mitigated by the installation of a filtration package on the platform.
- The CO_2 injection facilities will be decommissioned at least 1.5 years after the end of injection and post-closure monitoring will be executed until handover of the CO_2 store to the UK authority.

The CO_2 will be injected into the storage site at a depth >8255 ft [2516 m] below sea level into the previously gas bearing portion of the high quality Captain Sandstone Member – in total a 130 km long and <10 km wide ribbon of Lower Cretaceous turbiditic sandstone fringing the southern margin of the South Halibut Shelf, from UKCS block 13/23 to block 21/2. At the Goldeneye field, this sandstone has permeability of between 700 and 1500 mD.

Since 2004, the field produced 568 Bscf [16.1 Bscm] of gas and 23 MMbbl [3657 MMl] of condensate. During production, the field experienced moderate to strong aquifer support – which also served to end the gas production from the wells as each well sequentially cut water.

The primary CO_2 storage mechanism will be accommodation in the pore space previously occupied by the produced gas and condensate from the Goldeneye field. A secondary mechanism will be immobile capillary trapping in the water-leg below the original hydrocarbon accumulation combined with dissolution of CO_2 in the formation water.

When CO_2 is injected into the field it will displace the invaded aquifer back into the aquifer. The CO_2 will form a layer due to gravity and unstable displacement effects and some of the injected CO_2 be displaced towards and possibly below the original oil-water contact. Once CO_2 injection has stopped the CO_2 is predicted to flow back into the originally gas bearing structure. However, between 20% and 30% of the CO_2 that was displaced into the water-leg will remain trapped in place due to capillary forces.

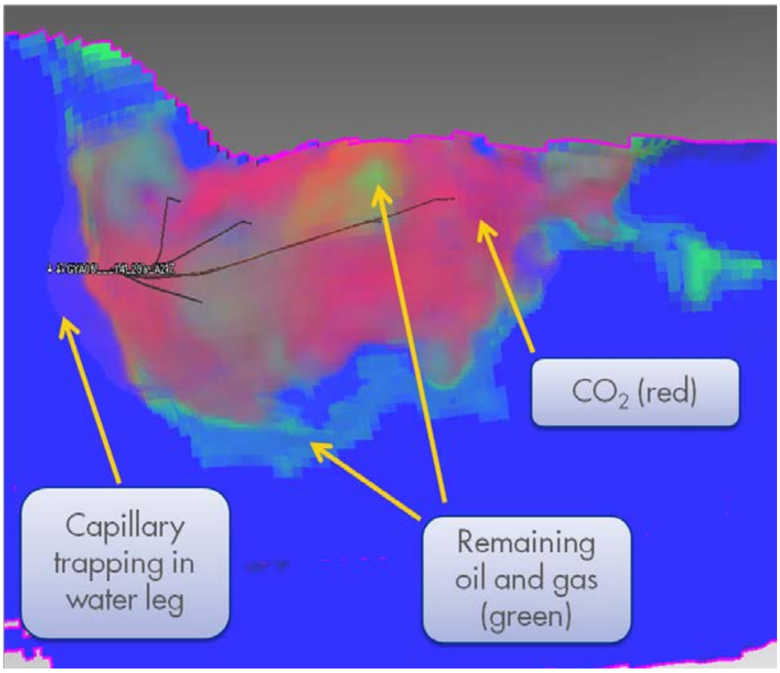


Figure 2-2: CO_2 plume after injection.

Note: Green: Hydrocarbon, Red: CO_2, Blue: Water

Analysis and modelling have shown that the field and water-leg have sufficient capacity to store over 30 million tonnes of CO_2 – more than sufficient for the 15 million tonnes proposed in the UK competition.

The Goldeneye field is hydraulically connected through the Captain Aquifer water-leg to the neighbouring fields in the east (Hannay, 14/29a-4 discovery – named Hoylake by Shell – and Rochelle) and in the west (the no longer producing Atlantic & Cromarty fields and, potentially the still producing Blake field). The pressure support from the Captain Aquifer has limited the decline in Goldeneye pressure, from an original of 262 bara to a little under ~145 bara (at datum level of 2560 m TVDSS).

Injection of 15 million tonnes of CO_2 will raise the pressure in the main interval, the Captain D to around ~259 bara at the end of injection.

Vertical containment is provided by the 130 m thick *storage seal*, a package including part of the Upper Valhall Formation, Rødby Formation, Hidra Formation and the Plenus Marl Bed. No gas chimneys are observed above the Goldeneye complex. The sealing capacity of the Rødby Formation is considered to be excellent as it acts as the primary seal for all hydrocarbon fields in the Captain fairway.

The site contains four exploration and appraisal (E&A) wells within the Captain reservoir and one immediately to the north (Figure 2-3). All of the E&A wells have good quality abandonment plugs at reservoir seal level.

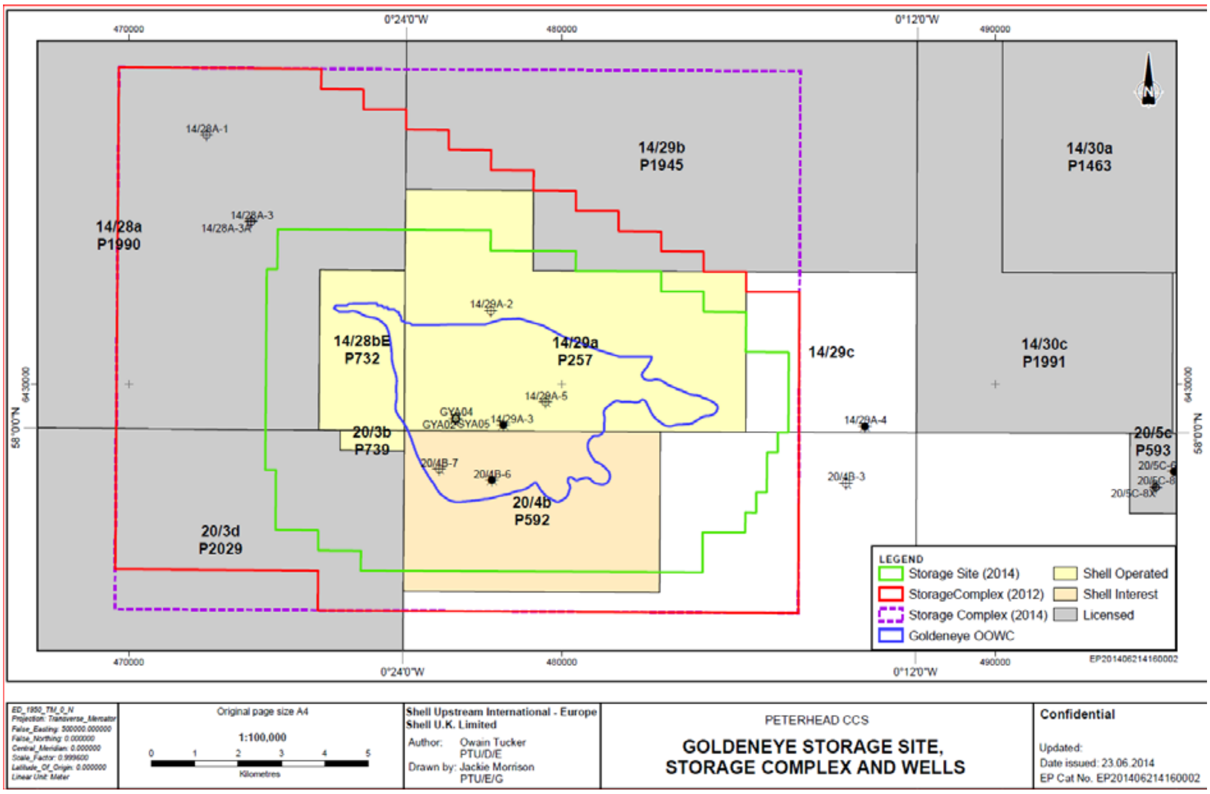


Figure 2-3: Wells in the site (demarked by green line).

