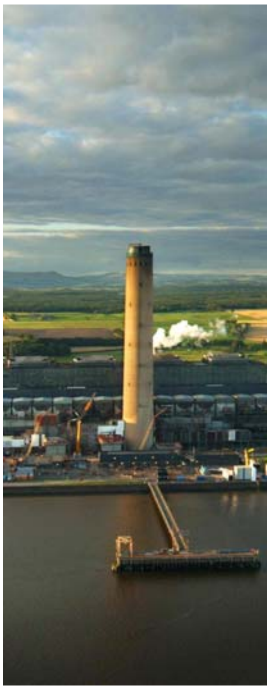

UK Carbon Capture and Storage Demonstration Competition

UKCCS - KT - S7.23 - Shell - 001

WRM Plan

April 2011

ScottishPower CCS Consortium

SCOTTISHPOWER nationalgrid

Carbon Capture & Storage Consortium

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WRM Plan

April 2011

ScottishPower CCS Consortium

ScottishPower Generation Limited
Longannet Power Station
Kincardine on Forth
Clackmannanshire
Scotland

ScottishPower Consortium UKCCS Demonstration Competition: Knowledge Transfer

KEYWORDS

Goldeneye, CO_2, .

Produced by Shell U.K. Limited

ECCN: EAR 99 Deminimus

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1. Executive Summary

The Well and Reservoir Management (WRM) plan in Goldeneye is an integral part of the MMV plan (Monitoring, Measurement and Verification).

One of the main objectives of the MMV plan is the Verification and validation (or conformance) of dynamic earth models in the short term, in order to estimate the long-term behaviour of the CO_2 plume. This activity will inform the frequency and duration of the monitoring plan and aid confirmation of secure containment.

The objective of the Well and Reservoir Management (WRM) team during the CCS project is optimisation of the injection phase. The WRM plan therefore details the strategy for optimising long term injection and storage of CO_2 whilst safeguarding the facilities and wells. Since reservoir behaviour is complex in a CO_2 injection project, WRM focuses on continuous performance monitoring, identifying issues/problems and acting upon these variances.

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

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

2. Objectives of the WRM plan

2.1. WRM Philosophy

Well and Reservoir Management (WRM) planning in Goldeneye is an integral part of the Monitoring, Measurement and Verification (MMV) plan[1] .

The WRM philosophy for the Goldeneye CCS 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 very active monitoring of the wells and reservoir from start up, through acquisition of baseline data during the workover operations 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.

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

WRM is tailored to the management of the well, reservoir and facilities for a medium period of time (1-3years). The surveillance plan is generally updated every year.

2.2. Key Value drivers

- Ensure well integrity
- Ensure facility (platform) integrity
- Maintain optimum contracted injection rateActive well and reservoir models update

2.3. Objectives of WRM

The main objectives of the well and reservoir management plan are:

1. **Integrity management of the CO_2 in the injector wells.**

1a. Minimize well failures

The initial well design is the main barrier against well failures. During the injection phase adequate maintenance and well servicing should reduce the risk of failure.

1b. Integrity issues identification

Well surveillance is required to identify potential well integrity issues as early as possible.

1c. Remedial integrity activities

Once the action is properly identified then remedial plans can be executed.

2. **Optimise CO_2 injectivity during the life of the project.**

2a. CO_2 downhole injectivity

[1] Shell 2010, MMV Plan

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.

Hydrate inhibition and filtration are important elements to maintain the integrity of the injection. Surface rate control might be required to avoid 'hot spot' erosion of the sand screens installed in the lower completion.

2b. Understand the CO_2 behaviour in the well

The injection is to be carried out in the dense phase and the wells will be operated in a regime which ensures that this phase is maintained.

Under normal injection conditions the CO_2 should be in dense phase along the well because of the created friction. As such, the minimum wellhead pressure under injection conditions should be 45bar. This pressure needs to be continuously monitored in order to ensure that it is maintained. The maximum pressure available at the wells is ~115bar.

2c. Manage CO_2 arrival rates

Longannet gas capture operations will not always be at Base Load. Fluctuations in the CO_2 arrival rate to the platform are expected. The arrival rate will be monitored and optimisation of the well selection will be carried out to manage the injection rates.

3. Monitor the reservoir performance under CO_2 injection.

3a. Reservoir pressure increase (re-pressurisation)

The reservoir pressure will increase during the CO_2 injection phase. The reservoir pressure will be monitored to ensure that it does not exceed the initial reservoir pressure.

3b. CO_2 monitoring

The focus is to monitor the exact location of the CO_2 plume to calibrate reservoir modelling.

