Government of **Western Australia**
Department of **Mines and Petroleum**

South West CO_2 Geosequestration Hub

Project Activity and Progress Report

Harvey Shire Councillors visiting the Harvey 1 well drilling site.

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Contents

Executive Summary

The South West CO_2 Geosequestration Hub project (the South West Hub) is a government industry partnership led by the Western Australian Department of Mines and Petroleum (DMP).

The South West Hub industry partners are Verve, Perdaman Chemicals and Fertilisers, Premier Coal Limited, Griffin Energy Developments and Alcoa Australia. An Unincorporated Joint Venture (UJV) Agreement has been developed by the South West Hub partners to progress the project.

The South West Hub is Western Australia's first on-shore Carbon Capture and Storage (CCS) trial project.

CCS is part of a portfolio of solutions to combat climate change and will contribute towards the Australian Government's goal of reducing CO_2 emissions by 80 per cent (of year 2000 levels) by 2050.

The Australian Government's carbon pricing legislation presents a commercial driver for deployment of CCS technology. Western Australia's environmental agency, the Environmental Protection Authority (EPA) has also indicated its desire for industry to consider ways of making significant cuts to its atmospheric emissions.

In June 2011 the Commonwealth Government, through the $1.68 billion CCS National Flagships Program, awarded $52 million to the South West Hub for its on-going project development. This funding is being used for geological data acquisition, preliminary studies (including risk assessment, social impact assessment, pipeline study and environmental impact statement), front end project engineering, design and management. Further funding will be required as the project proceeds past the feasibility stage.

The South West Hub will be developed as a phased project with the phases known as the 'Preparation Phase', 'Enabling Case', 'Base Case' and 'Extended Cases'.

The Preparation Phase (2011-2014) involves pre-competitive data acquisition and analysis to test the suitability and capacity of the Triassic Lesueur Sandstone formation in the southern Perth Basin (Lesueur) for CO_2 geosequestration. The geographic region being considered is an area south of Mandurah and north of Kemerton Industrial Park, in the Shire of Harvey and a small area in the Shire of Waroona.

Other investigative works will be carried out as part of the project's preparation phase.

The Enabling Case (2015-2016) will take approximately 350,000 tonnes per annum (t/a) of CO_2, from an existing chemical plant in Kwinana and transport it via a new pipeline. Approximately 250,000t/a will be sequestered in bauxite residue ponds at Alcoa's Pinjarra and Wagerup alumina refineries.

In addition, for the first one to two years approximately 100,000 tonnes will be compressed at an initial geosequestration site to test the storage characteristics of the Lesueur.

The Base Case (2017) involves commercial scale capture, transport and storage of 2.45Mt/a of CO_2 from the proposed Perdaman Chemicals and Fertilisers' plant in Collie. A pipeline will be constructed from the Collie region and CO_2 will be transported, in a compressed form, to the yet to be determined location for geosequestration.

The Extended Cases (2020-2023) will be undertaken in two phases and will allow for the nominal CO_2 capture, transport and storage capacity of the South West Hub (5-6Mt/a) to be reached. The Extended Cases are based around new build power stations, new industrial developments and/or retrofits in the Collie area.

The South West Hub is currently in the preparation phase, focussing on pre-competitive data acquisition. This phase commenced with the analysis of existing data and modelling work conducted in 2010 that calculated a potential storage volume of up to 260 million tonnes at an injection rate of 6.5 mtpa over 40 years. This provided enough confidence to proceed with a 2D seismic program.

Based on 2D seismic results, the South West Hub conducted a drilling program in the investigation area in March 2012. The Geological Survey WA (GSWA) Harvey 1 stratigraphic well was drilled to 2,945 metres in order to :

- Confirm the predicted stratigraphy;
- Obtain data from which to evaluate the sealing capacity of the Eneabba Formation, which lies above the Lesueur, and test for the presence of a lower shale unit in the formation;

- Collect fresh core samples from both the Eneabba Formation and Lesueur Sandstone to assess seal capacity, reservoir characterisation and injectivity testing;
- Run modern down-hole evaluation logs; and
- Assist in the planning and development for future wells and seismic programs to further evaluate the area.

All of the Harvey 1 well objectives have been achieved, with the exception of the evaluation of the sealing capacity of the Eneabba Formation which is on-going.

Initial results confirm expectations that the Lower Lesueur Sandstone or Wonnerup Member is a potential CO_2 storage reservoir.

Core samples recovered from the borehole and electronic measurements made after drilling show that the quality of the Wonnerup Member sandstone was better than expected and should provide a good target for CO_2 storage. The Upper Lesueur Sandstone, or Yalgorup Member, and the Eneabba Formation lying above it would potentially form a seal over such a reservoir to trap the injected CO_2 permanently.

These results have provided the South West Hub with sufficient confidence to continue the investigation into the potential of the proposed storage area.

In October 2012, the South West Hub awarded a contract to Geokinetics to undertake a 3D seismic survey of the area of investigation. The main objectives of this seismic survey are:

- To evaluate the area for possible CO_2 injection and monitoring sites;
- To map the Lesueur Sandstone and base Eneabba Formation in the area;
- To analyse the data for regional stress (anisotropy);
- To map faults in the area and build structure maps of the area; and
- To acquire the seismic data with the least invasive acquisition whilst still achieving a high resolution survey.

The proposed survey will be approximately 115 square kilometres in size being 9.567 km wide (E-W) and 15.788 km long (N-S). It will consist of a 200 x 200 metre N-S orthogonal grid with source lines at 200 metre spacing in a N-S direction (48 lines) with a total source line length of 758 kilometres.

The 3D survey was originally scheduled to commence in quarter 1, 2013. However, due to complexities associated with contracting, meeting regulatory requirements and coordination of land access with seasonal change, the 3D seismic survey will now commence in the first quarter of 2014.

The project is currently managed by the Department of Mines and Petroleum (DMP). The DMP will facilitate and manage early stage activity including the provision of detailed geological information, the establishment of research capability, commencing baseline data acquisition and establishing community consultation processes.

The UJV will lead the commercial deployment of the project when it transitions from the pre-competitive data acquisition phase to CO_2 transport and trial injection (Enabling Case).

A number of related activities are being undertaken in parallel to progress the project. In particular, a legislative and regulatory regime has been developed to allow for the capture, transport and storage of CO_2 in Western Australia.

The planning for CO_2 transportation has commenced with the completion of a detailed mapping exercise of the proposed pipeline route from Kwinana to the Harvey region. A flora and fauna survey of the Dampier to Bunbury Pipeline easement between Kwinana and Harvey Shire is being finalised.

Open and transparent community consultation is a central feature of all project activities. A community consultation committee has been established, and it will operate throughout the project's development phases.

The DMP has also conducted a series of local engagement programs and events designed to provide the local community with information on the project. The programs were designed so that the local community could engage with project managers and representatives from the research community.

A number of risks and challenges must be managed to bring the project from the conceptual stage to reality. Of these, the future clean energy policy frameworks, the global carbon pricing mechanism and community engagement will have a significant bearing on the South West Hub's development. Other issues of significance include contractual arrangements, project management (timing and budgeting), geological data acquisition and research and development.

Introduction

The Australian Government has committed to emissions reduction targets of at least 5 per cent below 2000 levels by 2020 and 80 per cent below 2000 levels by 2050. As the only technology available to significantly reduce emissions from the use of fossil fuels, carbon capture and storage (CCS) has the potential to make a major contribution to achieving these targets.

Western Australia is one of the most vulnerable regions to climate change in the developed world. The State is already experiencing climate change impacts and further substantial impacts are inevitable. The Western Australian government is committed to minimising the effects that climate change will have on the environment, economy and community and recognises the role for complementary action with national programs that will allow abatement to occur in the least-cost and most economically efficient manner.

The Western Australian Government is committed to minimising the effects that climate change will have on the environment, economy and community; and recognises the role for complementary action with national programs that will allow abatement to occur in the least-cost and most economically efficient manner.

The South West of Western Australia is a major industrial region generating billions of dollars of domestic and export revenue. The region is also a significant CO_2 producer. The investigation of CCS provides the region with an opportunity to potentially reduce carbon emissions while also maintaining its competitive edge by capitalising on the State's geology and industry expertise.

The South West Hub (SWH) is a government industry partnership led by the Western Australian Department of Mines and Petroleum (DMP).

The project has the potential to be a multi-user CO_2 hub providing opportunities for a variety of industry operations to connect to a common storage facility. The estimated total of CO_2 available for capture from new and potential projects in the SWH region is in the range of five to six million tonnes per annum by 2020.

The coal miners, coal user industries and a major alumina refining company in the area have developed an Unincorporated Joint Venture (UJV) to investigate carbon storage opportunities, in a geological strata known as the Lesueur.

The UJV industry partners (Verve, Perdaman Chemicals and Fertilisers, Premier Coal Limited, Griffin Energy Developments and Alcoa Australia) are developing or considering billions of dollars worth of new projects, utilising post combustion capture technologies, integrated gasification carbon capture or permanent CO_2 chemical sequestration in bauxite residue.