3. WRM principles

The WRM Plan for Peterhead Goldeneye CCS complements the MMV activities by detailing the operational activities for effective management of the coupled wells and injection system.

The MMV objectives are the verification of the CO_2 containment in the storage complex and the validation (conformance) of the long term behaviour of the CO_2 injection. The security of storage will be ensured through MMV planning, complying with current and emerging UK and EU regulations. MMV activities will demonstrate compliance with UK and EU regulations regarding the monitoring programme for injection and storage of carbon dioxide.

The plans for MMV will be submitted to the Department of Energy & Climate Change (DECC) for its approval as part of the Storage Permit. The WRM plan complements the plans for MMV by adding the injection system. The WRM plan focuses on the operation of the injection systems and wells.

The WRM plan philosophy for the Goldeneye project is to ensure optimal CO_2 injection to meet the contractual agreement while maintaining overall system integrity (wells, reservoir and facilities). This will be done through active monitoring of the wells and reservoir from start up through acquisition of baseline data during the pre-injection phase and continuous acquisition of pressure, temperature and other required data in the wells and reservoirs. The acquired data will be used to calibrate the well and reservoir models for active well and reservoir monitoring.

In addition, the WRM plan summarises the most important elements of the plan for MMV, which affect the managing of the wells, facilities and reservoir.

In this first of a kind project, WRM focuses on continuous performance monitoring, recognising issues/problems and acting upon these variances.

The facilities integrity will be ensured through data gathering of key facilities data and preventive maintenance using the assigned maintenance schedule.

WRM activities will be adapted through time to meet the different requirements of the MMV and to reflect any operational issues arisen during the injection period. The surveillance plan is normally updated every year.

4. Key value drivers

The information below is adapted from the WRFM Strategy and reflects the changes to the project in the last year during FEED.

The WRM philosophy for the Peterhead Goldeneye CCS project is to ensure optimal CO_2 injection to meet the contractual agreement while maintaining overall system integrity (Surface Facilities - Capture Plant, CO_2 conditioning, compressor, pipeline, platform), wells and reservoir.

The key value drivers for the project are:

1. Storage containment.
    - a Integrity of injection wells.
    - b Abandoned E&A wells.
    - c Geological integrity.
2. Conformance.
    - a Monitoring CO_2 plume development.
    - b Monitoring pressure development.
3. Ensure operational and technical integrity.
4. System operability. Manage CO_2 rates in the system.
5. Maintain downhole CO_2 injectivity.
6. CO_2 inventory accuracy.
7. Management of CO_2 phase behaviour in the pipeline and wells.
8. Learning for future CCS projects – knowledge transfer.

4.1. Storage containment

The plan for MMV is designed according to a systematic risk assessment to ensure containment to demonstrate the safety of CO_2 storage and to protect human health and the environment.

4.1.1. Integrity of injection wells

The general philosophy to maintain the integrity of the injector wells is:

1. Design. Material selection, pressure and temperature rating of the different well components and CO_2 specification.
2. Maintenance.
3. Surveillance.
4. Identification/Analysis - Risk Assessment.
5. Remedial Activities.

The initial well design is the main barrier against well failures; appropriate tubing selection and material specification for injectors is required. Annular fluid in injectors should be chosen to minimise risk of corrosion.

Well surveillance is required to identify potential well integrity issues as early as possible. Once the action is properly identified it is then possible for remedial actions to be executed.

4.1.2. Abandoned E&A wells

There are seven plugged and abandoned E&A wells located within the storage complex. They provide an unlikely, but potential pathway to the seabed.

Of these seven, only four of the abandoned E&A wells will be in contact with the predicted CO_2 plume in the Captain reservoir and have been assessed to have good cement plugs across the primary seal. A fifth abandoned E&A well is within the field area but does not reach the Goldeneye reservoir.

Seabed monitoring will be performed in the vicinity of the wells to assure the absence of any CO_2 emission to the water column.

4.1.3. Geological integrity

The Goldeneye storage site is an area centred on the depleted Goldeneye gas condensate field as the primary container for the CO_2 planned to be stored from the Peterhead power station.

Based on an extensive site characterisation, there are no known migration pathways for fluids to escape upward out of the Goldeneye storage complex.

The bottomhole injection pressure should be maintained below a recommended limit dictated by the characteristics of the cap rock and the injection conditions.

4.2. Conformance: Well and reservoir performance under CO_2 injection

The plan for MMV includes the following performance targets for conformance monitoring:

1. Monitoring pressure development.
2. Monitoring CO_2 plume development.

The injection target is the upper part of the Captain 'D' sub-unit where the CO_2 will displace and mix with the remaining reservoir hydrocarbon and the aquifer water that has swept the reservoir during production. The CO_2 will refill the voided hydrocarbon structure. As the refilling takes place there will be a front of CO_2 moving though the original hydrocarbon volume, displacing the encroached water. If the CO_2 front moves into the aquifer leg of the reservoir seismic monitoring will detect the change in formation properties. When the front encounters the monitoring well GYA03 logging and pressure monitoring aims to identify the change in fluid properties.

The reservoir pressure will increase due to the CO_2 injection and the aquifer strength. The completion is selected taking into consideration the whole range of reservoir pressure from the start of injection to the end of injection. The reservoir pressure will be monitored.

A reservoir model will be developed and calibrated with reservoir pressure and plume location in order to predict further CO_2 plume movement.

4.3. Technical integrity

Operating envelopes for major facilities items and wells need to be approved. These operating envelopes should be followed to reduce equipment failure, operating in a steady state manner leading to maximisation of the project indicators.

4.4. System operability

Peterhead Gas Turbine GT-13 operation is expected to operate at base load. However, fluctuations in the CO_2 arrival rate to the platform needs to be managed by the system considering the technical limitations of each system. The arrival rates will be monitored and well selection will be carried out to manage the arriving injection rates. De-packing of the pipeline can be used for short term adjustment of the system.

4.5. Maintain CO_2 injectivity in the wells

Downhole injectivity needs to be monitored and maintained during the life of the project. Early deviations to the plan need to be recognized for planning of remedial activities if required. The plan aims to ensure injection of up to 15 million tonnes.

The design capacity of the capture plant is approximately 137 t/h. A particular well or a combination of wells should be able to achieve this injection rate during the life of the project.

A minimum rate of approximately 89 t/h (65% of the maximum rate) needs to be achieved by wells on injection.

Hydrate inhibition and filtration are important elements to maintain the integrity of the injection.

