CO2CRC ANNUAL REPORT

2019 2020

CO2CRC BUILDING A LOW EMISSIONS FUTURE

HIGHLIGHTS

1 JULY 2019 – 30 JUNE 2020

Completed installation of Otway Stage 3 Project infrastructure including drilling 4 new monitoring wells over 59 days at the Otway National Research Facility. It involved 7km worth of directional drilling, 11km of steel casing, 13km of fibre optic cable and 458 tonnes of cement.

Successfully installed on-demand remotely operated technology at the Otway National Research Facility allowing Stage 3 baseline data to be collected for pressure tomography and SOV sources.

Completed Otway Stage 2C project demonstrating the stabilisation of a CO_2 plume and developed a methodology for predicting, monitoring, verifying and assuring CO_2 storage in saline formations.

Hosted 130 national and international delegates at CO2CRC's 2019 Symposium comprising 50 technical presentations and 2 specialist workshops.

Welcomed ExxonMobil and Santos as new members of CO2CRC

Completed delivery and installation of gas refining package for Hydrogen Energy Supply Chain (HESC) project

Joined forces with National Energy Resources Australia (NERA) to support an evaluation of the economic and technical feasibility of using CO2-EOR to enhance the recovery of oil from Australia's onshore basins and reduce greenhouse gas emissions through CO_2 storage.

Successfully tested, with University of Melbourne researchers, new hybrid technology for post combustion capture at Vales Point power station

Established CO2CRC CCS Policy Forum (CPF) comprised of senior representatives from its member organisations, to develop an industry consensus view on a desirable Australian CCS Policy Framework.

Provided over 200 school children with the opportunity to learn about CCS during National Science Week at the Gippsland Tech School in sessions delivered in collaboration with CarbonNet.

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A GLOBAL LEADER IN CCS RESEARCH

Operating since 2003, CO2CRC is a world leader in carbon capture, utilisation and storage (CCS) research. It is an incorporated not-for-profit research organisation (company limited by guarantee) funded through government grants, membership fees and direct investments from industry and research bodies.

CO2CRC owns and operates the Otway National Research Facility located in Nirranda South, south-west Victoria, Australia. It has been at the forefront of Australian advances in CCS for over 15 years. To date over $100 million has been invested in the Otway facility to demonstrate real-world capture, injection, storage and monitoring techniques.

CO2CRC is Australia's key designer, initiator, and manager of CCS research. It is the only company in Australia to have demonstrated CCS end-to-end. It brings together the world's best scientists, engineers and industry leaders to advance the implementation of CCS worldwide.

* The terms CCS (carbon capture and storage) and CCUS (carbon capture, utilisation and storage) are both used in this document and are interchangeable.

OUR VISION

The world's leading CO_2 storage technology centre, globally recognised for innovative carbon capture and utilisation solutions.

OUR MISSION

Add value to customers by testing, developing and demonstrating CCUS research, products and services as viable options for a lower emissions future.

OUR VALUES

Excellence | Integrity | Delivery

CHAIRMAN AND CEO'S REPORT

The financial year 2019 - 2020 has been memorable like no other year, for reasons no-one could have predicted back in July 2019.

The COVID-19 global pandemic has affected everyone in some way – industries, universities, researchers and individuals. It is a great testament to our industry supporters and research partners that despite the challenging circumstances, we have been able to continue to keep our work programs on track. This has applied equally to the Otway National Research Facility but also in the different universities and research institutions organisations with which we partner. Like many organisations, we have all found new ways to adapt to remote working practices.

In July 2019, CO2CRC embarked on its largest ever capital investment, the Otway Stage 3 Project. By the end of October, we had successfully completed the installation of new infrastructure at the Otway site including four new monitoring wells. Each well is equipped with the latest technologies in fibre optics sensing and instrumentation together with ancillary surface infrastructure. The upgraded capability of the facility means that it is able to provide CO_2 monitoring data on demand. We now have what is arguably the most advanced field scale CCUS research site globally, located in south-western Victoria.

Throughout, we have successfully maintained our record of no lost time injuries (LTI) and are aiming to achieve the milestone of over 5,000 hours without LTI in late 2020.

In November, we hosted the biennial CO2CRC Research Symposium in Torquay. Delegates from all over Australia and the world attended, with the program covering a wide range of topics including technical sessions on advancements to reduce the cost of capture, optimise storage operations and enhance carbon dioxide utilisation.

Notwithstanding the focus on our Stage 3 project, there were notable achievements across CO2CRC's wider research portfolio:

- The Otway Stage 2C project successfully completed its third and final technical objective - verifying plume stabilisation. The five-year project was delivered on time, within its $16.5M budget and met all project objectives. The three project outcomes (establishing a minimum seismic detection limit, observation of plume development and verification of plume stabilisation) provide significant demonstration effects for industry. Indeed, the selection of technologies for the Stage 3 project has been strongly influenced by findings from the Stage 2C project.
- The Otway Fault Project continued working towards the science case and well injection design and monitoring plan. Mechanical testing and petrophysical analysis of the core and fault material recovered from the two appraisal wells has been conducted. This work is currently under review and the outcomes from this experiment will greatly improve our understanding of the influence of faults on the safe long-term storage of injected carbon dioxide.
- At the Vales Point power plant in NSW, CO2CRC and The University of Melbourne research team conducted a world's first continuous pilot scale demonstration of capturing carbon dioxide using membrane gas-solvent contactor technology, while

simultaneously undertaking carbon dioxide (CO_2) capture and solvent regeneration, which makes the technology much easier to install. The reduced size of the equipment and the hybrid nature of capture technology could offer significant cost savings.

CO2CRC continued to engage and work closely with a number of industries on new projects and collaborations:

- With our industry member Total, we tested the performance of Helically Wound Cables (HWC) against traditional straight fibre optic cables. Over 1,300 metres of HWC were successfully deployed at site with high quality data acquired. The data will help industry to explore different deployment techniques to reduce costs and improve data resolution.
- We led a study (funded by Coal Innovation NSW) exploring pathways for reducing greenhouse gas emissions in BlueScope's steelworks in Port Kembla by converting steel mill exhaust gases into fuels and investigating the viability of deploying CCS.
- National Energy Resources Australia (NERA) and CO2CRC joined forces to support an industry-led landmark study to evaluate the economic and technical feasibility of using CO_2-EOR to enhance the recovery of oil from Australia's onshore basins and reduce greenhouse gas emissions through CO_2 storage.
- As part of the Hydrogen Energy Supply Chain (HESC) Project, CO2CRC delivered a hydrogen refining plant to AGL's Loy Yang facility in Victoria's Latrobe Valley. The HESC project will build Australia's first coal to hydrogen pilot plant. If the project proceeds to the commercial phase, combined with CCS through the CarbonNet Project, it promises a 'clean hydrogen' use for the Latrobe Valley's vast coal reserves. CO2CRC is delighted to be playing a part in a project which aims to create a new hydrogen export industry for Australia.
- In February, CO2CRC established a CCS Policy Forum (CPF) comprised of senior representatives from its member organisations, to develop an industry consensus view on a desirable Australian CCS Policy Framework. The CPF is providing industry input to the federal government's development of a CCUS methodology that would enable a stronger commercial incentive for CCUS projects through the generation of carbon credits (ACCU's).
- Over the last year, we welcomed internationally significant energy companies, ExxonMobil and Santos, as members of CO2CRC. Discussions with two further international companies are at advanced stages and we hope to announce additional members in the 2020/2021 financial year.

We also introduced an Associate Membership category, tailored towards industry users of CCUS, industry bodies, technology and equipment vendors and consultancy firms. We were pleased to welcome NERA as our inaugural Associate member.

New memberships and discussions with wider industry and technology providers ran in parallel to announcements by the Federal Government's Technology Investment Roadmap identifying CCUS as a priority technology. We welcome the recognition of CCUS as a critical technology for lowering emissions, while preserving economic prosperity. The federal government's commitment to developing a CCUS crediting methodology, has contributed to a renewed sense of optimism in the CCUS industry.

Australia is well-placed to be a world leader in CCUS, with recent project activity demonstrating that CCUS is not a dream for the future but a reality today:

- We congratulate Chevron and its Gorgon LNG Project participants, Shell and ExxonMobil on their achievement in having successfully stored 3 million tonnes of CO_2 by September 2020.
- Santos is examining a large-scale commercial CCS project to be located in the Cooper Basin with a scalable potential to store up to 20 Mtpa of CO_2 per year.
- The Victorian CarbonNet Project is making good progress on its plans to geologically store around five Mtpa CO_2 each year offshore Victoria; and
- CTSCo is progressing the development of a commercial scale CCUS project in Queensland's Surat Basin

It is exciting to think what can be achieved next year as we (hopefully) emerge from the strict constraints of the pandemic to again embrace the benefits of in-person collaboration between researchers and industry. This will be vital for the next wave of CCUS scientific and technological breakthroughs.

In closing, we thank our funders, partners, members and Otway landowners for their support over the past year. We recognise the considerable efforts of CO2CRC staff, including our researchers, in adapting to the unique challenges we have faced while at all times, keeping the organisation on track to meet its commitments.

Martin Ferguson AM
Chairman

David Byers
CEO

CO2CRC'S BUSINESS STRATEGY

CO2CRC BUSINESS STRATEGY

CO2CRC's Business Strategy is built from the achievements of the past 16 years – applying the best scientific research to develop next generation technologies and operational methods that support the commercial deployment of CCUS.

Over the period 2020 to 2025, CO2CRC's business plans are aligned under four strategic focus areas:

- Optimising Storage
- Reducing Capture Costs
- Enhancing CO_2 Utilisation
- Collaboration and Leadership

Development plans for individual projects under each area are long-term in nature but sufficiently dynamic to allow the incorporation of new ideas and emerging technologies. This dynamic component has enabled CO2CRC to adapt to changes in industry conditions and focus on areas with the greatest opportunity.

The strategy contemplates an expanded range of fee-for-service offerings by CO2CRC across all four strategic focus areas in Australia and internationally.

The diagram below highlights key projects or activities under each strategic focus area. A brief description of each area follows:

1. Optimising storage

The optimising storage program of CO2CRC will develop new and innovative technologies and enable the deployment of CO2CRC's demonstrated technologies for commercial scale application.

The Otway National Research Facility is the centre piece of CO2CRC's business plan and key to developing national R&D capabilities, informing policy and regulatory settings and conducting community education. The facility, with the addition of the Otway Stage 3 Project, will enable CO2CRC's demonstration of optimal storage technology solutions and pave the way for the commercial deployment of emerging storage research.

CO2CRC plans to build on these strengths to convert the Otway facility into an internationally prominent test centre for applied carbon capture and storage R&D – the Otway International Test Centre (OITC). The research facility will also be made accessible for global customers and researchers, across the various industry sectors pursuing CCUS technology applications to collaborate, trial and validate technology and processes at field scale.

CO2CRC's strategic areas

1 — CO_2 OPTIMISING STORAGE

S1 – Otway International Test Centre

Leverage Otway facility to internationally position it as the preferred centre to trial storage technologies, and expand CO2CRC's capabilities for effective modelling and monitoring solutions.

S2 – New generation CO_2 storage M&V

Develop commercially ready, cost effective and risk-targeted CO_2 storage M&V solutions, using OITC validated technologies, enabling at scale and on-demand surveillance in onshore and offshore geological reservoirs.

S3 – Cost effective storage appraisal and development

Develop streamlined, fit-for-purpose appraisal methods, and transformational technologies to cost-effectively manage CO_2 storage in alignment with national priorities.

S4 – Hydrogen geological storage at Otway

Field scale demonstration of geological hydrogen storage to support an emerging hydrogen industry in Australia, and validate hydrogen storage and extraction processes.

S4 – Fee-for-service and project management services

- Deliver value for long-term projects - CCS projects, Future Fuels (Hydrogen)
- Consultancy, RD&D, field trials and asset deployment
- IP & knowledge sharing including the provision of datasets, models & methodologies

2 — REDUCING CAPTURE COSTS

C1 – Gas separation & CO_2 capture–membranes, adsorbents & hybrid systems

- Materials testing at Otway International test Centre (Capture Facility)
- Further develop selected membrane/adsorbent materials for high CO_2 content gas
- Techno-economics and upscaling studies to modularise hybrid membrane/solvent contactor technology for dilute, low pressure gas separation
- Technologies that separate methane from CO_2

C2 – Developing hybrid CO_2 separation technologies to optimise separation under different conditions

- Maximise participation in the Hydrogen Economy(HESC Project in LV, OITC, and other projects)
- Expand fee-for-service offerings (project management, desktop studies, feasibility studies, technology development, field trials & monetisation of IP and datasets)

3 — ENHANCING CO_2 UTILISATION

U1 – Lead an Australia-wide regional study to understand the potential for EOR.

U2 – EOR – Assess the EOR potential of selected fields in most prospective basins (Bowen, Cooper /Eromanga; Gippsland)

U3 – Industrial application of CO_2 Utilisation

- Facilitate the development of a biorefinery industry in the LV starting with development of business case (biomass to fuel, energy & chemicals)
- R&D collaboration on converting CO_2 to products, fuels and building products

4 — COLLABORATION & LEADERSHIP

- Lead technical nexus & forum for the CCUS community in Australia
- Provide expert CCUS advice for government industry, and key decision makers
- Collaborate with Australian CCS community to overall CCUS advocacy leveraging technical proficiency and research track record (CO2CRC Policy Forum)
- Pursue training & education opportunities (e.g. CarbonNet support)

The unique infrastructure, surface equipment and knowledge of the subsurface allows the OITC to investigate other opportunities, such as supporting the National Hydrogen Strategy by researching hydrogen storage, alongside the core of next generation CO_2 storage monitoring and verification and cost effective storage appraisal and development.

CO2CRC's storage R&D program will focus on collaborative research in the following areas:

- *Next generation CO_2 storage M&V:* This program aims to mature CO_2 storage monitoring capabilities towards commercial application, enabling at scale effective and compliant life-of-project surveillance both onshore and offshore. A key storage monitoring example is the development of subsurface-based monitoring through the Otway Stage 3 project. Other key activities proposed in this focus area include developing an overarching storage monitoring workflow (methodology); assessing saturation and residual gas trapping; and conducting baseline and commercial assurance monitoring for the onshore and offshore environment
- *Cost effective storage appraisal and development:* This program aims to mature the modelling capability of appraising potential CO_2 storage sites, optimising storage operations, and predicting long term fluid trapping processes. This will safely enhance storage of CO_2 and improve the confidence in long term storage for both CCUS operators and regulators to enable ultimate closure of a storage site. Key activities proposed include effectively modelling a migrating plume's distribution; maximising efficiency in use of storage reservoirs; and developing well integrity solutions

2. Reducing capture costs

CO2CRC's capture research builds on the long-standing history of the organisation in developing innovative carbon capture systems. Since 2003, research and development of membrane, adsorbent, potassium carbonate-based solvent (precipitating and non-precipitating) and cryogenic capture technology has been undertaken at a range of scales from laboratory to demonstration scale.

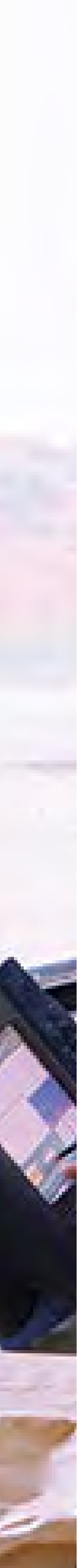
Key areas of focus include:

- Progressing our membrane gas-solvent contactor technology. The reduced size of the equipment and the hybrid nature of capture technology could offer significant cost savings, with the next phase of research involving upscaling the pilot scale to larger modules. This technology has the potential to be applied low pressure and hard to abate industries to reduce capture costs and preliminary techno-economic studies estimate a reduction in CO_2 capture cost of potentially below $40/tonne CO_2
- Focusing on developing adsorbents after successful trials at CO2CRC's capture skid at the Otway National Research Facility. We operated the PSA facility up to 50 bar to separate CO_2 from actual natural gas in first of its kind operation and the novel adsorbent HZ2 have shown ~30% higher working capacity (meaning less material/OPEX required) than commercial adsorbent. Early techno-economic analysis look promising and will be more intensely evaluated after synthesis with higher rate pilot testing is completed
- Supporting the National Hydrogen Strategy:
  - Achieving 99%+ CO_2 capture from fossil fuel-based H_2 production. Achieving 50 – *60%* CO_2 capture rates (i.e., process related emissions) from a typical fossil fuel based H2 production plant is relatively cost-effective. However, to enable large-scale 'CO_2-free' production of hydrogen from fossil fuels, energy-related emissions across the facility must be captured. CO2CRC are investigating techno-economic studies

3. Enhancing CO_2 utilisation

There is a growing demand for the conversion of CO_2 into value-added products to offset the cost of implementing CO_2 capture and storage technologies:

- CO2CRC is conducting a major study on CO_2 Enhanced Oil Recovery (CO_2-EOR) which is being undertaken in two phases. The first phase, led by CO2CRC in collaboration with Geosciences Australia and supported by LETA, will rank Australian oil and gas basins for the potential use of CO_2-EOR. The second phase of the project, supported by NERA, will provide insight on potential opportunities for CO_2-EOR at the field level in Australian onshore basins – to enhance the recovery of oil and reduce greenhouse gas emissions through CO_2 storage.
- Other areas of focus include a feasibility study exploring the development of a carbon-negative biorefinery based on the valorisation of non-food biomass and CO_2 to produce biofuels and biodegradable plastics. The technology involves the fermentation of lignocellulose into platform chemicals which are then upgraded into biofuels and biodegradable plastics. The project will commence with a feasibility study for a demonstration scale plant and assess the development of a large commercial scale biorefinery and the impact on regional economies
- Providing products and services along various aspects of the utilisation chain. Areas of current interest include micro-algae and the conversion of steel mill and industry exhaust gases into fuels. Further opportunities are currently under development.



4. Collaboration and leadership

CO2CRC accesses the expertise of many of the world's best researchers across the fields of carbon capture, utilisation, storage and monitoring. The strength of this partnership has resulted in more than a decade of successful research outcomes from desktop and laboratory scale trials to field scale demonstrations.

This track record, together with its established relationships with industry, government and regulators has allowed CO2CRC to become a trusted technical focal point and knowledge hub for the CCUS community in Australia and internationally. The biennial R&D CO2CRC Symposium in November 2019 welcomed more than 130 Australian and international delegates to participate in over 50 technical presentations, discussions and focused technical workshops.