Two prominent projects for the South West Hub are the Perdaman Chemicals and Fertilisers proposed 2Mt/a coal to urea plant, which is currently in the final approvals stage; and Alcoa Australia is proposing to sequester CO_2 in its bauxite residue.

The two key drivers for the industry partners are:

1. A step reduction in CO_2 emissions to meet their corporate requirements and the expectations of both the State and Federal regulatory authorities; and
2. Managing the costs associated with the imposition of carbon pricing and a future emissions trading scheme.

A Statement of Intent was signed by all of the project partners as a precursor to developing a submission for funding from the CCS Flagships program.

The signatories to the Statement agreed to cooperate in good faith with a view to developing the South West Hub by:

- Testing the validity of the Lesueur as a carbon dioxide storage formation;
- Establishing a carbon capture and transport system that will facilitate the sequestration of CO_2;
- Supporting ongoing research and education to assist and encourage the implementation of this technology on a national and international basis; and
- A commitment to community consultation.

The participants recognise that the establishment of the South West Hub through a development process towards an operating entity, will facilitate staged investment decisions in a carbon constrained world.

Purpose of the report

The purpose of this report is to provide an overview of the South West Hub project and an update on recent activity and outcomes of the Harvey 1 well drilling program.

Project Description

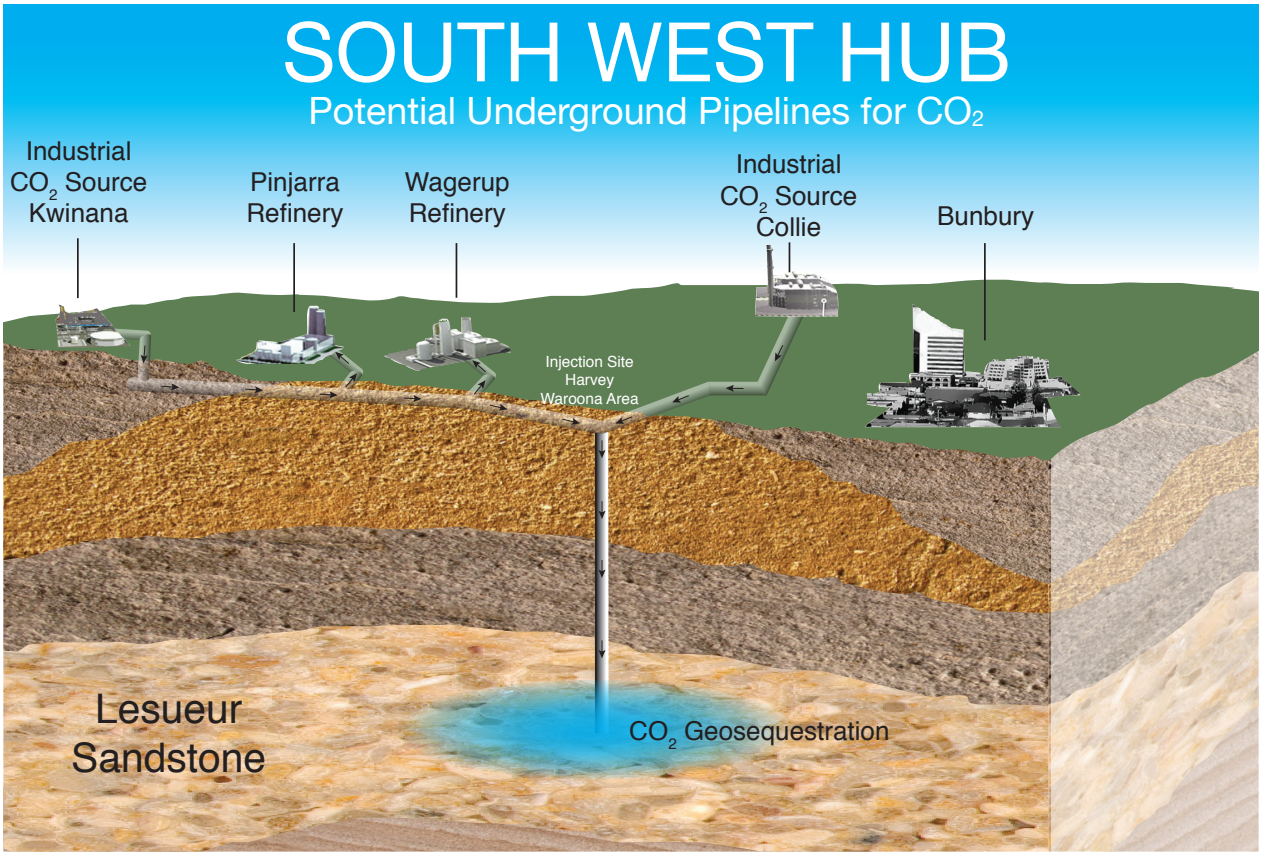
The SWH project is an alliance formed by the State government with regional industry participants and aims to be a leading initiative in the attempt to reduce Western Australia's greenhouse gas emissions.

The Kwinana industrial area, located 38 kilometres from Western Australia's capital city of Perth, is the State's premier strategic heavy industrial area and a major driver for the WA economy. Industries within the area include fabrication and construction facilities, through to large scale processing, such as alumina, nickel, titanium and oil refineries.

The SWH is a CCS cluster project that seeks to capture CO_2 from a number of emission points, transport the CO_2 via pipeline to a storage site, and inject deeply into a saline aquifer contained within the Lesueur Sandstone formation in the shires of Harvey and Waroona, approximately 150 kilometres from Perth.

Key elements of the project include:

- Establishing a pipeline from the Kwinana industrial area to transport CO_2 to injection site into the Lesueur;
- Possible industrial carbonisation projects utilising the CO_2 to treat alumina refinery residue that could then be used commercially; and
- The establishment of a pipeline from the Collie industrial area to tap CO_2 emissions from coal industries.



Business Case

In order to demonstrate the potential viability of the project, a pre-feasibility study was completed articulating the business case, transport and storage options as well as a high level execution plan. Seven key aspects for a CCS project in Western Australia were addressed:

- Preliminary site selection, storage mapping and characterisation – to characterise the storage capacity of the Lesueur and to identify possible injection sites.
- Carbon capture – identification of carbon capture readiness requirements.
- Carbon transportation – pipeline transport requirements.
- Regulatory framework – State and Federal Government requirements and the need for new State legislation.
- Commercial framework for a carbon capture and storage project.
- Stakeholder engagement – Government and community issues.
- Research – arrangements with research institutions in compliance with the Education Investment Fund (EIF) criteria.

Supported by financial modelling, the business case concluded that the South West Hub could operate on a commercial basis, provided that:

a) Appropriate levels of capital investment are made available to project proponents through the CCS Flagships program; and

b) Carbon is adequately priced, either via the direct tax or future emissions trading scheme.

In 2009, the Business Case was submitted to the Australian government for funding consideration under the CCS Flagships program. On June 11, 2011, the Australian Government awarded $52 million to the South West Hub.

This funding is being used for geological data acquisition, preliminary studies (including risk assessment, social impact assessment, pipeline study and environmental impact statement), project engineering and management. Further funding will be required as the project proceeds.

Project Phasing

The South West Hub is being developed in a number of project phases. Based on assumptions that were valid at the time, the Business Case outlined the following timeframe for the project's development:

Preparation Phase (2011 – 2014)

The Enabling Case (2015 – 2016)

The Base Case (2017)

Extended Case 1 (2020)

Extended Case 2 (2023)

The Preparation Phase involves pre-competitive data acquisition, including the drilling of a stratigraphic well and analysis to test the suitability and capacity of the Lesueur. Other investigative works will also be carried out as part of the preparation phase including a 3D seismic study and further stratigraphic well drilling. The timeframe for this phase of the project has now been extended to 2014.

The Enabling Case is essentially a small scale CO_2 sequestration and trial injection phase of the project, nominally involving 350,000t/a of CO_2. Approximately 250,000t/a will be transported (via a 109 km pipeline network) from an existing chemical plant in Kwinana to residue ponds at Alcoa's Pinjarra and Wagerup alumina refineries where it will be sequestered in the residue.

In addition, approximately 100,000t will be injected, over the first one to two years, as storage demonstration of the Lesueur (the exact storage demonstration site is yet to be determined). Research and development will be ongoing throughout this phase.

The Base Case involves commercial scale capture, transport and storage of 2.45Mt/a of CO_2 from the proposed Perdaman Chemicals and Fertilisers' plant in Collie transported via pipeline, in a compressed form, to a yet to be determined site in the Lesueur for geosequestration. The timing of this phase has now been extended out to 2017.

The Extended Cases will be undertaken in two phases (Extended Case 1 & 2) and will allow for the CO_2 capture, transport and storage capacity of the Hub to expand to 5-6 Mt/a. The Extended Cases are based around new build power stations, new industrial developments and/or retrofits in the Collie area being

incorporated into the pipeline with the CO_2 being produced under the Base Case for geosequestration in the Lesueur.

The project is currently in the Preparation Phase and is working towards a decision to proceed with the Enabling Case in 2015. When made, this decision will be a significant project milestone.

Governance Structure

The project is currently managed by the Department of Mines and Petroleum (DMP) with support provided from industry partners. The DMP will facilitate and manage early stage activity including the provision of detailed geological information, the establishment of research capability, commencing baseline data acquisition and establishing community consultation processes.

