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Accelerating Australian Demonstration Projects Through Focused Research & Development

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Abstract

Australian coal exports make up a third of the internationally traded coal with approximately 180 million tonnes/year supplying the power generation sector in developing countries. Forecasts suggest this demand will remain and grow even as we transfer power generation to a broad portfolio of generation technology. ANLEC R&D has developed a portfolio of research shaped by the priorities for reducing investment risk for commercial scale demonstration projects. Research investment by ANLEC R&D aims to deliver the body of scientific evidence that:

- Enables and accelerates the deployment of CO₂ Storage in Australian basins and
- Underpins the environmental performance and permitting of CO₂ Capture processes in Australian conditions.

Since its inception in 2010 ANLEC R&D has deployed a CCS research effort in excess of \$100 million dollars. This partnership jointly funded by the Australian Coal Industry and Australian Government will continue. Currently it has completed 55 research projects and 29 current projects with 70 technology reports over both capture and storage research objectives. Early projects focused on cost reduction and adaptation of CO₂ capture processes in Australian conditions with particular focus on the successful Callide Oxy-fuel Demonstration and the environmental implications of post combustion solvent capture. The Australian research priority has now shifted to sub-surface CO₂ storage in three Australian basins: Gippsland Basin, Victoria, Perth Basin, Western Australia and the Surat Basin in Queensland. This work has included several innovations such as nested 3D seismic survey designs, permanent passive seismic array design, hyperspectral scanning of reservoir outcrops and a \$A10M program high resolution CT core scanning with a rigorous process to up-scale from core to logs for the sub-surface characterisation of the demonstration sites. These projects have been undertaken using the formidable Australian research capabilities at the CO₂CRC, CSIRO, Universities of Melbourne, Newcastle, NSW, ANU, Sydney, Queensland, Curtin and Western Australia. ANLEC R&D continues to build its research portfolio and over the next 3 years will leverage the effort with work aimed to capture international best practice for the benefit of the developing projects in Australia. This paper will summarise the strategic research investment approach and highlight selected key research outcomes in both capture and storage illustrating the range and depth of our research impact in CCS.

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Keywords:

1.1. Introduction

The Australian National Low Emissions Coal Research & Development (ANLEC R&D) conducts research that underpins the development of low emissions coal technologies (LECT) in Australia. In particular, ANLEC R&D aims to provide independent and objective analysis, data and expertise to effectively facilitate the design, permitting and operation of LECT plants using Australian coal under Australian conditions. The project is co-funded by both the Australian Government and the Australian coal industry, which are each contributing \$75 million towards the project over a ten year period. The primary objective of ANLECR&D is to deliver the applied R&D that can reduce the risk of Low Emission Coal Technology (LECT) deployment in the 2010 to 2020 timeframe, thereby underpinning and accelerating the early commercial deployment of LECTs. This focus is driven by the recognition that these early projects must succeed for LECT to be accepted as a viable option in the portfolio of approaches required to achieve substantial global reductions in CO₂ emissions while meeting growing energy demand.

1.2. Australian Context

The world's leading science academies have affirmed "that climate change is happening and that anthropogenic warming is influencing many physical and biological systems." Among other actions, the recent Paris Agreement also urges all nations to take "appropriate economic and policy measures to accelerate transition to a low carbon society." They further identify that stabilizing the climate will require "emissions limited to the net absorption capacity of the earth". This move to "zero net emissions" will require radical transformation of the global energy systems, ultimately replacing the conventional fossil based infrastructure. The scale of this effort is unprecedented, effectively requiring a new industrial revolution and will almost certainly require access to all available "near zero emission" electricity options, including LECTs. The time frame targets are immensely challenging with broad international agreement that LECT should be available for commercial implementation by 2030. Australia has large resources of low cost coal which currently provide over 80% of Australia's electricity and delivers, to Australians, amongst the lowest electricity prices in the developed world. This low cost power in turn helps support both Australia's life style and export focused heavy industries and production. Coal exports are in themselves among Australia's largest exports by value. While a variety of processes are potentially available to reduce CO₂ emissions from coal fired power stations, experience is developing worldwide with commercial scale deployment of these technologies. It is therefore in Australia's national interest to ensure rigorous investigation of LECT as an option for achieving near zero carbon energy supply. It is important to note that Gorgon - one of the largest CO₂ storage projects for gas production - will commence in the north-west shelf of Australia next year.