3c. Reservoir Modelling

The validated reservoir model would then be able to predict further CO_2 plume movement in directions where wells do not exist.

4. Surface Facilities

4a. CO_2 rates

Quantification of in-flow of CO_2 both in absolute terms and well allocation through use of appropriate flow meters

4b. Gas detection

Gas detection is required in and around the facilities (for the protection of staff and the environment).

4c. Preventive Maintenance

In order to ensure high reliability, adequate preventive maintenance will be carried out based on the requirements for CO_2 injection. The detailed requirements will be developed in the execution phase.

3. Well and Reservoir Surveillance Strategy

3.1. Surveillance Strategy

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

- Re-complete existing wells to be CO_2 injectors, together with a monitoring well
- Remote monitoring
- Routine and non-routine data acquisition
- Monitor plume migration in the monitoring well to calibrate reservoir models

3.2. Surveillance Strategy

The Well and Reservoir Surveillance strategy for this field will ensure the acquisition of relevant data at required intervals for the optimisation of injection and monitoring of the injected fluid. The key data acquisition needs are shown in Table 3-1 below, whilst further explanations are provided in the narrative section which follows the table:

Activity	Description	Time / Frequency	WRM Objective
Injection Wells			
Zonal isolation / Integrity check	Cement bond logging	During workover, prior to recompletion	Baseline condition of cement bond between casing and formation. Objective: 1a, 1b
	Casing integrity logging.	During workover, prior to recompletion	Baseline condition of casing thickness. Objective: 1a, 1b
	Tubing integrity logging. Caliper logs	First one in the third year, subsequently Every five years	Ensure tubing integrity. Objective: 1a, 1b
Surface P/T monitoring	Temp and press sensors installed on each well. Basic elements to be monitored: wellhead, A, B and C annulus and control lines.	Continuous	Ensure the pressures and temp are within the acceptable limits Objective: 1b, 2a, 2b, 2c
Well pressure and temperature monitoring	Permanent Downhole Gauges (PDG) (monitor flowing bottom hole pressure)	Continuous	Give a good indication of injectivity of the well from drawdown parameters. Objective: 1b, 2a, 2b, 2c, 3a, 3c
	Distributed Temperature System (DTS)	Continuous	Indicate leakage along tubing by temperature profile. Objective: 1a,1b, 2a

Reservoir			
Reservoir pressure and temperature monitoring (Note: same PDG and DTS in the wells)	PDG (reservoir pressure during shut in)	Continuous	Accurate and stable pressure measurements are essential for long-term reservoir monitoring. Objective: 1b, 2a, 2b, 2c, 3a, 3c
	Distributed Temperature System (DTS	Continuous	Indicate reservoir temperature profile. Objective: 1a,1b, 2a
CO_2 migration	Geochemical Tracer injection	Continuous	For distinguishing between injected CO_2 and CO_2 from other sources. Objective: 3b, 3c
Monitoring Well (GYA03)			
Fluid contact monitoring	For HC/water delineation For CO_2 / HC /water delineation	Baseline acquired at workover, pre-injection Subsequent acquisition between years 5 -10	Baseline to determine if neutron and porosity logs are applicable. Subsequent runs differentiate and quantify CO_2 breakthrough during injection phase. Objective: 3b, 3c
Fluid Sampling	Downhole and Wellhead fluid sampling	Variable. Depending on plume arrival predictions	Identify CO_2 concentration profile for saturation performance modeling
PDG	Reservoir Pressure Monitoring	Continuous	Objective: 1b, 2a, 2b, 2c, 3a, 3c
Surface Measurement			
Injection rates measurement	Total Flow meter	Continuous	Monitor injection total flow rate from power plant. Objective: 4a
	Individual flow meter with Temp and press sensors installed	Continuous	Ensure the pressure, temperature and injection rate into each well are within the acceptable limits. Objective: 4a
Gas Detection	Line-of sight technique and point detectors	Continuous	Measure the accumulation and migration of gas clouds within and between process modules respectively. Objective: 4b
In-flow Composition monitoring	Full spectrum composition analysis – at Longannet.	Continuous	Determine the composition of CO_2 stream for injection to ensure it is within specification wrt. Impurities.
CO2 sea floor monitoring	Analysis of seawater characteristics underneath the platform	Continuous	CO_2 leaks identification in the injection wells

Table 3-1. Summary of Key Well and Reservoir Data Acquisition requirements and other surveillance tools

3.3. Injection Well Data Acquisition

Standard surface monitoring is recommended in the Goldeneye wells. The wells will be equipped with elements to facilitate surveillance like Permanent Downhole Gauge (PDG) and Distributed Temperature Sensor (DTS).