The UJV that has been established will be the means by which industry will lead the South West Hub through its future development phases.

Current Project Status

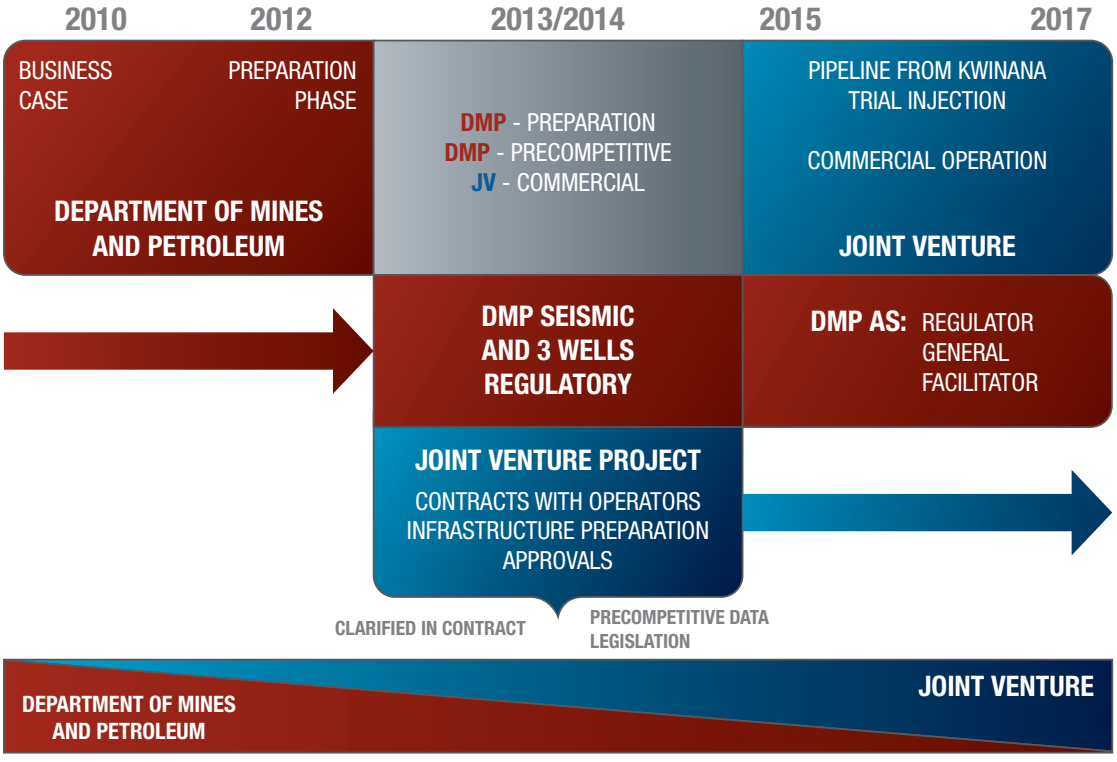
The South West Hub is currently focussing on the collection and analysis of pre-competitive data to test the CO_2 storage capacity of the Lower Lesueur which is located near the town of Harvey, roughly 150 kilometres from Perth.

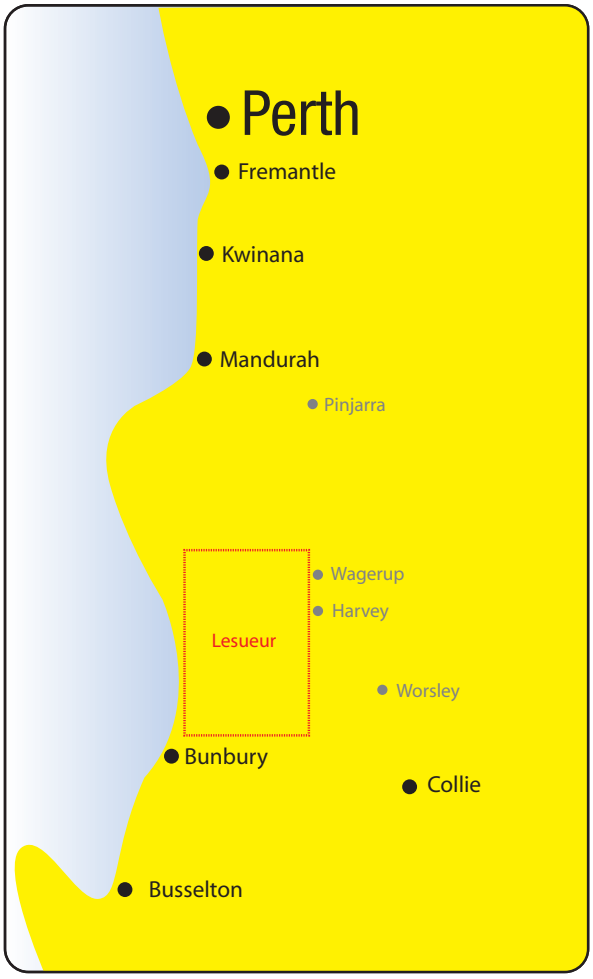
Background

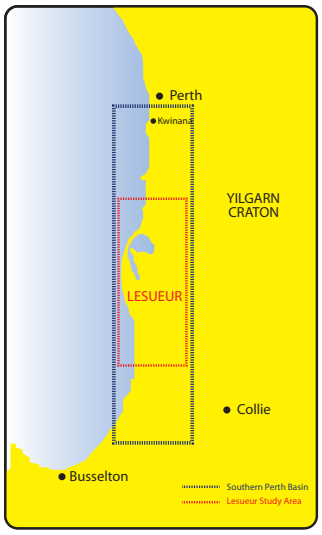
A series of field works and data evaluations was conducted in 2011 and 2012 in order to assess storage site suitability. This included a 2D seismic survey conducted in 2011 which traversed approximately 106kms of road reserves in the target investigative area. The survey lines were of a high quality but widely spaced at five to ten kilometres between each line. This data helped to better describe the geological structures in the area and confirmed initial available data.

Based on the positive results and advice received from the analysis of the 2D seismic, a 2,945m deep stratigraphic well was drilled in the Shire of Harvey at a site near Cookernup.

TRANSITION FROM DMP TO JV 2010 TO 2017







Harvey 1 Well

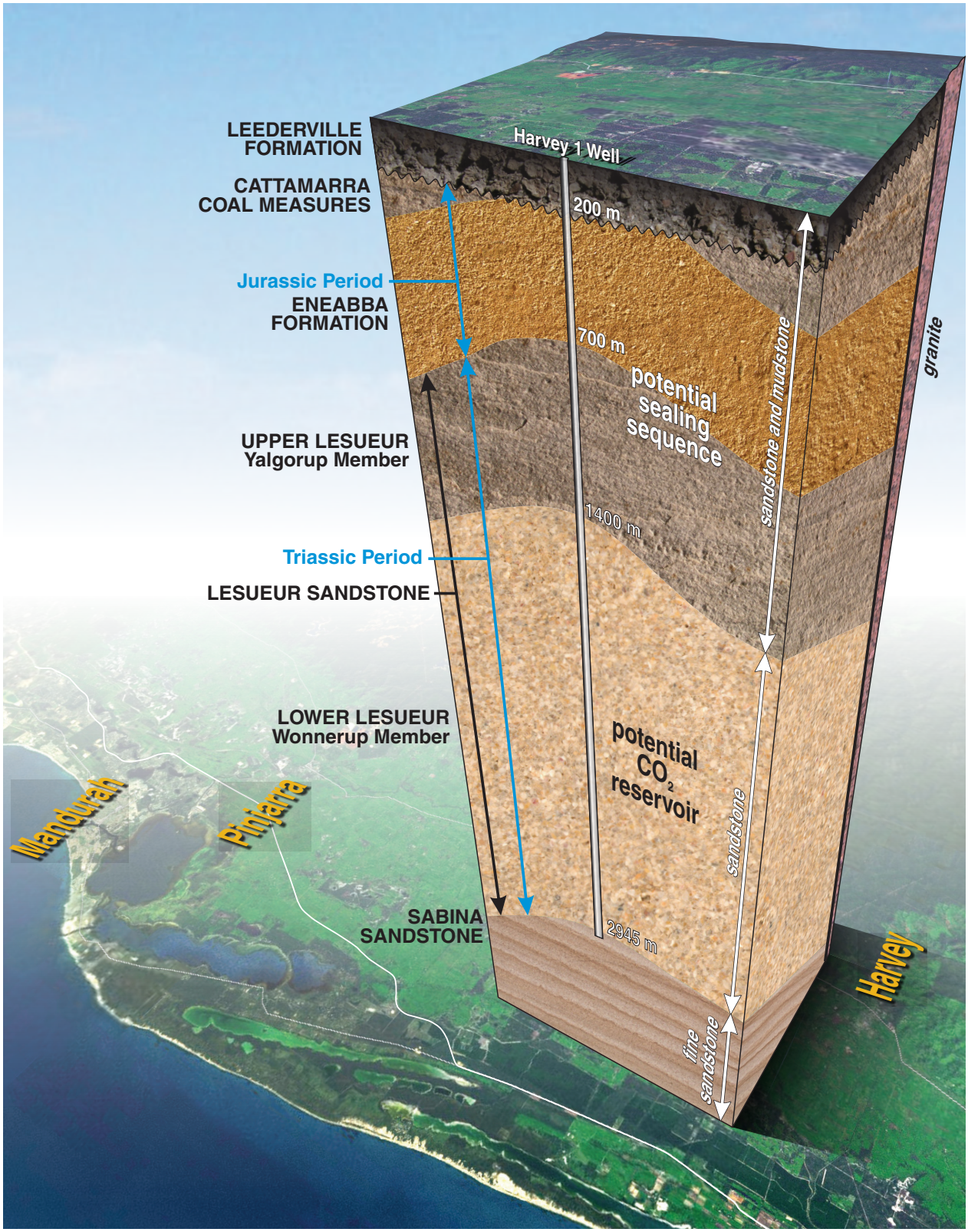
Harvey 1 well drilled in February-March 2012, was a stratigraphic well designed to provide data and core samples from the underlying rock strata and reduce the geological data gaps in an area north west of Harvey town site.