1.3. Project governance

ANLEC R&D is a unique initiative in which research support services are provided to proponents of commercial-scale technology demonstration for low emissions coal fired power generation. This approach allows research, development and innovation to be targeted to objectives that specifically reduce project investment risk and cost.

Projects are undertaken as discrete activities or as an integrated set of activities that deliver specific outcomes. As projects are developed in close association with the early demonstration projects, they are needs-based, such that they serve both a scientific knowledge objective as well as deliver information for improved project decisions. In this respect, the ANLECR&D project development system requires the ability to respond flexibly. It prescribes that ANLECR&D management will effectively need high levels of delegated authority at the operational level. A consultation cycle with the demonstration projects has been established with the concept of a Demonstration Embedded Technology Manager (ETM). This role has been made available to identify, assess and prioritise current and emerging technical, environmental and regulatory challenges that may be addressed by prescient research. It also serves as a gate-keeper for the interests of the commercial scale project. Due to the commercial relationships of the demonstration project with its candidate technology vendors in particular, there is a high level of trust. Protocols have been developed so ANLECR&D can access the information it needs to specify useful and relevant research. The

following figure (Figure 1) illustrates project development processes. The embedded technology manager who is fully engaged within the proponent demonstration development process, together with the science leaders, identifies potential concepts that would address the risk and uncertainties of the proponent's project. Research Gap statements are drawn up, which ANLEC R&D reviews and distributes to all research providers. Expression of Interest (EOI) research proposals addressing these concept statements are then competitively evaluated by ANLEC R&D together with senior science advisers. A research program with milestones and deliverables is agreed with the chosen research party and delivered through ANLEC R&D management processes to the benefit of the proponent. This provides transparent and fully developed research outcomes to the demonstration proponent.

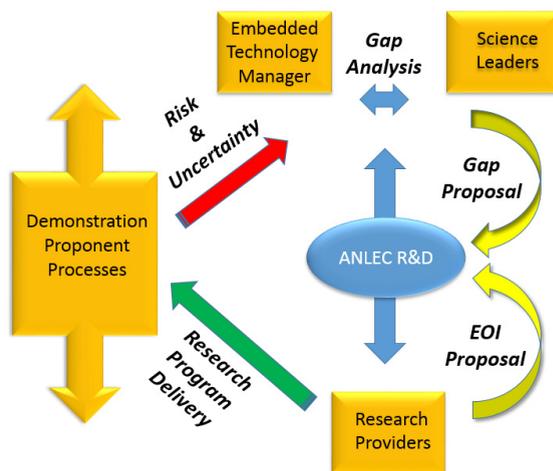


Figure 1. Research program process integrity flow chart.

ANLECR&D develops activities where technical capability and capacity are most relevant and suited to execute the projects. It engages Australian and where necessary international researchers in relevant joint research collaboration. Each Project is managed by a Project Leader (PL) who retains responsibility for delivery of the project. Projects are managed and assessed in three dimensions subject to strategy and performance reviews. Performance indicators include:

- Scientific and technical integrity assessed by the designated ANLECR&D Science Leaders.
- Relevance and utility of the output assessed by the relevant Embedded Technology Managers and Industry.
- Overall Performance and Communication assessed by the ANLEC R&D Executive Management.

1.4. ANLEC R&D capture research in Australia

The cost of CO₂ capture from coal fired power generation sources remains one of the biggest hurdles to commercial deployment of CCS. While comparative techno-economics show it remains competitive with other clean energy options, without substantive deployment experience, domestically, it will be difficult to exploit a learning rate to deliver commercially relevant cost reduction. The Callide Oxy-fuel Project (COP) is the only CO₂ capture technology demonstrated at scale in Australia. ANLEC R&D has engaged in a vibrant research program to support the Callide project since its inception [1]. With the completion of the Callide Oxy-fuel Project demonstration phase, prospects for applied research on demonstration of capture technologies in Australia are limited. In the absence of a new capture demonstration initiative in Australia, ANLEC R&D will continue to seek opportunity to work with international demonstration proponents to understand and inform items such as environmental permitting – especially in conditions

relevant to Australia. There is also growing awareness that the international demand for coal fired power generation in the developing world continues to increase over the medium term. This suggests that substantive emissions reductions may be realised from widespread deployment of high efficiency low emissions (HELE) technologies and its development. When considered with recognition that the grids of the developing world are also in their development phases, these economies will have opportunity to exploit the emergence of disruptive low emissions energy technologies. Therefore, ANLEC R&D will continue to support HELE coal technologies that offer disruptive opportunities for emissions reduction in established and emergent coal markets. It is especially important to consider technology developments that enable coal to integrate into a modern grid that requires fast ramp up and ramp down supporting high levels of renewables.