CO2CRC has bolstered its efforts at the national and state level to provide advice on contemporary developments in CCUS science and policy globally as well as practical on-the-ground research and development. As well as providing submissions to government inquiries, key areas of focus include:

- Formulating a detailed response to the Federal Government's Technology Investment Roadmap and providing a thorough analysis of economic stretch goals for the cost of CCUS
- Establishing a CO2CRC Policy Forum (CPF) comprised of senior representatives from member organisations, to develop an industry consensus view on a desirable Australian CCS Policy Framework. The CPF is currently providing industry input to the federal government's development of a CCUS methodology that would enable a stronger commercial incentive for CCUS project through the generation of carbon credits (ACCU's)
- Publication of a regular newsletter to inform stakeholders nationally and locally about key developments in global CCS and CO2CRC research and development

CO2CRC'S RESEARCH

OPTIMISING STORAGE

Otway Project Stage 2C

Project owner: Professor Roman Pevzner, Curtin University

Objectives

- Detect injected CO_2 in the subsurface: ascertain minimum seismic detection limit
- Observe the gas plume development using time-lapse seismic
- Verify stabilisation of the plume in the saline formation

Outcomes

- A workflow for predicting, monitoring, verifying and assuring CO_2 storage in saline formations
- Technical limits of various seismic technologies to detect and monitor CO_2. Results from this project shall inform stakeholders of minimum detection limits for various subsurface seismic monitoring technologies
- Trialling novel seismic monitoring tools, such as distributed acoustic sensing and permanent seismic sources (surface orbital vibrators)
- Evaluation of the performance of permanently deployed fibre optic sensors and permanently deployed seismic sources, with results used to design the seismic monitoring program for the CO2CRC Otway Stage 3 project, in which it is planned to demonstrate feasibility of this approach through a field experiment
- Ascertain when the injected gas becomes effectively stabilised in line with the definition established at the start of the project. This includes demonstration of Stage 2C plume stabilisation and application of the process used in this project in larger scale CCS projects

Introduction

In Australia, the storage of CO_2 in saline formations is an important carbon abatement option, with adequate capacity for the country's CO_2 storage needs. To assess CO_2 storage in deep saline formations, the interplay of various trapping mechanisms during CO_2 plume migration needs to be better understood. Seismic (both surface and well-based), when used in conjunction with pressure measurements and reservoir modelling, has demonstrated previously to be a key storage surveillance technology. In order to optimise the use of seismic monitoring, it is important to understand its limitations in terms of resolution and sensitivity when detecting small quantities of CO_2 in different geological formations. In particular, an important consideration is the unlikely migration of supercritical CO_2 into overlaying aquifers.

Overall, while time-lapse seismic has been effective in tracking large CO_2 plumes (such as Sleipner and Snøhvit offshore Norway), detection and quantification of CO_2 leakage from the target formations is an important topic of current research. This is particularly topical for onshore Time Lapse (TL) seismic monitoring, which faces additional challenges due to temporal variations of near-surface conditions, coupling of sources and receivers to the ground, and ambient noise caused by wind, rain and human activity.

Stage 2C of the CO2CRC Otway Project addressed these challenges by injection of 15,000 tonnes of Buttress-sourced gas (80% CO_2 and 20% CH_4) into a saline aquifer at the Otway site 240 km west of Melbourne, Australia, accompanied by TL seismic monitoring.

The project is now concluded with all three objectives achieved. The forward modelling and the field data results show that detection of as little as 5,000 tonnes of the injected Buttress gas can be done by visual inspection of the 4D seismic difference volumes between the baseline and first survey after 5,000 tonne injection. The time-lapse seismic data of Stage 2C were also able to successfully detect the growth of the plume in the subsurface at each stage of the injection.

To demonstrate the plume stabilisation, three different time horizons are introduced, 1. When repeated monitoring shows small changes, 2. When the gas plume ceases to migrate to any significant extent, 3. When (and if) the whole injected gas fully dissolves in the formation water, and all geochemical reactions reach equilibrium. CO2CRC introduced a workflow for this purpose and investigated the plume stabilisation for Horizons 1 and 2.

Methods and outputs

The Stage 2C operation and implementation program included the following main activities:

- Detailed feasibility study and experiment design
- Design and installation of the buried receiver arrays
- Acquisition of the baseline seismic data in 2015
- Injection of 15,000 tonnestonnes of Buttress gas into the saline aquifer (Lower Paaratte Formation) located at 1.5 km depth
- A total of five 3D seismic surveys were undertaken throughout the project. The first baseline survey was conducted before the injection in February 2015 (Base Line, BL), then after 5,000 (Monitor 1, M1), 10,000 (M2) and 15,000 (M3) tonnes of injection. Two post injection surveys were also performed in 2017 and 2018 (M4 and M5 respectively)
- Acquisition of a baseline and three 4D Vertical Seismic Profiling (VSP) surveys
- Downhole pressure measurements before, during and after injection in the injection zone and above zone to history match models with to be used in the plume stabilisation workflow

All three objectives of the project have been met and summarised below:

Minimum seismic detection limit

To ensure the detectability of the small-scale CO_2 injection, a realistic 4D synthetic seismic data set was generated. The synthetic data set was based on existing geological and rock physics models and was very valuable in the design and training of the processing workflow. The forward modelling and the field data results show that detection of as little as 5,000 tonnes of the injected CO_2 can be done by visual inspection of the 4D seismic difference volumes between the baseline and M1 surveys (Figure 1).

A quantitative analysis was performed to assess detection and migration by observing the changes in seismic amplitude and travel-time due to the Buttress gas injection. The established inversion workflow produced a Time Lapse (TL) anomaly consistent with other monitoring techniques such as the Full Waveform Inversion (FWI), Vertical Seismic Profile (VSP) and rock physics forward models at CRC-1. The inversion results showed good repeatability of the plume signatures.

The ability to be able to detect 5,000 tonnes of CO_2 in the subsurface is the equivalent of detecting 0.1% of injected CO_2 on a commercial scale project injecting 5 million tonnes per annum. The ability to detect such a small amount of CO_2 provides operators with confidence that if CO_2 were to migrate out of the storage reservoir, they would be able to detect the migrating CO_2 easily and mediate quickly.

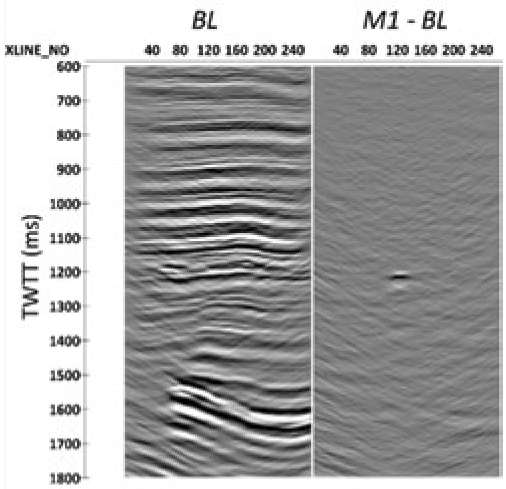


Figure 1. PSTM Seismic section along inline110. Middle panel and right hand panels are difference cubes BL-M3 and BL-M4 respectively.

Observe the gas plume development

The Stage 2C experiment showed that seismic-based methods (4D surface seismic and VSP) are well suited to not only detect small quantities of CO2, but also to monitor the progression of the plume as the plume sweeps through the reservoir. Surface seismic data were recorded with the buried geophone arrays while the downhole geophones in wells recorded time-lapse seismic signal along each seismic survey (BL, M1-M5). Onshore 4D seismic data is generally of poor repeatability. However, this deficiency was able to be improved during Stage 2C by using buried array geophones, 4D forward modelling and a specific seismic processing workflow. Consequently, the time-lapse seismic data of Stage 2C were able to successfully detect the growth of the plume in the subsurface at each stage of the injection.

The seismic processing flow was calibrated based on the synthetic data to detect the plume changes during the injection. The flow is a broadly applicable procedure to predict, monitor, verify and assure CO_2 migration and trapping in deep saline aquifers.

The ability to predict, monitor, verify and assure CO_2 migration and trapping in deep saline aquifers using the technologies and methodologies deployed as part of Stage 2C will provide operators with the ability to demonstrate to regulators and local landowners that the CO_2 is behaving as predicted and is securely stored in the subsurface.

Verify stabilisation of the plume

One of the key goals of the CO2CRC Stage 2C Project was to establish a workflow to evaluate the plume stabilisation. Stability can be discussed within three horizons:

- The first horizon is when repeated monitoring of the plume indicates minimal change between observations (within the resolution of the technique and natural variability). This was achieved for Stage 2C using time lapse seismic. The time scale for Horizon 1 is early years post injection (depends on monitoring requirements post injection)
- The second horizon is when the gas-phase plume ceases to migrate to any significant extent. This is also demonstrated for Stage 2C. We developed a workflow for this purpose which uses a combination of the results of the monitoring techniques and history matched simulation models. The time scale for Horizon 2 is hundreds of years
- The third horizon is when (and if) the whole injected gas fully dissolves in the formation water, and all geochemical reactions reach equilibrium (which was outside of the scope of this work). The time scale for Horizon 3 is hundreds to thousands of years
- The most critical data, in terms of stability, come from M4 and M5 monitoring surveys which show high level of similarity for the boundaries and relative thickness of the plume

For horizon 2, plume stabilisation is defined as follows: Stabilisation is defined as the point in time where 'significant' plume migration stops, due to various physical and chemical trapping processes. Minor plume change will continue as the reservoir re-equilibrates (pressure & temperature) and CO_2 continues to dissolve. Verification of stabilisation occurs by fitting acquired data (seismic and pressure) to models (static and dynamic), adjusting uncertain parameters within the plausible range, and forward projecting model if necessary, to show timing of stabilisation with high confidence.

A workflow was established for this purpose. Different steps of the workflow to meet the definition of stabilisation are:

- Observe plume evolution from 4D seismic
- Make reservoir models compliant with both seismic and pressure data
- Run the history matched model over long-term post injection
- Report the progression of the simulated plume over time
- Establish key performance indicator(s) (KPI) for stabilisation of the plume
- Determine if the plume has stabilised, based on performance against KPIs

Using the workflow above, CO2CRC demonstrated that the Stage 2C plume has stabilised. Moreover, the process carried out to demonstrate plume stabilisation as part of the Otway Stage 2C experiment illustrates what is possible for demonstrating stabilisation in larger scale CCS projects. Dynamic simulation models, an essential tool for project design and approval, are history-matched to monitoring data during operation, to reduce the uncertainty of the underlying numerical model. This model can then be run forward in time and analysed via a set of metrics to demonstrate the cessation of plume migration that correspond to the second horizon of stability.

Commercial CCS projects will span decades and with the resulting stored CO_2, taking geological times scales, hundreds to thousands of years, to stabilise. Commercial CCS Project operators can apply the methodologies demonstrated in the Stage 2C project to accurately model and demonstrate plume stabilisation, thus significantly reducing any on-going risk of the stored CO_2 migrating outside of the intended storage reservoir.

Key publications

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Glubokovskikh, S, Pevzner, R, Gunning,J, Dance, T, Shulakova, V, Popik, D, Popik, S, Bagheri, M and Gurevich, B, 2019. *How well can time-lapse seismic characterise a small CO_2 leakage into a saline aquifer: CO2CRC Otway 2C experiment (Victoria, Australia)*. International Journal of Greenhouse Gas Control

Popik, S, Pevzner, R, Tertyshnikov, K, Popik, D, Urosevic, M, Shulakova, V, Glubokovskikh, S and Gurevich, B, 2019. *4D surface seismic monitoring the evolution of a small CO_2 plume during and after injection: CO2CRC Otway Project study*. Exploration Geophysics

Next steps

The project has concluded and the final DRAFT report submitted to funders for review and comments.

Highlights

Achievements in the reporting period:

- Simulation of the models for 200 years showed that the plume location and extent vary little up to 50 years and the changes are insignificant after 100 years into the future (Figure 2). A comprehensive set of conformance metrics was introduced in this work which are also applicable to plume stabilisation. All of these metrics show small to no change in the Stage 2C plume
- A comprehensive final report, detailing the outcomes of the five-year Stage 2C research project, was submitted to project investors as the final deliverable including the topics below:
  - Integration of seismic and flow simulation modelling to assess plume stabilisation
  - 4D surface seismic monitoring
  - Time lapse bore hole seismic monitoring
  - Exploring novel methods of time-lapse seismic monitoring
  - Stabilisation workflow and verification

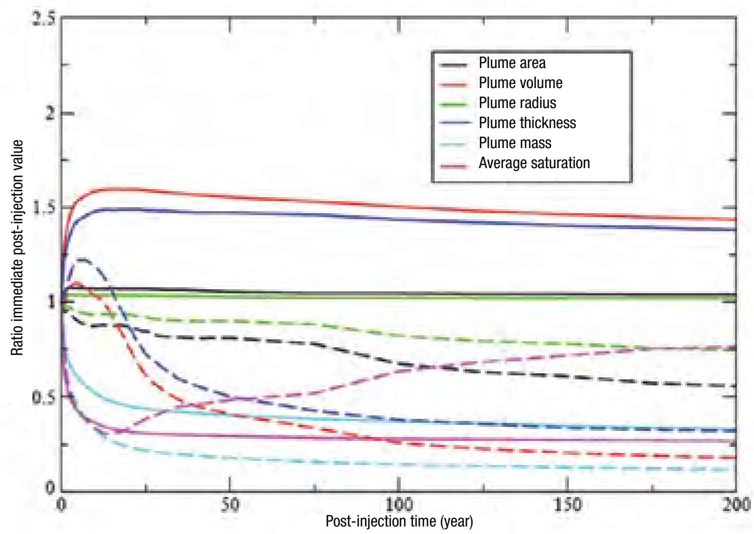

Figure 2. Integrated plume properties relative to their value at the end of injection. Solid lines are for the total saturation, and dashed lines for the mobile saturation.

Multiscale flooding dynamics of Otway

Project owner: Dr Mark Knackstedt, Australian National University

Objectives

The aim of this project is to demonstrate the application of digital core analysis (DCA) in estimating single phase and multi-phase flow properties of core plugs and their impact on the efficiency and reliability of reservoir characterisation and modelling. This will ultimately reduce the cost of reservoir characterisation whilst improving the reliability of the models to predict the behaviour of the injected CO_2 plume.

Outcomes

The main deliverables of the project are:

- Whole core scanning and analysis
- Continuous porosity and permeability data
- Rock property database and correlation to other available data including well logs, core description and routine core analysis
- Anisotropic rock properties (single and multiphase parameters)
- Upscaled the results from pore scale to the whole core scale using dynamic reservoir solvers
- Generated anchored SCAL data
- Application of DCA in reservoir characterisation and modelling including upscaling workflow
- For this purpose, 40m of CRC-3 cores from Paaratte formation was used to perform DCA experiments

Introduction

The CO2CRC Otway Stage 3 project requires accurate predictions of the extent of plume movement within the storage reservoir, however small-scale geological features and heterogeneities have a significant impact in the subsurface that cannot be directly incorporated into field scale simulation models because of limitations in computer speed.

These small-scale heterogeneities can now be accounted for via an integrated multiscale workflow proposed here. The project utilises a multiscale workflow being developed in a parallel ANLEC R&D project to consistently address the impact of small-scale geological heterogeneity on static and dynamic rock properties.

Methods and outputs

The main conclusions and added value of DCA workflow are summarised below:

- DCA can derive poro:perm relationships for different facies units. This enables one to get a comprehensive data set on core material that is not achievable from conventional routine core analysis (RCA)
- DCA will offer a better estimate of Kv:Kh (vertical and horizontal permeability) which is an important controlling parameter in reservoir modelling and characterisation
- Reliable facies association can be obtained using a combined result from log and digital core analysis to be used in the final static model for plume modelling
- Comparison of porosity and permeability data measured using conventional core analysis and DCA (considering the history matching results), highlights the two main advantages of DCA below:
  - DCA could generate porosity and permeability for an important injection interval in CRC-3 for which data was missing from RCA
  - Poro:perm relationship obtained from DCA was in a good agreement with the final poro:perm relationship obtained from history matching in the Otway site. This is mainly because DCA data measurement is much more frequent than RCA data enabling us to capture the heterogeneity of microscale features (Figure 3)
- Although DCA has sampled the same distributary channel (DC) facies association as SCAL, there are different rock types within this facies association which may or may not show similar results. Conventional SCAL data does not have the capacity to test every single rock type due to cost, required length of core for experiment and core recovery issues. But it is much easier for DCA to test different rock types within a facies association
- DCA is capable of measuring anisotropic relative permeability data which is an important parameter to be used in reservoir characterisation and modelling

- All multiphase flow parameters can be obtained from a single core sample using DCA. This not only reduces the cost of reservoir characterisation compared to conventional SCAL experiments but also helps to deploy more representative multiphase flow parameters in the reservoir modelling
- Once a workflow is established and depending on the length of required experiments, DCA results can be finalised within weeks whereas SCAL results usually will take months (up to ~ 6 months). DCA may expedite decision making

Key publications

Knackstedt, Bagheri, M, M, Dance, T, Zhang,Yul, Turner,M, Saadatfar,M, Ruspini,L and Ã˜ren,P, 2020. *Multiscale flooding Dynamics of Otway Core Year 2 Report Update: Upscaling of static properties*. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT20-6225

Knackstedt, M., 2019. *Multiscale flooding Dynamics of Otway Core, Phase 2*, Melbourne: CO2CRC

Knackstedt, M et al., 2019. *In-situ pore-scale imaging and image-based modelling of capillary trapping for geological storage of* CO_2, International Journal of Greenhouse Gas Control (accepted)

Next steps

- The project is in its final stage, a revised document has been submitted to ANLEC R&D to address reviewers' comments and close out the project

Highlights

Key achievements in the reporting period:

- An extensive rock property database was developed for geological and multiphase flow parameters and correlated to other information
- The workflow proved its efficiency in creating anisotropic absolute and relative permeability.
- Demonstration of the application of DCA results and their advantages over conventional core experiments using Otway data this included:
  - Upscaling geological facies
  - Relationship between porosity and permeability
  - Multiple SCAL data from one single plug
- An abstract on the application of DCA workflow in reservoir characterisation was submitted to APPEA 202

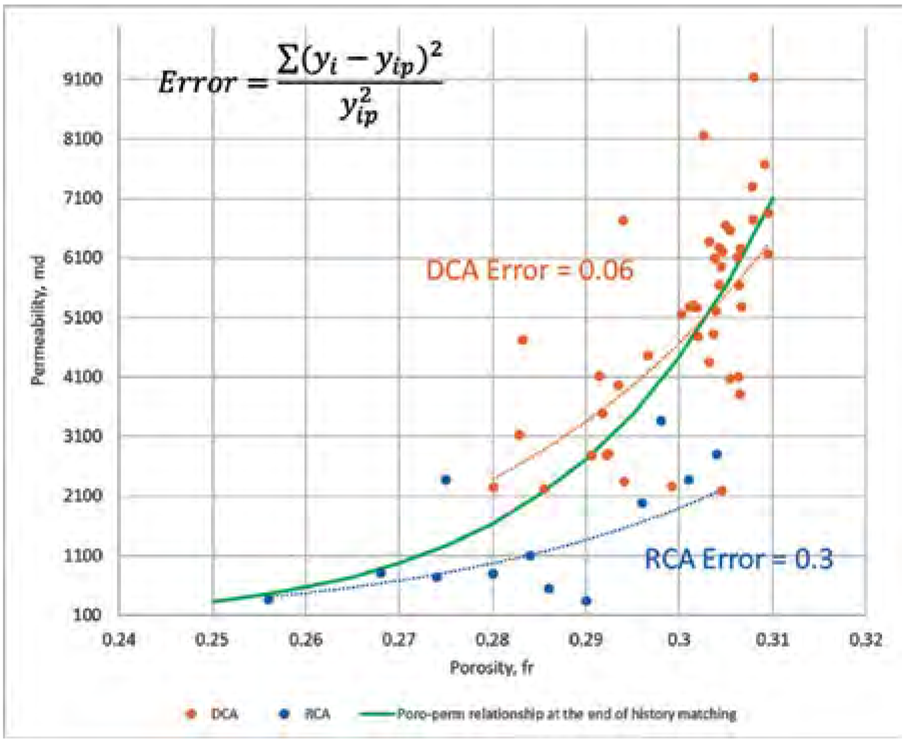

Figure 3: Relationship between porosity and permeability obtained from DCA vs RCA data for good sand facies, distributary channels (The orange dotted line is the best fit to DCA data, the blue dotted line is the best fir to RCA data and the green line is obtained from history matching of the dynamic model to observed data).

