Executive Summary

The Collie—South West CO₂ Geosequestration Hub project (The Collie Hub) is a government industry partnership led by the Western Australian Department of Mines and Petroleum (DMP). The Collie Hub industry partners are Alcoa Australia, BHP Billiton Worsley Alumina, Griffin Energy, Perdaman Chemicals and Fertilisers, Verve Energy and Wesfarmers Premier Coal.

The Collie 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 CO₂ emissions by 60 per cent (of year 2000 levels) by 2050.

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

The Preparation Phase (2011-2012) involves pre-competitive data acquisition and analysis to test the suitability and capacity of the Triassic Lesueur Sandstone Measures of the Southern Perth Basin (Lesueur) for CO₂ geosequestration. The geographic region being considered is an area south of Mandurah and north of Kemerton Industrial Estate, in the Shire of Harvey. Other investigative works will be carried out as part of the project's preparation phase.

The Enabling Case (2012-2015) will take approximately 350,000 tonnes per annum (t/a) of CO₂, in a gaseous form, from an existing chemical plant in Kwinana for transportation 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 sequestration site to test the storage characteristics of the Lesueur.

The Base Case (2015) involves commercial scale capture, transport and storage of 2.45Mt/a of CO₂ from the proposed Perdaman Chemicals and Fertilisers’ plant in Collie. A pipeline will be constructed from the Collie region and CO₂ will be transported, in a compressed form, to the yet to be determined location for geosequestration.

The Extended Cases (2018-2023) will be undertaken in two phases and will allow for the nominal CO₂ capture, transport and storage capacity of the 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 recent passage of carbon tax legislation through Federal Parliament 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.

The first significant project milestone was achieved in June 2011 when the Commonwealth Government, through the CCS National Flagships Program, awarded $52 million to the Collie Hub for its ongoing project development. This funding is the first instalment of a total funding arrangement for $330 million being made available to The Collie Hub under the Flagship Program. The initial funding will be 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 provided as the project proceeds.

The Collie Hub is currently in the preparation phase, focussing on pre-competitive data acquisition. Based on 2D seismic results obtained from a recent survey, a drilling program is planned to collect data from a 3,000 metre deep well in the investigation area. The data collected will inform decision making with respect to future 3D seismic surveys and additional wells.

An Unincorporated Joint Venture (UJV) Agreement is being finalised by The Collie Hub industry partners. The UJV will lead the commercial deployment of the project when it transitions from the pre-competitive data acquisition phase to CO₂ 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 is being established to allow for the capture, transport and storage of CO₂ in Western Australia. A discussion draft of the legislative changes has been released for public review.

The planning for CO₂ transportation has commenced with the commissioning of a detailed mapping exercise of the proposed pipeline route from Kwinana to the Harvey region.

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.

A number of risks and challenges must be managed to bring the project from the conceptual stage to reality. Of these, the future global carbon pricing mechanism and community engagement will have a significant bearing on the Collie Hub’s development. Other issues of significance include contractual arrangements, project management (timing and budgeting), geological data acquisition and research and development.
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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 CO₂ producer. The area from Kwinana to Collie is the focus for the Collie-South West CO₂ Geosequestration Hub (The Collie Hub).

The coal miners, coal user industries and major alumina refining companies in the area are developing an Unincorporated Joint Venture (UJV). The UJV will be a vehicle to investigate carbon storage opportunities, in a geological strata known as the Lesueur.

The UJV partners are Alcoa Australia, BHP Billiton Worsley Alumina, Griffin Energy, Perdaman Chemicals and Fertilisers, Verve Energy and Wesfarmers Premier Coal. These industry partners are developing or considering billions of dollars worth of new projects, utilising post combustion capture technologies, integrated gasification carbon capture or permanent CO₂ chemical sequestration in bauxite residue.

Two prominent projects for The Collie 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 CO₂ in its bauxite residue.

The estimated total of CO₂ available for capture from new and potential projects in the Collie Hub region is in the range of five to six million tonnes per annum by 2020.

Figure 1: SW MAP
2. Project History

2.1 Origins

The impetus for investigations into Carbon Capture and Storage (CCS) in Western Australia stemmed from coal miners, users and the Government coming together as the Coal Futures Group in 2006 having jointly recognised the need to make a step change in atmospheric emission levels. Coal has the potential to remain one of Western Australia’s major energy sources for many decades to come, creating the need to deploy new technology to reduce emissions from this source. The group identified two critical technologies to help achieve this aim: CCS and coal gasification1.