1.5. Highlights of ANLEC R&D capture related projects during 2010-2015

ANLEC R&D has supported and completed a number of capture related projects [2]. These include pilot studies validating process control and operating parameters for stable performance of concentrated piperazine as a CO₂ capture agent. It has published guidelines for estimating CCS first-of-a-kind (FOAK) to Nth-of-a-kind (NOAK) costs, scoping and estimating early mover CCS projects. It has established that in an oxy-fuel flowsheet flue gas contaminants can be extracted as near food grade compression condensate, ready for CO₂ storage. It has established mechanisms for mercury and NO_x transformation reactions resulting in potential elimination of de-NO_x equipment. Due to low sulphur Australian coals, de SO_x equipment may also be eliminated, in combination these outcomes could result in significant capital cost savings. Within projects for post combustion capture processes, it has developed important tests and protocols for accurate environmental monitoring of solvent use, including the chemical transformations likely to occur beyond the stack. These assessments also concluded that emissions from amine solvents will be lower than those from comparable industrial processes or conventional coal fired power generation. In its support for innovation in emergent and disruptive technologies include adopting/adapting High Efficiency Low Emissions (HELE) technology for coal fired power generation to distributed energy systems locally and in SE Asian markets. Direct Injection Coal Engine (DICE) is a good example of such a technology.

1.6. Storage Research Strategy

The importance of storage geology to early mover demonstrations cannot be overstated. Project timelines, and indeed the viability of the early demonstrations, will be strongly dependent on storage availability, how this storage can be proven, and how well the storage geology can be monitored and controlled. The storage geology is the most critical technical component of any LECT project and the least well understood, consequently requiring a strong applied R&D effort. Key targeted outcomes from the ANLEC R&D subsurface program include: reduced project development risk via increased acceptance of the project; reduced cost and time required to find and define storage capacity; increased understanding of the opportunities available for enhanced injectivity and uncertainty reduction, reducing the number of wells and consequent costs; reduced cost to operate through understanding opportunities to move away from an oil and gas industry cost basis to a cost basis that reflects the lower returns available in the power sector.

1.7. CCS focus in Australia

The research portfolio is defined within the dimensions of a timescale in relative technology readiness against external and project viability risks (Figure 2). These are of increasing importance from site injectivity and capacity to public acceptance and containment.

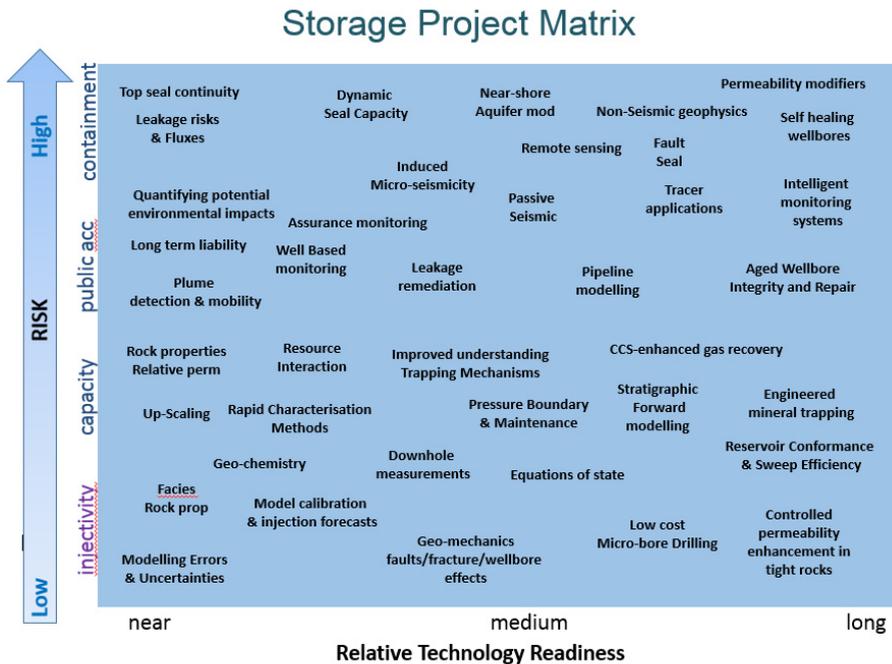


Figure 2: Relative ranking of project risk focus against relative technology readiness