Otway fault project (prediction and verification of shallow CO_2 migration) – Phase 2

Project owner: Dr Andrew Feitz, Geoscience Australia

Objectives

The objectives of Phase 2 are to:

Reduce the risks of the potential injection experiment (Phase 3) by drilling and coring two appraisal wells through Brumbys Fault and collecting critical information on the nature of the fault and the sub-surface geology, which are:

- Rock strength, which will be used to determine the maximum and safe injection pressure for the experiment
- Permeability, identify the best injection interval and enable modellers (+ max injection pressure) to estimate the total volume of CO_2 that can be safely injected
- Mineralogy, which will enable modellers to estimate the extent of impact on groundwater chemistry
- Fault extent, physically confirm that the fault extends to the base of the clay layer
- Fault thickness, collect core to confirm the width of the damage zone

Outcomes

- Two appraisal wells (Brumbys-1 and Brumbys-2) were drilled and cored through the shallow fault
- Analyses of the acquired data (core, logs and seismic) during Phase 2 of this project confirms the experiment is technically feasible and can be done safely
- The static and dynamic models indicate the extent of the fault, the rock strength, the best injection depth (80m) and the likely path of the CO_2 migration. Core flooding experiment also measured the level and mobility of the naturally occurring minerals and heavy metals
- An initial mitigation/risk matrix is suggested as a plan forward based on the learnings of Phase 2 for the injection phase

Introduction

The ability to predict the influence of faults on the migration of the injected CO_2 is important in understanding the parameters of long-term safe CO_2 storage. Development and testing of new strategies to predict fluid migration pathways in the near surface will enable enhanced modelling and increased confidence in injected gas behaviour.

This project seeks to harness the improvements in monitoring techniques demonstrated over the last decade that have been applied for tracking CO_2 migration in both the reservoir (e.g. Otway 4D seismic, DTS) and near surface (e.g. Ginninderra soil gas) and use these techniques to image CO_2 migration up fault in the shallow sub-surface. If able to progress to the next phase, the project would also investigate the potential mitigation options for any unexpected flow through the faults. This will provide unparalleled insight into CO_2 migration up a fault and an opportunity to assess the effectiveness of contingency monitoring and mitigation, i.e. in the event that leakage from a storage complex has been detected, how to ramp up the monitoring response and target more likely leakage pathways and mitigate.

In addition, the experiment provides a unique opportunity to evaluate the effectiveness of near surface monitoring strategies and validate the theories of 'hot spot' surface expression and of CO_2 gas migration into the vadose zone.

CO2CRC has embarked on a phased project to characterise the near surface, design, execute and operate a controlled release and monitoring project, as follows:

- **Phase 1:** Characterisation of the CO2CRC Otway site near surface, including the identification of a suitable structural control (fault) for CO_2 migration (Opportunity Definition) – completed 2017
- **Phase 2:** Experiment site appraisal and subsurface sampling (Evaluate & Define) – This project
- **Phase 3:** Controlled release experiment execution and operation (Execute & Operate) – proposed

CO2CRC in partnership with Geoscience Australia has appraised the region in the vicinity of Brumbys Fault at the Otway Research Facility, identified during Phase 1 of this project, and determined its suitability for hosting the injection of a small volume of CO_2.

Methods and outputs

Phase 1 of this project used the following methods to characterise the Otway near-surface and to locate a fault suitable for injection:

- Ultra-high-resolution 3D shallow focused seismic survey
- Two electrical resistivity imaging surveys, mapping the thickness of the top clay layer
- Ground penetrating radar and EM31 surveys, looking for ‘holes’ in the clay layer
- Groundwater slug tests to determine the permeability of the Port Campbell Limestone aquifer.
- NMR logging of groundwater wells to determine porosity and estimate the vertical distribution of permeability in the Port Campbell Limestone aquifer
- LIDAR and aerial imagery survey to map elevation

In Phase 2 the completed tasks to achieve the objectives included:

- Drilling two appraisal wells, Brumbys-1 and Brumbys-2 through a shallow fault and collection of first core from the Port Campbell Limestone (PCL)
- Mechanical testing and petrophysical analysis of PCL core and fault material
- Fluid-rock testing of PCL core and evaluation of contamination potential from CO_2 impacts
- Baseline soil gas and soil flux surveys across the fault and assessment
- Updating of the Otway shallow geology static model with appraisal well data
- Assessment of fault and site suitability for fault injection experiment
- Installation of piezometers and collection of accurate groundwater table information
- Vertical seismic profile survey and collection of formation velocity data to determine feasibility of VSP for monitoring the injected CO_2
- A methodology for appraising faults as potential leakage pathways
- A Science Case for the planned controlled release experiment, including well injection design and monitoring plan for Phase 3 is currently under review

The large body of appraisal, modelling and characterisation work undertaken in this project suggests that it is technically feasible to safely conduct a controlled CO_2 injection experiment into a shallow fault at the CO2CRC Otway National Research Facility. The modelling work indicates that various monitoring techniques would be able to track CO_2 plume migration (Figure 4), providing the first ever imaging of CO_2 flow vertically up a fault towards the ground surface. The results from this important field-scale experiment would form a foundation dataset for the international CCS community to calibrate and improve models predicting CO_2 migration behaviour in faults, increasing confidence by validation of modelling predictions from several numerical codes and design mitigation options to address potential leaks.

Key publications

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Tenthorey, E, Dewhurst, D and Takemura, T, 2019. Geomechanical characterisation of the Brumbys Fault and surrounding lithologies. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT19-6117.

Wang, L, Green, C, Radke, B, Tenthorey, E, Ennis-King, J and Feitz, A, 2020. SRD3.3 Prediction and verification of Shallow CO_2 Migration Phase 2: Static model version 2 and CO_2 migration simulations. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT20-6181. 90pp.

Glubokovskikh, S, Pevzner, R, Sidenko, E and Tertyshnikov, K, 2020. SRD3.3B.3.2: Feasibility study of seismic monitoring of the controlled shallow release at the Otway site. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT20-6177.

Harris, B, Schaa, R, Pethick, A and Curtin University, 2020. Assessment of EM methods for the Otway CO2CRC Project 3.3 SRD shallow CO_2 release experiment. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT20-6215.

Schacht, U, Radke, B and Feitz, A, 2020. SRD3.3 Prediction and Verification of Shallow CO_2 Migration: Near Surface Baseline Surveys. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT20-6182.

Feitz, A, Ricard, L, Radke, B, Chan, K, Glubokovskikh, S, Tenthorey, E, Pevzner, R, Tertyshnikov, K, Urosevic, M, Lebedev, M, Ennis-King, J, Schacht, U, Vialle, S, Harris, B, Wang, L, Coene, E, Green, C, Kalinowski, A, Sidenko, E, Ziramov, S, Schaa, R, Teo, B, Pethick, A, Costall, A, Takemura, T, Dewhurst, D, Lavin, M, Elebrac, E, Idiart, A, Silv, O, Grandia, F, Sainz-Garcia, A, Jordana, S and Credoz, A, 2020. SRD3.3 Science Case for Phase 3. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT20-6218.

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Ziramov,S, Tertyshnikov,K, Pevzner, R, Urosevic, M, Harris, B, Costall,A, Pethick,A, Schaa,R, Buckerfield,S, Fowlkes,C, Goodwin,J, Fomin,T and Feitz, A, 2016. *High resolution geophysical baseline surveys of the Otway site: Interim report for project SRD3.3*. Melbourne: CO2CRC.

Radke,B, Hossain,M, Harris, B, Schaa,R, Tan,K, Pethick,A, Ziramov,S, Urosevic, M, Kalinowski,A, Tenthorey, E, Pan,Z, Ennis-King, J, Gunning,M, Lai,E, Ransley,T, Schacht, U and Feitz, A, 2017. *Otway Static and preliminary Dynamic Model: 3D Geological modelling of the fault and shallow sequence at the Otway site*. Melbourne: CO2CRC.

Feitz, A, Wang,L, Pan,Z and Ennis-King, J, 2017. *SRD3.3 Prediction and verification of Shallow CO_2 Migration (Phase 1): 3D CO_2 migration simulations and recommendations*. Melbourne: CO2CRC.

Radke,B, Hossain,M, Harris, B, Schaa,R, Tan,K, Pethick,A, Ziramov,S, Urosevic, M, Kalinowski,A, Tenthorey, E, Pan,Z, Ennis-King, J, Gunning,M, Lai,E, Ransley,T, Schacht, U and Feitz, A, 2017. *Otway Static and preliminary Dynamic Model: 3D Geological modelling of the fault and shallow sequence at the Otway site*. Melbourne: CO2CRC.

Feitz, A, Radke,B, Hossain,M, Harris, B, Schaa, R, Pethick,A, Ziramov,S, Urosevic, M, Tenthorey, E, Pan,Z, Ennis-King, J, Wang,L, Gunning,M, Lai,E, Ransley,T, Tan,K, Schacht, U, Kalinowski,A, Black, J and Pevzner, R, 2018. *The CO2CRC Otway shallow CO_2 controlled release experiment: Geological model and CO_2 migration simulations*. In: GHGT-14, Melbourne, 22-26 October.

Next steps

Phase 2 of the project is near completion and all deliverables for sub tasks have been approved. The last deliverable of this phase is the science case for Phase 3 of the project which is currently under review and will be finalised in 2020.

The recommendation is that a Phase 3 injection experiment is feasible and can be done safely with significant added value to the CCS industry. The project would proceed to Phase 3 (shallow injection adjacent to the fault) subject to a thorough environmental impact assessment and further funding. The estimated costs for the third phase are $4M.

Highlights

Key achievements during the reporting period are as follows:

- Core experiments recommended to conduct the experiment at approximately 80 m depth rather than the 40 m originally proposed. This provides more confining pressure and will ensure that the injection pressure does not exceed the fracture pressure
- Monitoring planning also showed, a deeper injection provides better spatial and timing conditions for geophysical monitoring and tracking the plume
- Simulations suggest only a small 10 tonne CO_2 injection experiment would be required to monitor CO_2 migration using geophysical techniques
- Higher than expected levels of naturally occurring heavy metals have been found in drill core from the overlying Hesse Clay and to a lesser degree within the Port Campbell Limestone. The widespread and relatively laterally uniform distribution of the metals suggests that they are naturally derived. The metals appear to be currently stable with only low levels present in the groundwater. Preliminary laboratory experiments indicate there could be a small release of heavy metals within the experimental zone of the Port Campbell Limestone should the injection go ahead in phase 3. The upper Hesse Clay appears to act as a trap. It is considered that the risk of contamination and adverse impacts beyond the immediate research area is low
- To capture the output of the experiment, a robust, flexible and integrated monitoring program is proposed
- The key scientific risks identified were:
  - CO_2 fractures aquifer during injection
  - CO_2 migrates outside CO2CRC licence area
  - CO_2 does not migrate up fault and does not meet science objectives
  - CO_2 injection leads to contamination of aquifer
  - Injection interval too low permeability
  - Fault does not extend to surface

Each of these risks has been comprehensively addressed in this phase of the project through laboratory, field, and modelling studies. A scientific risk analysis along with potential impact and consequence of each risk element was provided as part of this work.

> "Development and testing of new strategies to predict fluid migration pathways in the near surface will enable enhanced modelling and increased confidence in injected gas behaviour."

Testing Helically Wound Cables (HWC) cables on Otway site

Project owner: Dr Mohammad Bagheri, CO2CRC Senior Manager – Subsurface

Objectives

The main objective of this project was to test Helically Wound Cables (HWC) vs Straight Fibre Optics (SFO) and geophones for detecting seismic signals to ultimately monitor the CO_2 plume underground. This would help to reduce the cost of surface seismic compared to geophones and improve the performance compared to SFO.

This project was funded by TOTAL.

Outcomes

The outcomes of the project are to test the performance of HWC fibre optic cables with respect to:

- seasonal variations;
- cable design; and
- deployment strategy.

Introduction

This HWC-Test allows a new receiver technology to be tested and benchmarked during the baseline seismic survey and potentially during continuous monitoring at Otway site using stationary orbital Vibrators (SOV).

CO2CRC has procured and deployed the HWC with input and design specifications from Curtin University and TOTAL. Around 1km of HWCs were deployed in the trench of the newly constructed gathering line connecting the gas supply from CRC-2 to CRC-3 in February 2020.

A baseline surface seismic survey was acquired in March/April 2020 as part of Stage 3 which was also used to acquire data from HWCs. The acquired data is being processed by TOTAL (out of scope of this project, but in close collaboration between TOTAL, Curtin university and CO2CRC).

This phase of the project was called Phase 0 of the HWC-Test project and might be potentially extended by further phases. The intention of this phase was to optimise the HWC parameters such as deployment methodology, angle, soil moisture, and coupling materials to assess its suitability for CO_2 plume imaging.

The project started on September 2019 by testing the impact of seasonal variation on the performance of HWCs and concluded on June 2020 after finalising the data acquisition and delivering the pre-processing and geometry report to TOTAL.

Methods and outputs

CO2CRC's Otway National Research Facility layout with a focus on the deployed HWCs is shown overleaf. The blue line in the figure is called 'line 5 HWC' which was deployed in 2015 but used in this project to perform seasonal variation test. The green line is the Silixa HWC deployed as part of this project (~1,000m). The cables are deployed on a sand bed in the trench between wellpad C and CRC-2 and are grouted with a mixture of fly ash and cement between CRC-2 and Wellpad B. The dashed line in this figure is HWC provided by Sercel (~250 m) and the yellow dots are SOVs.

Using the installation above, the main project elements were:

- Testing HWC cable performance deployed in seismic line 5
- Evaluating changes in performance of HWC cable with soil saturation using SOVs and HWC in line 5 between September 2019 and March 2020
- Deploying HWC with Constellation Fibre between Well Pad C and the seismic hut and trialling its performance during Stage 3 baseline survey
- Add geophones between Well Pad C and seismic hut on top of the crossline to be used during the Stage 3 baseline survey as benchmark

Testing the seasonal variation showed HWC performance degrades from wet to dry seasons.

During the baseline seismic, two truck mounted seismic sources (26,000 lbs Inova UNIVIB vibroseis) were deployed for the acquisition. Interrogator iDAS v3 Carina P17 unit was used to record data from the Silixa HWC cable; Fotech Theta interrogator was utilised to acquired data from Sercel/Fotech HWC cable. The data were also acquired from line 5 HWC. All of the data were pre processed and transferred to TOTAL as part of the deliverables of this project. The main deliverables of this project included:

- Baseline acquisition report including observer's log
- SEGY files with correlated shot records
- Pre-processing report and Geometry information

Key publications

Tertyshnikov, K and Pevzner, R, 2020. *Testing HWC Cables Pre-Processing Report and Geometry Information*. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT20-6233.

Tertyshnikov, K, Bergery,G, Freifeld, B and Pevzner, R, 2020. *Seasonal effects on DAS using buried helically wound cables*. In: EAGE Workshop on Fiber Optic Sensing for Energy Applications in Asia Pacific.