4.6. CO_2 inventory accuracy

The accuracy of the reported CO_2 stored will comply with regulations and protocols. It is important to clearly indicate the amount of CO_2 injected into the storage.

It will be important to monitor the CO_2 produced at the capture plant for operational and optimisation reasons and to fiscally monitor the CO_2 rates entering the pipeline.

Individual well meter allocation is important to calibrate the reservoir model.

4.7. Active management of CO_2 phase behaviour in the pipeline and wells

The minimum pressure of the pipeline should be kept above 75 bara to avoid two phase CO_2 flow performance issues.

The injection in the well is to be carried out in the dense phase and the wells will be operated in such a manner as to ensure that this phase is maintained.

Under normal injection conditions the CO_2 should be in dense phase along the length of the well because of the back pressure created by friction. As such the minimum wellhead pressure under injection conditions should be 50 bara. This pressure needs to be continuously monitored to ensure it is maintained. The maximum pressure available at the wells is approximately 115 bara.

Closing-in and starting-up operations need to be carefully monitored and followed. Operational procedures will be developed during detailed design of the project.

4.8. Learning for future CCS projects

The Peterhead Goldeneye CCS project has an important element of demonstrating CCS. As such, the ability to convey a clear message internally within Shell and externally to different parties is paramount.

5. Management of Risks / Uncertainties

The WRM plan also considers the Risks and Uncertainties in the project. The main Risks/Uncertainties for the different parts of the project are presented below affecting the WRM process. The majority of the risks are based on the CCS operating phase (constructions risks are excluded as they are not considered in the WRM plan).

5.1. Subsurface and wells operability risks and uncertainties

Table 5-1: Subsurface and wells operability risks and uncertainties

Threats /Uncertainties	Impact	Likelihood	Severity	Ability to Influence	Mitigation Remediation	Surveillance Activities
Injection Wells. Uncontrolled CO_2 expansion during injection.	Integrity in the top of the well	VL (small tubing)	VH	VH	Maintain a minimum pressure/rate in the wells Operational procedure for closing-in / open-up the wells	Pressure and Temperature monitoring
Injection Wells. Hydrates formation.	Injectivity deterioration and integrity	VL (hydrate inhibitor)	M	VH	Inject hydrate inhibition during shut-ins Number of wells to be completed (back-up)	Pressure and temperature monitoring Hydrate inhibitor injection
Injection Wells. Injection of big Particulates.	Injectivity deterioration	VL (with filtration)	M	VH	Filtration specified at the platform Number of wells to be completed (back-up)	Filters pressure monitoring
Injection Wells. Presence of	Injectivity Economics	VL-M VL after	L	VL	Displace hydrocarbon gas with water and CO_2	Pressure monitoring. Wellhead samples

hydrocarbon gas before starting CO_2 injection.	(intervention)	workover M in the monitor well			Intervention required in case of finding hydrocarbon gas in the well	
Low temperature during testing of SSSV.	Integrity Economics	L	M	VH	Well design. SSSV development Operational procedure.	Measure temperature along the well and pressure and temperature at the wellhead.
Pitting of 13Cr tubing material.	Integrity Economics	VL	H	VH	Removal of O_2 in the CO_2 stream	Monitoring of CO_2 contaminants
External corrosion of conductor and surface casing.	Integrity Economics	L	L	H	Corrosion assessment, evaluation. Preventive measurements depending on corrosion Possible intervention to replace biodegraded rape seed oil in the C-annulus.	PEC surveys
Small Leak/Release at the wellhead/Christmas tree to atmospheric conditions.	Integrity Economics	VL	L	VH	Assessment of well conditions during small leak/release. Well design to minimise leakage impact.	Temperature monitoring SSSV periodic testing
Uncontrolled leak (blowout).	Integrity Economics	VL	VH	VH	Well design to avoid uncontrolled leak (i.e. SSSV installation and development)	SSSV periodic testing
Integrity of Existing GYA wells.	Integrity Economics	L	VH	M	Well monitoring Maintenance plan	PEC surveys Pressure and Temperature

						monitoring
Inability to safely perform offshore well intervention in CO_2 wells.	Economics Limited surveillance	VL	M	VH	Equipment designed to manage well conditions. Well control equipment. Operational procedures	Pressure, temperature, and alarms (level, gas detection) in the intervention equipment.

5.2. Subsurface and wells containment and conformance risks and uncertainties

Based on an extensive site characterisation, there are no known migration pathways for fluids to escape upwards out of the Goldeneye storage complex. Prior to implementing MMV/WRM, several safeguards are already in-place to reduce the risk of any unexpected loss of containment due to an unknown migration pathway. There are two distinct types of safeguards or barriers: preventative safeguards that reduce the likelihood, and corrective safeguards that avoid, mitigate or remediate the potential consequence of any loss of containment.

Table 5-2: Subsurface and wells containment and conformance risks and uncertainties

Threats /Uncertainties	Impact	Likelihood	Severity	Ability to Influence	Mitigation Remediation	Surveillance Activities
Injection Well. Tubing leak.	Containment	VL (O_2 control)	VH	VH	Site selection Well design (material selection, CO_2 management and CO_2 specifications)	In-well monitoring, well surveillance
Injection well. Behind production casing cross flow.	Containment	VL	M	VL	Site selection Well design. Modelling of stress of injection in cement. Corrective Measures Plan.	In-well monitoring, well surveillance (Temperature logs). Cement log during workovers
Leakage through	Containment	VL	VH	VL	Site selection	Seafloor monitoring

plugged and abandoned wells.					Well Abandonment assessment of the primary and secondary seal. Corrective Measures Plan.	
Stress of Injection under injection conditions.	Containment. Localised failure of seal integrity	VL	M	H	Maintain injection pressure below a recommended limit.	In-well monitoring (PDG, DTS), surface pressure monitoring.
Acid Fluids reaction with cap rock and interaction with existing faults.	General Seal Integrity	VL	L	VL	Modelling of this long term process	In-well tools monitoring (DAS)
Acid Fluids reacting in the formation.	Weakening of the formation, possible damage to lower completion	VL	VL	VL	Modelling and laboratory analysis	Injection pressure/behaviour
Existing faults, mapped/unmapped crossing primary seal.	Containment	VL	M	VL	Storage selection	CO_2 monitoring, seismic survey
Lateral migration beyond the storage complex.	Conformance	VL	L	M	Site selection Modelling Selection of injection wells	Seismic survey, CO_2 plume monitoring (CO_2 breakthrough in wells)
Reservoir Pressure increase more than predicted.	Conformance. Injectivity	L	L	VL	Number of wells to be completed	Reservoir pressure monitoring Aquifer monitoring

5.3. Integration risks and uncertainties

Table 5-3: Integration Risks and Uncertainties.

Threats /Uncertainties	Impact	Likelihood	Severity	Ability to Influence	Mitigation Remediation	Surveillance Activities
System Operability. Not able to inject the CO_2 rates.	Economics	M	M	VH	Different components of the chain to have similar operating envelopes Optimisation process. Modelling of the CCS chain	CO_2 rates, pressure and temperature monitoring in different parts of the chain.
System Uptime poorer than expected.	Deferment Economics of the project	L	M	VH	Preventive maintenance, equipment sparing philosophy, adequate system metallurgy. Commissioning period of the capture plant.	Frequent surveillance of operating conditions.
Onerous site closure obligations and post-closeout monitoring requirements.	Economics	VL	L	L	Demonstration project. Delay in obtaining the storage permit.	MMV and WRM plan updates
Operations staff lack of CO_2 operating experience	Reputation Operability Integrity	L	L	VH	Follow operational procedures Training	Training
Installation of wrong materials in the chain.	Integrity Cost	VL	H	VH	Design. Install proper materials	Pressure and Temperature monitoring

						CO_2 gas detection
CO_2 thermodynamic behaviour	Integrity Operability	L	VL	H	Use enough safety and operability margins in equipment selection / design and operating procedures.	CO_2 composition monitoring.