The Coal Futures Group (through the Department of Mines and Petroleum) commissioned the CO2CRC to identify possible sites for geosequestration within a 50 km radius of the Collie power stations. In May 2007 the Regional Study on Potential CO2 Geosequestration in the Collie Basin and the Perth Basin of Western Australia discounted the use of the local Collie and Wilga Basins, due to the lack of depth of the possible reservoirs and sealing issues within the basins. The study identified the deep saline formation known as the Lesueur 50-70 km west of Collie, as having potential for the storage of a large volume of CO2. (For further information on the geology of the region and possible sequestration sites, see Appendix 1)

The Department of Mines and Petroleum (DMP) together with BHP Billiton Worsley Alumina, Griffin Energy, Perdaman Chemicals and Fertilisers, Verve Energy and Wesfarmers Premier Coal then signed a Memorandum of Understanding (MOU) to jointly fund further investigations of the Lesueur. In 2009, Schlumberger Carbon Services was contracted to undertake a detailed analysis of existing data and to test core from previously drilled nearby wells. Later, Alcoa of Australia joined the group and a second MOU was signed.

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

The signatories to the Statement of Intent have worked well together. This has been demonstrated in the last two years by the commitment to the orderly development of the Collie Hub, the signing of two MOU’s, co-funding studies into the geosequestration potential of the Lesueur and the development of a business case.

2.2 Timeframes

The Collie 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 – 2012)
- The Enabling Case (2012 – 2015)
- The Base Case (2015) (see fig. 2)
- Extended Case 1 (2018)
- 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. This is discussed in further detail in section 3.1. Other investigative works will also be carried out as part of the preparation phase including a 3D seismic study and further stratigraphic well drilling (see section 4).

The signatories to the Statement agreed to cooperate in good faith with a view to developing the Collie 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 CO2;
- 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.

A Statement of Intent was then signed by all of the project partners as a precursor to developing a submission for funding from the CCS Flagship program (see section 5.1).

\[1\] The Department of Mines and Petroleum, and Verve Energy, were significant contributors to a confidential January 2008 report by the Cooperative Research Centre for Coal in Sustainable Development (CCSD) Coal Gasification Testing of Four Australian Coals which has provided the confidence that Collie coal is suitable for gasification technologies.
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 via pipeline in a compressed form to a yet to be determined site in the Lesueur for geosequestration.

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.

![Figure 2 – A conceptual diagram of the Collie Hub.](image-url)
2.3 The Business Case

In order to apply for funding under the Commonwealth Government’s CCS Flagships Program, a business case was developed. At a high level, seven key aspects for a carbon capture and storage project in Western Australia were addressed:

1. Preliminary site selection, storage mapping and characterisation – to characterise the storage capacity of the Lesueur and to identify possible injection sites.

2. Carbon capture – identification of carbon capture readiness requirements.

3. Carbon transportation – pipeline transport requirements.


5. Commercial framework for a carbon capture and storage project.


7. Research – arrangements with research institutions in compliance with the Education Investment Fund (EIF) criteria.

Supported by financial modelling, the Business Case concluded that the Collie Hub could operate on a commercial basis, provided that:

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

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

On the 11 June 2011 the Federal Minister for Resources, Energy and Tourism, Martin Ferguson MP announced the awarding of $52 million to the Collie Hub under the Flagship Program (see section 5.1). The funding will be 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 provided as the project proceeds.
3.1 Pre-competitive data acquisition and analysis

The Collie Hub is currently focusing on the collection and analysis of pre-competitive data to test the CO₂ storage capacity of the Lower Lesueur.

In March 2011, a 2D seismic survey traversing approximately 106 km of road reserves in the target investigative area was completed. Results from the seismic survey are being analysed, with Schlumberger Carbon Services expected to deliver the final report in 2011. A detailed results analysis will be available in the next project status report to the Global Carbon Capture and Storage Institute (GCCSI).

Based on advice received from the analysis of the 2D seismic, planning is well advanced to drill the first 3,000m deep stratigraphic well. The site has been selected, community consultation has commenced² and the tendering process is underway to procure a drilling contractor. It is anticipated that the stratigraphic well will be drilled in the first quarter of 2012 with data analysis to commence in parallel with the drilling.

The purpose of the well is to:

- Confirm the predicted stratigraphy;
- 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.