The purpose of the well was to:

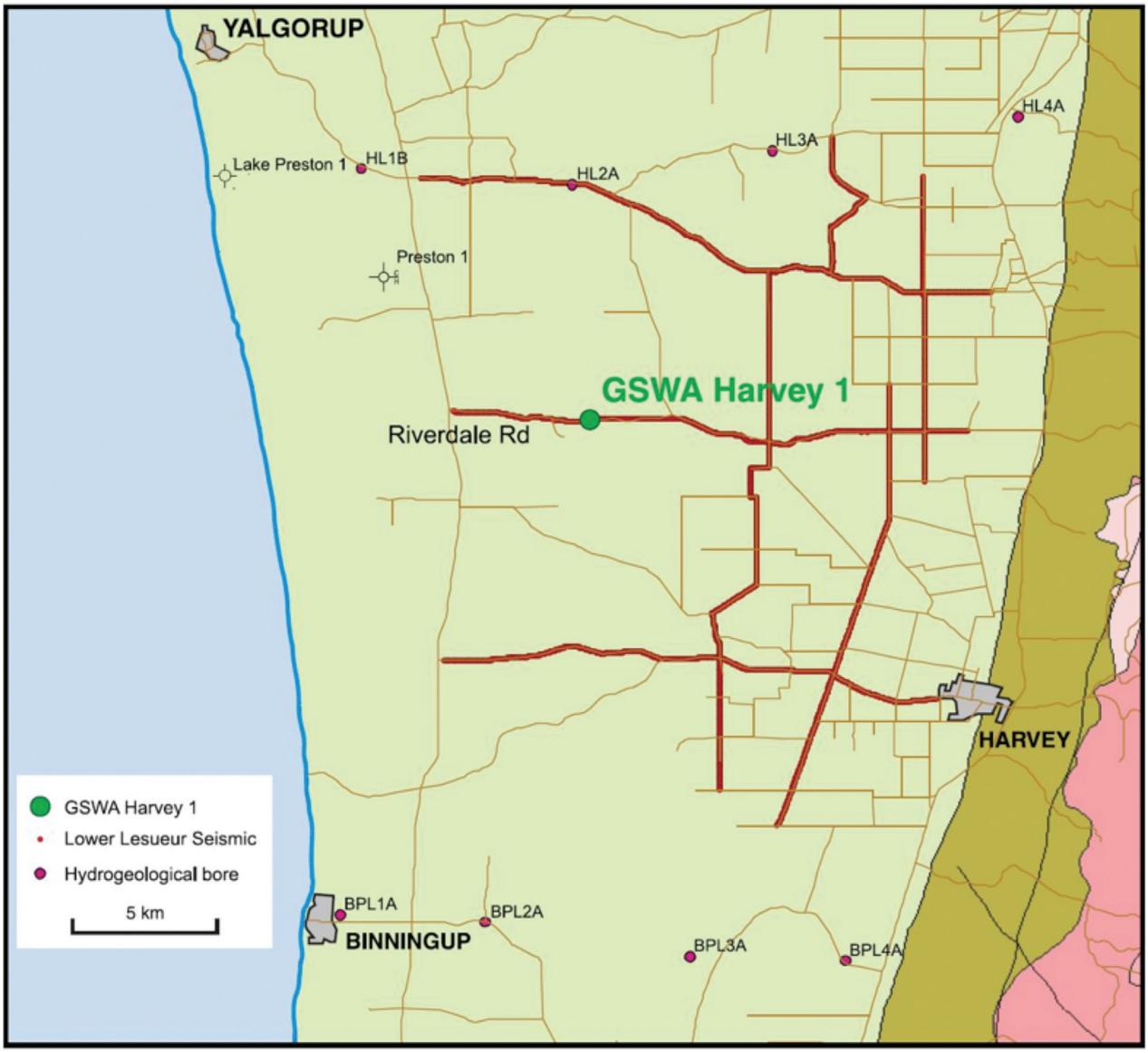
- Confirm the predicted stratigraphy;
- Obtain data from which to evaluate the sealing capacity of the Eneabba Formation which lies above the Lesueur and test for the presence of a lower shale unit in the formation;
- Collect fresh core samples of both the Eneabba Formation and Lesueur Sandstone to assess seal capacity, reservoir characterisation and injectivity testing;
- Run modern down-hole evaluation logs; and
- Assist in the planning and development for future wells and seismic programs to further evaluate the area.

The location for Harvey 1 was chosen based on data from the 2D seismic survey and other pre-existing data, and where the most information could be gained on understanding the potential of the geological formations to become a storage reservoir for carbon dioxide (CO_2).

DMP's Geological Survey of Western Australia (GSWA), which has been gathering and publishing information on the State's geology since the 1880s, undertook the management of the drilling of the Harvey 1 well.



Onshore southern Perth Basin stratigraphy: Harvey 1 well.



Site map showing the Lower Lesueur 2D seismic survey lines.

Harvey 1 core samples from the Lesueur Sandstone; from top, Yalgorup Member at 1335m, at 1336m, at 1337m and Wonnerup Member at 2491m.

Core samples

The Harvey 1 well led to the recovery of 217m of core samples collected from the Lesueur Sandstone.

Testing of the core samples will provide critical input into building a 3D model of the area's subsurface rock strata and determining the potential for the Lesueur Sandstone to become a CO_2 storage reservoir.

The process of opening the cores and making preliminary descriptions took six weeks. The core plug sampling, core slabbing and the first sets of physical and chemical analysis were completed within six months. The core samples have been assigned to different formations based on the core observations and the well logging data from the down hole probes. Harvey 1 well has been plugged and abandoned and there has been no attempt to inject CO_2 into the Harvey 1 well. The core samples are currently undergoing further testing programs. Research on the core samples will be specifically directed at the behaviour of CO_2 in a supercritical state, as it comes into contact with the various subsurface strata intersected by the Harvey 1 well. Further information on this research section of this report.

Outcomes

The Harvey 1 well program was successful, achieving 95 per cent of the data acquisition objectives set for the drilling project. All of the Harvey 1 well objectives have been achieved, with the exception of the evaluation of the sealing capacity of the Eneabba Formation which is on-going.

Initial results confirm expectations that the Lower Lesueur Sandstone or Wonnerup Member is a potential CO_2 storage reservoir. Core samples recovered from the borehole and electronic measurements made after drilling show that the quality of the Wonnerup Member sandstone was better than expected and should provide a good target for CO_2 storage.

The Upper Lesueur Sandstone, or Yalgorup Member, and the Eneabba Formation lying above it would potentially form a seal over such a reservoir to trap the injected CO_2 permanently.

What geologists expected to, and did, find was that the Lesueur Sandstone consisted of porous sandstone in a saline (salty) aquifer. It has overlying strata of denser mudstone (a mix of silt and clay) and shale (mudstone

that is laminated or fissile) which could act as a sealing mechanism, retarding the upward migration of CO_2 towards the surface.

Harvey 1 also confirmed that the Lesueur Sandstone contains water with relatively high salinity, thus the injection of CO_2 does not present a risk of contamination of waters as saline water is not suitable for community use. The water pressure in the formation is 'normal hydrostatic', which means it is at the pressure expected for the depth that the water samples were taken based on gravity, and the area is not hydrocarbon bearing.

This subsurface modelling of the Lesueur Sandstone will continue to evolve with the acquisition of more data from a planned 3D seismic survey, drilling additional wells, laboratory testing of core samples and other analyses and data sources.

Proposed 3D seismic program

In October 2012, the DMP awarded a contract to Geokinetics to undertake a 3D seismic survey of the Lesueur area.