Although no well intervention work has yet been carried out on Goldeneye wells, several studies had been undertaken in support of hydrocarbon production in order to investigate a number of well intervention scenarios that could potentially take place on the Goldeneye platform. The conclusion was that the execution of wireline and even coiled tubing operations are feasible on Goldeneye. There are some limitations in terms of tool lengths and weights, which need to be considered (especially) during the first activities. A full site survey will be required prior to intervention operations.

3.3.1. Zonal isolation / Integrity check

Initial cement bond check and casing integrity logging will be performed during the workover operation. This will evaluate 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.

In order to ensure the integrity of the tubing and all tubing accessories during the injection phase, tubing integrity log will be run. The first will be carried out after 3 years of injection and subsequently after every 5 years.

3.3.2. Wellhead Pressure and Temperature Monitoring

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 provide assurance that the injection pressure and temperature are within the designed operating envelope in order to ensure that the injected CO_2 remains in the dense phase throughout the injection period. It is also important to monitor the annular pressures and temperatures, 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.

Surface samples in the different annuli in the wells may be required in the event of suspected leak problems.

3.3.3. Permanent Downhole Gauge and Distributed Temperature Sensor

Permanent downhole gauges will be installed in both the injection and monitoring wells for continuous measurement of the downhole injection pressure and reservoir pressure. It is planned to install two PDG in tandem in each of the four injection wells for reservoir pressure monitoring, and up to four gauges in the monitoring well to give better discrimination of the multiple fluids contacts that could occur in the reservoir.

Gauges are currently qualified for a 10-year life cycle and have drift stability better than +/- 7kPa at 82,740 kPa and 150 °C (+/- 1°C at 12,000psi and 302°C). Standard NPQG pressure gauges are routinely calibrated for temperatures in the range 25°C-150°C (65°F-302°F). Therefore, the selected PDG will require to be specially calibrated for the lower BHT (20°C-35°C (68-95°F)) expected when injecting CO_2.

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

3.4. Reservoir Data acquisition

The injection target is the upper part of the Captain 'D' subunit 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. Viscous forces will tend to dominate over gravity forces and there is potential for a tongue of CO_2 to move below the original hydrocarbon water contact.

The reservoir pressure will increase due to the CO_2 injection and the aquifer strength. The completion is selected considering the increase of reservoir pressure from 2750psi (lowest predicted pressure at the start of CO_2 injection) to 3800psi (highest predicted reservoir pressure at the end of the CO_2 injection – 20 million tonne).

The first stage will involve creating a reliable baseline for each domain in order 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 intensive monitoring to validate and update numerical models and ensure safe injection operations.

Reservoir monitoring requires the installation of pressure gauges and the measurement of saturation in observation wells.

The following are specified for the general surveillance activities related to the reservoir during the injection phase:

3.4.1. Permanent Downhole Gauge and Distributed Temperature Sensor

PDG and DTS installed in the well (see section 3.3.3) will also be used to monitor the reservoir temperature and pressure under static conditions.

3.4.2. Geochemical tracer injection

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 a 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.

There are two feasible options for the point of tracer injection,: St Fergus and Goldeneye platform. Different fluids may 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.

3.5. Monitoring Well Data Acquisition

The focus is to monitor the exact location of the CO2 plume in order to calibrate reservoir modelling. The validated reservoir model would then be able to predict further CO2 plume movement in directions where wells do not exist. GYA03 will be initially used as a monitoring well for this purpose.

The data gathering plan for this well includes fluid contact monitoring by logging and sampling 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 CO2 plume will reach the monitoring well (GYA-03 in the base case scenario) and the number of saturation data points required to characterise the model.

3.5.1. Saturation logging

A baseline saturation logging is essential to determine the Gas Water Contact (GWC) in the field prior to start of injection. This will only be of use if there is water in the reservoir. The result of the log will be used to characterise the reservoir model so that later in the injection phase, breakthrough of CO_2 into the water leg can be detected and quantified. If the baseline log indicates absence of water in the reservoir, then subsequent runs during the injection phase will not be carried out.

3.5.2. Downhole sampling

The fluid profiling interpretation of the saturation log will give an indication of the hydrocarbon gas and water columns. This will form the basis for the sampling. At least three samples are required for each run, two from the interpreted hydrocarbon gas column and one from the water column. The final number of samples will be determined by the quality of fluid profiling interpretation. The samples in the gas column provide an analysis of concentration of remaining light hydrocarbon (pre-injection) and the sample in the water column provides analysis of the amount of dissolution of gas in the water.