Next steps

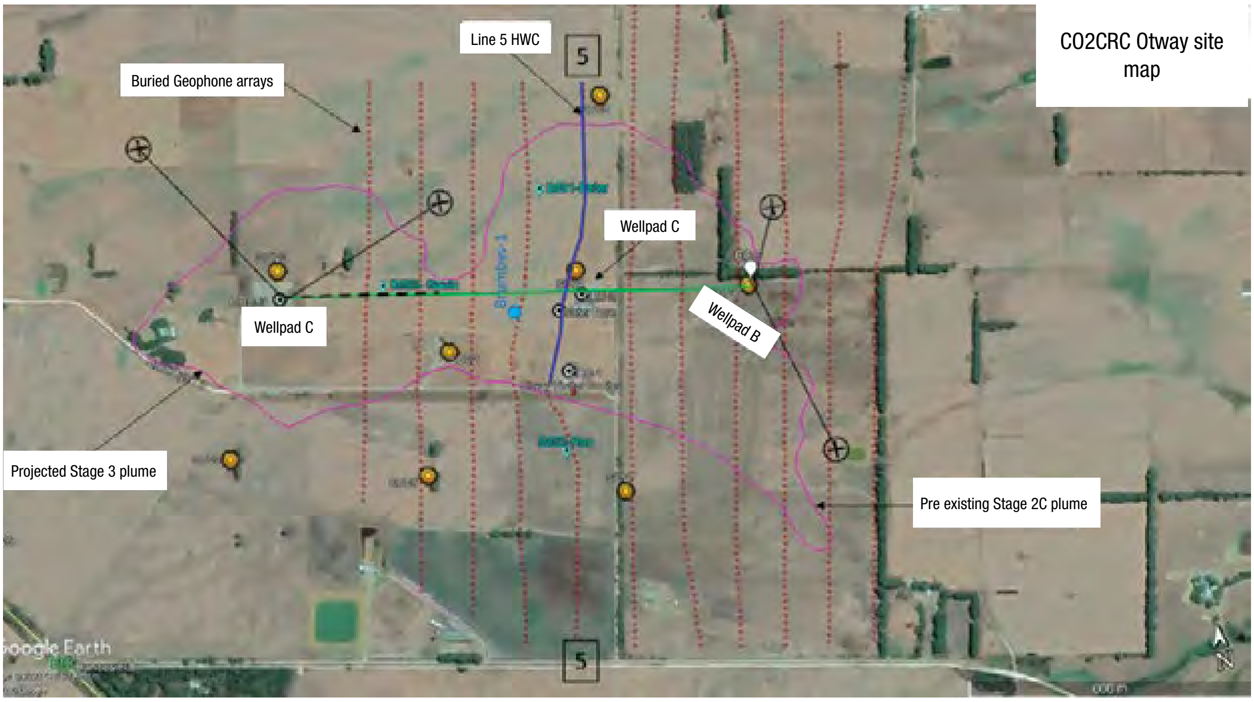
The project was concluded in June 2020 and all deliverables approved by TOTAL. TOTAL has assigned a resource to this project to process and analyse the data in close collaboration with Curtin university and CO2CRC.

A potential follow-up for this project would be to deploy HWCs in shallow HDD wells to investigate the possibility of removing seasonal impact on the acquired data.

Highlights

Approximately 1,300m of HWCs were deployed at CO2CRC's Otway National Research Facility as detailed below:

- ~700m of Silixa HWC coupled with sand
- ~350m of Silixa HWC coupled with fly ash mixture (to investigate the impact of grouting materials on seasonal variation)
- ~250 m of Sercel HWC (DeRgt) co located with Silixa HWC in a same Trench as No.1 and coupled with sand
- Data acquisition on all cables above in addition to surface 3C geophones was performed successfully during Mar/April 2020 despite the limitations caused due to the COVID 19 pandemic
- Seasonal test of the HWC line 5 cable showed clear deterioration of the data quality from Wet seasons in Otway (October-November) towards dry seasons (December-January)
- The project concluded on time and on budget in June 2020



Otway site layout with focus on deployed HWCs.

Otway assurance monitoring

Project owner: Dr William Howcroft, Dr Svetlana Stevanovic & Professor Wendy Timms, Deakin University

Objectives

To provide a comprehensive soil gas, ground water and reservoir fluid dataset for assurance monitoring and to meet regulatory KPIs.

Outcomes

Environmental monitoring has indicated no indication of CO_2 migration to shallow levels as a result of CO2CRC Otway operations.

Introduction

Otway Assurance Monitoring continues routine groundwater and soil gas monitoring of Otway site to meet EPA Victoria requirements.

At the CO2CRC Otway National Research Facility, an environmental monitoring program has been in place since 2006. It was designed to assure compliance with regulatory requirements and to verify that the injected CO_2 is behaving as predicted.

In addition to providing evidence that the projects are meeting key performance indicators established with the regulators, Environment Protection Authority (EPA) Victoria, the Otway monitoring program has been designed to meet the following objectives:

- Ensure safe operations
- Demonstrate compliance with regulatory requirements
- Evaluate a range of monitoring methods
- Provide data with which to calibrate models
- Ensure monitoring is both technically sound and cost effective

Methods and outputs

Environmental monitoring methods that have been applied at the CO2CRC Otway National Research Facility since Otway Project inception include the following measures to confirm that the plume remains within the subsurface:

Annual measurement of soil gas composition at approximately 2m depth on a 2km grid, to determine any changes to the naturally occurring CO_2 in the soil. These analyses are designed to determine if any changes in soil gas composition are attributable to CO2CRC storage activities (this project).

Annual measurement of groundwater chemistry in wells penetrating the 800m-deep Dilwyn aquifer and from wells penetrating the shallower Port Campbell aquifer. These data analyses monitor any changes to the groundwater composition to determine if any are attributable to CO2CRC's storage activities (this project).

Key publications

Boreham, C, Underschultz, J, Stalker, L, Kirste, D, Freifeld, B, Jenkins, C and Ennis-King, J, 2011. *Monitoring of CO_2 storage in a depleted natural gas reservoir: gas geochemistry from the CO2CRC Otway Project, Australia*. International Journal of Greenhouse Gas Control, vol. 5 (4), pp. 1039-1054

de Caritat, P, Hortle, A, Raistrick,M, Stalvies, C and Jenkins, C, 2013. *Monitoring groundwater flow and composition at a demonstration site for carbon dioxide storage in a depleted natural gas reservoir: the CO2CRC Otway project*. Applied Geochemistry, vol. 30 (3), pp. 16-32.

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Schacht, U and Jenkins, C, 2018. *CO2CRC Otway Project: Soil gas monitoring conducted 1–11 May 2017*. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT18-5829.

Schacht, U and Jenkins, C, 2019. *CO2CRC Otway Project: Soil Gas Monitoring Conducted 30 April–10 May 2018*. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT19-5989.

Schacht, U and Jenkins, C, 2020. CO2CRC Otway Project: Soil Gas Monitoring Conducted 28 April – 8 May 2019. CO2CRC Ltd, Melbourne, Australia, CO2CRC Publication Number RPT20-6179. Under review

Next steps

Complete reporting for 2020 surveys conducted in Q1 – Q3 2020.

> "Environmental monitoring has indicated no indication of CO_2 migration to shallow levels as a result of CO2CRC Otway operations."

CO2CRC strategy from completed Storage projects

In addition to the projects above, four key projects were concluded prior to 2020's reporting period as follows:

- Rapid Plume Forecasting: Opportunity Definition
- Passive Seismic and Seismic Interferometry: Opportunity Definition
- Marine Monitoring and Verification Method Development
- Enhanced Containment through Barrier Formation

CO2CRC is considering outputs from the projects above into its forward Strategy and planning for further follow up projects (subject to funding) as follows:

Machine learning

Application of Machine learning to predict the CO_2 Plume behaviour real time during the injection. CO2CRC Stage 3 results would provide invaluable dataset for this purpose and the steps below could be taken:

- Development of the neural network framework model for the time-lapse (TL) seismic data.
- Generation of the training dataset.
- Incorporation of the multi-physics observations.
- Subsurface model updating and alarm system.
- Validation of the proposed framework using Stage 3 of the Otway Project

Passive seismic monitoring

Feasibility study of passive seismic data in Otway Stage 3 showed several ambient signals can be detected including ocean waves, local and distant seismic events as well as surface seismic events linked to human activities. The potential next step would be to perform a field trial and use these signals to illuminate an injected CO_2 plume. CO2CRC Stage 3 results would create invaluable data for this trial given several potential sources involved including injection into CRC-3.

Marine Monitoring and Verification Method Development

This work centred on the use of testing the CO_2 plume detection capability and sensitivity under a range of seabed conditions, of the SIMRAD Wide Band Transceiver (WBT) Mini acoustic sensor that can be mounted to Sail drone acoustic equipment. Through bubble release experiments, the acoustic sensor's detection capability was demonstrated. CO2CRC as part of its strategy is planning to marinise monitoring technologies. The knowledge gained from understanding this project will inform the design of coastal MM&V programs around Australia and internationally, where development of marine MM&V is at an early stage of development.

Enhanced Containment through Barrier Formation

One of the main outcomes of this project was identification of a low-cost reagent and the related reaction mechanisms to form a flow barrier in the form of a silica gel. The barrier is formed when the reagent contacts supercritical CO_2 or CO_2-enriched water. CO2CRC as part of its strategy will be looking at two key projects which are most common potential for a leak from a CO_2 storage site: faults and legacy wells. Part of these projects is to provide mitigation if a leakage was detected through either of these elements. Trailing and testing Silica gel to cure these leakage paths would be suggested as a potentially effective mitigation.

CO_2 depleted reservoir storage

Project owner: Dr Max Watson, Senior Manager – Technology Development

Objectives

To provide effective, risk-based solutions for key challenges in the utilisation of depleted or near depleted reservoirs for CO_2 storage.

Outcomes

A technology review will be conducted and a workscope developed to improve the effectiveness in CO_2 Depleted Reservoir Storage use.

Introduction

Depleted oil and gas reservoirs, a primary candidate for large-scale CO_2 storage, are in many cases likely to be a lower cost and lower uncertainty geological storage solution. However, whilst these reservoirs are often well characterised, there are some other issues resulting from production operations, such as low pressure or legacy wells' integrity that may require further assurance or interventions to ensure an acceptably low operational and containment risk for CO_2 storage.

CO2CRC's PAC members noted (Nov 2019) a technical shortfall for CO_2 storage in depleted oil and gas reservoirs and requested CO2CRC to consider how to address these issues to the benefit members. A Depleted Reservoir Storage working group was established, with representatives from BP, Chevron, ENI, ExxonMobil, Santos, Total and Woodside, with the aim of scoping a R&D plan to address these technical challenges (phase 1) and potentially design lab and/or field experiment to validate them (phase 2).

The CO_2 Depleted Reservoir Storage Project (CO2-DRS) aims to provide effective, risk-based solutions for key challenges in the utilisation of depleted or near depleted reservoirs for CO_2 storage. A technology review will be undertaken and a workscope developed to improve the effectiveness in CO2-DRS use.

This workscope will then be assessed for applicability for key Australian and international sites/regions by the working group. An important element for testing the workscope is the availability to relevant reservoir data. Agreed topics for consideration include:

- Flow assurance of CO_2 in depleted reservoirs
- Well integrity for existing active and inactive wells
- Geomechanical integrity assurance for re-inflation
- Enhanced hydrocarbon recovery for improved economics

Methods and outputs

CO2CRC commenced the CO2-DRS by reviewing existing literature and engaging our R&D partners. Focussing on the following topics:

- Flow assurance of CO_2 in depleted reservoirs – (CO2CRC). As CO_2 in its liquid or supercritical state is injected at surface conditions into a subsurface formation with a pore pressure lower than the critical pressure, CO_2 will vaporise within the well tubing or in the near-wellbore region in the reservoir, causing several flow assurance issues (density drop, viscosity drop). Vaporisation will also result in localised cooling and solid hydrate formation, impairing injectivity. A workflow to prevent, characterize and manage flow assurance will form the basis of this study
- Well integrity for existing active and inactive wells – (R&D partner – CSIRO). Ensuring well integrity, both during and post project closure, is a critical challenge in CO2-DRS. As well as the recognised challenges of well integrity in O&G production, storage of CO_2 adds further integrity risk by changing chemical conditions downhole which may impact wellbore material. CSIRO have suggested several novel techniques for characterising well integrity risk in CO2-DRS

- Geomechanical integrity assurance for re-inflation – (R&D partner - Geoscience Australia). Minimum horizontal stress magnitude decreases during depletion, yet during repressurisation will not return to initial condition. Depending on the elasticity of the repressurisation, this can potentially result in shear failure. Further, injection of cold CO_2 into a reservoir can reduce the minimum stress and induce tensile fracturing, particularly in the caprock near the injection wellbore. A workflow to prevent, characterize and manage repressurisation risks will form the basis of this study
- Enhanced hydrocarbon recovery for improved economics – (CO2CRC). To be defined

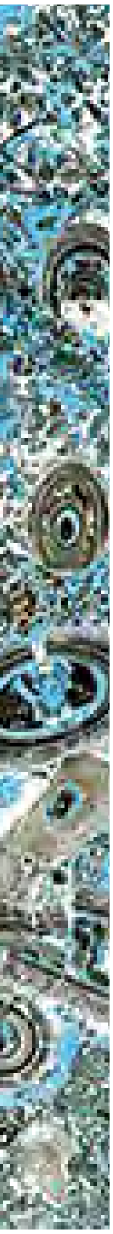
Key publications

N/A

Next steps

- CO2-DRS working group will discuss and refine workplans for each key topic in November 2020
- Key potential CO2-DRS sites in Australia and internationally will be identified for assessing the applicability of the workplans
- CSIRO and GA external studies will commence in Q1 2021
- Phase 1, the scoping of a R&D plan, on track for completion ~end Q2 2021

“A Depleted Reservoir Storage working group was established, with representatives from BP, Chevron, ENI, ExxonMobil, Santos, Total and Woodside”



Otway Stage 3 Project

Project Leader: Paul Barraclough, CO2CRC
Science Leader: Dr Charles Jenkins, CSIRO/CO2CRC

Objectives

The project develops and field tests innovative sub-surface monitoring technologies, which will significantly reduce the cost and environmental impact of monitoring programs for commercial CO_2 storage projects. The proposed techniques will also provide regulators and communities with ongoing confidence that CO_2 injected deep underground is permanently stored within the bounds of a storage formation. These innovative techniques provide a permanent, on-demand monitoring solution, which will enable faster acquisition and analysis of plume data.

Outcomes

CO2CRC's Otway Stage 3 Project ($45.8m) ` field tests innovative technologies to enable CCS Storage Projects around the world. It does this by offering monitoring technologies and associated operational workflows that provide:

- Fit-for-purpose data
- On-demand monitoring
- Cost effective monitoring programs
- Minimised impact to the environment and communities

The experimental infrastructure is in place and the project is on target for an injection commencing at the end of 2020. Preliminary cost analysis shows the proposed subsurface monitoring techniques can replace conventional monitoring technologies and thereby reduce storage monitoring cost by up to 75%.

Finally, the Otway Stage 3 Project is a long-term investment in the Otway International Test Centre that offers industry and the research community an accessible and fully instrumented test centre for benchmarking M&V tools, testing CO_2 storage processes and management techniques, and field testing technologies that have uses in a wide range of industrial applications.

Introduction

CO2CRC is developing fit-for-purpose monitoring technologies that aim to provide on-demand, key information on CO_2 storage sites with minimal surface impact. This will deliver substantial cost savings in future storage site monitoring design.

Initiated in 2015, the Stage 3 Project is the largest project at the Otway National Research Facility, costing $45.8M and delivering five new wells with cutting-edge downhole seismic and pressure monitoring equipment. A trial injection of 15,000 tonnes of CO_2 will be used to validate innovative subsurface monitoring techniques on the resulting CO_2 plume. The primary monitoring methods are pressure tomography and inversion, and downhole seismic, with other monitoring modalities and techniques being investigated as added components to the base design where possible.

The Otway Stage 3 Project injection well, CRC-3, was drilled in April 2017 to initially serve as the geological appraisal well and provide the data necessary to validate the proposed location of the additional monitoring wells. In July 2019, a drilling program was initiated to install the remaining four monitoring wells and their associated downhole sensors. By September 2019, the wells were drilled and completed, with injectivity testing and reservoir evaluation beginning in October 2019. In early 2020, surface infrastructure works commenced to complete the required installation of equipment to support the experiment. This included: a gas gathering line extension, seven new surface orbital vibrator (SOV) stations, power, communication and electrical infrastructure to support the new monitoring systems and connect downhole instrumentation and computers and data storage to support the significant amount of data generated from the site. These systems were in place and commissioned by June 2020 in preparation for baseline data acquisition prior to the injection commencing in November 2020.

In a demonstration of the flexibility of the newly installed seismic system, the Stage 3 Benchmark 3D Seismic Survey was completed in April 2020, despite the imposition of quarantine restrictions midway through the program. The survey was completed with the local support of a vibroseis driver and personnel from CO2CRC finalising the field work with remote supervision and guidance from the researchers in Western Australia. Similarly, with the site closed off to all but local personnel, the commissioning and running of the systems to acquire the initial, pre-injection dataset was done remotely with teams in Melbourne, Canberra, Western Australia and the USA remotely accessing the site to perform the necessary tests.

Methods and outputs

The project will inject 15,000 tonnes of high CO_2 natural gas into a saline aquifer at a depth of 1.6km, via a single injector well. The subsurface monitoring techniques will then be tested on the resulting plume using the array of monitoring wells and associated infrastructure. Primary monitoring methods will be:

- Pressure tomography and inversion
- Downhole seismic utilising permanently deployed sources

The pressure tomography and inversion technique will locate the gas plume in the subsurface by inducing a pressure wave into the storage aquifer and recording the response at the monitoring wells. This technique is especially useful in monitoring the boundary of the gas plume as it nears a high-risk area or sensitive boundary and could provide an early warning function should the plume migrate in an unexpected manner. This technique can be fully automated with data transmitted and analysed remotely to provide a history of plume position episodically or on-demand.

Downhole seismic measurements will use permanently deployed, low profile surface orbital vibrators (SOV), which generate sufficient source energy that can be detected by the sensitive fibre optic cables installed in the monitoring wells. Each SOV can provide a 2D image of the subsurface to each of the monitoring wells, creating a multitude of sub-surface transects that can be used to monitor the position of the plume as it migrates in the sub-surface. This innovative technique can be used as part of an ongoing, long term monitoring program, by replacing conventional seismic surveys, which require extensive source and receiver arrays, with a significantly reduced number of permanent sources and monitoring wells.

The new subsurface infrastructure installed on site will also be used to test the feasibility of further novel monitoring techniques. These techniques include passive and micro-seismic monitoring and the use of earth tides to detect plume movement in the subsurface.

The key outputs will be finalised in Dec 2022 and include:

- A fit-for-purpose, on-demand monitoring capability. The technologies will provide an early warning solution for industry and regulators that can be implemented in commercial projects immediately
- Non-invasive monitoring techniques that will be acceptable for community and regulators
- A prospectus of technologies and workflows that can be used to define costs in commercial monitoring projects

This validated toolbox of techniques will present a range of options for commercial CCS projects to ensure low cost, fit-for-purpose, real-time monitoring operations that addresses local needs, manages expectations of the wider public, and ensures minimal impact from an environmental, socio-political, economic and governance perspective.