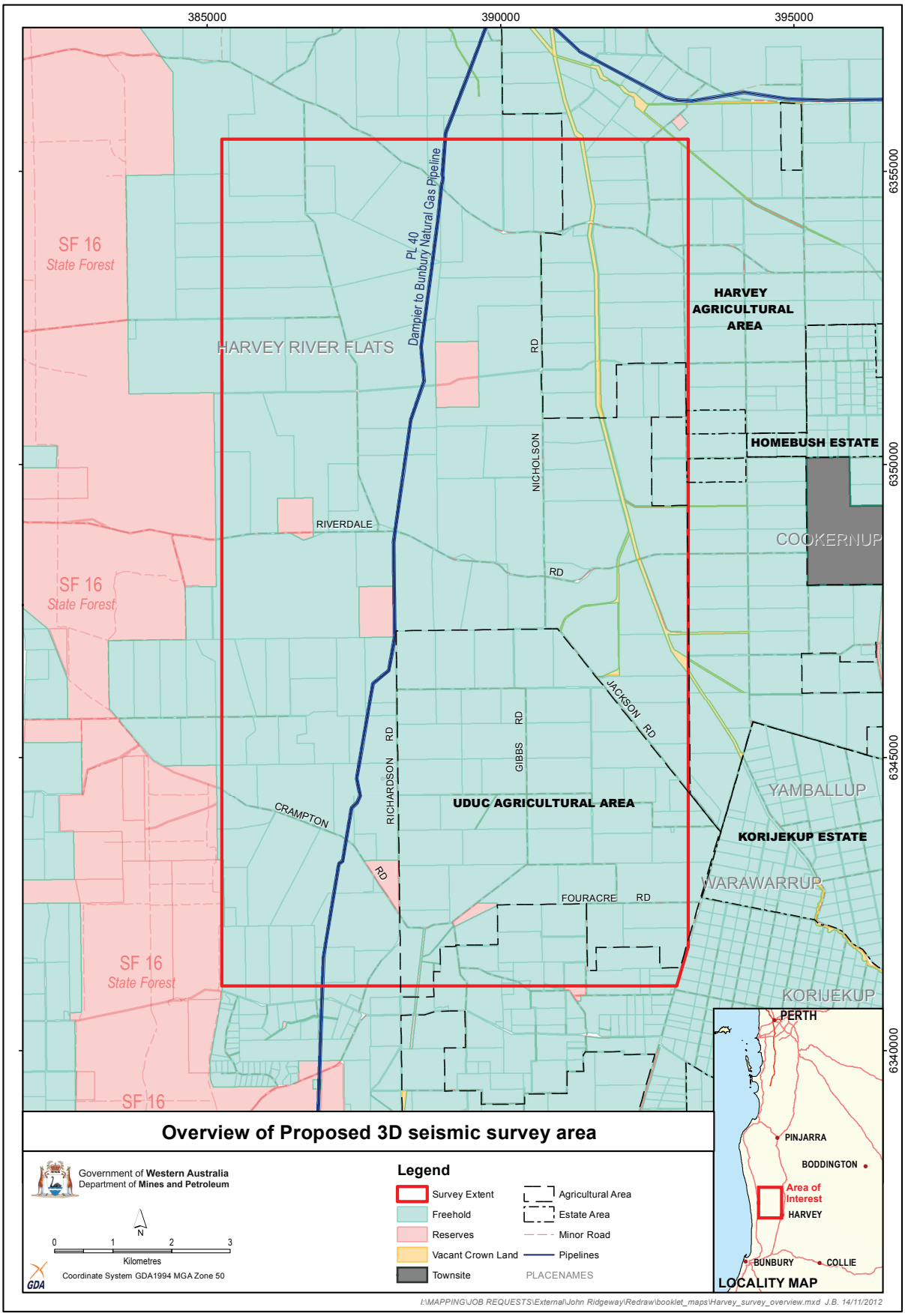
The main objectives of this seismic survey are to:

- Evaluate the area for possible CO_2 injection and monitoring sites;
- Map the Lesueur Sandstone and base Eneabba Formation in the area;
- Analyse the data for regional stress (anisotropy);
- Map faults in the area and build structure maps of the area; and
- Acquire the seismic with the least invasive acquisition whilst still achieving a high resolution survey.

The proposed survey will be approximately 115 square kilometres in size being 9.567 km wide (E-W) and 15.788 km long (N-S). It will consist of a 200 x 200 metre N-S orthogonal grid with source lines at 200 metre spacing in a N-S direction (48 lines) with a total source line length of 758 kilometres.

Core samples recovered from Harvey 1

Core #	Start depth (m)	End depth (m)	Recovered metres	% Recovery	Formation	Lithology
Core 1	895	931	36.62	101.72%	Yalgorup Member, Lesueur Sandstone	Sandstone, minor Claystone
Core 2	1266	1320	53.16	98.44%	Yalgorup Member, Lesueur Sandstone	Interbedded Claystone, Sandstone, Siltstone
Core 3	1320	1336	15.22	95.13%	Yalgorup Member, Lesueur Sandstone	Interbedded Claystone and Sandstone
Core 4	1336	1345	7.76	86.22%	Yalgorup Member, Lesueur Sandstone	Claystone with Sandstone at base
Core 5	1896	1950	51.64	95.63%	Wonnerup Member, Lesueur Sandstone	Sandstone
Core 6	2480	2534	52.59	97.39%	Wonnerup Member, Lesueur Sandstone	3 metres Claystone at top, remainder Sandstone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SF 16
State Forest
HARVEY RIVER FLATS
PL 40
Dampier to Bunbury Natural Gas Pipeline
HARVEY
AGRICULTURAL
AREA
HOMEBUSH ESTATE
COOKERNUP
NICHOLSON RD
RIVERDALE
RD
JACKSON RD
GIBBS RD
RICHARDSON RD
CRAMPTON RD
UDUC AGRICULTURAL AREA
YAMBALLUP
KORIJEKUP ESTATE
WARAWARRUP
FOURACRE RD
KORIJEKUP
Overview of Proposed 3D seismic survey area
Government of Western Australia
Department of Mines and Petroleum
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The 3D survey was originally scheduled to commence early in 2013. However, due to complexities associated with contracting, meeting regulatory requirements and coordination of land access with seasonal change, the 3D seismic survey will now commence in the first quarter of 2014.

Legislative and regulatory processes and requirements

Western Australia's legislation is not adequate for a capture, transport and storage project of this magnitude. However, this has not been a hindrance to the development of the South West Hub project with pre-competitive data acquisition activities being conducted under the provisions of the State's Mining Act 1978. The project has also been conducted on the basis that planned legislation will adequately assist the project.

The DMP is responsible for developing the legislation and regulations for the management of greenhouse gas storage in Western Australia. After consultation with stakeholders, legislative amendments were put before Parliament in late 2012. The passage of this legislation has been delayed due to State Government election and the amendments will need to be reintroduced by the new Parliament. This is expected to occur during 2013.

The proposed amendments will be incorporated into the existing WA Petroleum and Geothermal Energy Resources Act 1967, and the Petroleum Pipelines Act 1969 and other legislation where required. These amendments reflect many of the provisions of the Commonwealth's Offshore Petroleum Amendment (Greenhouse Gas Storage) Act 2008.

The project is also subject to a wide range of Federal and State legislative and regulatory requirements as well as local government regulation appropriate for a development proposal of this complexity.

A preliminary Legislative and Regulatory Issues analysis was conducted as part of the Business Case to map the suite of approvals necessary to implement the various elements of the project.

Approvals are being sought for each element of the project as it progresses. The long lead time associated with obtaining some of the approvals requires planning to have commenced well in advance.

This is particularly evident in the case of approvals associated with constructing and operating CO_2 pipelines.

The DMP is currently finalising the required environmental approvals for the 3D seismic program.

CO_2 Transport Planning

CO_2 transport options were broadly investigated as part of the South West Hub Business Case. The CO_2 Transport Report concluded that a pipeline was the most viable option for the South West Hub. An existing pipeline easement owned by the Western Australian Government may provide land access and thereby largely determine route selection for the pipeline. The report concluded that further in-depth studies will be needed to fully evaluate this and other options.

DMP and other State Government agencies completed a constraint mapping exercise of the Dampier to Bunbury Natural Gas Pipeline easement. The maps are facilitating route selection, pipeline engineering and design and other regulatory approval studies.

An Environmental Approvals Strategy has been mapped for the pipeline project. The strategy outlines the range of licences, permits and approvals that need to be obtained to build the pipeline (and the timelines associated with obtaining them). This information is being used in the project management plan to prioritise and schedule future works.

Research

The South West Hub has established a research partnership with the Western Australian Energy Research Alliance (WA:ERA) a joint venture between Australia's premier research body the CSIRO, The University of Western Australia and Curtin University. This alliance was identified in the submission to the CCS Flagships program as an essential component of the South West Hub and met the requirement for a research partner.

This requirement has led to the formation of the National Geosequestration Laboratory (NGL) which received $48.4 million in Commonwealth government support under the Education Investment Fund. The NGL is centred on the Australian Resources Research Centre in Bentley (Perth, Western Australia) designed to conduct research and development support for large-

scale geological storage of CO_2. The new infrastructure will consist of scientific laboratory equipment, mobile and re-deployable field instrumentation and equipment plus scientific equipment installed in an in-situ reservoir scale field laboratory. The facility will further boost the:

- Organic and geomechanical laboratories, to efficiently analyse fluid samples from the reservoir and confirm storage effectiveness;
- Rock mechanics laboratory with core flooding and triaxial equipment specifically designed for CO_2; and
- Sensors laboratory to develop novel, low cost and remote sensors.