There are three principle geographical areas and basins in Australia where CCS demonstration projects are active; Queensland in the Surat Basin, Victoria in the Gippsland Basin and Western Australia in the Southern Perth Basin. ANLEC R&D has developed a portfolio of research shaped by the priorities for reducing investment risk for these three basins.

1.7.1 Queensland – Surat Basin:

Queensland proponents have drilled their first assessment well in the Surat Basin in August 2015 and completed acquisition of its initial 3D seismic survey. Cores delivered from the well are the subject of advanced analysis that will supplement conventional methods to improve and inform project development decisions. The outer fringes of the Surat Basin are a relatively well explored resource. The proponent has confidence in the geological structures available for CO₂ storage in the reservoir. While capacity and injectivity estimates are being refined, this area provides the opportunity for research to also explore other project investment risks. There is a particular need to understand storage in reservoirs containing relatively fresh formation water, resource management of carbon storage with coal seam gas development (and produced water re-injection) and groundwater resource utilisation from the Great Artesian Basin (GAB). The most recent results [3] from research supporting this basin has informed the demonstration of cheaper, faster and more accurate measurement of reservoir properties from digital rock imaging. Better understanding of water and CO₂ flow in the reservoir rock that will ensure robust permitting and regulation.

1.7.2 Victoria – Gippsland Basin:

In Victoria, a substantial history of geological characterisation has occurred in the Gippsland Basin owing to conventional oil and gas development offshore, Brown Coal development and substantial groundwater resource utilisation onshore. Previous regional characterisation of storage capacity has described the far offshore commercial storage potential in the Gippsland Basin as arguably the best in Australia. A commercial proponent is targeting a near-shore location for an initial demonstration and have selected its preferred site from a number of near-shore carbon

storage options. In the near-shore Gippsland Basin there is a particular need to understand carbon storage in reservoirs in a marine environment. There is also need to exercise resource management between carbon storage, conventional oil and gas production and groundwater resources of the Latrobe aquifer system. The near-shore environment and shallow water depths present specific operational requirements for seismic acquisition and drilling operations. This results in the need for highly reliable baseline characterisation together with innovative accurate MM&V requirements. The most recent results from research supporting this basin has delivered supporting evidence for the resilience of the local containment rock to geochemical reaction with CO₂ and informed more accurate modelling for the Gippsland reservoir to inform both design and scope of marine monitoring research opportunity for the Gippsland Basin.

1.7.3 Western Australia -Southern Perth Basin

Feasibility for this demonstration proponent commenced in December 2011. It is currently characterising the storage potential of the Lesueur sandstone formation in an on-shore location of the south Perth Basin. This is a fluvial sandstone therefore reservoir quality can be expected to vary in the lateral direction. This project recognises an opportunity to be a first demonstration of CO₂ storage in a geological storage reservoir with containment units that are other than the conventional marine shale strata. Early assessments suggest that there are prospects evident for CO₂ storage capacity in the saline reservoir. Investigation is on-going to interrogate the nature of the stratigraphy that will act to contain the CO₂ at the site and thus enhance the residual and dissolution trapping mechanisms. The proponent drilled its first stratigraphic well Harvey-1 well in February 2012. Returning selected cores from a total depth of 2913m, potential reservoir and seal sections were identified. 3D seismic surveys were recorded in February 2014 and two additional cost-effective cored slim-hole wells were completed in June 2015 to confirm lateral continuity of seal and reservoir. Historical data is sparse as the region is not well explored. Research on breakthrough MM&V techniques have the potential to reduce the cost and undesirable intrusive nature of conventional time-lapse seismic. This is important because the site is located on-shore in a region with high intensity surface land use. The most recent results from research supporting this basin [4] have assisted to validate improved methods for assessing characteristics for storage reservoirs for CO₂, improved accuracy for estimating the volume of CO₂ they can hold and testing and proving the best design and technology for monitoring CO₂ over long periods of time

