STORAGE RESEARCH

Program Management:
Dr Matthias Raab
Storage Program Manager

CO2CRC's Storage Research Program focused on understanding fundamental mechanisms of geological carbon storage resources in saline aquifers in Australia and worldwide; and to reduce risk and improve processes in the characterisation, injection and assurance of CO_2 storage sites. The Program comprised 10 major research projects and associated sub-projects that involve a range of applied research projects to develop suitable technologies and strategies for managing CO_2 injection and storage. Projects are based in the field – at the CO2CRC Otway Project site – in laboratories and via desktop studies.

Commercial geological storage projects in Australia will require geological formations, in most cases saline formations, to store millions of tonnes of CO_2 a year. Safe and permanent geological carbon storage in saline formations relies on dissolution, and residual saturation, with some mineral trapping of CO_2, all within the bounds of a permitted storage complex. Stage 2C of the CO2CRC Otway Project focuses on the interplay between various trapping mechanisms during CO_2 migration, changes to the subsurface and stabilisation of the CO_2 plume through a series of injection and monitoring experiments. While surface and well-based seismic have been demonstrated to be key storage surveillance technologies, the full capabilities and limitations of seismic will be further developed through detailed migration monitoring in 4D during the Otway Stage 2C experiment, allowing CO2CRC to grow its understanding of 'fit-for-purpose' monitoring.

Significant resources from across the reservoir engineering and geophysics research divisions of the storage program were committed, and technical inputs provided from Upstream Production Solutions (UPS) and Lawrence Berkeley National Laboratory (LBNL), to finalise the injection and monitoring plans, as well as prepare the Basis of Design and Project Execution Plan for Final Investment Decision. Long lead procurement was required to secure the petroleum rig for the CRC-2 well re-completion and purchase of geophone equipment for the buried seismic receiver array.

As noted in the CEO's report, Otway Stage 2C commenced its Execution Phase in November 2014. This activity will include the CRC-2 well re-completion for accessing the Stage 2C new injection interval; and installation of the square kilometre buried seismic geophone and fibre-optic receiver array for high resolution imaging of the future 15,000 tonne CO_2 plume's migration and stabilisation. Geophysical equipment including the seismic source units and vertical seismic profiling tool will be provided by the National Geosequestration Laboratory, funded under the Australian Government's Education Investment Fund (EIF) program.

CO2CRC executed the Stage 2B Extension Project from 1 October to 24 December 2014. The project consisted of two key parts. For part 1, CO2CRC was contracted by Callide Oxyfuel Services Pty Ltd to perform a geochemistry test and inject captured Callide CO_2 and trace-level impurities at the CO2CRC Otway Project site. The resulting analysis of sampled fluids are currently being analysed to assess the impact to the formation's chemistry. The second part of the experiment, also referred to as the Reservoir Characterisation Test, entailed the injection of CO_2 and was partly a repetition of the Otway Stage 2B test conducted in 2011. Data resulting from this work are currently being analysed with outcomes expected by June 2015. This part of the test will provide a measure of the repeatability and accuracy of the characterisation measurements. It will also confirm that CO_2 was successfully injected into, and remains in the formation, at what residual saturation level and at what distance into the reservoir.

In total, the Stage 2B Extension experiment entails the cumulative injection of around 130 tonnes of

CO_2 gas in various stages, with and without trace level impurities/noble gases, into the existing perforated interval in the Paaratte Formation via the wellbore CRC-2. This project has clearly shown that high impact research can be gained from low volume injections at the Otway Project site.

CO2CRC led the NSW Darling Basin CO_2 Storage Study to support the efforts of the Division of Resources & Energy, within the NSW Department of Trade and Investment, Regional Infrastructure and Services. This work helped identify and characterise a viable subsurface site within the Darling Basin to form the CO_2 storage component of the integrated Delta Demonstration Project. The study was tightly linked with the NSW drilling program and involved the geological characterisation of the target area, dynamic injection and plume migration modeling, geomechanical evaluation, and geochemical analysis and modeling. The work concluded in October 2014.