Priority access to the NGL will be for CCS Flagships projects and the South West Hub in particular. A Science Committee has been established to review and prioritise projects and activities, which utilise the NGL according to an agreed set of assessment criteria.

As the South West Hub is investigating and researching the Lesueur as a saline aquifer with a non-traditional trapping mechanism, the partnership with WA:ERA is considered vital to proving the science behind the carbon storage proposal.

The South West Hub also has strong research ties with Australian National Low Emissions Coal Research and Development (ANLEC R&D) and the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC).

The South West Hub has a range of research projects associated with the Harvey 1 well including:

- **Stratigraphic forward modelling for the Lesueur Sandstone**
  This demonstration will assess storage reservoir characteristics and produce a static model of the predicted grain size distribution in subsurface strata.
- **Facies-based rock properties distribution along the Harvey 1 stratigraphic well**
  This research project is designed to provide high end analysis of core samples to support stage gate decisions on:
  1. the South West Hub 3D seismic data acquisition and processing workflow, and
  2. site selection for a pilot CO_2 injection.
- **Geochemical characterisation of gases, fluids and rocks in the Harvey 1 data well**
  This project will obtain geochemical data from the Harvey 1 well which is required as input for improving the understanding of the geology in the target region for the South West Hub.
- **Integration of data from Harvey 1 well to support decisions – fault seal**
  This project will evaluate the hydraulic behaviour of faults within the Lesueur Sandstone and Eneabba formations. A secondary objective is to investigate the distribution of sub-seismic fractures and their impact on the trap integrity and reservoir compartmentalisation.
- **Advanced geophysical data analysis for the South West Hub Harvey 1 well site**
  The outcomes of the geophysical data analysis will be used to assist further development of the South West Hub project, including designing the 3D seismic acquisition and processing program, updating the storage site 3D geological model and targeting positions for the next set of wells. Geophysical data analysis will assist with assessment of the storage site key parameters: reservoir storage capacity, injectivity, sealing potential and long term site stability (stress, seismicity, and seal).

Communication and Community Relations

Stakeholder Engagement Plan

In May 2010 a stakeholder engagement plan was developed with the objective of supporting the business case for CCS Flagship funding.

The plan outlines the various pathways for stakeholder engagement, including risk assessment, briefings for community groups, the establishment of a Lesueur Community Consultative Committee (LCCC) and a media strategy. Implementation of the stakeholder engagement plan has commenced and will continue to be reviewed and revised to account for changing circumstance throughout the life of the project.

CSIRO Community Workshop

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) workshop funded by the Global CCS Institute was held in February 2011 in Harvey.

Following the workshop, CSIRO compiled a report on the participant views towards low emission technologies and the potential for carbon capture and storage in Western Australia's South West.

Information was presented to participants on climate change and low emission energy sources and related technologies, followed by a presentation on CCS and the South West Hub project. The results from the workshop have been made widely available in order to ensure that the outcomes were disseminated to the widest possible audience.

Lesueur Community Consultative Committee

To ensure the community plays a critical role in the assessment and evaluation of the South West Hub, in 2011 the WA Minister for Mines and Petroleum established the Lesueur Community Consultative Committee (LCCC).

The LCCC provides a forum for open and accurate communication. Members of the LCCC have a means to be involved in the project assessment process through the identification of issues, monitoring of trials and input to project planning and development.

The LCCC also provides a forum where broader community concerns can be aired, knowledge gaps identified and methods of information sharing and community involvement can be agreed.

The LCCC is independently chaired by a local Harvey resident and includes self-nominated members, members nominated by local authorities and the local members of both State and Federal Parliament. Through the chairperson, the LCCC can report directly to the WA Minister for Mines and Petroleum.

The first meeting of the LCCC was held on the 31 August 2011 and regular meetings are held on a quarterly basis.

Harvey Information Session

In January 2013, the DMP hosted an information session to provide the local Harvey community with an opportunity to learn about the proposed 3D Seismic Survey.

The format of the session was designed so that members of the local community could approach a series of stations where they could ask experts about any aspect of the project. This provided an opportunity for the local community to directly engage with the project managers, researchers and contracted third parties associated with the 3D seismic program in a one-on-one format.

CarbonKids

CarbonKids is an educational program being developed by the CSIRO that combines the latest in climate science with education in sustainability. It aims to provide primary and secondary schools with resources enabling them to encourage their community to address climate change and support a reduction of greenhouse emissions in schools and local communities through direct action.

In August 2012, the Global CCS Institute launched 'Introduction to carbon capture and storage' – an inquiry based education resource pack designed to help teachers and students learn about CCS.

The South West Hub has been actively involved in the development of the Carbonkids CCS program with schools in the Harvey region participating in the pilot program.

Pipeline Research Project

The South West Hub is participating in a CO_2 pipelines research project established to:

- Identify effective processes for engaging constructively with communities potentially affected by CO_2 pipelines to:
  - Improve public acceptance,
  - Integrate public concerns and aspirations in planning and decision making,
  - Encourage safe practices amongst community members; and
- Explore how organisational design and safety incentive schemes can promote positive safety cultures and practices in pipeline construction, operation and maintenance.

The study is being conducted by the Australian National University for the Australian government and the Energy Pipelines Cooperative Research Centre. The project focuses on risk communication and public engagement of CO_2 pipelines and uses the premise that no risk becomes relevant until is observed and communicated and that the response to the communication may amplify or attenuate the risk.

Harvey Show

In April 2013, the SWH partnered with the CSIRO in hosting a stand at the Harvey Shire Agricultural Society Annual Show.

This provided an opportunity the local community to learn about the project through direct engagement with project managers and scientific experts involved in the SWH.

Risk and Challenges

New Industry

CCS is a new industry in Western Australia and consequently there are no local benchmarks against which community and government can compare the South West Hub. This fact brings with it a number of challenges in itself, most notably the need for education on CCS.

The new status of the industry also presents challenges when dealing with government agencies, particularly those who will be involved in issuing regulatory approvals for the project. No standard conditions of approval exist for a CCS project and the limited level of knowledge within decision making agencies will act as an impediment.

To address these challenges, the South West Hub Project proponents have and continue to engage with government and non-government stakeholders to educate, identify issues of concern and consider practical solutions.

Carbon Pricing

The Australian Parliament passed the Clean Energy Act on 8 November 2011. The carbon pricing mechanism started on 1 July 2012. It applies to Australia's biggest polluters who have to report on, and pay a price for, their carbon pollution. The price is fixed each year for the first three years, starting at $23 a tonne in 2012–13. Then from 2015–16 the price will be set by the market.

The South West Hub Joint Venture Partners will take account of the positive impacts the carbon price has on the project's economics in any future decision-making. Whilst the passage of the pricing legislation through Parliament was a positive incentive to continue with the phased development of the project, the absence of a global carbon pricing mechanism will remain a critical risk for the project.

CO_2 Storage sites

A risk to the development of the project is that the targeted Lesueur Sandstone formation proves to be geologically unsuitable to sequester large volumes of CO_2. This risk is being managed by progressing data acquisition and decision gates to build confidence.

A further risk is that the unconventional seal mechanism fails to adequately satisfy the assessment criteria and is therefore considered to be unsuitable to safely trap CO_2 for permanent storage.

In order to manage these risks, DMP is undertaking a desk-top analysis of other potentially suitable geological sites in Western Australia. This work is being done in parallel with the current pre-competitive data acquisition at the Lesueur.

Delivering Milestones

Delivering milestones on time and on budget is a significant challenge for any project, including the South West Hub. While there is no single solution to addressing this challenge, some of the strategies being employed include:

- Early and transparent stakeholder consultation, supported by a robust communications plan;
- Setting and continually reviewing project milestones;
- Regularly reviewing and updating project management plans and schedules to identify critical paths andkey decision points;
- Regular project team and joint venture meetings;
- Regularly reviewing project resource allocation and budgeting; and
- Membership of the Global CCS Institute to learn lessons from international CCS projects.

Contractual Arrangements

Multiple funding parties, all with different objectives and approaches to contract management, are involved in the South West Hub.

To date, one of the challenges has been translating funding allocations into a series of detailed contractual arrangements between the Federal and State Government, research organisations and JV partners.

The various parties involved in the project have different corporate and legal structures, and each has its own commercial interests. Sufficient flexibility needs to be built into the UJV agreement to accommodate these factors.

Community Engagement

As with any CCS project around the world, the South West Hub must gain the understanding and support of local community members if it is going to be a successful venture.

A risk is that the Stakeholder Engagement Plan's implementation fails to gain the required support.

This risk is being managed by early and ongoing consultation with key stakeholders. A broad spectrum of communication mediums are being employed to engage in meaningful dialogue with stakeholders, particularly the local community members that will be directly affected.