6. Surveillance strategy

The plan for MMV conformance and containment is subject to different value drivers when compared. Conformance risks affect project value so conformance monitoring plans were selected according to their value of information. Containment risks affect project safety and environmental performance so containment monitoring plans were selected to ensure these risks are as low as reasonably practicable.

Considering the WRM value drivers and the risks and uncertainties in the projects drives the surveillance strategy.

The facilities surveillance is based on the following:

- Remote monitoring.
- Mostly routine data acquisition.

The Goldeneye well and reservoir surveillance strategy is based on the following:

- Re-complete existing wells to CO_2 injectors and a monitoring well. These wells will be equipped with significant monitoring equipment.
- Remote monitoring.
- Routine and non-routine data acquisition.

6.1. Surface

The required high level surveillance in the surface facilities applicable to the value drivers are:

Table 6-1: Surface Surveillance.

Value Driver	Surveillance
Storage Containment	• Geochemical tracer injection (storage / leak detection objectives).
Conformance (Well and Reservoir)	• GPS (for surface deformation events)
Technical Integrity	• Pressure and Temperature monitoring of different surface elements. • Compositional analysis of the CO_2 (mainly water, oxygen and light contaminants) • Leak detectors • Pipeline Intelligent-Pig
System operability	• Pressure drop across the filters • Power consumption • Chemical Usage • Monitor non-hydrocarbon samples during hydrocarbon freeing of pipeline (already done) • Hydrate inhibitor meter
CO_2 injectivity	• Flow meters • Wellhead pressure, flowrate
CO_2 inventory	• Flow meters (volumetric and pipeline leak detection) • Leak detectors

Management of CO_2 phase behaviour	• Pressure and temperature monitoring of different surface elements.

6.2. Injector wells

The required high level surveillance in the wells-reservoir are:

Table 6-2: Injector Well Surveillance.

Value Driver	Surveillance
Storage containment	• Downhole pressure monitoring • Well intervention (temperature log) • Annul monitoring • In-well monitoring (PDG and DTS)
Conformance (well and reservoir)	• Downhole pressure monitoring • Flowmeters • Well intervention - logging
Technical integrity	• Initial integrity measurements in the wells (e.g. cement bond log & calliper log) • Wellhead maintenance in existing well • PEC survey • Annuli monitoring • In-well monitoring
System operability	• Flowmeter • Surface pressure monitoring • Seabed survey (for constructability)
CO_2 injectivity	• Flowmeter • Surface pressure monitoring • In-well monitoring (Downhole gauges)
CO_2 inventory	• Individual well flowmeter
Management of CO_2 phase behaviour	• Pressure and temperature measurements • Individual well flowmeter

6.3. Reservoir data acquisition

The first stage will involve creating reliable baselines variability assessment for each domain to establish a pre- injection condition.

Monitoring of the reservoir performance starts during the pre-injection phase by recording and analysing the reservoir pressure.

During the injection phase there will be a period of continuous monitoring to validate and update numerical models and ensure safe injection operations.

Table 6-3: Reservoir Data Acquisition Surveillance

Value Driver	Surveillance
Storage containment	Store, Exploration & Abandoned wells • Geochemical probe for seawater monitoring (around the platform) • Seabed map • Seabed samples • Seismic (base, mid-life and post-injection)
Conformance (well and reservoir)	• Downhole pressure monitoring • Monitoring well (well intervention) • Flowmeters

6.4. Monitoring well

The focus is to monitor the location of the CO_2 plume to give early warning of unexpected migration behaviour.

The data gathering plan for this well includes fluid contact monitoring by logging, which will confirm CO_2 arrival at the well.

Dynamic simulation prediction drives the start and duration of the surveillance programme in GYA03. It suggests the timing when the CO_2 plume will reach the monitoring well (GYA03 in the base case scenario).

7. Surveillance Plan

The surveillance plan for this project will ensure the acquisition of relevant data at required intervals for the optimisation of injection and monitoring of the injected fluid.

The surveillance plan below indicates the level of surveillance required from the compressor/conditioning unit to the reservoir.

The key data acquisition requirements are reported according to the different phases of the project:

1. Pre-Injection phase.

   Baseline information is required to be obtained at this phase for further comparison with injection or post injection surveillance to verify the store. Equally, early information will allow informed decisions on the injection system.

2. Operational Phase – Routine surveillance.

   Steady information feeding the system. Frequency is variable depending on item.

3. Operational Phase – Non routine surveillance.

   Usually this non-routine surveillance requires intervention.

4. Post-Injection Phase.

   Some monitoring activities continue during this phase to manage containment risk and to demonstrate that storage performance is consistent with requirements for long-term secure storage.
   Post-closure activities will be executed including facilities decommissioning, pipeline abandonment and reclamation, and wells abandonment and reclamation.
   Shell will apply for transfer to UK Competent Authority following the execution of post-closure activities.

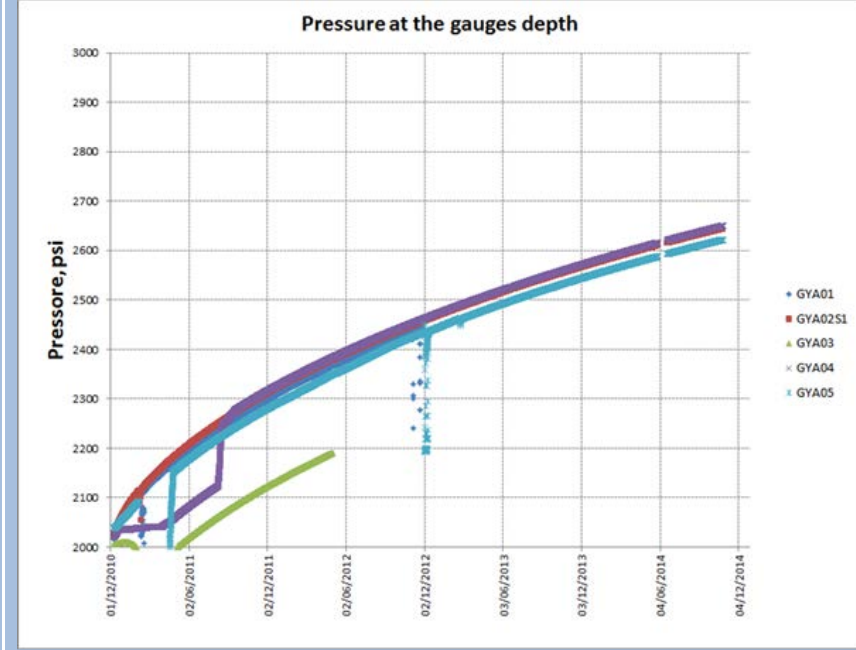
The surveillance plan is also subdivided in the different elements of the project:

1. Compressor and Conditioning Unit.
2. Transportation (Pipeline – Platform).
3. Store (Wells – Reservoir).
4. General – Integration.