Figure 3 – The red box shows the stratigraphy in the target area where the top layers have eroded

²DMP produced a pamphlet to facilitate consultation with local residents – see Appendix 2.
3.2 CO₂ Transport Planning

CO₂ transport options were broadly investigated as part of the Collie Hub Business Case. The CO₂ Transport Report concluded that a pipeline was the most viable option for The Collie Hub. An existing pipeline easement owned by the Western Australian Government might 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 is currently working with other State Government agencies to complete a constraint mapping exercise of the Dampier to Bunbury Natural Gas Pipeline (DBNGP) easement. Once completed the maps will facilitate 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.

3.3 Carbon Capture

Approximately 350,000t/a of high quality CO₂ is required and may be available from an existing chemical plants in Kwinana to support The Collie Hub’s Enabling Case.

The ‘Base Case’ and ‘Extended Cases’ rely on The Collie Hub partners and its future users making their own corporate decisions on capture technology.
The project will continue to undertake activities in the Preparation Phase for the remainder of 2011 and throughout 2012.

Following data collection and analysis from the first stratigraphic well, planning will commence to undertake a 3D seismic survey in the Harvey region. This will involve stakeholder consultation, property access arrangements, preparing for and the obtaining of the necessary regulatory approvals, commissioning and scheduling the seismic work.

Depending on the results of the 3D seismic survey, up to four additional data wells could be drilled in the area of interest. A number of decisions will be necessary before this work program can occur.

Work on a preliminary Front End Engineering Design (FEED) study will be commissioned shortly to progress the establishment of the pipeline. This is an essential component of the project to ensure that an effective and efficient method of transporting CO$_2$ is available when the UJV is ready to trial sequestration.

Research and development will be an ongoing project activity through the National Geosequestration Laboratory (see section 8).
5. Milestones

The project identified four key milestones that must be achieved for the project to proceed, these are outlined below.

5.1 Flagship Program

In 2009 the Australian Federal Government announced the CCS National Flagships Program. The program is designed to accelerate the development and demonstration of CCS technologies. The program promotes the wider dissemination of CCS technologies by supporting a small number of demonstration projects, which will capture CO₂ emissions from industrial processes and safely store CO₂ underground in stable geological formations to mitigate global warming.

In November 2009 the Federal Government announced that the Collie Hub was one of four National Flagship Projects. In June 2011, the project was allocated $52 million in funding from the program (up to $330 million could be made available to the Collie Hub should it proceed beyond the current stage).

The Flagship funding has enabled The Collie Hub to effectively move to the next phase of decision making which includes further pre-competitive data acquisition and analysis of the potential storage area.

5.2 Unincorporated Joint Venture (UJV)

The UJV is currently being finalised between the industry partners. This UJV will be the means by which industry will lead the Collie Hub through its future development phases.

Once established, the UJV will appoint a project manager who will gradually replace the DMP as project leader. DMP’s involvement with the project will, thereafter, be as a facilitator and eventual regulator.

DMP will transition from being The Collie Hub project lead proponent to being the lead Government agency for the regulation of CCS in Western Australia in 2012/13.

5.3 Enabling Case Decision

The project is currently in the Preparation Phase and is working towards a decision to proceed with the Enabling Case in late 2012. When made, this decision will be a significant project milestone.

5.4 Base Case Decision

A decision to proceed with the Base Case is several years away and is dependent upon the successful implementation of the Enabling Case.

Further details will be provided in subsequent reports to the GCCSI to gauge progress towards achieving milestones 5.2, 5.3 and 5.4.
6. Legislative Interactions

6.1 CO$_2$ Legislation

Western Australia’s legislation is not adequate for a capture, transport and storage project of this magnitude. This has not been a hindrance to the development of The Collie Hub as it has been conducted on the basis that planned legislation will adequately assist the project.

To date and in the absence of a CO$_2$ legislative regime, pre-competitive data acquisition activities have been conducted under the provisions of the State’s Mining Act 1978.

DMP is responsible for developing the legislation and regulations for the management of greenhouse gas storage in Western Australia.

Wide based consultation with stakeholders has occurred and an exposure draft of proposed legislative changes has been released. The legislation is expected to go to Parliament in 2012.


6.2 Other Legislation and Regulations

The Collie Hub project is 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.
7. Public Communications

7.1 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 throughout the life of the project.

7.2 CSIRO Community Workshop

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) workshop funded by the Global Carbon Capture and Storage Institute (GCCSI) 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 (CCS) 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 Collie Hub project.