1.8. Storage highlights from the period 2010-2015

In the first five years of ANLEC R&D amongst the many projects directed towards reducing uncertainties around geological storage, results showed the prospects for enhanced injectivity using geochemical testing and provided a study showing the use of authigenic carbonates as a natural analog for mineralization trapping in the Surat Basin , marine monitoring was scoped for the Gippsland Basin and high resolution nested seismic surveys for the southern Perth basin provided higher resolution imaging of the fault structures in the near surface. ANLEC R&D co-funded the field work for the CO₂CRC Otway 2B residual saturation “Huff and Puff” testing and the infrastructure and permanent seismic monitoring for the Otway 2C injection pilot project. A major ANLEC R&D funded project to develop a pore-to-core scale workflow was commissioned and developed [5], [6]. This program’s objective was to combine new Australian developed step-change technologies of 3D Digital Rock Technology (DRT) with conventional oil industry Routine Core Analysis (RCA) and Special Core Analysis (SCAL). The DRT workflow presents a paradigm shift in the geoscience industry’s approach to core analysis. The program has leveraged a comprehensive data set of Surat Basin core material and property data along with an unprecedented understanding of the physics of CO₂-brine systems at the pore scale. Implications to quantitative understanding of properties at larger scales, whole core to log to geo-cellular scales have also been established. This workflow can be used to assess other potential CO₂ storage sites. The research outcomes were built on the expertise in micro-CT technology pioneered at the Australian National University over the last 10 years. The collaborating groups at University of Queensland, UNSW and CSIRO are leaders in the fields of conventional CO₂ flow analysis studies, geochemical reactivity and dissolution trapping of CO₂ and upscaling data from pore to reservoir scales. The workflow includes the building of an integrated geological description and calibrated static and flow property database from pore to whole core scales on a continuous 100 meters of core. Creating a library of discrete facies-based, single geo-cell scale models and their associated static reservoir properties and developing dynamic reservoir solvers that honour the physics of dynamic flow and geological heterogeneity at

scales up to the reservoir grid block scale. This workflow is illustrated in the figure below (Figure 3). A complimentary workflow that clusters the rock and fluid properties, over 18 orders of magnitude, from micro-CT to geocell scale, has been developed in parallel. The workflows are designed to upscale single-value rock properties, as well as saturation-dependent properties that depend on the relative saturations of the fluids in the reservoir including CO₂.