These are presented in Table 7-1 below.

Table 7-1: Peterhead CCS Surveillance Plan

Phase	Unit	Activity	Remarks
Pre-injection	**Compressor and Conditioning Unit**	N/A	Not built yet.
	Transportation	Intelligent pig run	Plan for the pre-commissioning phase. Intelligent pig for existing (and new) pipeline wall thickness evaluation.
		General maintenance of the platform	Maintain equipment which can be reused for the project. Follow maintenance practices.
		Hydrocarbon freeing of pipeline	Already carried out. Sampling of any non-hydrocarbon material in the pipeline.
		GPS	GPS sensors to be installed on the platform to monitor subsidence. They need to be installed as soon as possible after FID. Data from the GPS sensor need to be transmitted to shore and linked to PI Process Book.
	Store **(Wells and Reservoir)**	Wells	
		Reservoir pressure monitoring	Reservoir pressure to be monitored in the existing wells. Deep set plugs were set above the PDG in three of the existing wells (GYA02S1, GYA04 and GYA05) which allows monitoring of the reservoir pressure build up during this phase. This pressure is currently monitored, Figure 7-1

Phase	Unit	Activity	Remarks
			 **Figure 7-1: Reservoir pressure increase post-injection** This information is important for aquifer understanding related to the final reservoir pressure after injection and design of the tubing X-Over point between 4 ½" and 3 ½" [114 mm and 89 mm].
		Wellhead maintenance	The Christmas tree valves are required to be maintained as normal practice during this phase despite the installation of a deep set plug in the wells. Note: Christmas trees will be replaced.
		Annuli monitoring	Monitor A, B annulus pressures Top-up, bleed-off pressure as required. As per eWIMS. In case of top-up required in the B-annulus, it is recommended that

Phase	Unit	Activity	Remarks
			seawater should be displaced with freezing point depressing.
		Pulse Eddy Current - PEC survey	Information required for evaluating the condition of the casing and conductor in terms of corrosion rate. Last survey was carried out in June 2014. It is recommended that the PEC survey be carried out every three to four years.
		Surface casing movement	Monitoring of surface casing eccentricity/movement with respect to the conductor.
		Retrieve and re-set downhole suspension plugs	Prior to the rig mobilisation it is recommended that a slick-line campaign to retrieve and re-set the downhole suspension plugs should be carried out. At the same time, it is also possible to test the existing Formation Isolation Valve (FIV) in each well.
		Cement Bond Logging Casing Integrity Logging	Initial cement bond logging and casing integrity logging will be performed during the workover operation. This will ensure cement bond quality and casing integrity to ensure that there is no micro annulus in the cement bond and no leaks / holes in the casing. The logging will be performed when the upper completion is pulled out of the hole.
		Sigma and neutron logging	CO_2 conformance. In the monitoring and injection wells. Baseline for fluid contacts.
		Workover operation - surveillance	Workover programme will include surveillance activities to maintain integrity and to minimise any possible lower completion/formation damage
		Seabed survey	For rig placement around the wellbore in the platform Seabed survey was carried out in May 2014. An additional survey might be required depending on the selected rig to perform the workovers.
		Distributed Temperature	Baseline for geothermal conditions

Phase	Unit	Activity	Remarks
		Sensor (DTS)	Monitoring and injection wells
		DAS VSP + DAS Noise + DAS Experimental micro-seismic	Baseline for containment monitoring near wells. Monitoring and injection wells.
		Seabed and Shallow Layers	
		Geochemical probe CDT	Seabed and water column profiling under platform. Baseline for indication of increased CO_2 flux and changes in environmental properties. Base line, pre-injection.
		MBES (Multi-Beam Echo Sounder)	Baseline for seabed leakage identification and quantification. Seabed map – Pockmarks monitoring. Applicable to the storage complex
		Seabed samples (seabed sediment and fauna)	Sampling points within storage complex- emphasis on high risk area (wells, seismic anomalies, platform). Baseline for seabed leakage identification and quantification
		Geosphere	
		3D Streamer	Baseline covering large area of field overburden and aquifer Storage Complex
		Ocean Bottom Nodes - OBN	Provides best seismic resolution in the vicinity of the storage site area (compared to undershoot) Surrounding platform area
Operational Routine	**General (Integration)**	Injection rate measurements	Surveillance, metering and allocation design principles guide the end to end of the metering system for the project. The meter's specification on the platform is discussed out with this report.

Phase	Unit	Activity	Remarks
			Meter before the compression and conditioning package Flow of CO_2 to the compression and conditioning package via pipework is to be metered using the appropriate technology and meet an accuracy of ± 7.5% (Tier 1). Composition of CO_2 will also be required via an analyser package. **CO_2 Export meter** The export metering of the CO_2 will be located at Peterhead between the compressor and the offshore pipeline. The metering package will be designed to accommodate the range of the CCS chain operations. The uncertainty in the measurement of mass flow of exported CO_2 will, with a confidence interval of 97 %, comply with the European Emission Trading Scheme (ETS) Tier 4 requirement of better than ±2.5%. **Offshore meter** A single venturi meter with 2 x 100% (redundancy) associated pressure and temperature instruments. Mass flow of CO_2 shall be metered upon entry to the platform and shall meet an uncertainty of ±2.5% for a mass rate over a range of 89 kg/h to 137 kg/h When the export rate from Peterhead drops below the minimum required for a single injection well, control on the platform will change from 'pipeline back-pressure control' to 'minimum injection flow rate control'. This is required to conserve line pack during outage or reductions in export from Peterhead and to avoid 'closing-in' the wells.

Phase	Unit	Activity	Remarks
			Individual well flowmeter Venturi type meters will be installed in the flow line to each well, downstream of the manifold, for identification of CO_2 injection in each well. Flow metering of each well is a particular requirement at the end of the project should two wells be required to inject the maximum capture plant rates (137 t/h). Ensure flowrate into each well is within acceptable limits. Uncertainty of measurement is to be in the order of 7.5%. Well flow allocation of CO_2 for multiple injection wells. The meters can be adapted to variable flow rates by changing the internals.
	Compressor and conditioning unit	Pressure, temperature readings	Different elements to be monitored. Inlet – Outlet of the compressor
		CO_2 Compositional analysis	CO_2 discharge from compressor package (prior to CO_2 Export Meter) Full spectrum composition analysis of the CO_2 entering the pipeline. Determine the composition of the CO_2 stream for injection to ensure it is within specification with respect to impurities. Important to monitor O_2 composition and water content. An analytical package shall be installed to monitor the required composition of CO_2 prior to injection in line with EU Directives. Dense phase CO_2 shall be analysed by means of on-line duty/standby gas chromatographs and outlet header water dew-point analyser at the discharge of the compression and conditioning package.
		Chemical usage for conditioning	Monitor for optimising the Hydrogen use for Oxygen removal and performance of the molecular sieves for dehydration
		Compressor Power consumption	Ability to optimise the performance of the compressor.