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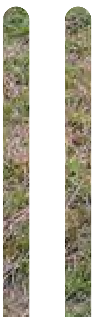

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Otway National Research Facility

Project Leader: Paul Barraclough – Senior Manager – Stage 3 and Operations

Objectives

The Otway National Research Facility (ONRF), equipped with seven deep purpose drilled injection and monitoring wells, a CO_2 production well, and a capture research skid, offers an unprecedented R&D platform to develop, demonstrate and advance CCUS technologies and progress their technology readiness level.

Introduction

By operating the Otway National Research Facility (ONRF), CO2CRC is a global leader in research advancing CCUS technology; contributing to the development and validation of CCUS technologies, informing state and federal policy and regulatory activities and conducting community education.

CO2CRC operates strategic projects to develop and demonstrate transferable CCUS technologies and solutions to support an emerging CCUS industry in Australia and overseas.

The portfolio comprises comprehensive sub-surface research projects to achieve cost-effective, high resolution and low footprint monitoring of industrial scale carbon storage and research on novel materials and technologies to develop high-performing compact capture technologies to separate CO_2 from natural gas in gas processing facilities.

All projects conducted at the ONRF complete comprehensive feasibility studies and pass rigorous international peer-reviews before commencement. CO2CRC collaborates with subject matter experts in each research discipline from Australia's leading research organisations. CO2CRC's staff and management have decades of experience in successfully delivering complex scientific project, and operating plant and facilities safely. Projects are governed by CO2CRC's Program Advisory Committee (Science) and the Operations, Safety and Environment Committee (Operations).

Active projects at the Otway National Research Facility in FY 2019/20

(The section below describes operational activities at the Research Facility. Scientific results are presented for each project under the Storage and Capture sections)

Annual assurance monitoring

The annual assurance monitoring for 2019/20 at the Otway National Research Facility was successfully completed despite some delays due to pandemic related state border closures. The annual report was submitted to the Environment Protection Authority to demonstrate compliance with licence conditions. As part of the assurance monitoring, the annual soil gas and groundwater surveys were conducted by Deakin University in June and July 2020, demonstrating that no injected gas could be detected at the surface.

Stage 2C seismic

The sixth and last seismic survey (M6) for Stage 2C project, also serving as the baseline survey for the upcoming Stage 3 project, was undertaken in March/April 2020. The number of acquisition points initially proposed was reduced due to COVID-19 related border closures impacting the availability of survey personnel. Additional points were obtained in April using local operatives with Curtin University overseeing the survey remotely from Western Australia to guarantee survey success. Well based DAS fibre was used in combination with the buried seismic array as a receiver.

Stage 3 Project

Drilling of four new deviated wells was successfully completed by 30 September 2019 using well engineering contractor inGauge and drilling company Easternwell. The wells, between 1,500 and 1,800m in depth are equipped with the latest technologies in fibre optics sensing and subsurface pressure and temperature gauges. CO2CRC's Stage 3 project represents the largest project undertaken by CO2CRC and will be used to validate technologies to provide data on demand and reduce the cost and impact of long-term CO_2 storage monitoring for CCUS projects. After obtaining the required regulatory approval, an extension to the gathering line connecting existing infrastructure to bring CO_2 rich gas from the Buttress-1 well to CRC-3 injection well for Stage 3 was constructed. An additional seven SOVs were installed and connected to subsurface power supply and control lines with operations commencing to obtain baseline measurements in May 2020. A special thanks is owed to the landholders where the SOV's are located for their ongoing cooperation and assistance in enabling CO2CRC to locate the SOVs on their properties. Piping was installed connecting the new monitoring wells to a purpose drilled groundwater well and storage tanks with down well water injections commencing in July 2020 to obtain baseline data to test pressure tomography as a stored CO_2 plume monitoring technique.

Commercial activities

1.2km of Helically Wound Fibre was deployed horizontally in a trench to undertake testing for TOTAL. All data and reports will be made available to CO2CRC members.

SRD 3.3 Project

SRD 3.3 Project aims to increase understanding of the influences of geological faults on injected CO_2 migration and is led by Geoscience Australia. Groundwater from piezo wells and new shallow wells installed in the vicinity of the shallow fault was monitored to better inform modelling of expected CO_2 migration channels.

Otway capture research

Phase 3 of capture research, investigated the impact of impurities such as H2S on the efficiency of various adsorbents and membrane materials, was completed using the Capture Research Skid installed at Buttress-1 and high pressure CO_2 rich gas from the Buttress-1 well. The Capture Skid allowed the testing of novel materials to separate CO_2 from methane in a high-pressure environment at various concentrations and pressures, as encountered in industrial gas processing facilities. CO2CRC is further developing an adsorbent that showed potential to be developed into a commercial material. The skid itself fulfilled its purpose and remains in a mothballed state at the site.

Operations and maintenance

Site operator, Upstream Production Solutions, continues to provide its services to the CO2CRC Otway National Research Facility. Preliminary rehabilitation work commenced over the summer on Wellpad B and Wellpad C. New transportable offices were installed at Wellpad C and at CRC-2 to accommodate technology used to interpret, collect and undertake preliminary analysis of seismic data obtained in Stage 3. Onsite storage facilities were upgraded. In May 2020 maintenance work commenced to prepare the research facility for the production, compression, transportation, and injection of 15,000 tonnes of CO_2 as part of Stage 3 research.

Local engagement and support

Close engagement with the local Nirranda and Nullawarre communities continues to be high priority for CO2CRC's Otway National Research Facility. Rig tours were offered to surrounding landholders and two people accepted this invitation. A Community Reference Group meeting was held in October 2019 chaired by Moyne Shire Councillor Colin Ryan with 19 people attending including landholders, regulators, our Site Operator and broader community members. Minutes were distributed to local landholders and interested parties. The March 2020 meeting was cancelled due to COVID-19 and a presentation on Site activities circulated to usual invitees. Routine newsletters were distributed to hundreds of local households in October 2019 and March 2020 to provide research updates on the Facility and other interesting and useful information about carbon capture and utilisation and CO2CRC. An Open Day planned for 2020 was cancelled due to the COVID 19 pandemic.

Site visits and visitor centre upgrade

CO2CRC hosted 66 visitors in 2019/2020 at the Otway National Research Facility, despite drilling operations and COVID-19 pandemic. In November 2019, 22 people from CO2CRC's Carbon Capture and Storage Symposium travelled to the Site for a tour of the new site infrastructure. Other visitors included representatives from CarbonNet and The State Department of Jobs, Precincts and Regions including employees from the Warrnambool Victorian Geological Survey Office. The Victorian Government Minister for Resources the Hon Jaclyn Symes visited the Research Facility in October 2019 and Bev McArthur MP and Daniel Meade the Mayor of Moyne Shire also enjoyed tours of the Site. Representatives of member organisations JPower and TOTAL travelled to the Site. CO2CRC always welcomes representatives of member organisations, the local community and people with a general or particular interest in Carbon Capture and Storage to contact us to arrange a tour or visit.

Highlights

- As of June 2020, Otway National Research Facility has, since its inception, achieved 4930 days (~13.5 years) without any lost time injury
- Significant infrastructure work on Site was completed including drilling and completion of four new deep monitoring wells and seven new stationary orbital vibrators plus an extension to the gathering line
- Operations on Site continued smoothly via technology and assistance from local contractors despite the challenges posed by the COVID-19 pandemic
- CO2CRC continues to sponsor the local Nirranda Football Netball Club and support the Nullawarre Primary School

"We are lucky to have a world-class research facility in regional Victoria to support the development of important regional infrastructure like CarbonNet to build new clean industries." Minister for Resources Jaclyn Symes

OTWAY STAGE 3 ALREADY DELIVERING COST REDUCTIONS

Initial techno-economic analysis of the Stage 3 monitoring technologies show preliminary long-term monitoring cost savings estimates for a large Australian project of up to 75% compared to conventional surface seismic-based methodologies. These cost savings will be further quantified when the monitoring technologies are field tested against the CO_2 injection in late 2020, early 2021.

THE INJECTION WELL

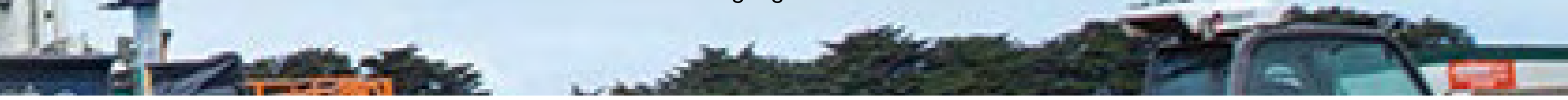
Features and cost saving initiatives:

- Installation of a hybrid TEF (tubing encapsulated fibre) cable outside of casing incorporating engineered, single mode and multimode fibres in a specifically designed bundle which is looped at TD and similarly included on the tubing as well – improving both well operating data and ongoing well diagnostics throughout the life of the well
- Using a specifically designed marker for the fibre optic bundle ensuring perforations were directed away from the TEF and removing the cost of repeat runs or redundant cable
- By incorporating only a tail of CO_2 resistant cement to isolate the injection zone and using standard cement above this, one significant element of the cost of well construction is optimised

THE MONITORING WELLS

Features and cost saving initiatives:

- By drilling multiple deviated monitoring wells from a single well pad and deploying the various sensing equipment successfully in the deviated wells, reduced the cost to the project and provides options for future projects to confidently use the same approach
- Installation of a hybrid TEF (tubing encapsulated fibre) cable outside of casing incorporating engineered, single mode and multimode fibres in a specifically designed bundle which is looped at TD
- Removing the reliance on tubing deployed pressure gauges and instead utilising an approach where the gauges are suspended from the wellhead provides significant flexibility and reduces the cost of hardware (tubing and redundant gauges), rig time, and the need for expensive workovers in the event of gauge failure
- Utilising the same suspension system to deploy a suspended fibre in the well also establishes the opportunity to retro-fit existing/legacy wells with in-well fibre for the acquisition of DAS data for plume monitoring



REDUCING CAPTURE COSTS

Gas refining package for Latrobe Valley Hydrogen Energy Supply Chain

Project owner's name: K S Chan, CO2CRC
Project Leaders: Saw Hong Lim, Dr Jai Kant Pandit

Objectives

- To design, engineer and supply the gas refining package on EPCM basis to produce 99.999% pure hydrogen from coal gasification syn gas.

Outcomes

Design and delivery of a gas refining and hydrogen purification process skid for the pilot plant of the Victorian Hydrogen Energy Supply Chain project that can produce 99.999% pure hydrogen.

Introduction

After completing two feasibility study projects (Gas clean-up & hydrogen purification, CO_2 capture for HESC project) with industrial partners focusing on the conversion of brown coal to hydrogen, CO2CRC has been awarded a contract to implement the section of syngas refining for H2 production in their HESC project at Latrobe Valley, Victoria.

The gas refining project commenced in August 2018. The gas refining part involves purification of syngas obtained by gasification of brown coal. The gas refining unit was designed and built by CO2CRC's contractor GLP. GLP is a Melbourne based engineering company that specialises in modularised process plants and equipment.

In the gas refining section, the syngas from coal gasification plant will be cleaned to remove impurities like chlorides, sulphides and cyanides. The cleaned gas will undergo shift reaction to enhance hydrogen recovery and finally will be purified using pressure swing adsorption (PSA). The final product will be 99.999 % pure hydrogen.

Methods and outputs

Following methods/tools are used to deliver the project on time and to meet the quality and performance standards

- Subcontracting major works
- Design Review
- Risk assessment
- Hazop workshop
- 3D model
- Hazid workshop
- Third party inspection
- Inspection and test plans
- Technical discussions and design deviation
- Document control and management

Project outputs:

- Basic engineering documents like PFDs, P&IDs, control philosophy, functional description, process set point list, cause and effect diagram
- Detailed engineering documents like general arrangement drawings, equipment datasheets, 3 D model, electrical equipment, PLC design, electrical junction boxes, electrical and mechanical calculations, electrical single line diagrams.
- Hydrotesting and NDT of equipment
- Black assembly
- Equipment installation procedure
- Commissioning manuals, operation and maintenance manuals
- Performance Testing

Key publications

Not available, the engineering details of the project are commercial in confidence

Next steps

The equipment has been installed at AGL's Loy Yang facility in Victoria's Latrobe Valley, and has entered the commissioning and performance stage. This includes:

- Completion of HAZOP actions related to commissioning and operation stage
- Completion of all punch list items
- Pre-commissioning activities for gas refining package.
- Procedures for catalyst loading and catalyst reduction
- Catalyst loading and reduction
- Introduction of Syngas and commissioning of the gas refining package
- Performance guarantee test run

After demonstrating the performance (production of 99.999% pure hydrogen) in late 2020, the plant will be test run for one year. Successful operation of the plant will demonstrate the hydrogen production component of the HESC project and may lead to a full scale Hydrogen production facility in the Latrobe Valley by 2030.

Reduction of greenhouse gas emission in steel production

Project Leader: Dr Mohammad Bagheri, Senior Manager – Subsurface
Project and Science Leader: Dr Jai Kant Pandit, CO2CRC

Objectives:

- Analysis of CO_2 emissions with respect to emission sources and their location for an integrated steel plant
- Evaluation of CO_2 capture options from all major emission sources at the BlueScope integrated steel making facility at Port Kembla
- Evaluation of emerging global technologies for emission reduction from BlueScope's integrated steel making facility at Port Kembla
- Ascertain suitability of bio-chemical process to convert by-product gases to value added ethanol as an alternative fuel for transport industry
- Evaluate viability of various transport and storage options for captured CO_2 including a review of potential CO_2 storage locations and a high-level review of the economics and viability of CO_2 transport options to these sites. (trucking, piping, shipping)
- Assist BlueScope with technical and costing information to develop concept level financial evaluations that allow comparison between, and viability of, various emission reduction options

Outcomes:

- CO_2 capture could potentially reduce the CO_2 emissions at BlueScope's Port Kembla Steelworks by 45%. The cost of CO_2 avoidance including capture, transport and storage was estimated at A$174. This cost also includes modification of gas pipe network to transport flue gas from emission source to the capture plant
- Utilisation of CO and CO_2 in steel mill gases to produce Ethanol using biochemical process of LanzaTech is an economically viable option that could potentially reduce total emissions by 7%
- Production of Methanol from steel mill gases using chemical conversion is feasible only if clean and cheap hydrogen is available at Port Kembla Steelworks
- Use of Biochar in steel making process can reduce the emissions significantly. However, at this stage it is not economically viable in Australia due to availability of good quality coal at low cost
- In the long term, when hydrogen has a cost of < A$ 2/kg, the use of hydrogen as reducing agent would reduce the emissions substantially and could be an economically viable option

Introduction

Steel making is an energy and carbon intensive process in which coal has traditionally been used as a source of energy and carbon. As a result, the steel industry is a major source of industrial greenhouse gas emissions and accounts for 7-9% of direct emissions from the global use of fossil fuel. The iron and steel industry provide both challenges and opportunities in reducing the greenhouse gas emissions and making the industry sustainable. In January 2019, Coal Innovation New South Wales (CINSW) of the Department of Planning, Industry and Environment of NSW state government has engaged with CO2CRC to conduct a research study into reducing greenhouse gas emissions in steel production. CO2CRC received a strong support from BlueScope Steel for this project and has been providing the relevant information for this study from their steel works in Port Kembla.

Method and outputs

- Review of global program/initiatives to reduce emissions from steel production
- Analysis of CO_2 emission data provided by BlueScope Steel, which form the basis of the full study
- Evaluation of CO_2 and steel mill gases utilisation technologies (biochemical as well as chemical) for reducing CO_2 emissions by producing value added products
- Evaluating carbon capture and storage for CO_2 from major emission sources

Project Outputs

- Summary of global initiatives and technology status for emission reduction and suitability of various emission reduction processes and technologies for BlueScope
- Technical and economic assessment of utilisation of steel mill gases for producing valuable products by chemical and biochemical processes
- Cost of CO_2 avoidance for CO_2 capture, transport and storage
- Potential measures to improve energy efficiency of steel production at BlueScope
- Possible pathways for emission reduction at BlueScope's Port Kembla Steelworks
- Submission of final report to CINSW

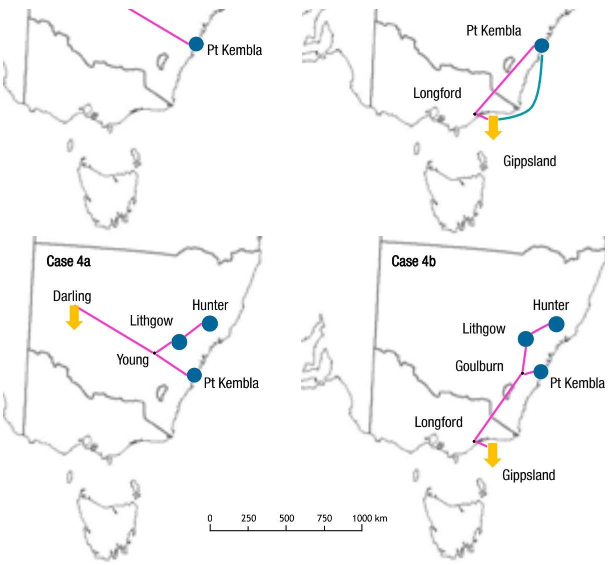
Key publications

- Final report to CINSW, also available in PTS (RPT20-6205)

Next steps

BlueScope Steel may develop a cost benefit analysis and a business case for the utilisation of steel mill gases containing CO_2 and CO to reduce the emission from it Port Kembla Steel Works.

CO2CRC is assessing the applicability of CCUS technologies explored in this project to hard to abate emissions from other industries such as cement, chemicals, and refineries.



Transport and storage options considered for captured CO_2 from BlueScope's Port Kembla Steelworks.

Highlights

- Utilisation of steel mill gases has potential economic and emission reduction benefits
- Energy efficiency measures and utilisation of steel mill gases can reduce the emissions potentially by 10%
- Carbon Capture and Storage has the potential to reduce the emissions by 45% if economically viable
- Hydrogen does play a crucial role both in utilisation and emission reduction if clean hydrogen is available at competitive rates

International Cooperation In Carbon Capture Technologies

CO2CRC is a member of the International Test Centre Network (ITCN), participating in international meetings to share knowledge on operational experience, establish generic performance indicators and promote technology standardisation for CCS. Current members include the US National Carbon Capture Centre (NCCC); the Norwegian Technology Centre Mongstad; CSIRO Australia; the UK CCS Research Centre; the Canadian CCS Knowledge Centre, SINTEF in Norway, CERI and NICE in China and KIER in Korea. Participation in the network confirms that CO2CRC's is a recognised partner within a group of global capture research and development leaders.