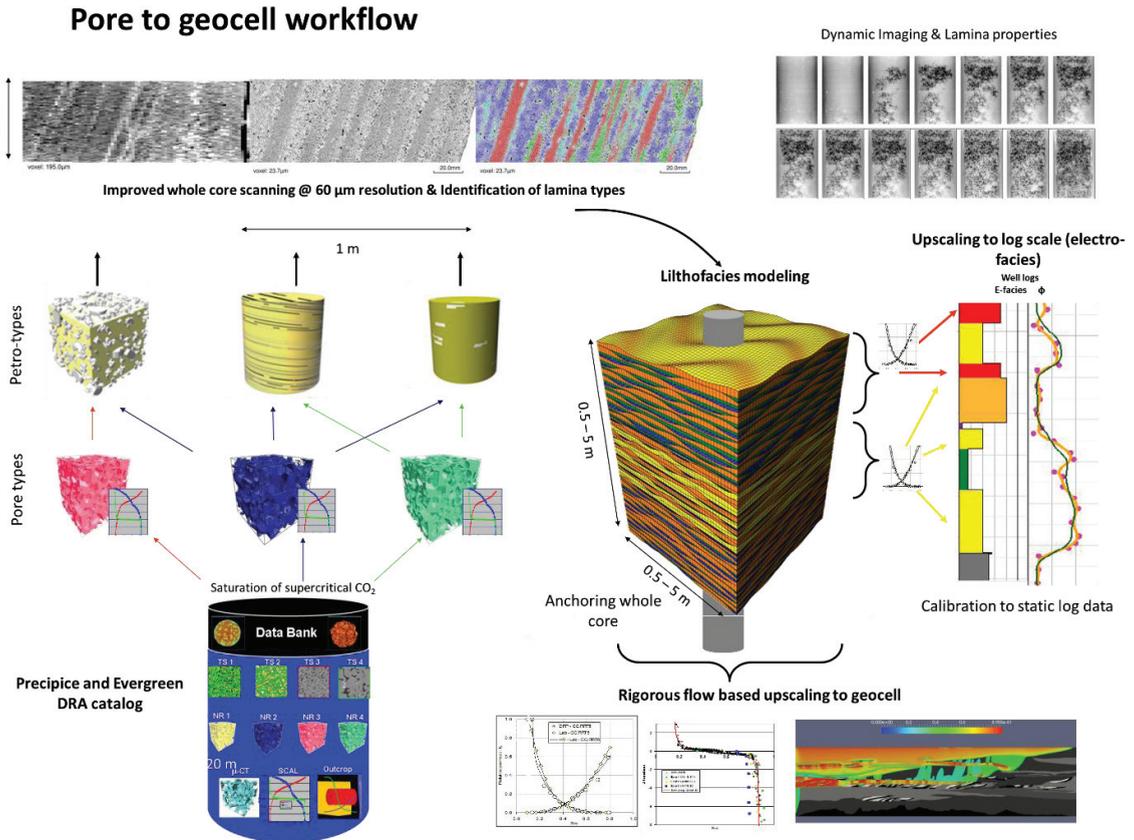


Figure 3: Workflow diagram from micro-CT core to geo-cell scale.

1.9. Conclusions.

Since its inception in 2010 ANLEC R&D has deployed an extensive CCS research effort. This partnership jointly funded by the Australian Coal Industry and Australian Government will continue. Currently it has completed 55 research projects and 29 current projects with 70 technology reports over both capture and storage research objectives. Early projects focused on cost reduction and adaptation of CO₂ capture processes in Australian conditions with particular focus on the successful Callide Oxy-fuel Demonstration and the environmental implications of post combustion solvent capture. The Australian research priority has now shifted to sub-surface CO₂ storage and includes innovations in nested 3D seismic survey designs, permanent passive seismic array design, hyperspectral scanning of reservoir outcrops, and a \$Aus10 m program high resolution CT core scanning with a rigorous process to up-scale from core to logs for the sub-surface characterisation of the demonstration sites. These projects have been undertaken using the formidable Australian research capabilities at the CO₂CRC, CSIRO, Universities of Melbourne, Newcastle, NSW, ANU, Sydney, Queensland, Curtin and Western Australia. ANLEC R&D continues to build its research portfolio and over the next 3 to 5 years will leverage the effort with work aimed to capture international best practice for the benefit of the developing projects in Australia.