Phase	Unit	Activity	Remarks
		Geochemical tracer injection	This item is still under research. The use of geochemical tracers in CO_2 gas injection is still in its early stages. If the technique proves effective, then it could be added to the Goldeneye CO_2 stream using continuous injection method. The primary aim of adding a tracer is to uniquely tag the Goldeneye CO_2 stream, which will help with the identification of sources of any CO_2 detected outside the Goldeneye complex. For the point of tracer injection, there are two feasible options: Peterhead and Goldeneye platform. Different fluids can be used: Commercial Per-fluorocarbon (PFC), Noble Gas (Xe, Kr, He, Ar, Ne) or Non-Tracer based. This will be decided in the detailed design phase but an injection tie-in point is required after the compressor.
	Transportation	Pressure, temperature readings	Different elements to be monitored (in the pipeline, platform and into the wells).
		Pressure drop across the filter package	Evaluation of the performance of the filters and define change/out frequency.
		Gas detection	Measure the accumulation and migration of gas clouds within and between the process modules respectively. Line of sight technique and point detectors
		Hydrate inhibition meter	Hydrate inhibitor (methanol) shall be metered from the onshore facilities prior to entering the pipeline and also offshore as the existing methanol line enters the platform. By using two meters this will provide the means to perform leak checks on the subsea methanol line. An accuracy of ±7.5% (Tier 1) will be required for the provision of methanol.
	Store (Wells and Reservoir)	Wells	
		GYA03. Monitoring well	The GYA03 well will be used primarily as a monitoring well; although it will be equipped as the injector of last resort.

Phase	Unit	Activity	Remarks
		Wellhead information (Pressure and temperature sensors on each well.)	In order to monitor the injection pressure and temperature as well as annular pressure and temperature, pressure and temperature gauges will be installed at the wellhead for monitoring the tubing, annuli A, B and C as well as the control line. This is to ensure that the injection pressure and temperature are within the designed operating envelope to ensure that the injected CO_2 remains in the dense phase throughout the injection period. It is also important to monitor the annular pressure and temperature, as any abnormal changes will be a fast indication of tubing or casing integrity problems. The data from the gauges will be transmitted online to the control room for integration into the database.
		Annular pressures	Annular pressure gauges will be installed on the A and B annuli at the well head.
		In-Well monitoring	These are direct measurements of down-hole changes by permanent sensors incorporated into the well design. This group of technologies provides detailed information about changes within the well and the near-well environment (e.g. within 5m), but provides no information about changes further afield. PDG, DTS and DAS (see below)
		Permanent Downhole Gauges (PDG)	It is planned to install three gauges in each of the three injection wells for reservoir pressure monitoring. Two injection wells (the first to be used) will receive an additional gauge close to the cross over point of injection tubing to facilitate calibration of flow modelling software and enhance knowledge transfer. Down Hole Pressure Gauges (DHPG or PDG) provide single point pressure measurements in wells. The PDG will measure both temperature and pressure and are hence often referred to as P/T

Phase	Unit	Activity	Remarks
			gauges. The main reasons for installing the PDGs are: (i) Monitoring and understanding the CO_2 behaviour in the tubing (ii) Early identification of injectivity issues (iii) Monitoring of reservoir pressure to be able to calibrate the subsurface models (iv) Others: understanding of the well start-up, identification of tubing leaks and in general it will help to understand any operational issue in the wells. PDGs will be installed in both the injection and monitoring wells for continuous measurement of the downhole injection pressure and reservoir pressure. A PDG will be installed deep in the A-annulus to give fluid pressure due to the complexity of annulus surface interpretation using the N_2 and the base oil in the A-annulus.
		Distributed Temperature System (DTS)	Distributed Temperature Sensing (DTS) obtains temperature information through a fibre optic system based on backscattering of laser pulses. Installed in a well, the system measures the temperature continuously along the full length of the fibre optic cable. Changes in temperature that result from changing fluid mixtures or reservoir conditions can be monitored in detail. DTS will require fibre optic capabilities in the wells and on the platform. The DTS provides temperature measurements at approximately 1.0 m intervals along the length of the fiber optic cable producing a profile of temperature effects along the injection tubing. The main reasons to install the system in the wells are: (i) Help in the optimisation of the wells start-up (ii) Tubing leak identification

Phase	Unit	Activity	Remarks
			(iii) Potential identification of out of zone injection (iv) Understand and reduce SSSV testing timing DTS will be installed in both the injection and monitoring wells for continuous measurement of the temperature along the tubing down to close to the production packer. The DTS is especially important in monitoring transient conditions in the top of the well.
		Distributed Acoustic System (DAS) -	DAS will be installed in both the injection and monitoring wells for continuous measurement of the acoustic signal. DAS turns a single mode fibre optical cable into a distributed microphone (acoustic sensor). It can use an existing single mode fibre in a DTS control line. Although the installation of the DAS clamped to the tubing is not a problem or major cost, the ability of the DAS to measure leakage needs to be evaluated. DAS for noise evaluation (well leak) will be used in a continuous mode.
		Seabed and Shallow Layers	
		MBES (Multi-Beam Echo Sounder)	Leakage identification and quantification. Seabed marks and pockmarks. Applicable to the site and storage complex. To be carried out at mid of injection approximately 5-7 years.
		Seabed samples (seabed sediment, flora and fauna)	Wells (E&A) surface location Indication of increased CO_2 flux and change of environmental properties. To be carried out at mid of injection approximately 5-7 years for site. Options included Van Veen Graag and Vibro Corer. Technologies

Phase	Unit	Activity	Remarks
			need maturation, will be selected in next phase.
		Water column and seabed profiling	Around the injector wells. Seabed and water column under platform. Indication of increased CO_2 flux and change of environmental properties. Bubble detection during Remote Operated Vessel inspection of the platform legs; normally carried out every 3-4 years.
		GeoSphere	
		DAS VSP	DAS in VSP mode (time-lapse seismic) for containment near platform wells. Mid injection. CBN seismic as back-up.
Operational Non-Routine	**Compressor and Conditioning Unit**		
	Transportation	IP Run	Currently not-planned as the flow rate of CO_2 is unlikely to be sufficient to meet the minimum run speed of an intelligent pig tool.. There is a possibility of running intelligent pig run during the project life to verify the pipeline status. This can be carried out in case of severe or frequent water excursions from the conditioning unit. The pigging operation can be made affecting the injection rates and will be part of manned visits.
	Store (Wells and Reservoir)	Wells	
		Surveillance well logging	The well logging for Goldeneye-Peterhead CCS will consist mainly of containment checks and CO_2 plume monitoring. These are direct measurements of down-hole changes made by

Phase	Unit	Activity	Remarks
			occasional intervention in the well. This group of technologies provides detailed information about changes within the well and the near-well environment (e.g. within 5 m), but provides no information about changes further afield. **For Tubing Integrity:** - Tubing integrity. Calliper logs or image logs. For the efficiency of the evaluation, only the wells that have been actively injecting would undergo tubing integrity checks. - Cap Rock Integrity. Temperature log. DTS will give information on cap rock integrity above the packer. It is planned to run Temperature logs (slick-line) to complement the DTS below the packer in selected wells in case of observing anomalies in the DTS system. **For CO_2 plume monitoring:** The focus is to monitor the CO_2 plume breakthrough to calibrate reservoir models. The PDGs installed in the injector/monitor can be used to infer it from fluid gradient changes. The well intervention plan includes fluid contact monitoring by logging and sampling which will confirm CO_2 arrival at the well. - Downhole Fluid Sampling (slick-line) - Sigma and Neutron log (E-line)
		Surveillance well Intervention	**Year 3**, 3 wells (possible 4) 3* Tubing Integrity Logging + Temperature log. Possibility of downhole fluid sample in a well in case injection has not taken place in the well **Year 7**, 4 wells