Frank Morton, Director Technology Development for the National Carbon Capture Center (NCCC), visited the capture test facility at CO2CRC's Otway National Research Facility after attending the CO2CRC Symposium. The site visit and attendance at the Symposium generated some good discussion around potential future collaborations, in particular on the membrane solvent contactor technology that CO2CRC trialled at the Vales Point power station in NSW together with The University of Melbourne.

ENHANCING CO_2 UTILISATION

High-level screening of Australia's geological basins for potential of enhanced oil recovery utilising carbon dioxide

Project owner: Dr Mohammad Bagheri, Senior Manager – Subsurface

Objectives:

To assemble all the key geological information from relevant Australian basins and screen them according to their suitability for CO_2-EOR and associated CO_2 storage

Outcomes

- Inventory of key petroleum and basin parameters relevant for CO_2-EOR
- Acquisition of key parameters for major onshore basins will be prioritised and expedited for incorporation into the second phase of this project
- Basin ranking document outlining identifying prospecting basins for CO_2-EOR and associated CO_2 storage

Introduction

CO_2 enhanced oil recovery (CO_2-EOR) is a proven technology that can improve the yield of oil over time and extend the life of oil fields. The addition of CO_2 into the oil reservoir increases the overall pressure of an oil reservoir, forcing the oil towards production wells. The CO_2 can also blend with the oil, improving its mobility and so allowing it to flow more easily. In CO_2-EOR, some portion of the injected CO_2 remains in the subsurface. If the CO_2 that returns to the surface is separated and reinjected to form a closed loop, this results in permanent CO_2 storage.

Although CO_2-EOR has been used successfully for decades around the world, it has not been deployed in Australia to date. The mature fields that are in the later stages of their life offer significant potential in terms of immediate CO_2-EOR development.

The goal of this study is to compile all the relevant CO_2-EOR data on Australian basins and develop a national integrated screening and ranking inventory that various stakeholders can use to gauge the broad potential for CO_2-EOR in each basin.

The inventory will assess each basin on a case-by-case basis, systematically analysing the key subsurface parameters that determine a successful CO_2-EOR prospect. International experience indicates that the following oil and reservoir parameters are the dominant controls on CO_2-EOR success:

- Oil gravity (°API)
- Viscosity
- Depth of oil-bearing formation
- Temperature
- Pressure
- Permeability

In addition to focussing on the key geological parameters that are critical for CO_2-EOR, each basin will be assessed broadly in terms of its proximity to the significant CO_2 sources that can potentially be used in the recovery process.

This project is funded by Low Emission Technology Australia (LETA). Geoscience Australia is the main project partner and CO2CRC provide project management services and technical peer review.

Methods and outputs

The main elements of the scope of work are:

- Basin selection for inclusion in the study
- Inventory of key petroleum and basin parameters relevant for CO_2-EOR:
  - Tabulation of oil API gravity, together with associated wells and formations
  - Basin Pressure and Temperature tabulation and minimum miscibility pressure analysis if possible

- Approximate reserve and volume of oil remaining in place
- Key producing formations
- (Acquisition of the above data will most likely need to proceed basin by basin, and prioritised if necessary)

› Acquisition of key parameters for major onshore basins (Cooper and Surat) will be prioritised

› Semi-quantitative understanding of the potential for EOR associated CO_2 storage at each basin level

› Basin ranking document outlining identifying prospecting basins for CO_2-EOR and associated CO_2 storage

Ten major oil producing basins of Australia have been evaluated for their CO_2-EOR potential in this study. The basins were categorised in to three Tiers in terms of their potential for CO_2-EOR based on their location, proximity to infrastructure, potential cost, proximity to CO_2 sources, and data availability. The finalised Tiers are:

› Tier 1 basins: Cooper, Eromanga, Surat, Bowen, and Gippsland

› Tier 2 basins: Carnarvon, Bonaparte, and Amadeus

› Tier 3 basins: Canning and Browse

The other main outputs of the project are:

› Remaining oil in each basin that could be a target for CO2 EOR has been estimated using some assumptions

› The potential of each basin for incremental oil recovery has been estimated using a range of recovery factor for CO_2-EOR from literature

› The potential of each basin for CO_2 storage while CO_2-EOR has been estimated using analogous projects in the literature

Key publications

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Next steps

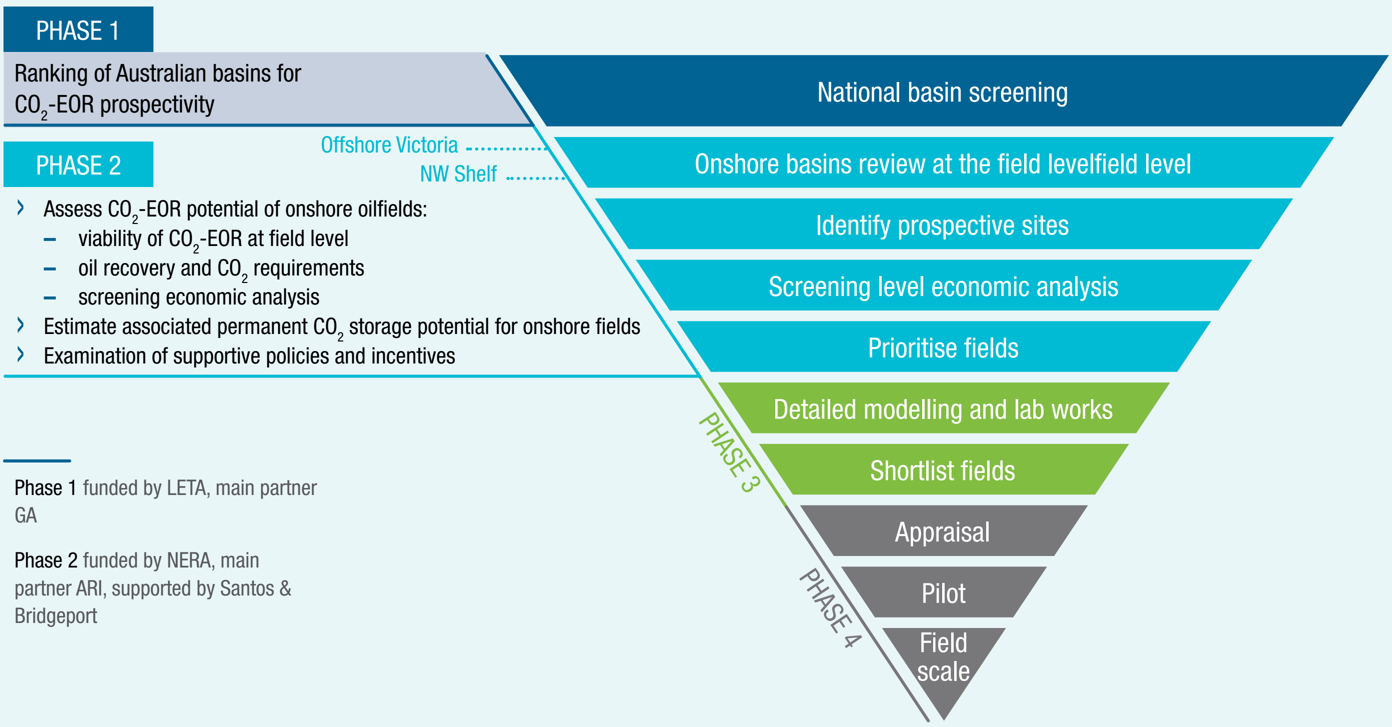
The next step of this works is to quantify the potential of CO_2-EOR and its associated CO_2 storage at field level in each basin. This work is partly started by investigating onshore Australian oil fields.

Highlights

The major achievements in this project to date are as follows:

› A methodology has been established to rank Australian basins for CO_2-EOR

› Potential of each of the studied basins for CO_2-EOR and associated CO_2 storage are estimated



Phase 1 funded by LETA, main partner GA

Phase 2 funded by NERA, main partner ARI, supported by Santos & Bridgeport

CO2CRC CO_2-EOR national study

Using CO_2-EOR to reduce the energy sector's GHG emissions and improve oil recovery from Australia's mature onshore oil fields

Project owner: Dr Mohammad Bagheri, Senior Manager – Subsurface

Objectives

To provide insight to the industry and government about potential opportunities around CO_2-EOR, associated net CO_2 storage, and high-level economics of the process at detailed field level for onshore Australian oil fields. Through this project, we envision providing a landmark study that would help industry more readily and efficiently pursue CO_2-EOR options in Australia.

Outcomes

The main expected outcomes of the project are:

- Onshore oilfields potential and screening for CO_2 EOR by:
  - Estimating the viability of CO_2-EOR at field level
  - Estimating oil recovery and CO_2 requirements
  - Screening economic analysis
- CO_2 storage potential with the application of EOR for the fields above
- Examination of supportive policies and incentives that would help accelerate the use of CO_2-EOR

Introduction

Two operators in Australia have recently started to investigate CO_2-EOR opportunities in the Cooper and Surat basins.

According to a CO_2-EOR report by US Chamber of commerce, based on the current projects in the United States, CO_2-EOR delivers approximately as much production as primary recovery. Recoverable Australian liquid hydrocarbon using primary production is ca. 11 billion barrels according to Geoscience Australia. In the Australian context, although we do not expect that CO2 EOR will be able to produce as much as primary production (due to higher primary recovery factor than in US), liquid hydrocarbon reserves would increase by a significant factor. But in the absence of an integrated study, it is difficult to understand the estimated value of the CO_2-EOR and its potential in Australia to not only increase liquid hydrocarbon reserves but to also contribute to greenhouse gas abatement efforts.

The focus of this Project is to evaluate Australia's onshore oil reservoirs (predominantly in the Cooper and Surat basins) to investigate the feasibility of CO_2-EOR at field level to:

- Enhance the oil recovery
- Store CO_2 whilst enhancing oil recovery and reduce emission

The methodology and systematic approach developed for this project is equally applicable to offshore oil reservoirs in Australia and once the methodology is well developed and understood, it can be extended to Australia's offshore basins.

The study will deliver a landmark report that will assist industry more readily and efficiently

pursue CO_2-EOR options in Australia. Long-term outcomes from the application of CO_2-EOR include:

- Advancing energy production and improving oil recovery of an additional 5% to 25% of the original oil in place from mature oil assets. The outcomes from the study will provide a better understanding of the additional potential recoverable oil from Australian onshore fields including those in the Cooper and Surat basins using CO_2-EOR
- A means for the oil, gas, and resources industries to make deep reductions in greenhouse gas emissions. CO_2-EOR will require the use of CO_2 captured from industrial and power plant emission sources. 100% of captured CO_2 will be permanently stored in underground reservoirs by the end of the operational life cycle
- Contributing to the national future oil supply. Increasing the volume of technically recoverable domestic crude oil could help reduce Australia's trade deficit and enhance national energy security by reducing oil imports
- The outcomes of this project will provide stakeholders with a high-level understanding of the techno-economics of applying CO_2-EOR on a commercial scale

This project is funded by NERA and being jointly performed by CO2CRC and Advanced Resources International (ARI), a US based expert in CO_2-EOR.

Utilising international organisations with decades of experience with similar studies will enable the transfer of knowledge domestically and build capacity within Australia to provide similar services into the future.

Methods and outputs

This project started on May 2020 and is planned to be concluded by October 2021.

The main tasks of this work include:

- Fit for purpose data gathering and assimilation for onshore oilfields with respect to CO_2-EOR and storage
- Review the onshore fields for their technical feasibility for CO_2-EOR
- Estimate the oil recovery and CO_2 storage potential at field level
- Identify CO_2 sources and cost per region
- Undertake economic scoping analysis for each field
- Examine policies, incentives, and legislations

Key publications

This project has just started and in the data compilation phase.

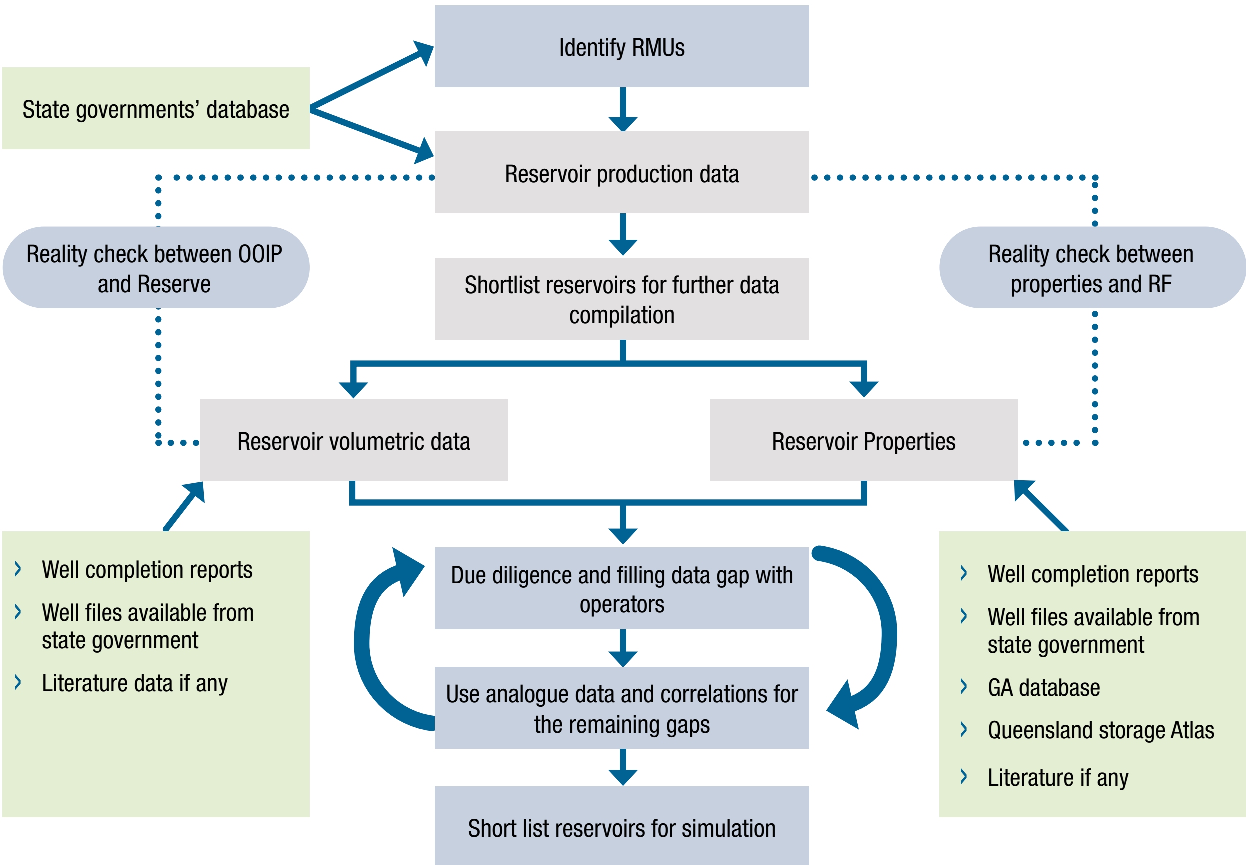
Next steps

Next major step in the project is to receive operators' feedbacks on the database and finalise the project's database. This will then feed into TASK 2 and TASK 3 where reservoirs will be screened and the potential of each field for CO_2-EOR and CO_2 storage will be investigated.

Highlights

To date, the project team have identified 144 oil reservoirs (EUR > 0.5mmbbls) in South Australia and Queensland with total EUR of 464 million barrels of oil.

A comprehensive database has been put together solely from publicly available data. The data from all of the geological and reservoir engineering reports as well as well completion reports available from SA and QLD state governments were used to achieve this database.



Database compilation workflow used in investigating CO_2-EOR potential in onshore Australian oilfields

CCSNET AND GIPNET

Research Organisations involved:
CO2CRC, University of Melbourne, CSIRO , University of Wollongong, ANU
University of Adelaide, Federation University

Objectives

To establish a research infrastructure network to produce technologies that will drive down costs and make CCS a price-competitive emissions reduction technology.

Outcomes

CCSNET has delivered the following infrastructure:

- Otway Subsurface Laboratory (OSL)
- Gippsland Monitoring Network (GipNet)
- LabNet Storage
- LabNet Capture

These assets have and continue to enable the realisation of the five-year research programs. The outcomes and added value from the assets and research programs are summarised in Table 1.

Introduction

CCSNET comprises laboratory upgrades, new plant and equipment located at universities and national research centres in Victoria, ACT and South Australia. These build upon existing research and development infrastructure at the CO2CRC Otway National Research Facility and enhance its global profile as one of the premier CCS subsurface laboratories in the world.

CCSNET is funded via an Australian Government Education Investment Fund (EIF) grant and its primary objective is to support the Victorian Government's CarbonNet Project, which is also a proxy for other offshore CCS projects in Australia and worldwide. CarbonNet is investigating the potential for a commercial-scale CCS hub in Victoria. It is jointly funded by the Commonwealth and Victorian governments and aims to bring together multiple CO_2 capture projects in Victoria's Latrobe Valley, transport CO_2 via a shared pipeline and inject it deep underground, into offshore storage sites in Bass Strait.

CO2CRC utilised its strong governance processes to review assets for fitness for purpose and direct benefit to CCS research and development in Australia, including for the benefit of CarbonNet, and to oversee the procurement and development of the five-year research plans. The CCSNET Steering Committee considered advice from the Joint Project Committee and the Scientific Advisory Committees (Storage and Capture) and then took their own recommendations to the CO2CRC Board.

Methods and outputs

Table 2 overleaf outlines the infrastructure and equipment deployed under CCSNET. All four projects, Otway Subsurface Laboratory (OSL), Gippsland Monitoring Network (GipNet), LabNet Storage and LabNet Capture are all successfully completed.

The CCSNET funding was for capital works and the operational and research funding had to be sought by asset owners from other sources. The assets have been able to leverage $50 million dollars of research funding and in-kind support. This support has come from the Universities and Research Organisations themselves but also from external funding sources such as ANLEC R&D, CO2CRC and the Australian Research Council.