Lessons Learnt

Whilst the South West Hub is still in its early stages of development, a number of important lessons have already been learnt. These include:

- Demonstrating that multiple organisations, including competitors, can work together to achieve a common goal. Each of the industry partners has committed to the project for varying reasons and brings different commercial structures, corporate cultures and interests to the table. A common position can be negotiated where there is a will to do so.
- Pre-competitive data acquisition should commence as early as possible, given the long lead times associated with planning seismic surveys, well programs and the subsequent analysis of collected data.
- Coordination of the South West Hub project is currently being led by DMP out of Bunbury, the largest regional centre in the South West of WA; the UJV project manager is also operating out of Bunbury. Having a local presence within the target investigative area has given South West residents easy access to South West Hub project leaders, and gives confidence that the government and industry partners are committed to genuine stakeholder engagement.
- From a government perspective, DMP has learnt that there are many challenges associated with its unique involvement as project leader and future facilitator and regulator. For example, DMP has had to step outside of its traditional regulatory responsibilities and consider the project from a commercial perspective. This has necessitated a different approach when dealing with stakeholders.
- Participants at every level within the South West Hub have come to learn that while timeframe planning is important, self-imposed deadlines are frequently found to be unrealistic.

  Valid assumptions were made about project timing during the development of the business case, however due to the complexity of the project, continual identification of issues and a number of unforeseen circumstances, there have already been delays in achieving some of the project milestones.

  For example, the 3D seismic survey was originally scheduled to commence in quarter 1 2013. Due to complexities with contracting, meeting regulatory requirements and coordination of land access with seasonal change, the 3D seismic survey will now commence in quarter 1 2014.

  The commercial partners have also experienced delays in their project timetables. Delays of this nature have a 'flow-on' impact on all other project activities.

Conclusion

The South West Hub has the potential to make a significant contribution to controlling future emissions of CO_2 in WA. Since its inception, the project has received broad support from both the Commonwealth and State Government and industry.

Consultation has commenced and is on-going with all key stakeholders in a continual effort to educate and understand community concerns about CCS, and more specifically, the South West Hub project. All parties to the project are aware that its future development is dependent on community understanding and support.

The project continues to be developed in a phased approach with focus on pre-competitive data acquisition and analysis to test the suitability and capacity of the Lesueur for CO_2 geosequestration.

The finalised UJV will enable the industry members to manage the project as it moves into the CO_2 sequestration demonstration phase (Enabling Case), before eventual transition to commercial scale CO_2 geosequestration (Base Case and Extended Cases).

One issue outside of the control of the South West Hub proponents tha t will have a significant bearing on the future development of the project is the global carbon pricing mechanism. The introduction of an Australian carbon price needs to be matched by the global community.

Other risks and challenges also represent project hurdles, but can be addressed through careful management and learning from international CCS counterparts.

Future reports to the Global CCS Institute will share detailed geological models and data interpretation of the investigative area as seismic analysis and stratigraphic well drilling are completed.

Further Reading

The Department of Mines and Petroleum website contains information and documents on the South West Hub. These can be accessed at: Department of Mines and Petroleum http://www.dmp.wa.gov.au

The following information provides further detail on various aspects of the South West Hub Project: http://www.dmp.wa.gov.au/documents/Collie_Hub_brochure.pdf

Carbon Capture and Storage Frequently Asked Questions: http://www.dmp.wa.gov.au/documents/FAQ.pdf

Results from the CSIRO Community Workshop: http://www.dmp.wa.gov.au/documents/Collie_hub_workshop_report_.pdf

Abbreviations

ACALET	Australian Coal Association Low Emission Technology Fund
CCS	Carbon Capture and Storage
CO_2	Carbon dioxide
CO2CRC	Cooperative Research Centre for Greenhouse Gas Technologies
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBNGP	Dampier to Bunbury Natural Gas Pipeline
DIISR	Department of Innovation, Industry, Science and Research
DMP	Department of Mines and Petroleum
DRET	Department of Resources, Energy and Tourism
EIF	Education Investment Fund
EPA	Environmental Protection Authority
FEED	Front End Engineering Design
GSWA	Geological Survey of Western Australia
JV	Joint Venture
km	kilometres
LCCC	Lesueur Community Consultative Committee
MOU	Memorandum of Understanding
Mt/a	Million tonnes per annum
PGERA	Petroleum and Geothermal Energy Resources Act
SPV	Special Purpose Vehicle
t	tonnes
UJV	Unincorporated Joint Venture
WA	Western Australia
WA:ERA	Western Australian Energy Research Alliance

Appendix 1: Geology of the South West of Western Australia

Disclaimer

This appendix has been taken from a report contracted between:

The Department of Mines and Petroleum (DMP) and Schlumberger Carbon Storage Solutions Pty Ltd (CSS). Funding for this contract came from a Memorandum of Understanding between DMP and BHP Billiton Worsley Alumina Pty Ltd, Griffin Energy Development Pty Ltd, Premier Coal Limited, Electricity Generation Corporation (Verve Energy) and Perdaman Chemicals & Fertilisers Pty Ltd. The summary is a fair presentation of the results.

Cautionary Statement

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Geology of the South West of Western Australia

The Perth Basin was initiated about 300 million years ago as a rift valley when the supercontinent of Gondwanaland began to split up into the distinct tectonic plates of India and Australia. Material was eroded from the largely granitic Yilgarn block and deposited on the rift valley floor and later the continental edge, gradually building up deep layers of sedimentary rock. This process was not continuous resulting in distinct layers or strata corresponding to different geological epochs.

The sediment ranges in depth from 11000m in the Bunbury trough to 3000m on the Vasse Shelf. Stresses released by the drift of the continents generated a number of faults, all currently inactive, which cut across the strata in places and resulted in more complex geology.

The Perth Basin strata was deposited during four geological periods above the basement Precambrian rock. These include the Permian Sue Group of mainly consolidated sandstone and siltstone with some coal measures. This group is little understood since it has rarely been penetrated by wells due to its extreme depth. The Sue Group is believed to be up to 4000m thick in places. It contains the Whicher Range natural gas field and may contain other pockets of hydrocarbons.

Overlying this and laid down in the Triassic period is a relatively thin (50-200m) belt of Sabina sandstone and a much thicker layer of Lesueur sandstone, which is subdivided into the Myalup and Wonnerup members. Lesueur sandstone is on average 1600m thick and consists of mainly coarse-grained sandstone. It generally holds highly saline water. On the data available to date, both the Myalup and Wonnerup members appear suitable as reservoir rocks.

Over this is the Jurassic Cockleshell Gully formation defined in the northern Perth Basin as Eneabba member and Cattamarra coal measures. The Cockleshell Gully formation consists of river-borne deposits of fine to coarse-grained sands interbedded with shale and silt over much of its area. It is between 600m and 2000 metres thick.

Over the Cockleshell Gully formation is the Yarragadee formation consisting mainly of poorly sorted and unconsolidated sands. The Yarragadee is an important fresh-water aquifer, which supplies water to Bunbury, Busselton and potentially to Perth. It occupies only parts of the Southern Perth Basin. In the area of interest the Yarragadee formation has been lost by erosion between Kemerton and Mandurah.

More recent Cretaceous units including the Leederville formation and the Coolyena Group overly the Yarragadee formation. The Coolyena Group consists of shale, siltstone and silty sandstone and acts as a confining layer over the Leederville aquifer. The Leederville formation is the main strata of the Warnbro group. It is an important aquifer for irrigation in the southern part of the Southern Perth Basin, but is limited in thickness further north.

Nearer the surface are thin Cainozoic carbonates outcropping as coastal limestone.

All strata are not continuous so it is possible to identify areas where some are missing and other strata can be found.

Groundwater salinity typically rises rapidly with depth. For example the Yarragadee aquifer is generally less than 1000mg/L while salinity rises to nearly 15000mg/L 150 metres below the base of this aquifer in the Cockleshell Gully formation.

The southern Perth Basin, specifically between Bunbury and Mandurah, was identified as having good geosequestration potential. While parts of the basin were deemed inappropriate, one area in particular between Bunbury and Mandurah has a number of favourable aspects.

The Perth Basin is a north-trending, sediment-filled trough situated on the south-western margin of the Australian continent. The area of interest is south of 33°S and bounded by the Darling and Dunsborough faults. This coincides with the geological area known as the Harvey Ridge, which is a northwest-southeast trending structural high. Distinct structural units exist in the area.

In order to understand the geology of the target area, numerous wells in the region (water bores, stratigraphic and exploration wells) have been investigated.

The N-S cross-section of the figure below shows the structural geometry, with the pre-Cretaceous sequences dipping away from a high, known as the Harvey Ridge just to the south of Lake Preston. In this location, the Yarragadee Formation is absent. In terms of resource conflicts, this factor is of major regional significance as the Yarragadee is one of the main drinking water aquifers for Perth and the South West.

The overlying Leederville Formation is also an aquifer for the South West region, but pinches out near the Harvey Ridge structure.

Possible Geosequestration Sites

A review of the geology of the Collie basin and the South Perth basin (the only areas close enough to the main source of captured CO_2 suitable for sequestration) prepared by the CO2CRC in 2007 reached these conclusions:

Collie Basin

The Westralia Sandstone and the Ewington Coal Measures in the Cardiff Sub-basin, the western lobe of the Collie Basin, appear to have the characteristics of a suitable reservoir and seal pair. However, the storage capacity for supercritical phase CO_2 appears to be insufficient for the 10 Mt/yr of CO_2 emissions anticipated from Collie over the long term.