Phase	Unit	Activity	Remarks
			3 * Tubing Integrity Logging + Temperature log 1 * Monitor: Downhole fluid sample + Sigma/Neutron Log **Year 11**, 4 wells 3 * Tubing Integrity Logging + Temperature log 1 * Monitor: Downhole fluid sample + Sigma/Neutron Log **Year 13**, 1 well 1 * Monitor: Downhole fluid sample + Sigma/Neutron Log
		DAS – VSP mode	DAS VSP Applicable to the injector and monitor wells. Containment monitoring near wells.
		Seabed and Shallow Layers	
		Seabed map – Pockmarks	MBES (Multi-Beam Echo Sounder) Applicable to the storage site complex Leakage identification and quantification
		Seabed samples (seabed sediment, flora and fauna and pore gas sampling)	Sampling points within storage complex. Indication of increased CO_2 flux and change of environments properties
		Geosphere	
		Seismic – storage complex	Indication of CO_2 migration in overburden and aquifer – similar to baseline. This is planned to be done with DAS-VSP in the wells. After ± 5 years of injection

Phase	Unit	Activity	Remarks
		Seismic - Surrounding platform area	Provides best resolution in vicinity of platform (compared to undershoot) Indication of CO_2 migration surrounding and underneath platform Mid-life of injection (~6-8 years)
Post - Injection	**Compressor and Conditioning Unit**		
	Transportation	Seabed samples (seabed sediment, flora and fauna and pore gas sampling)	Sampling points within storage complex could provide indications of increased CO_2 flux and change of environments properties.
	Store **(Wells and Reservoir)**	Wells	
		Pressure conformance	Permanent Downhole Gauges (PDG). For 1-2 years after injection Characterise pressure behaviour after injection Long term gauge after platform / wells abandonment might be included as a technology that needs maturation.
		DAS VSP	Containment monitoring surrounding platform area Pre-handover of the project. Year 1 after injection
		Seabed and Shallow Layers	
		MBES (Multi-Beam Echo Sounder)	Leak identification and quantification Seabed maps (pockmarks) Year 1 post injection, pre-handover of the complex
		Seabed samples (seabed sediment, flora and fauna)	Sampling points within storage complex Year 1 post injection, pre-handover of the complex

Phase	Unit	Activity	Remarks
		Geosphere	
		Ocean Bottom Nodes - OBN	Provides best seismic resolution in the vicinity of the seismic area (compared to undershoot) Surrounding platform area Year 1 post injection, pre-handover of the complex

8. WRM Actions

Surveillance activities monitor and gather information. This chapter describes in general some of the activities to be carried out with the gathered information.

8.1. Field Integrity Plan

In order to ensure field integrity and prevent failure of the wells and key surface equipment, a robust management plan for the wells, reservoir and facilities will be adopted. Wells, reservoir and facilities operating envelopes will be established and the field will be operated within these established envelopes.

8.1.1. Compressor and Conditioning Unit

In order to ensure compressor and conditioning unit integrity, preventive maintenance of all the equipment will be done according to their recommended frequencies. Surveillance data in terms of chemical usage and power consumption will allow optimising maintenance schedules and reducing costs.

The CO_2 composition after the conditioning unit is very important to warranty the proper integrity of downstream equipment in the chain (pipeline and wells). Reactive operations in terms of excursions of contaminants, water and Oxygen will be developed in further phases of the project.

8.1.2. Transportation (Pipeline and Platform)

The platform facility will continue to be not normally unmanned. In order to ensure facility integrity, preventive maintenance of all the equipment will be done according to their recommended frequencies. However, in order to minimise field visits, the maintenance of the various equipment will be synchronised as much as possible.

Occasional pigging of the pipeline will be made affecting injection rates and will be part of manned visits to the platform.

A detailed preventive maintenance plan will be prepared during the execution phase.

8.1.3. Wells

Routine wellhead maintenance, which will involve 6-monthly wellhead maintenance and 6- monthly SSSV checks, will be carried out.

In order to ensure casing integrity, continuous annular pressure monitoring will be carried out. A detailed annular management plan will be developed for managing annular pressures if they occur. This will be done in the further phases of the project.

In order to ensure hydrate inhibition in the well, batch methanol injection will be carried out prior to starting the well up during the initial stages of the injection. At a later stage, if water is introduced in the wells then methanol batch injection should continue.

The acquisition and interpretation of the tubing integrity logs will aid in ensuring that the well is integral and there will be no well failures.

The operating of the wells would likely require to be controlled. Closing-in and Starting-Up operations in the wells will require control to avoid moving the wells out of operating zone. This is also applicable to the testing of the SSSV.

8.1.4. Reservoir

In order to ensure that the reservoir is operated within the desired envelope, the PDG will be used to:

- Monitor the bottomhole injection pressure to ensure it does not go above the maximum allowable bottomhole pressure so as to reduce the risk of fracturing the seal above the formation.
- Measure the reservoir pressure to ensure the initial reservoir pressure is not exceeded so as to also not fracture the formation seal.

In addition, time of CO_2 breakthrough will need to be monitored in order to adjust the dynamic reservoir models for verification of lateral CO_2 plume migration in the store.

8.2. Metering Plan

The CO_2 export metering for the project will be handled at Peterhead after the conditioning unit. At the platform, there will be meters that will measure the total flow received. Individual flow meters will also be installed on each well for allocation.

There will also be the capability and requirement to carry out sampling on the platform at start-up to determine the quantity of water in the CO_2 stream.

8.3. Information and Data Management

The data from the PDG, well head temperature, pressure measurements, and flow rates will all be transmitted to the platform control room which has robust databases that store all acquired data on site with local backup. All data will be screened to prevent cyber-attack for internal and external sources.

Live data from different surveillance tools are required. The total data transmission from the well/ reservoir and chemical sensor is estimated at ~1 Mbits/s, and divided as follows:

- PDG/DTS: low band with~ 260 kb/s is required for data transmittal to Tullos office. Downhole P&T gauges require 4U + 1U airspace space in the platform. DTS will require 1U space in the platform.
- DAS system. The DAS system will also require data transmission to the office for calibration purposes and flow measurement; 100 kb/s is necessary for operation of the DAS VSP, micro-seismic and noise equipment. The space required is 42U for all wells. DAS will be normally run in noise/flow mode with SSV/micro-seismic will run on a demand occasion.
- DAS VSP. 250 kb/s is required to operate the DAS VSP/micro-seismic. During VSP surveys the amount of generated data is very high to be transmitted either by line of sight or satellite. Storage on the platform for the DAS data is required. It can be recovered during the regular visits to the platform by the operations group, between 2-3 months. This is based on operational requirements and the amount of data to be transmitted.
- DAS system in flow/noise mode. 200 kb/s.
- Chemical sensor: Data transmission from the chemical sensor is estimated at 160 kb/s.