The outputs from CCSNET can be divided into two sections, 1) assets and 2) research outcomes. The CCSNET assets have all been successfully purchased, installed and commissioned. The research outcomes from the 5-year research plans associated with these assets are in different phases, with some assets such as the OSL only just beginning to work on the 5-year research plan and outcomes will be seen in the next few years, whereas some assets in the LabNet storage and capture projects have been operating for a number of years and have achieved the research outcomes.

The final report on CCSNET detailing the status of outcomes of the 5-year research plans with a thorough review by a committee will be submitted to the Department of Education, Skills and Employment by 31 December 2020.

Key publications

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Highlights of the 2019-20 projects

This financial year saw the deployment of the remaining CCSNET infrastructure:

- 3D Imaging;
- Ocean Bottom Seismometer (OBS) deployment; and
- Otway Subsurface Laboratory.

3D Imaging

The 3D imaging equipment was a component of ANU's CCSNET assets that included Special Core Analysis (SCAL) equipment, Quantitative Mineralogy and building refurbishment. All these assets combined have enabled:

- Quantifying residual trapping. This will assist storage operators to utilise the available pore space effectively and support their M&V plans to reduce risk and inform regulators and reduce cost
- Identifying the influence of various factors on residual trapping, including wettability, initial saturation and injection rate. A major focus is to use cross-scale imaging, modelling and experiment to construct better methods for upscaling these trapping efficiencies in heterogeneous formations such as laminated sands
- The new CCSNET assets at ANU when compared to traditional methods of core analysis have increased resolution from 10s of centimetres to millimetres and processing time reduced from months to weeks, leading to risk and cost reduction

ANU's CSNET assets have supported research and industry collaborations from all over Australia and the world, including the USA, UK, France, Norway, Brazil and has supported 5 PhD students, 1 MSc and 4 Honours level students and a further 6 students are currently studying towards a PhD at the facility. The CCSNET assets were central to successful bid for the 2019-2023 ARC Training Centre for Multi-scale 3D imaging and analysis. This will ensure research into CCS to continue on this equipment.

Ocean Bottom Seismometer (OBS) Deployment

The OBS test deployment tested the performance of the instrument in shallow-water Australian conditions for the very first time. It gathered vital information of noise levels in the deployment environment and the information was used to constrain input parameters for theoretical models describing the minimum magnitude detection and location thresholds of the GipNet networks.

The Seismology Monitoring Network has established operational protocols (e.g. selecting an appropriate mix of instruments, site selection and deployment, data transfer, maintenance) applicable to seismic monitoring in shallow marine environments in general, for which off-the-shelf monitoring solutions are not available. This work enables high quality seismic monitoring of offshore CCS sites.

Noise analysis of onshore instruments and the OBS has also been completed to quantify the level of monitoring able to be provided across the offshore CCS sites by different instruments at different locations (hard rock sites v coastal sites v OBS). These results will help inform future decisions within the CCS industry about the level of monitoring required, and how this is best achieved.

The outcomes of the Seismology Monitoring Network enables high quality seismic monitoring of offshore sites and understanding of the level of monitoring required, which will lead to risk reduction and lower long-term monitoring costs.

The Otway Subsurface Laboratory (OSL)

The CCSNET assets for the OSL saw CO2CRC engage in their largest operations to date. In July 2019, a 59-day drilling program started to install the remaining four monitoring wells and their associated downhole sensors. The wells were drilled and completed by

September 2019, and injectivity testing and reservoir evaluation beginning in October 2019. In early 2020, surface infrastructure works commenced to complete the required installation of equipment to support the Stage 3 experiment. This included: a gas gathering line extension, seven new surface orbital vibrator (SOV) stations, power, communication and electrical infrastructure to support the new monitoring systems and connect downhole instrumentation and computers and data storage to support the significant amount of data generated from the site. These systems were in place and commissioned by June 2020 in preparation for baseline data acquisition prior to the injection commencing in November 2020.

Initial techno-economic analysis of the Stage 3 monitoring technologies show preliminary long-term monitoring cost savings estimates for a large Australian project of up to 75% compared to conventional surface seismic-based methodologies. The research objectives of the Otway Stage 3 Project are detailed on page 30.

The CCSNET assets that have been installed at the Otway National Research Facility have ensured that CO2CRC and Australia remain at the fore-front of field scale CCUS research. The combination of wells and surface infrastructure at the site is globally unique and will enable CO2CRC to fulfil their ambition to elevate the site to an international test centre.

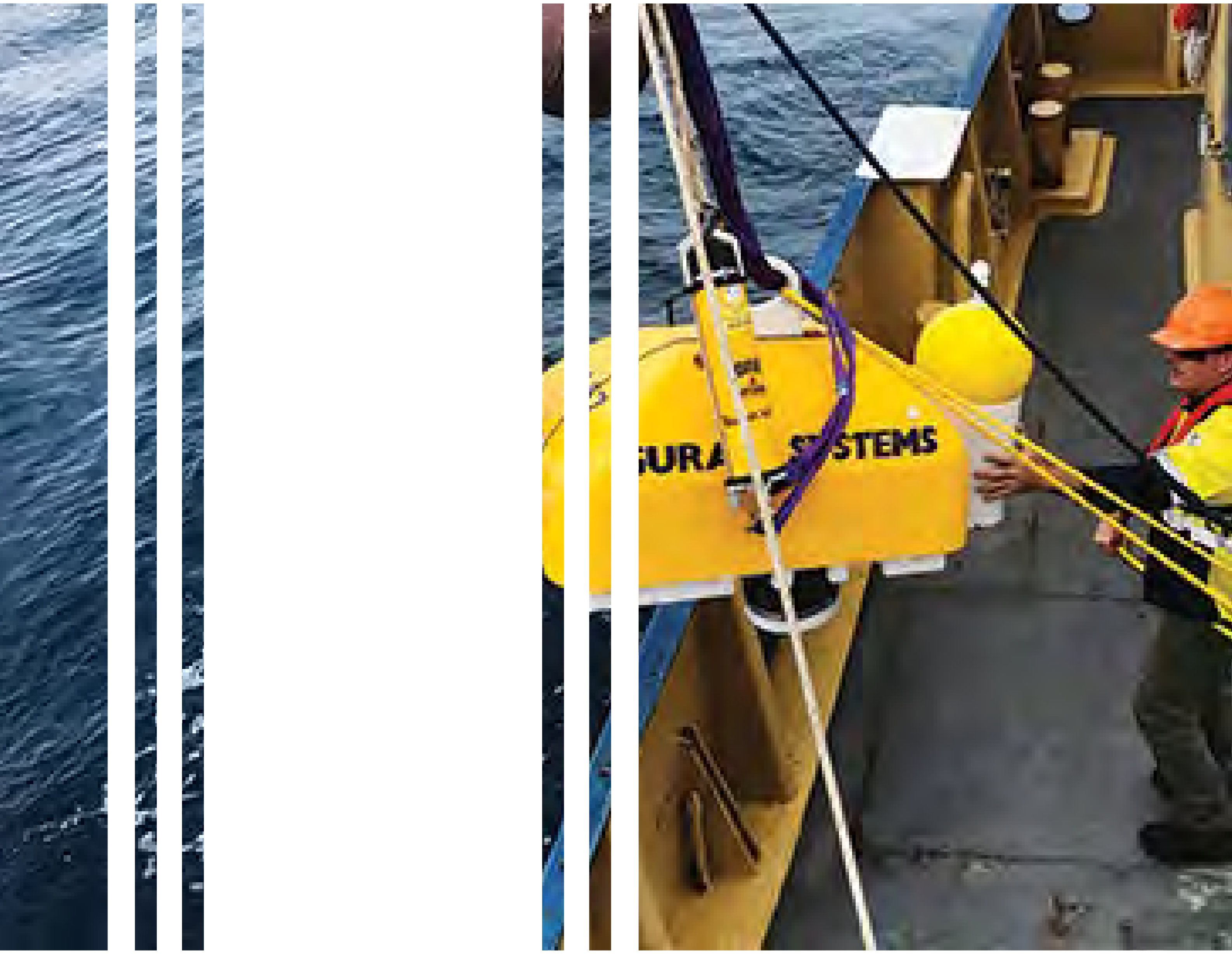


Table 1: Expected outcomes and added values of the five-year research plans associated with the CCNET assets

ASSET	OUTCOMES AND ADDED VALUES FROM THE FIVE-YEAR RESEARCH PLANS
Otway Subsurface Laboratory	**Outcome:** › A thoroughly equipped subsurface laboratory with 7 interconnected wells to be used by the CCUS industry to test and verify technologies to de risk the CCUS projects **Expected research outcomes:** › Long-term monitoring cost reduction › Reduction of the environmental footprint of monitoring techniques › Development of on-demand, sub-surface and permanent monitoring solution incorporating current market-available technologies › Faster acquisition and continuous transmission of plume monitoring data for immediate user access
GipNet	› Development and validation of a combined model-measurement assurance system › Establishment of multiple scales of verification of the atmospheric state. › Understanding of natural variability around future storage site from a network of fixed platforms and mobile ASV monitoring platform › Established operational protocols applicable to seismic monitoring in shallow marine environments in general, for which off-the-shelf monitoring solutions are not available
LabNet Storage	› Construction of an integrated geological description and flow property database from pore to plug scale › Generation of routine and special core data using digital core analysis methodology as a more efficient technology than traditional RCA and SCAL experiments › Upscale measured properties through DCA at core scale to well and reservoir scale › The formation of silica-gel has been tested and verified as an effective flow barrier under CO_2 storage conditions. The results have successfully completed technology readiness level (TRL) 4 › Loss of injectivity from dry-out near the well is verified through laboratory experiments and can be predicted through modelling
LabNet Capture	› Novel Solvent research for CO_2 Capture › Efficient use of membranes for CO_2 from Flue Gas to Microalgae Ponds › World-first demonstration of hybrid membrane gas-solvent contactors on a coal fired pilot plant › Analysed and evaluated an industrial model for carbon capture wastes (CO_2 and amine) utilisation for carbon negative product manufacturing › Characterised waste and product streams associated with different pre-and post-combustion capture technologies › Recommendations for treatment of degraded capture system components

Table 2: CCSNET Asset Summary

NO.	ASSET	RESEARCH ORGANISATION	EIF GRANT [$M]	CONTRACTED FINISH DATE	DEPLOYMENT COMPLETION STATUS [%]
Otway Subsurface Laboratory					
#01	Otway Subsurface Laboratory	CO2CRC	27.04	Dec-19	100
Gippsland Monitoring Network					
#04	Seismology Monitoring Network	The University of Melbourne	1.28	Aug-19	100
#05	Atmospheric Monitoring Network	The University of Melbourne	0.40	Sep-18	100
#06	Marine Monitoring Network	CSIRO	4.07	Dec-17	100
LabNet Storage					
#07	3D Imaging	ANU	1.50	Oct-19	100
#08	Quantitative Mineralogy	ANU	0.85	Aug-14	100
#09	Special Core Analysis Equipment (SCAL)	ANU	1.01	Sep-18	100
#10	Building Refurbishment	ANU	1.68	Sep-18	100
#11	Bioreactor Laboratory	The University of Melbourne	0.25	Nov-14	100
#12	High Resolution Display-Wall Modelling Room	The University of Melbourne	0.42	Dec-17	100
#13	Fluid Flow and Geochemistry Laboratory Refurb and Equipment	The University of Melbourne	3.56	Dec-15	100
#15	MICP Replacement	University of Adelaide	0.16	Mar-17	100
LabNet Capture					
#16	Analytic Capture Equipment	The University of Melbourne	1.48	Jul-15	100
#17	Dynamic CCS Modelling Platform	The University of Melbourne	0.75	Dec-17	100
#18	Building Refurbishment	The University of Melbourne	2.27	Mar-16	100
#21	Building Refurbishment + Analytical Equipment	Federation University	2.30	Mar-16	100

CO2CRC CCUS SYMPOSIUM

19 – 20 November 2019
RACV Resort Torquay

CO2CRC welcomed over 130 Australian and international delegates from the USA, Germany, Japan, France and Italy attended the event. Chevron, TOTAL, Shell, ExxonMobil, Santos, Woodside, ENI, Japan CCS and J-Power were among the organisations to attend.

The symposium program covered a wide range of topics including technical sessions on advancements to reduce the cost of capture, optimise storage operations and enhance carbon dioxide utilisation. Additional workshops and forums were organised around the two-day event to provide delegates with opportunities to explore collaborations and make the most of new technological developments.

HIGHLIGHTED PRESENTATIONS

Chevron's CO_2 Team Leader Mark Trupp presented on progress on the Gorgon carbon dioxide injection and storage project, the world's largest commercial-scale CCS project which began operations in August in Western Australia.

Mark McCallum, CEO of COAL21 highlighted his company's commitment to develop a commercial scale CCUS project in Queensland's Surat Basin with a final investment decision to begin construction of a $150m carbon capture plant at the Millmerran Power Station scheduled for 2020.

Ian Filby, Project Director for The CarbonNet Project detailed the progress to date in investigating the feasibility for a commercial-scale, multi-user CCS network in Gippsland, Victoria, Australia and confirmed drilling of an offshore appraisal well was expected to commence at the end of 2019.

CO2CRC AWARD WINNERS

Dr Charles Jenkins (CSIRO): John Tyndall Award for Excellence in CCS Research

This award is for Charles' outstanding contribution as Science Lead of the Otway Stage 3 project. Charles' inputs were pivotal in several key decision points along the seven year journey of the project. Charles fostered the development of fundamental science and led it with the team to pass multiple international peer reviews. Along the way, he coached and directed researchers to experience the difficult juncture of science, innovation, funding, risks, and management to make the crucial Stage 3 project happen.

Charles is an outstanding, internationally recognised scientist, and we are delighted to have him in our team.

Dr Tess Dance (CSIRO): Award for her Strong Geological Contribution to all Otway Projects

Tess has been the Otway geologist for over a decade and her knowledge of geology of the Otway site is the key to all our projects. She published a series of journal papers of outstanding quality that have advanced our understanding of the design of storage.

Professor Paul Webley (The University of Melbourne): Award for Innovation in Addressing Energy Challenges involving CCS

Paul was deeply involved in the Otway Capture Skid as the key designer and innovator, and the driving force behind the adsorption unit.

Associate Professor Roman Pevzner (Curtin University): Award for Continuous Innovation in Seismic Monitoring and Industry Engagement

Roman is the thought leader of a team that is continuously and rapidly leveraging learnings from today's work to initiate the next generation of seismic monitoring techniques.

Dr Colin Scholes (The University of Melbourne): Award for Innovation on Novel Membrane-Solvent Contactor Technologies

Colin steered the implementation of a continuous absorption and desorption process in the Membrane-Solvent Contactor plant at Vales Point, which was the world's first trial of that kind.

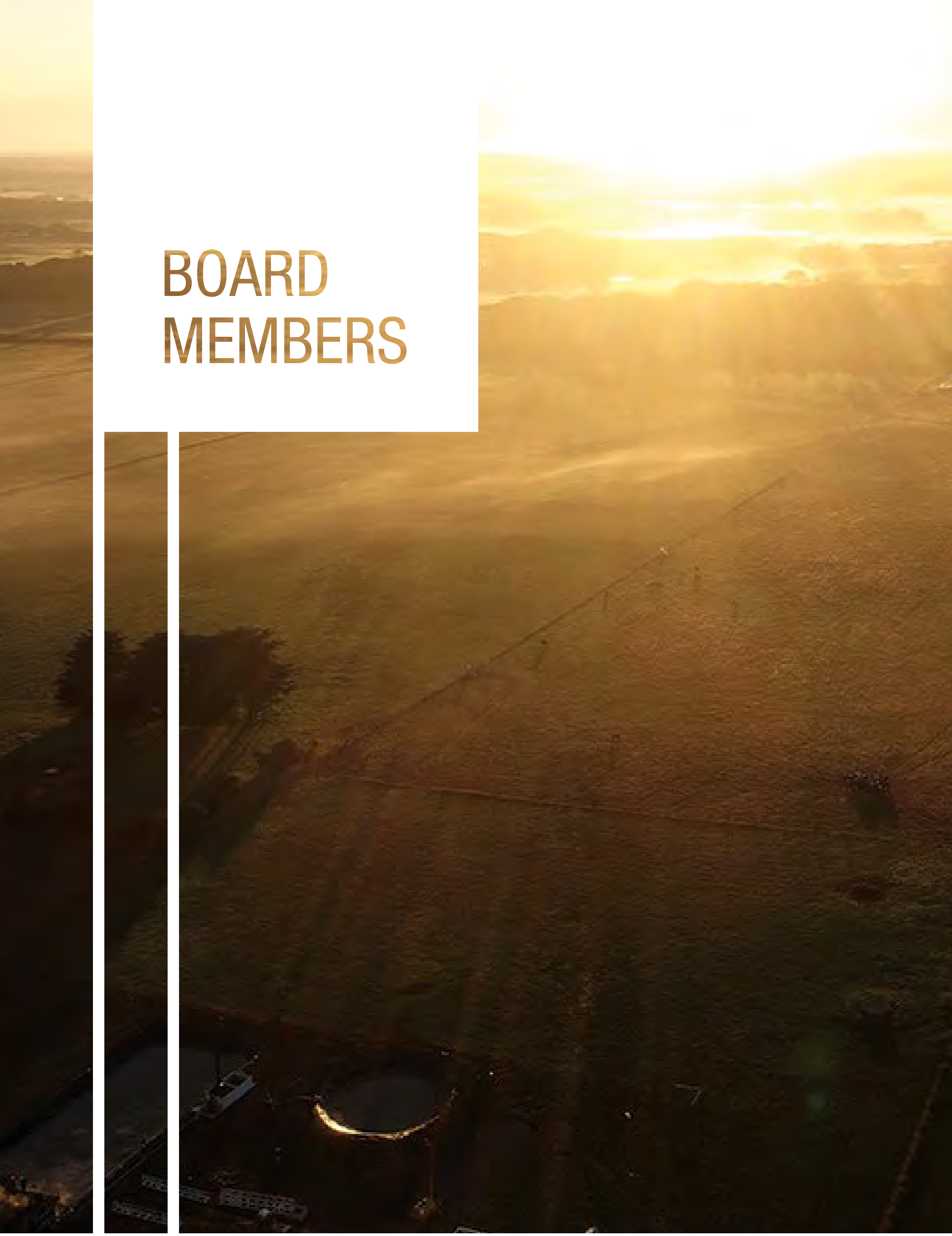
Dr Jonathan Ennis-King and Dr James Gunning (CSIRO): Award for Developing the Fundamental Science behind Pressure Tomography

Over the last few years, both researchers developed the fundamental equations and algorithms to a point where the application is now a monitoring concept mature enough for field testing and potential application in industrial scale CCS projects.