CO2CRC analysis of available data indicates that the Pondie Range Trough of the Darling Basin is potentially viable for geological CO_2 storage within the range 48–1,730 Mt. This storage potential warrants further investigation which the NSW Department of Trade and Investment, Regional Infrastructure and Services is undertaking in 2015.

As outlined later in this report under Facilitating CCS, CCSNET assets will support research and technology development related to the CCS Flagship projects in Australia.

The Otway Subsurface Laboratory will support Stage 3 of the CO2CRC Otway Project; $23.5 million has been allocated to test a risk-based 'downhole monitoring' program at the CO2CRC Otway Project site. The concept is to develop and test cheaper alternative CO_2 monitoring methods. By monitoring between vertical boreholes across key parts of the geological storage system, downhole seismic and pressure methods for near continuous surveillance of the storage formation can be tested, providing a potentially cheaper alternative to repeat surface or marine seismic, as well as reducing the surface monitoring footprint. The pre-feasibility study for this experiment commenced in July 2014 and will be available in mid- 2015. Additional co-investment for operating the Stage 3 project is required.

A special publication of the international journal *Chemical Geology*, titled 'Measuring and predicting the geochemical impacts of CO_2 storage on reservoir rocks' neared completion in 2014. The publication will be a collection of nine articles from CO2CRC's geochemistry team. To be released in late March 2015, this special publication showcases the high quality R&D that has emerged from just one of our 10 projects.

"Commercial geological storage projects in Australia will require geological formations, in most cases saline formations, to store millions of tonnes of CO_2 a year."

CAPTURE & ECONOMICS RESEARCH

Program Management:
Professor Dianne Wiley
Capture Program Manager

The focus of the CO_2 Capture Research Program is on the research, development and deployment of technologies to cut capture costs by up to 80 per cent, and provide Australia with a research and education capability to support industries using these technologies. A framework of economic evaluation is used to measure and validate research directions, and integrates with energy-production systems, transport networks and storage infrastructure.

Our capture research program undertakes research activity at three levels: basic laboratory research, pilot-scale demonstration projects and future large-scale designs.

The objective of all projects in the capture research program is to lower the cost of CO_2 capture by reducing the energy penalty associated with capture, as well as improving the different capture technologies.

For the period July to December 2014, the solvents and engineering research teams have focused on finalising evaluation of the CO2CRC UNO MK 3 precipitating potassium carbonate solvent system. This has involved analysis and simulation of the solvent system based on data obtained from the University of Melbourne's laboratory mini-plant, part-funded by ANLEC R&D, as well as data obtained from the pilot-scale facility co-funded by Brown Coal Innovation Australia (BCIA) in the Latrobe Valley. Such research is essential for the development and validation of models that can then be used in the design of larger plants. For example, CO2CRC has estimated that integration of the capture process with a power station should result in a reduction of at least 25 per cent in the energy use for this system compared to commercial monoethanolamine (MEA) systems.

The membrane research teams are developing new materials and systems for CO_2 separation. Our technique for production of ultra-thin membranes using continuous assembly of polymers (CAP) synthesis has now been patented. Results at small scale in the laboratory suggest that these membranes should have the necessary combination of selectivity and permeability to be economic for large-scale implementation, but their ability to achieve these performances in the presence of real world impurities is yet to be tested. Membrane samples will soon be sent to the United States for testing under pre-combustion conditions.

Field trials of our latest high flux hollow fibre membranes have been completed. Despite many practical challenges, results continue to indicate that further material development and good system design is likely to result in a membrane process that would be competitive for post-combustion capture applications.

Further laboratory trials of our integrated silica metal oxide membrane for separation of CO_2 from hydrogen continue to achieve improved stability and separation capability.

The adsorbents materials and process teams have continued to refine their rapid screening tool for post-combustion capture of CO_2 for Pressure Vacuum Swing Adsorption (PVSA) and thermal swing adsorption (TSA). Further development of chabazite materials for CO_2 separation from natural gas continues to deliver promising outcomes especially from a revisiting of the behaviour of zeolite 3A. Polyethylenimine (PEI) materials have been successfully pelletised and small-scale testing of the material is underway.