In addition, various technologies are available to integrate the acquired data into any IT environment. Industry-standard technologies such as the Modbus communication protocol, OPC open connectivity, well site information transfer, standard markup language (WITSML), and SQL database replication can be used to deliver the data in real time to SCADA systems, data historians, the Schlumberger Inter ACT real-time monitoring and data delivery secure Web service, or simply to Microsoft Excel® software on a personal computer.

All the documents generated by the team and the models will be stored in the team's directory. The details of the data management plan will be covered in the execution phase.

8.4. Modelling Strategy

Models will be required both to monitor the performance of the wells and to monitor the movement of the CO_2 in the reservoir. Already, there are individual WePs and Prosper models for the wells. For integrated production system modelling purpose, IPSM models will be built. The reservoir dynamic model will also be updated. Hall plots and pressure transient analysis will be carried out in the injectors.

8.4.1. IPSM

The Integrated Production System Model for the wells, reservoir and facility will be built. This will be used to monitor the integrated system performance and will be particularly useful for optimising injection among the different wells during any fluctuation in the CO_2 supply from the power plant.

The models will be updated annually except when there is significant change in well and reservoir behaviour or when new subsurface data are acquired.

8.4.2. Dynamic Reservoir Model

A pre-injection reservoir dynamic model has been built. This will be updated with the baseline seismic survey and then with the first set of data that will be acquired post workover. Further updates of dynamic reservoir models are required after significant events occur in the store (e.g. CO_2 breakthrough) or approximately every 2 years of injection.

8.4.3. Maps

The reservoir maps will be updated whenever there is new seismic acquisition that indicates change in reservoir-wide fluid contacts.

8.4.4. Surface Facility Model

The surface facility model for the field will be built and updated annually or if there is any major change in the operating conditions.

OLGA and PipeSim models will be updated with operational information.

9. Execution of WRM plan

9.1. WRM resources

A WRM team will be formed to manage the Peterhead CCS wells and reservoir. This will involve subsurface, wells and surface disciplines. Peterhead CCS will require a strong experienced WRM team. In addition, training on specific aspects on CO_2 will be required.

Typically a WRM is formed by the following disciplines:

- Senior Production Technologist.
- Reservoir Engineer.
- Operations Engineer / Programmer.
- Facility Engineer.
- Production Geologist.
- Petrophysicist.

- For CCS this team will also include access to monitoring specialists: geophysics and environmental monitoring and well engineering.

The members of the WRM team will be variable with time. It is expected that more resources are required during the start-up of the project (Production Technologists, Programmer and Facility Engineer). It is likely that many of the members of the WRM team will be part time.

It is a requirement that all staff working in the team complete WRM and CO_2 aspects training prior to start up.

The staffing levels and experience should be defined in the detailed design phase of the project.

9.2. Annual Budget

Annual Budget will be required for the maintenance of the facility, wells and data acquisition needs post initial workover. This annual budget will be made every year based on the WRM plan of the following year.

9.3. Reviews

Multi-disciplinary reviews should be conducted daily (using exception based surveillance methodology) to review performance against operating envelopes, conduct quick analysis of injection changes, propose intervention (immediate operational actions) or escalate for more detailed analysis as necessary.

Well and reservoir reviews should be conducted monthly to review well - reservoir interactions, injection trends; and to identify data gathering and intervention opportunities and requirements.

Reservoir performance reviews should be conducted annually to achieve a systemic understanding of reservoir behaviour and performance. This will identify key issues and uncertainties that need to be addressed, and allow data gathering and intervention plans to be tailored. Highlights of the evaluation and the follow-up actions may then be documented in a comprehensive Reservoir performance review book.

Similar in-depth annual reviews will be required for wells and facilities, which will be documented in well books and facility review documents.

10. References

1. **Shell, PCCS-05-PTD-ZP-9025-00003 (DECC Deliverable Y11).** *Storage Permit Application Part III, (Metering, Monitoring and Verification Plan).* 2015.

2. **Shell, PCCS-00-PT-AA-5726-00001.** *Storage Development Plan, (Key Knowledge Deliverable 11.128).* s.l. : Shell Peterhead CCS, 2014.

11. Glossary of terms

13Cr	13 percent chrome content metallurgy
'A' annulus	Annulus between the production tubing and production casing string
Annuli	The space between adjacent strings of tubing or casing
'B' annulus	Annulus between the production casing and intermediate casing string
Blowout	Uncontrolled release via the wellbore to surface
Bscf	Billion Standard Cubic Feet
Bscm	Billion Standard Cubic Meters
Cap rock	The shale layers above a reservoir that provide geological isolation to upward migration and provide the primary seal
CCCP	Carbon Capture and Conditioning Plant
CCS	Carbon, Capture and Storage
CDT	Conductivity Depth and Temperature
CO_2	Carbon Dioxide
Completion	The conduit for production or injection between the surface facilities and the reservoir. The upper completion comprises the tubing and packer, etc. The reservoir completion is the screens, etc., across the reservoir interval.
DAS	Distributed Acoustic Sensing
DECC	Department of Energy and Climate Change
Define	FEED phase
DHPG	Down Hole Pressure Gauges
DTS	Distributed Temperature Sensing
E&A	Exploration and Appraisal wells
ETS	Emission trading scheme
EU	European Union
Execute	Post-FEED and post-FID phase
FEED	Front End Engineering Design
FID	Final Investment Decision
FIV	Formation Isolation Valve
GPS	Global Positioning System
HIPPS	High Integrity Pressure Protection System
IPSM	Integrated Production System Model
kb/s	Kilobytes per second
MBES	Multi Bean Echo Sounder

MEG	Mono Ethylene Glycol
MMbbl	Million Barrels
MMl	Million Litres
MMV	Measurement, Monitoring and Verification
Mtpa	Million Ton Per Annum
OBN	Ocean Bottom Node
Operations	Post-Execute phase
PDG	Permanent downhole gauge
PEC	Pulse Eddy Current
Petrel	3rd Party software "seismic to simulation"
Production casing	The casing providing the secondary wellbore barrier during production or injection (valid term even in injection mode)
SCADA	Supervisory control and data acquisition
Select	Pre-FEED phase
SSSV	Subsurface Safety Valve
TVDSS	Total Vertical Depth Subsea
UKCS	United Kingdom Continental Shelf
VSP	Vertical Seismic Profile
WRM	Well and Reservoir Management
WRFM	Well, Reservoir and Facilities Management

12. Glossary of Unit Conversions

Table 12-1: Unit Conversion Table

Function	Unit - Imperial to Metric conversion Factor
Length	1 Foot = 0.3048 metres 1 Inch = 25.4 millimetres
Pressure	1 Bara = 14.5psia
Temperature	°F=(1.8)(°C)+32 °R=(1.8)(K) (absolute scale)
Weight	1 Pound = 0.454 Kilogram
Volume	1 Bscf = 0.0283 Bscm
	1 MMbbl = 159 MMl

Table 12-2: Well Name Abbreviation Table

Full well name	Abbreviated well name
DTI 14/29a-A3	GYA01
DTI 14/29a-A4Z	GYA02S1
DTI 14/29a-A4	GYA02
DTI 14/29a-A5	GYA03
DTI 14/29a-A1	GYA04
DTI 14/29a-A2	GYA05