Acknowledgements

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References

- [1] Key Callide Oxy-Fuel Projects - www.anlecrd.com.au
1. Gas quality impacts, assessment and control in oxy-fuel technology for CCS: Part 2. Mercury removal with SO₃ in the fabric filter and with NO_x as liquids in CO₂ compression, Prof. Terry Wall et al. 2015 Univ of Newcastle
 2. Impacts of trace components on Oxy-combustion for the Callide Oxyfuel Project, Prof. Peter Nelson et al. 2014 Univ of NSW
 3. Gas quality impacts, assessment and control in oxy-fuel technology for CCS, Prof. Terry Wall et al. 2014
- [2] Representative Capture Projects - www.anlecrd.com.au
1. Guidelines for scoping & estimating early mover CCS projects, Prof. Chris Greig et al. 2014 Univ of Queensland
 2. DICE Techno Economics Study, Lewis Jeffery et al. 2014 Consultant
 3. Australian Power Technology Generation Technology (APGT) Study, CO₂CRC Geoff Bongers Consultant. 2016
 4. Environmental Impacts of Amine based CO₂ Post Combustion Capture (PCC) Process, Dr. Merched Azzi et al. 2013 CSIRO
 5. Novel gas-liquid contactor concepts for PCC capital and operating cost reduction, Dr. Leigh Wardhaugh et al. 2014 CSIRO
 6. Impact of Flue gas impurities in PCC plants, Dr. Merched Azzi et al. 2013 CSIRO
 7. Concentrated piperazine based post-combustion capture process for Australian power plants, Mr Michael Sinclair et al. 2012
 8. Development of the advanced aqueous ammonia based post combustion capture technology, Dr. Hai Yu et al. 2016 CSIRO
 9. Chemical Looping Oxygen Generation for Oxy-fuel Combustion and Gasification, Prof. Behdad Moghtaderi et al. 2014 CSIRO
 10. Designer Amines for Post-Combustion Carbon Dioxide Capture, Dr. Qi Yang et al. 2013 CSIRO
 11. Reduced cost post-combustion CO₂ capture from coal fired power stations with enzymes, Dr. Victoria Harritos et al. 2014 CSIRO
 12. Membranes for tonnage oxygen separation suited to supply oxy-fuel and coal gasification applications, Prof. Joe da Costa et al. 2015
 13. Cost-Effective Membrane Technologies for Carbon Dioxide Capture - Membrane Processes for Amine Contaminant Removal, Prof. Dianne Wiley et al. 2014 Univ. NSW
 14. Model-based optimisation of highly-integrated post-combustion carbon capture processes, Dr. Ali Abbas et al. 2015 Univ of Sydney
 15. Low Cost Hybrid Capture Technology Development, Prof. Dianne Wiley et al. 2013 Univ of NSW
 16. Large Scale Cost Reduction through Adsorption Based Oxygen Generation Technology, Prof. Dianne Wiley et al. 2014 Univ of NSW
 17. Nano-structured Carbon Fibre/ Carbon Nanotube Composite for CO₂ Capture, Dr. Shi Su et al. 2014 CSIRO
 18. Alloy CMR for H₂ production, Dr. Michael Dolan et al. 2015 CSIRO
 19. IGCC solids disposal and utilisation, Dr. David Harris et al. 2012 CSIRO
- [3] Representative Surat Basin Storage Projects - www.anlecrd.com.au
1. Authigenic carbonates in the Great Artesian Basin as a natural analogue of mineralisation trapping in CO₂ geosequestration, Prof. Sue Golding et al. 2016 Univ of Queensland
 2. Geochemical impacts and monitoring of CO₂ storage in low salinity aquifers, Dr. Ralf Haese et al. 2015 Univ of Melbourne
 3. Improved discretization and dynamic modelling of CO₂ solubility during injection and subsequent convective dispersion, Dr. Jonathan Ennis-King et al. 2014 CSIRO
 4. Achieving Risk and Cost Reductions in CO₂ Geosequestration through 4D Characterisation of Host Formations, Prof. Sue Golding et al. 2014 Univ of Queensland
 5. Impacts of Surat Basin geological CO₂ storage on groundwater flow, Dr. Karsten Michael et al. 2013 NGL, CSIRO,
- [4] Representative South Perth Basin Storage Projects - www.anlecrd.com.au
1. Feasibility and design of robust passive seismic monitoring arrays for CO₂ geosequestration, Prof. David Lumley et al. UWA 2016
 2. Estimating Vertical Permeability in the Lesueur Formation, Dr Yingqi Zhang et al. 2015
 3. Nested 3D Seismic Survey to Determine Shallow Features, Dr. Milovan Urosevic et al. 2015 Curtin Univ
 4. Lessons from project level community engagement, Peta Ashworth et al. 2014 Univ of Queensland
 5. Desktop design study on enhancing residual and dissolution trapping, Mr Guy Allinson et al. 2014 Univ of NSW
 6. Comparison of Schlumberger and updated SedSim models, Guy Allinson et al. 2014 Univ of NSW
 7. Harvey 2D test seismic survey – issues and optimisations, Dr. Milovan Urosevic et al. 2014 Curtin Univ

8. Integration of Data from Harvey-1 well to support decisions – Fault Seal, Dr. Laurent Langhi et al. 2013 CSIRO
9. Facies-based rock properties distribution along the Harvey 1 stratigraphic well, Dr. Claudio delle Piane et al. 2013 NGL CSIRO
10. Advanced Geophysical Data Analysis at Harvey-1, Prof. David Lumley et al. 2013 UWA
11. Geochemical characterisation of gases, fluids and rocks in the Harvey-1 data well, Dr. Linda Stalker et al. 2013 NGL CSIRO

[5] Maximising the value of digital core analysis for carbon sequestration site assessment. sub-project 1-6, 2016 M. Knackstedt et al - www.anlecrd.com.au

[6] Multi-scale reservoir characterisation – from pore to core to geocellular Model sub-project 7, 2016 A. Curtis et al - www.anlecrd.com.au