The economics team has completed an expanded assessment of the effect of a range of phasing pathways between 2020 and 2050 on changes in electricity costs and reductions in emissions in the National Electricity Market (NEM). Options considered include retrofitting CCS to existing fossil fuel

plants with and without power plant upgrading, building new coal and natural gas fired power plants with and without CCS and switching to various types of renewable energy sources with back-up open cycle gas plants. Our biomass research has also considered the impact of biomass on cost of electricity and emissions reduction by investigating biomass-fired auxiliary energy sources for providing electricity and steam for CCS at coal fired power plants and biomass-NG co-firing on NGCC plants. Our solvent improvement research has revolved around a comprehensive assessment of phase-change solvents. In our project ranking research, we have been gaining an understanding of how multi-criteria methods can be used to evaluate the tradeoffs in both phasing pathways and network development. We have also continued research into the optimisation of pipeline routing and economic trade-offs in storage site selection, including the development of a simplified decision tree to aid in storage site expansion over time.

The PhD related to the assessment of a hybrid adsorbent/cryogenic system will be completed in 2015.

Professor Joe Da Costa was awarded a highly prestigious Australian Research Council Future Fellowship.

Dr Greg Knowles received a prestigious Victoria Fellowship to undertake a visit to the University of Edinburgh to collaborate on adsorbent analysis.

Professor Geoff Stevens was awarded the Patricia Grimshaw Award for Mentor Excellence by Melbourne University.

Several of our PhD candidates were also recognised with awards. Jin (Eric) Shang was the most prolific award recipient collecting the Chancellor's Prize for his PhD thesis for Science and Engineering, the John Melvin Memorial Prize for Best PhD Thesis in the School of Engineering 2013 and the 2013 Chinese Government Award for Outstanding Self-Financed Students Abroad, as well as being a finalist in the UNSW Energy Future Collaborative Innovation Awards 2014. Other successful student award winners included Frank Wu, who was highly commended in Group A (Carbon Reduction) at the 2014 Australian Institute of Energy National Postgraduate Student Energy Awards; Joel Scofield and Willie Tang, who each received a Clive Pratt Travel Scholarship for students in Chemical Engineering and/or Biomolecular Engineering at the University of Melbourne; David Danaci who was awarded the Best Tutor in Chemical and Biomolecular Engineering Semester 1 2014; and Joel Yong who received an honourable mention for Best Tutor in Chemical and Biomolecular Engineering Semester 2 2014.

"The objective of all projects in the capture research program is to lower the cost of CO_2 capture by reducing the energy penalty associated with capture, as well as improving the different capture technologies."

FACILITATING CCS

Program Management:
Richard Aldous
Program Manager

CCSNET
David Hilditch
Program Manager

In 2013, CO2CRC was awarded $51.6 million for CCS research infrastructure under the Australian Government's Education Investment Fund (EIF). The project known as CCSNET has the objectives to build and establish research infrastructure to support carbon capture and storage demonstration, specifically the CarbonNet CCS Flagship Project as a priority; also the South West Hub Flagship Project (through the National Geosequestration Laboratory) and other Australian CCS projects such as the Surat Basin CCS Project in Queensland.

CO2CRC is working in collaboration with the University of Melbourne, Australian National University, Federation University Australia, and the University of Adelaide to build laboratory based infrastructure at these institutions; and with CSIRO to build marine monitoring infrastructure in offshore Gippsland. In addition CO2CRC will build the Otway Subsurface Laboratory at the CO2CRC Otway Project site in south-western Victoria

More specifically, CCSNET consist of 21 assets across 3 areas:

- **Australian CCS Research Laboratories Network (CCS LabNet)** – this national collaborative network of laboratories and capture research facilities will undertake research relevant to all aspects of CCS, especially CO_2 containment, injectivity, capacity and monitoring. LabNet will also facilitate pilot scale testing in the Latrobe Valley to enable the development of new generation capture technologies required to reduce the cost of CO_2 capture.
- **Gippsland Monitoring Network (GipNet)** – this will underpin research required to prepare for and design local and regional environmental monitoring regimes for CarbonNet in both onshore and offshore environments. It will establish the techniques, equipment and criteria for critical baselines, and will progressively increase in line with CarbonNet's activity.
- **The Otway Subsurface Laboratory (OSL)** – the world leading field research facilities at the CO2CRC Otway Project site in south western Victoria will be expanded to provide vital research for CarbonNet, including developing and testing emerging new low cost and high precision monitoring and verification technologies.