Participants found their understanding of climate change and related issues increased as a result of the workshop. The results from the workshop have been made widely available in order to ensure that the outcomes were disseminated to the widest possible audience3.

7.3 Lesueur Community Consultative Committee

To ensure the community plays a critical role in the assessment and evaluation of The Collie Hub, the WA Minister for Mines and Petroleum the Hon. Norman Moore MLC, established the Lesueur Community Consultative Committee (LCCC).

The LCCC is independently chaired by a 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 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 will also provide a forum where broader community concerns can be aired, knowledge gaps identified and methods of information sharing and community involvement can be agreed.

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

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The Collie 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 Flagship Program as an essential component of The Collie Hub and met the requirement for a research partner. This relationship has also extended to a separate submission to the Federal Government’s Education Investment Fund (EIF) for around $50 million.

The submission to the EIF proposed a National Geosequestration Laboratory4 (NGL) 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 CO₂. 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 proposal 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 CO₂; and
- Sensors laboratory to develop novel, low cost and remote sensors.

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

As The Collie 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.

4At the time of writing this report there has been no formal announcement of the EIF funding bid. However, the project has been reviewed and funding, governance arrangements and operational agreements between the Collie Hub and WA:ERA are being advanced to ensure that research can commence with the data well scheduled for the first quarter of 2012
9. Lessons Learnt

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

- The Collie Hub Project is 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 Collie Hub project is currently being led by DMP out of Bunbury, the largest regional centre in the South West of WA. Once established, it is intended that the UJV project manager will also operate out of Bunbury. Having a local presence within the target investigative area has given South West residents easy access to Collie 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 Collie Hub have come to learn that whilst 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, drilling the first stratigraphic well was originally scheduled to commence in Q3 2011. Due to complexities in tendering for the drilling contractor, it is now anticipated that the drilling program will commence in Q1 2012. Delays of this nature have a ‘flow-on’ impact on all other project activities.
10. Risk and Challenges

10.1 Carbon Tax and Global Carbon Price

The Australian Parliament passed the Carbon Tax Bill on 8 November 2011. The Collie Hub project has been modelled on the basis of the carbon tax coming into effect in July 2012. The Collie Hub Joint Venture Partners will take account of the positive impacts the tax has on the project’s economics in any future decision-making.

Whilst the passage of the carbon tax legislation through Parliament is 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.

10.2 CO₂ Storage Sites

A risk to the development of the Collie Hub is that the targeted Lesueur proves to be geologically unsuitable to sequester large volumes of CO₂.

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 CO₂ for permanent storage.

In order to manage these risks, DMP is mapping other potentially suitable geological sites. This work is being done in parallel with the current pre-competitive data acquisition at the Lesueur.

10.3 Community Engagement

As with any CCS project around the world, the Collie 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 (see section 7).

10.4 Contractual Arrangements

Multiple funding parties, all with different objectives and approaches to contract management, are involved in The Collie 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.

Seven major contracts are currently being finalised, a number of which have associated sub-contracts. In negotiating these contracts, issues such as intellectual property rights, knowledge sharing, confidentiality and the sharing of key performance indicators have been highlighted.

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.

10.5 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 Collie 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 Collie Hub Project proponents have engaged early with government and non-government stakeholders to educate, identify issues of concern and consider practical solutions.
Delivering milestones on time and on budget is a significant challenge for any project, including the Collie Hub. Whilst there is no single solution to addressing this challenge, some of the strategies being employed to date 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 and key decision points;
- Regular project team and joint venture meetings;
- Regularly reviewing project resource allocation and budgeting; and
- Membership of the GCCSI to learn lessons from international CCS projects.
The Collie 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 participants.

Consultation has commenced and is ongoing with all key stakeholders in a continual effort to educate and understand community concerns about CCS, and more specifically, the Collie Hub. 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 UJV will be finalised in the near future and will lead 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 Collie Hub proponents that will have a significant bearing on the future development of the project is the global carbon pricing mechanism. The introduction into Australia of a carbon tax needs to be matched by the global community adopting a pricing mechanism for carbon. 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 GCCSI will share detailed geological models and data interpretation of the investigative area as seismic analysis and stratigraphic well drilling are completed.
## 12. Abbreviations