Dr Andrew Feitz (Geoscience Australia): Award for International Engagement on Fault Characterisation relevant to CO_2 Storage

For over five years Andrew has been a passionate proponent of the need to characterise faults for CO2 storage and was the driving force behind initiating and designing the Otway Shallow Fault project, to which he has attracted many international research and industry stakeholders.

BOARD MEMBERS



Martin Ferguson AM
BEc (Hons)

Martin Ferguson has a long history of public service and work in economic and social policy.

From 1984 until 1990 Martin served as the General Secretary of the Miscellaneous Workers Union and from 1990 until 1996 as President of the Australian Council of Trade Unions (ACTU). As a senior trade union official, from 1984 until 1996 he sat on the ACTU National Executive, participating directly in shaping and implementing many of the economic reforms of the Hawke and Keating Governments.

In March 1996, Martin was elected as a Member of the Federal Parliament in the seat of Batman, in Melbourne, which he held until retiring in 2013. He was appointed a Member of the Order of Australia in June 1996.

During the Howard Government, Martin served in a range of economic shadow portfolios, including Employment and Training; Immigration and Multicultural Affairs; Regional Development, Infrastructure, Transport, Regional Services and Population; Urban and Regional Development, Transport and Infrastructure; Primary Industries, Resources, Forestry and Tourism; and Transport, Roads and Tourism.

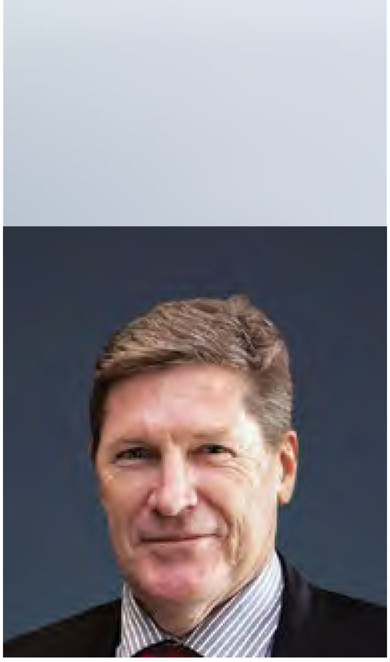
Upon the Rudd Government assuming office in December 2007, Martin was appointed the Minister for Resources and Energy and the Minister for Tourism, and acted as the Chair of the Standing Council on Resources and Energy and the Ministerial Council for Tourism. He held the Resources, Energy and Tourism portfolios until March 2013, when he resigned from the Ministry.

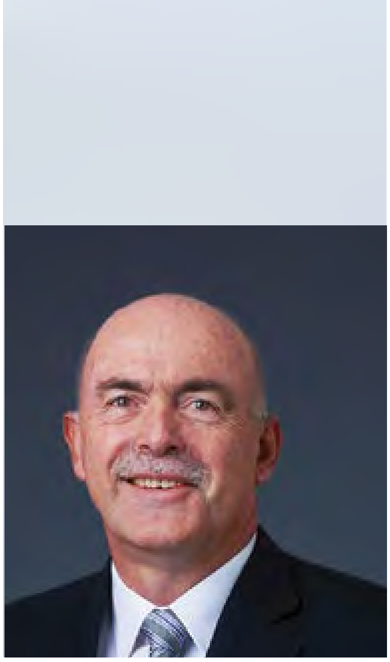
Martin is chair of an advisory board to the Australian oil and gas industry association, APPEA and is the Strategic Director of Natural Resources to SGH Energy. He also chairs the CO2CRC and Tourism Accommodation Australia organisations.

Martin was a member of the University of Western Australia's Industry Advisory Board on Resources and Energy from 2013 until it was abolished in late 2018. From 2014-16 he was an Independent Director of the BG Group in London prior to its takeover by Shell and he chaired the University College of London's, Adelaide Campus Advisory Board until it merged with the University of S.A. in late 2017.

Martin has an honours degree in economics from Sydney University.

Special responsibilities: Chairman of the Board, Chair of Appointments and Remuneration Committee.





David Byers
BEc, LLB, G Dip. Energy & Resources Law, GAICD

David joined CO2CRC as Chief Executive Officer in July 2018. He has more than 30 years' experience across the oil, gas and minerals industry in Australia and internationally with appointments in chief executive and senior leadership roles in public, membership and commercial organisations.

Some highlights include his appointment as interim Chief Executive of the MCA (Minerals Council of Australia) prior to joining CO2CRC, his earlier role as Vice President Government Relations and Public Policy for BHP, four years as Chief Executive of APPEA (Australian Petroleum Producers and Explorer's Association), three years as Chief Executive of CEDA (Committee for Economic Development of Australia) and 17 years working in senior leadership roles for ExxonMobil in Australia, Singapore and the United States.

In 2018, he was appointed a member of the Australian Statistics Advisory Council, the key advisory body to the Federal Assistant Treasurer and the Australian Bureau of Statistics (ABS) on national statistical services. He was recently appointed Honorary (Senior Fellow), Chemical Engineering, University of Melbourne and is a member of the Peter Cook Centre Advisory Council, Melbourne University.

Special responsibilities: Chief Executive Officer.

Mick Buffier
BE (Civil) (Hons) from The University of Sydney, MBA from The University of Newcastle

Mick is responsible for Sustainable Development and Industry Relations for Glencore's coal assets, a role he took on following Xstrata's merger with Glencore in May 2013.

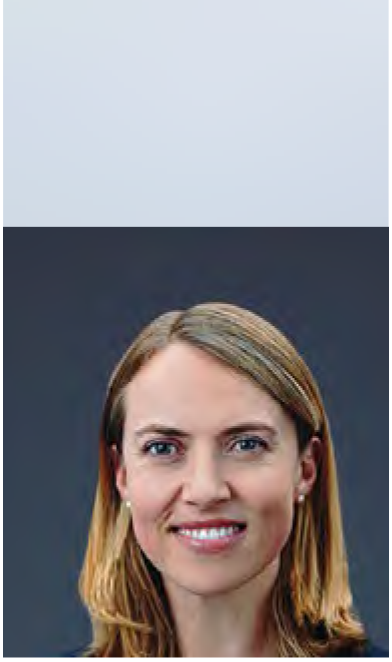
He has more than 30 years' experience in the coal mining industry. Appointed Group Executive, Xstrata Coal in March 2009, he was responsible for Corporate Affairs, Government Relations and Sustainable Development across Xstrata's global coal operations.

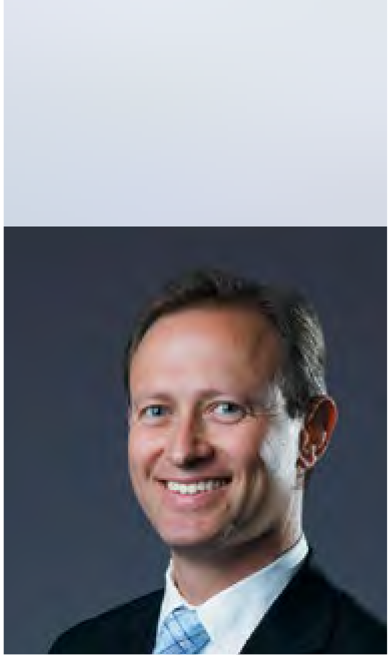
From 2002-09, he was Chief Operating Officer of Xstrata's NSW coal mining operation.

Mick is the former Chairman and a current director and member of the NSW Minerals Council (NSWMC), a ministerial appointee to the NSW Coal Innovation Council, a director of the Australian Coal Association Low Emission Technologies Pty Ltd (ACALET) and ANLEC R&D.

On an international level, he is a former Chairman and current Vice Chairman of the World Coal Association (WCA) and an Associate of the International Energy Agency (IEA) Coal Industry Advisory Board (CIAB).

Special responsibilities: Member of Finance, Risk and Audit Committee





Fiona Hick
Beng (Hons), BAppSci (Energy), FIEAust

Fiona has led Woodside's operations division since 2019. As Senior Vice President Operations, she is responsible for all of Woodside's global health, safety and environment, operations, producing facilities, subsea and pipelines, logistics and reservoir management functions.

Fiona has been with Woodside since 2001, holding positions including Vice President Strategy Planning and Analysis and Vice President Health, Safety, Environment and Quality. Prior to joining Woodside, Fiona worked for several years with Rio Tinto living and working in their remote locations.

Currently Vice President of The Chamber of Minerals and Energy of Western Australia (CME) and is a member of the Australian Institute of Company Directors, Associate Fellow of the Australian Institute of Management and a Fellow of the Institute of Engineers.

Fiona won the 2019 Chamber of Minerals and Energy Western Australia's Outstanding Woman in Resources Award.

She is also a Non-executive Director of CO2CRC and a member of University of Western Australia's Strategic Resources Committee.

Special responsibilities: Member of Finance, Risk and Audit Committee

Dr Andrew Heap
BSc (Hons), PhD

Dr Andrew Heap is the Chief of the Minerals, Energy and Groundwater Division at Geoscience Australia.

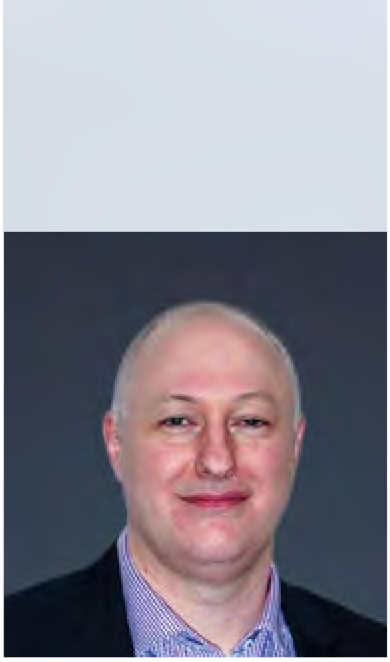
Andrew graduated 1st class Hons in Earth Sciences from the University of Auckland (New Zealand) in 1996 after which he completed his PhD at James Cook University in 2000.

Andrew has 20 years of professional experience in leading pre-competitive geoscience research within the Australian Government. This includes more than 17 years as a senior leader in Geoscience Australia, with responsibility for energy and mineral resources, carbon capture and storage, marine geoscience and groundwater programs. Andrew has published over 100 scientific and technical papers and is a member of 12 professional organisations.

Andrew has responsibility for building a national prospectus of energy and mineral groundwater resources across Australia through regional geological framework studies, and delivery of pre-competitive scientific data and information. A key outcome is to stimulate new exploration investment in frontier areas through an improved understanding of under-explored regions and sustainable water management.

As a member of the Australian Government's Ocean Policy Science Advisory Group Andrew had a lead role in drafting A Marine Nation 2009 and Marine Nation 2025 as blueprints for coordinating investment in marine science in Australia. Andrew represents Australia in the International Ocean Discovery Program (IODP) as Council Member of the Australia–New Zealand IODP consortium, is a member of the CO2CRC board and Program Advisory Committee, and is the Federal Government's representative on the COAG Energy Council Geoscience Working Group.

Special responsibilities: Member of Finance, Risk and Audit Committee



Brian Kitney
MA, MBA, GAICD

Brian has over 25 years' experience in the oil and gas industry in Australia and Asia. He is currently the Commercial Lead on AGL's proposed LNG import project to be located at Crib Point near Melbourne, Australia. Prior to this he held senior industry positions including Vice President Commercial at Osaka Gas Australia, spending nine years managing their upstream investments in Australia and Papua New Guinea. Brian has also held the position of Vice President Commodities at JPMorgan Securities Japan, based in Tokyo. He has also worked in senior marketing and development positions at Apache Energy Ltd and Mitsui & Co (Australia) Ltd.

Brian has an MBA from Curtin University, a Master of Applied Japanese Linguistics and a Graduate Diploma in Diplomacy and Trade from Monash University, a Graduate Diploma from Swinburne University and a Graduate Diploma of Applied Finance from Kaplan. Brian is also a Graduate of the Australian Institute of Company Directors and was previously Director and MD of a number of Osaka Gas subsidiaries.

Special responsibilities: Member of Finance, Risk and Audit Committee

Bill McKenzie
BE (Chem) Hons, FIChemE, CEng, RPEQ, MAICD

Bill is a chartered chemical engineer with significant experience across oil refining, coal bed methane developments and conventional oil and gas developments.

After 16 years with BP in refining, he joined Origin Energy in 2008 where he led their Oil & Gas Division's safety, engineering and operations functions before becoming General Manager Technical in 2010.

In 2011 he became accountable for APLNG's Upstream CSG operations as General Manager Qld CSG. In 2013 he joined QGC becoming Vice President Developments in 2015.

With the Shell acquisition of BG Group in 2016, Mr McKenzie joined Shell as General Manager QGC Development and was accountable for Shell's exploration, appraisal and development activities in eastern Australia. In 2019 he assumed his current role of GM Arrow accountable for Shell's shareholding in the Arrow Energy Joint Venture. Mr McKenzie has previously served as a member of the editorial panel of the Institute of Chemical Engineer's Loss Prevention Bulletin and has been appointed as a Fellow of the Institute of Chemical Engineers.

Special responsibilities: Deputy Chair of Operations, Safety and Environment Committee

Tim Walton
BA, MBA, GAICD

Tim joined the CO2CRC board in November 2014 as a research sector representative. He is the Director, Energy Research Initiatives, at Curtin University's Research Office in Perth, WA.

With a professional background in corporate communications, government policy and strategy, Tim has worked in science administration and resources development within the Western Australian Government's minerals and petroleum, and science and innovation portfolios.

Previously he has worked in a diverse range of areas including conservation education, natural resources management, policy and regulation, heavy industry and port logistics. He was the interim CEO and Bid Director for the Future Battery Industries CRC, which was awarded in round 20.

Tim is a board member of the Western Australian Marine Science Institute which oversees an alliance in coastal marine research; the Western Australian Defence Industry Council and the Fuels and Energy Technology Centre. He has been a board member of the Western Australian Energy Research Alliance, Centre of Renewable Energy in Sustainable Transport (CREST), the Parker Centre CRC for Hydrometallurgy and the Australian Centre for Natural Gas Management.

Special responsibilities: Chair of Operations, Safety and Environment Committee, Member of Appointments and Remuneration Committee

Dr Graham Winkelman
BE (Met), MEngSc, MAppFin, PhD

Graham is Practice Lead Climate Change at BHP based in Melbourne, Australia, where his global role covers BHP's response to climate change policy, including broad engagement across company executive leadership, federal and provincial governments, industry associations (including MCA, APPEA, BCA and CMI in Australia), peer companies, research institutes, think tanks and multilateral associations (e.g. IEA, UNFCCC). Graham's role also includes leadership of BHP's carbon capture and storage initiatives, with on-the-ground investment, research activity and policy engagement in various locations including Australia, the US, China, Canada, Japan and the UK.

Graham is Chair of the board of the International Carbon Capture and Storage Knowledge Centre (Regina, Canada) and a board member of the Australian Industry Greenhouse Network and the Energy Policy Institute of Australia. Graham has a PhD in Materials Engineering from Monash University, and has been contributing to the resource sector's response to climate change for 13 years in both direct and consulting roles.

CO2CRC DISTINGUISHED SCIENTISTS

Professor Peter Cook

Peter is one of Australia's foremost scientists and technology leaders in the areas of energy, greenhouse technology and sustainability. He is a Professorial Fellow at the University of Melbourne, a company director, author, consultant and senior advisor to organisations and governments worldwide. His work on CCS with the Intergovernmental Panel on Climate Change (IPCC), alongside Kelly Thambimuthu, made both contributors to the award of the 2007 Nobel Peace Prize to the IPCC, and prior to that in 2005, the adoption of CCS as a climate change mitigation technology under the United Nations Framework Convention on Climate Change (UNFCCC). Peter was CO2CRC's chief executive from its inception until 2011.

Professor John Kaldi

John is CO2CRC's former chief scientist as well as professor and SA State Chair of Carbon Capture and Storage at University of Adelaide. John's career includes being the inaugural head of the Australian School of Petroleum (ASP) and earlier, Director of the National Centre for Petroleum Geology and Geophysics (NCPGG) at University of Adelaide. Prior to academia, John spent 18 years working in the petroleum industry. He has received numerous awards, is an accomplished lecturer and trainer and has been the author and presenter of over 150 journal articles and technical conference papers.

Professor Kelly Thambimuthu

Kelly has over thirty years' experience in low-emissions technology. For over two decades he has chaired the IEAGHG, a technology collaboration program of the International Energy Agency to reduce greenhouse gas emissions. He pioneered advances in cleaner fossil fuel technologies while heading the Centre for Low Emissions Technology in Queensland from 2004 – 2009. Kelly has been a scientist and program director at CANMET Energy, Natural Resources Canada and professorial fellow at the University of Queensland and has received many awards for his work.

PUBLICATIONS

Selected CO2CRC publications from 1 July 2019 – 1 June 2020.

This list is a highlighted selection of the publications produced during this period. CO2CRC's research symposium generated over 50 presentations. Members of CO2CRC can find these presentations on the Publication Tracking System.

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PARTNERS

CO2CRC acknowledges and appreciates the strong relationships it has with industry, community, government, research organisations, and agencies in Australia and around the world

INDUSTRY

INDUSTRY

ANLEC R&D

(on behalf of LET Australia)

BHP

Chevron Australia

ExxonMobil

Global CCS Institute

J-POWER

Santos

Shell Australia

Total

Woodside Energy

ASSOCIATE

National Energy Resources Australia (NERA)

GOVERNMENT

Australian Government: Department of Education, Skills and Employment

Australian Government: Department of Industry, Science, Energy and Resources

CarbonNet Project

Coal Innovation NSW

NSW: Department of Planning and Environment

Victoria: Department of Jobs, Precincts and Regions

RESEARCH

Australian National University

CSIRO

Curtin University

Federation University Australia

Geoscience Australia

Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences

King Abdullah University of Science and Technology (KAUST)

Lawrence Berkeley National Laboratory (LBNL)

Stanford University

University of Adelaide

University of Cambridge

University of Edinburgh

University of Melbourne

University of NSW

University of Western Australia

University of Wollongong

UK CCS Research Centre

BUILDING A LOW EMISSIONS FUTURE

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