The Project became active in August 2013 following the formal execution between CO2CRC Limited and the Commonwealth of Australia of the EIF Funding Agreement. From that point to the end of the reporting period of this report, 31 December 2014, the project has been in progress for sixteen months.

Regular monthly meetings of the Joint Project Committee (JPC) between CO2CRC and CarbonNet have occurred to review CCSNET asset proposals. There have also been meetings of the CCSNET Scientific Advisory Committee (Storage), the CCSNET Scientific Advisory Committee (Capture) and the CCSNET Steering Committee.

As at 31 December 2014, the JPC had reviewed 10 of the 21 infrastructure proposals and had made recommendations to progress seven of them further through the Scientific Advisory and CCSNET Steering Committees and two further proposals are still under review. Seven infrastructure proposals progressed have achieved final approval and advanced to procurement planning and contracting. Four of these assets are located at Melbourne University, two at Australian National University and one at Federation University Australia. The seven assets which received final approval are:

- Melbourne University
  - Bioreactor Laboratory
  - Fluid Flow and Geochemistry

Laboratory Refurbishment and Plant and Equipment
  - Analytic Capture Equipment
  - Building Refurbishment
- Australian National University
  - Quantitative Mineralogy
  - Building Refurbishment
- Federation University Australia
  - Building Refurbishment plus Analytical Equipment

The building refurbishment work at Australian National University and Melbourne University's Bioreactor Laboratory and Fluid Flow and Geochemistry Laboratory Refurbishment and Plant and Equipment has reached practical completion and the new laboratories are in the process of being equipped.

Overall, progress on the CCSNET research infrastructure project has been steady with slight delays in lodgement of the final batch of CCS LabNet proposals. Action is being taken to accelerate the lodgement of the outstanding proposals together with lodgement of proposals for GipNet and the OSL in the first quarter 2015. As at 31 December 2014 the University of Melbourne Bioreactor Laboratory and Fluid Flow and Geochemistry Laboratory in the School of Earth Sciences refurbishments had reached practical completion, as had the Australian National University Building Refurbishment – CT Lab in the John Curtin Medical Research Institute.

The extensive planning and implementation of the CCSNET program will continue as a driver for the innovative and important work being undertaken on carbon, capture and storage technologies.

RISKS & IMPEDIMENTS

CO2CRC works within a framework that considers risks to business and associated mitigation strategies. In the six months to December 2014, three major company risks were identified and addressed including: long term funding for the organisation, confidentiality of data and community engagement.

Funding: CO2CRC has worked with existing partner organisations, to secure funding for 2015 and beyond. Most of this funding has been provided to support activities at the Otway Project site and will require additional funding to complete the proposed work program. Support from participants in the work of CO2CRC indicates the importance the industry places on CCS technologies as a potential option for emission reduction. The financial support pledged to date by participant organisations also means that the scientific and engineering base CO2CRC has built up over the past 11 years will continue, despite the lack of direct economic incentives to support CCS activities.

Confidentiality: confidentiality of data and reporting remains a risk for CO2CRC. Researchers are required to observe strict protocols, which CO2CRC reviews and updates as necessary to ensure maximum compliance.

Community engagement: it is important that CO2CRC understands and responds appropriately to any local community concerns regarding the Otway Project site. Social research in this area has helped CO2CRC fine tune its community engagement activities and communications, ensuring that it provides relevant, inclusive and timely information to the community on aspects of the project which may have an impact on the surrounding area. Communicating effectively with the community has helped CO2CRC gain ongoing support for the research it conducts at the Otway Project site. More broadly, activities at the project site provide a basis for assuring the community that the stored CO_2 is monitored effectively within State regulatory requirements. CO2CRC is vigilant in working alongside Nirranda and surrounding communities to maintain our social licence to operate which is so important for large-scale headline projects such as the Otway Project.

"The support from participants in the work of CO2CRC indicates the importance the industry places on CCS technologies as a viable path for carbon dioxide reduction."