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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACALET</td>
<td>Australian Coal Association Low Emission Technology Fund</td>
</tr>
<tr>
<td>CCS</td>
<td>Carbon Capture and Storage</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>Carbon dioxide</td>
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<tr>
<td>CO2CRC</td>
<td>Cooperative Research Centre for Greenhouse Gas Technologies</td>
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<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
</tr>
<tr>
<td>DBNGP</td>
<td>Dampier to Bunbury Natural Gas Pipeline</td>
</tr>
<tr>
<td>DIISR</td>
<td>Department of Innovation, Industry, Science and Research</td>
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<td>Department of Mines and Petroleum</td>
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<tr>
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<tr>
<td>EIF</td>
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<td>FEED</td>
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<td>Global Carbon Capture and Storage Institute</td>
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<td>Geological Survey of Western Australia</td>
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<tr>
<td>JV</td>
<td>Joint Venture</td>
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<tr>
<td>km</td>
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<tr>
<td>LCCC</td>
<td>Lesueur Community Consultative Committee</td>
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<tr>
<td>MOU</td>
<td>Memorandum of Understanding</td>
</tr>
<tr>
<td>Mt/a</td>
<td>Million tonnes per annum</td>
</tr>
<tr>
<td>PGERA</td>
<td>Petroleum and Geothermal Energy Resources Act</td>
</tr>
<tr>
<td>SPV</td>
<td>Special Purpose Vehicle</td>
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<td>t</td>
<td>tonnes</td>
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<tr>
<td>UJV</td>
<td>Unincorporated Joint Venture</td>
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<td>WA</td>
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<tr>
<td>WA:ERA</td>
<td>Western Australian Energy Research Alliance</td>
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13. Further Reading

The Department of Mines and Petroleum website contains information and documents on the Collie Hub. These can be accessed at:


The following information provides further detail on various aspects of the Collie Hub Project:


Appendix 1

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, Wesfarmers 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

Advice and opinion given in this document by Carbon Storage Solutions Pty Ltd, Schlumberger Carbon Services or Schlumberger Oilfield Services Pty Ltd (‘Schlumberger Companies’) and their management may contain forward looking statements. Forward looking statements do not guarantee performance and are not recommendations for action. Such statements are generally identifiable by the terminology used, such as “plan”, “forecast”, “expect”, “expectation”, “assumption”, “estimate”, “budget”, “probability” or other similar wording. Forward looking statements include, but are not limited to, references to drilling success rates and plans, the form of field developments, seismic activity, costs and margins, carbon dioxide injection rates and sources of change thereof, estimates of capacity related to geographic areas and geological formation, results of exploration activities, and dates by which certain area may be developed or may come on-stream, as well as other market and economic assumptions. These forward-looking statements are subject to known and unknown risks and uncertainties, and other factors which may cause actual results, levels of activity and achievements to differ materially from those expressed or implied by such statements. Many factors are beyond the control of ‘Schlumberger Companies’. The forward-looking statements contained in any advice are expressly qualified by this cautionary statement.

Disclaimer

Due to the fact that interpretations are opinions based upon inferences from measurements, empirical relationships and assumptions with respect to which analysts may differ, CSS cannot and does not warrant the accuracy or completeness of any interpretation, recommendation, reservoir description, analysis measurement, log or data furnished by CSS (“Information”).
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 freshwater 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.

Supercritical Fluids

Carbon dioxide is best injected into rock strata as a supercritical fluid. In this form it is much denser than in the gas phase and therefore more can be stored in the available pore space. The supercritical point for CO$_2$ is 31.1°C and 7.38 MPa (equivalent to a depth of about 800m).

A supercritical fluid can diffuse through solids like a gas, and dissolve materials like a liquid. In addition, close to the critical point, small changes in pressure or temperature result in large changes in density.

The density of supercritical CO$_2$ plateaus at 600-700kg/m$^3$, which is 30-40 per cent less dense than typical saline formation water. It is also from five to 20 times less viscous than brine. Because of this difference in mobility CO$_2$ does not uniformly displace the brine, it forms numerous ‘fingers’ of CO$_2$, which penetrate the brine. Fingering is less apparent at greater depths.
Geology of the South West of Western Australia cont.

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 CO₂ 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 CO₂ appears to be insufficient for the 10 Mt/yr of CO₂ emissions anticipated from Collie over the long term.

Moreover the folds in the strata that underlie the Nakina formation could allow upward migration of CO₂ 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 CO₂.

Ten existing bores, four exploratory bores and six bores of the Cardiff South well field could provide CO₂ 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 CO₂.