The sampling during the injection phase will monitor the movement of the injected CO_2 front.

3.6. Surface monitoring

The critical surface measurements are associated with CO_2 flow metering for flow rate determination, gas detection around the facilities for safety purposes and in-flow composition metering to assure the quality of the gas being injected into the reservoir.

3.6.1. Flow meter

The standard flow measurement unit for CO_2 throughout the installation will be mass flow. An orifice meter will measure the total flow of CO_2 onto the platform with density compensation capability and this will serve as input to the mass flow calculation. In order to measure the injection flow rate into each of the wells, individual orifice meters complete with temperature and pressure measurement will be installed in each injection flow line. Metering of CO_2 throughout the installation will vary with regard to operational pressure, temperature and phase.

3.6.2. Gas detection

Line-of-sight (LOS) detection techniques will be employed in order to measure the accumulation and migration of gas clouds within and between process modules. These detectors have a reliability advantage in the coverage of large areas.. For areas with a high risk of leakage (e.g., concentration of flanged joints, screwed joints, valve spindles/packing and complex instrumentation piping) point detectors using the IR absorption technique shall be employed.

3.6.3. In-flow composition monitoring

Compositional data is expected to be measured through the multiple points between the source at Longannet and the Blackhill Compressor Station. The data is accessible through the end-to-end telemetry system. At this point in time it is expected that full spectrum analysis using gas chromatographs will be installed at: Scottish Power Longannet; National Grid Longannet (x2); and

National Grid Blackhill (x2). Analysis will be carried out on a continuous basis but the sample processing time is in the order of 15 minutes.

4. 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.

4.1. 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.

4.1.1. 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 execution phase.

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 (<1year).

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

4.1.2. Reservoir

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

- Monitor the bottom hole injection pressure to ensure it does not go above the maximum allowable. This is 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 avoid fracture the formation seal.

4.1.3. Surface

The surface platform facility will be unmanned. In order to ensure facility integrity, preventive maintenance of all the equipment will be carried out according to the recommended frequencies in the preventive maintenance plan. In order to minimise field visits, the maintenance of the various equipment will be synchronised as much as possible.

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

4.2. Metering Plan

The fiscal metering for the project will be handled at the Longannet power plant. The platform will be provided with orifice meters with a +/- 2% error margin that will measure the total flow received. Individual flow meters will also be installed on each flowline leading into the individual wells. These are expected to measure within +/- 5% accuracy.

The fluid compositional analysis will be handled at the Longannet Power Station and National Grid plants in order to ensure that the CO_2 meets the required specification.

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

A detailed metering plan has been produced which will be updated as required.

4.3. Information and Data Management

The data from the Geochemical probe, DTS, PDG, well head temp and pressure measurements, and flow rates will all be transmitted to the control room which has robust databases that store all acquired data on site with local backup. 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, real-time monitoring and data delivery secure web services, 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.

4.4. 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. Shell proprietary software system models have already been constructed for the wells, and an integrated injection system model will follow. The reservoir dynamic model will also be updated.

4.4.1. IPIM

The Integrated Injection 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.

4.4.2. Dynamic Reservoir Model

A pre-injection dynamic model has been built. This will be updated with the first set of data that will be acquired post workover. Thereafter, the model will be updated every 6 months as more data is acquired.

The interpretation of the saturation log and acquired samples in GYA03, together with the interpreted reservoir pressure data, will be critical in using the dynamic model to further predict the movement of the CO_2 plume and the attainment of initial reservoir pressure.

4.4.3. Maps

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

4.4.4. Surface Facility Model

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

5. Management of the WRM plan

5.1. WRM team

A WRM team should be formed to manage the CCS in Goldeneye. Subsurface, wells and surface disciplines should be involved. Typically a WRM is formed by the following disciplines:

- Reservoir Engineer
- Production Technologist
- Production Geologist
- Petrophysicist
- Operations Engineer
- Facility Engineer
- Programmer

5.2. Annual Budget

An 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.

Abbreviations

BHT	Bottom Hole Temperature
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
DTS	Distributed Temperature Sensor
GWC	Gas Water Contact
HC	Hydrocarbon
IPSM	Integrated Production System Model
IT	Information and Technology
MMV	Monitoring, Measurement and Verification
OPC	Open Connectivity
PDG	Permanent Downhole Gauge
PFC	Perflurocarbon
SSSV	Sub Surface Safety Valve
WRM	Well and Reservoir Management

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