Moreover the folds in the strata that underlie the Nakina formation could allow upward migration of CO_2 after injection and subsequent release into the permeable and unconfined Nakina formation. There are also a number of faults in the basin that could provide vertical escape pathways for the CO_2.

Ten existing bores, four exploratory bores and six bores of the Cardiff South well field could provide CO_2 leakage pathways.

In addition the substantial resources of fresh groundwater are presently used for cooling during power generation in the Collie Basin. They will be at risk of contamination from CO_2.

Carbon dioxide storage could sterilise coal resources preventing future mining in the Cardiff Sub-basin.

While some coal measures may be unsuited to mining using present day technology future developments such as underground gasification and automated mining may make otherwise unmineable resources valuable.

Wilga and Boyup Brook Basins

The shallow depths of the Wilga Basin and the shallow depths of the basin, limited storage capacity and lack of an extensive sealing bed in the Boyup Basin preclude these basins from being a suitable CO_2 storage site.

Coal Bed Storage in the Collie Basin

The Muja Coal Measures are not suitable for coal seam storage of CO_2 as the coals are too shallow and are currently being mined.

The Premier coal seams are unsuitable for storage due to their faulted nature, and the fact that the coal seams extend near the ground surface. In addition, some seams are currently mined.

Harvey Ridge of the Southern Perth Basin

The CO2CRC study utilised existing petroleum well and seismic data as well as information obtained from four previously drilled 800m deep groundwater research bores between Binningup on the coastline and Benger near the Darling Scarp on the eastern edge of the Southern Perth Basin. It identified the Lesueur Sandstone formation in the geological fault line known as the Harvey Ridge as an area with the highest potential for storage of a large volume of CO_2 that is within 70 km of the Collie industries.

The Harvey Ridge (above) is a structural high extending northwest to southeast. It occurs just south of Lake Preston in the onshore part of the Southern Perth Basin. The structural geometry consists of Lesueur sandstone strata overlaid by the Cockleshell Gully formation, dipping down to the north and south of the ridge axis. This ridge also marks the location where the Yarragadee formation is absent and the Leederville formation is thin.

A thin freshwater wedge extends to 150m deep on the west, below this the salinity rapidly increases, reaching 25000 mg/L at 200m on the eastern side. The absence of a thick freshwater aquifer close to the surface in the Harvey ridge is unusual for the Southern Perth Basin. It suggests that the Cockleshell Gully formation, which is close to the surface there, has low permeability that inhibits freshwater recharge.

The CO2CRC proposal was to evaluate injection of CO_2 into potentially transmissive sandy zones between 2900m and 3300m depth in the lower part of the Lesueur Sandstone. The logs from the Lake Preston-1 exploration bore (near the top of the Harvey Ridge) indicate that the lower part of the Lesueur Sandstone (2900-3300 m) may contain less saline water. This suggests these strata may have good horizontal transmissivity and consequently potentially good injectivity.

Primary CO_2 migration will occur towards the North West within the lower Lesueur formation due to buoyancy. Secondary migration will take place vertically into the overlying strata of the upper Lesueur Sandstone and Cockleshell Gully formations.

These two formations contain a mixture of discontinuous sands, silts and muds, providing low permeability discontinuous vertical flow paths, with many local-scale baffles to inhibit vertical CO_2 migration. As a result, CO_2 migrating upwards has a tortuous path and therefore contacts a large pore volume of the strata. Thin shale baffles also have the ability to slow down or stop the vertical migration of CO_2 within a reservoir. No column of CO_2 builds up to exert a force on the seal, instead it spills sidewise. This means even a relatively low competency siltstone or shale has the potential to act as a baffle and extend the migration path.

Low permeability and reactive minerals may result in increased mineral trapping in the CO_2 migration path. As the plume migrates vertically, some of the CO_2 dissolves into the formation water thus increasing its density. The higher density CO_2 saturated water will migrate downwards.

This combination of trapping mechanisms coupled with the thickness (more than 2000m) of the overlying upper Lesueur Sandstone and Cockleshell Gully formations, may provide enough storage and containment security for the volume of CO_2 it is hoped to sequester.

The principle of geosequestration within the Harvey Ridge had been established through a previous study of simulated injection within the strata characterised

by the Cockburn-1 well near Kwinana. The average case scenario at Cockburn-1 predicted vertical migration of about 600m in 200 years at one million tons per year injection rate.

However, Harvey Ridge has far more favourable characteristics than those found at Cockburn-1. Therefore it could be a suitable location for safe storage of a considerable volume of CO_2.

Potential of the Lesueur Sandstone for CO_2 Geosequestration

Although the Lesueur sandstone appears to have the greatest potential for geosequestration in the region, there is limited existing seismic and well data available to demonstrate this.

Therefore DMP commissioned Schlumberger Carbon Services to determine the suitability of the site for geosequestration based on data from existing exploration wells drilled over the past decades and a number of seismic surveys over the same period.

Core data was available only from Pinjarra-1, Cockburn-1 and Lake Preston-1. Well completion reports were also available for Preston-1, Wonnerup-1 and Rockingham-1. These were drilled between 1965 and 1983. Due to the difference in time, the well reports often reported conflicting well log data. There were also four hydrology wells to 800m depth.

The core from Pinjarra-1 was chosen for analysis as it was in reasonable condition and covered both formations of interest, however it was drilled in 1965 and 30km from the most favourable location.

Seismic data was obtained from 68 lines of 10 surveys. It was of variable quality but showed that a continuous impermeable cap is unlikely. Containment must therefore depend on baffles to extend the migration path of CO_2 and increase its chance of being trapped by solubility, hydrodynamic, residual gas and mineral trapping mechanisms.

From this data the consultants were able to use numerical modelling to predict the characteristics of the Lesueur sandstone under the Harvey Ridge.

They first constructed a geological model to integrate our existing understanding of the site's geology. This enabled simulations to be carried out of CO_2 injection scenarios and the behaviour of injected CO_2 over space and time under a range of conditions.

Physical and mineral characteristics of the Eneabba formation and Lesueur Sandstone were evaluated using Pinjarra-1 cores.

The Lesueur Sandstone formation was found to have reasonable porosity (6-31 per cent) reducing at depth and moderate permeability (1- 500mD).

The Cockleshell Gully formation was characterised by the widespread presence of fine-grained clastic (redeposited) rocks, such as shale beds, up to 40m thick, indicating low permeability, which is likely to impede the upward migration of CO_2.

Tests were performed to determine the flow characteristics of rock-brine-CO_2 in the cores. However, no clear trend could be discovered, therefore published analog data were used as inputs to the dynamic reservoir model.

Faults were shown to withstand a pressure increase of up to 110 bar (10000 kpa) without leakage. The transmissibility of the faults varies in every direction. This outcome was also integrated into the reservoir model.

A 3D static model was built by integrating seismic interpretations, well data and previous studies. There is probably no continuous conventional seal in this area so containment must rely primarily on formation heterogeneity and baffles to increase the CO_2 migration path length and maximise residual trapping.

Major faults were interpreted for the model but not all faults are visible on seismic surveys due to sparse data coverage and therefore cannot be included in the model.

In addition to the base case model, lower connectivity and higher connectivity geological models were built by varying the amount of shale in the model, to capture uncertainties when performing CO_2 injection simulations.

Dynamic simulation provides a better understanding of how the injected CO_2 will behave as it migrates. It also shows how uncertainty in various parameters affects storage performance.

In one scenario CO_2 was injected for 40 years through six injector wells. In addition to injectivity and capacity, containment was examined by evaluating the amount of residual trapping produced in the models. The location of the injection wells were chosen to minimise

plume migration towards the faults and to maximise the volume of reservoir rock and aquifer contacted by the CO_2. They were also located in areas with good reservoir connectivity so more CO_2 may be disposed of without exceeding any pressure limits on the formation.

The models suggest that injection rates of 0.9-1.7 million tonnes/annum/well for a six-well injection scenario can be sustained for 40 years. This results in 200 to 260 million tonnes CO_2 being injected.

In the simulation, after 40 years the CO_2 injection was stopped and plume movement was modelled for an extended period of time. At the end of 1250 years, CO_2 was still contained within the structure with the majority trapped in the Myalup Member. The CO_2 plume reached the bottom of Eneabba Formation; however it did not percolate higher, nor did the plume reach the faults that bound the injection area.

During real site operation, monitoring will be required to ensure that the CO_2 plume does not reach the faults and that the injection pressure does not exceed the pressure needed to reactivate the fault. In the model the maximum pressure build-up of about 5000 kPa occurred across the Darling Fault, which is below its estimated reactivation threshold.

The models were created based on 2D seismic, core data from Pinjarra-1, which is 30 km away and logs from other wells that were drilled in the 60s and 70s. Consequently many assumptions were made to build these models in absence of site-specific data.

The greatest uncertainties for dynamic modelling are reservoir properties such as permeability and connectivity. Permeability accounts for between 50 and 80 per cent of uncertainty in injection rates. Available area and thickness distribution contribute most (40-70 per cent) to uncertainty in capacity estimates.

RISQUE modelling (URS Group) of CO_2 containment risks delineated a worst-case scenario where the project would still retain around 99.6 per cent of the injected CO_2 over 1000 years.

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