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 CO₂ storage site.

**Coal Bed Storage in the Collie Basin**

The Muja Coal Measures are not suitable for coal seam storage of CO₂ 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 CO₂ 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 CO₂ 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.
Potential of the Lesueur Sandstone for CO₂ 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 CO₂ 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.

Possible Geosequestration Sites cont.

Primary CO₂ 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 CO₂ migration. As a result, CO₂ 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 CO₂ within a reservoir. No column of CO₂ 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 CO₂ migration path. As the plume migrates vertically, some of the CO₂ dissolves into the formation water thus increasing its density. The higher density CO₂ 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 CO₂ 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 CO₂.
They first constructed a geological model to integrate our existing understanding of the site’s geology. This enabled simulations to be carried out of CO₂ injection scenarios and the behaviour of injected CO₂ 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 CO₂.

Tests were performed to determine the flow characteristics of rock-brine-CO₂ 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 CO₂ 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 CO₂ injection simulations.

Dynamic simulation provides a better understanding of how the injected CO₂ will behave as it migrates. It also shows how uncertainty in various parameters affects storage performance.

In one scenario CO₂ 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 CO₂. They were also located in areas with good reservoir connectivity so more CO₂ 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 CO₂ being injected.

In the simulation, after 40 years the CO₂ injection was stopped and plume movement was modelled for an extended period of time. At the end of 1250 years, CO₂ was still contained within the structure with the majority trapped in the Myalup Member. The CO₂ 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 CO₂ 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 CO₂ containment risks delineated a worst-case scenario where the project would still retain around 99.6 per cent of the injected CO₂ over 1000 years.
Top view of CO\(_2\) plume in Base model, display as CO\(_2\) saturation, at end of 10 years injection (top-left) and end of 40 years injection (top-right).

Top view of CO\(_2\) plume in Base model, display as CO\(_2\) saturation, at end of 250 years shut-in (top-left) and end of 1250 years shut-in (top-right).
Appendix 2

Data Well Drilling Summary

Following data collection from seismic survey work completed by the Department of Mines and Petroleum’s Geological Survey Division (GSWA) in March 2011, a preferred drill site has been selected to drill a 3,000 metre deep data well. The purpose of the well is to gather data to assess the capacity and viability of the lower Lesueur formation for CO2 geosequestration (carbon capture and storage). It will also provide data on geological formations, geothermal gradients, petroleum prospectivity and water resources within the local area.

The drilling program is jointly funded by State and Federal Government in collaboration with GSWA and Geoscience Australia.

Location

A site at Lot 1326 Riverdale Road, Cookernup has been selected as the preferred site to drill the data well.

The aim of the drilling program is to obtain data on the Lesueur Sandstone. The stratigraphic well is positioned to intersect the sandstone formations at predicted depths of less than three kilometres.

The site will be accessed via Old Coast Road and exist along the unsealed Riverdale Road. Site preparations will take 10 to 15 days. An approximate area of 100 metres x 100 metres (one hectare) will be cleared, levelled and packed with fill to create a hard surface.

The rig will take approximately 10 days to set up. Drilling will be conducted 24 hours a day for 30 days. The drilling operation will be managed in accordance with best practice health, safety and environmental requirements to minimise impacts.

For enquiries regarding the data well, contact:

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What you will see

Equipment and infrastructure for the proposed drilling operations include:

- Drill rig and equipment
- Support vehicles
- Diesel generators
- Temporary fencing, lighting and office accommodation
- A mud sump (pond) of approximately 30 metres x 30 metres x two metres deep to take drill cuttings from the well
- A water bore
- A water pond of approximately 30 metres x 30 metres x two metres deep, with water coming from the water bore. Approximately 2000 kilolitres of water will be taken during the operation.

What will happen

- Site preparation
- A water bore drilling rig will be used to drill both a water bore and a 13 3/8 inch diameter casing to be set and cemented to 100 metres
- Drill rig set up
- Drill 12.5 inch diameter hole to approximately 750 metres
- Geophysically log open hole
- Run, set and cement 9 5/8 inch diameter casing to 750 metres
- Drill 8.5 inch hole to approximately 3000 metres and remove approximately 300 metres for core samples
- Log open hole section
- Plug well
- Pack up rig (five to seven days)
- Rehabilitate site.
The Collie Hub project is supported by the Department of Resources, Energy and Tourism’s Carbon Capture and Storage Flagship Program.