THE UNIVERSITY OF MELBOURNE

Peter Cook Centre for Carbon Capture and Storage Research

ANNUAL REPORT

2018

CONTENTS

ABOUT US

The Peter Cook Centre for Carbon Capture and Storage (CCS) Research is a world class research centre at The University of Melbourne.

The research we perform underpins the development of enhanced technologies for carbon capture and storage in Australia. Working closely with our partners in industry and governments the Centre's outputs delivers the next generation of skills and research and development services in CCS.

The Centre is named after Professor Peter Cook, CBE, FTSE, an internationally distinguished expert in carbon capture and storage research and a pioneer of CCS research and development in Australia. His profile and worldwide reputation for excellence in the field of geological storage makes him a fitting choice as patron for the Centre.

The Centre is in a unique and advantageous position building on outstanding achievements and momentum from the projects that have been running for more than a decade. A very strong team of CO_2 capture experts has been assembled at the University of Melbourne for a long time while the Centre has facilitated the development and expansion of CO_2 storage research as well as interdisciplinary studies relating to CCS at the University over the past six years.

MISSION

To develop environmentally and socially acceptable, cost effective carbon capture and storage solutions for a carbon constrained world.

VISION

The development of scientific and engineering expertise and personnel in Australia to enable the deployment of advanced carbon capture and storage technologies, thereby contributing to the nation's economic, environmental and social well-being.

RESEARCH

Increasing greenhouse gas emissions to the atmosphere is a key environmental issue facing Australia and the world.

Carbon dioxide, primarily from the combustion of fossil fuels for energy, is the most common greenhouse gas emitted by human activities and is causing an adverse impact on climate. Emission reduction will require a full suite of responses: increased use of renewable energy, greater energy efficiency, fuel switching, increased capture and use and geological sequestration of carbon dioxide.

CARBON CAPTURE

The Capture Program's primary aim is to reduce the cost and environmental impact of carbon dioxide (CO_2) separation from a range of sources including; coal and gas fired power stations; from steel, cement and hydrogen production; as well as from natural gas. The research focuses on developing and demonstrating technologies that will significantly reduce the costs of capturing CO_2 thereby mitigating financial risk for industry. We are interested in exploiting the captured CO_2 and have a portfolio of projects examining utilisation strategies.

The program centres on the three technologies of solvent systems, membranes and adsorption all of which have application in specific areas. Research is being undertaken across a spectrum of work, from the fundamental through to demonstration of operating plants.

CARBON STORAGE

The Carbon Storage Program within the Centre is focused on the study and assessment of potential CO_2 storage sites through the provision of research, technical review and advice. The CO_2 storage research team is multidisciplinary with particular strengths in geochemistry, numerical modelling of subsurface fluid transport and the geological characterisation and modelling of sedimentary basins. Our projects are focused on developing a deeper understanding of the process of storing CO_2 in subsurface structures, with the aim of reducing the storage risks and developing monitoring and control technologies.

LEGAL AND SOCIAL POLICY

In today's political climate, carbon policy is uncertain. There is general acceptance that deep cuts in CO_2 emissions will be required of society in general, but inevitably with a major focus on major carbon emitters such those related to fossil fuels, power generation and energy-intensive industries. The Peter Cook Centre is a multidisciplinary research centre which crosses traditional discipline boundaries to provide access to expertise in carbon mitigation technology and address the legal, social and economic issues that will be critical to reducing greenhouse gas emissions in the future.

DIRECTOR'S REPORT

2018 was once again a busy journey for The Peter Cook Centre for CCS Research at The University of Melbourne.

I would like to take the opportunity to express my gratitude to everyone in the Peter Cook Centre for their dedication, perseverance and creativity to drive our research and our engagement on low-emission technologies and particularly CCS. Once again, Assoc. Prof. Malcolm Garrett and Prof. Peter Cook helped the Centre by keeping us connected to our stakeholders and ensuring the Peter Cook Centre is meeting the needs of the changing CCS landscape. We passed a number of milestones throughout the year and finished with a strong presence at the GHGT-14 conference in Melbourne. Let's revisit some of our highlights:

The year started with a two-day review of the Peter Cook Centre by an external panel of highly experienced research leaders. The overall outcome of this health check was very positive and constructive recommendations were given for areas where we can improve.

In March, the Peter Cook Centre hosted a one-week workshop of the GeoCquest consortium on the role of small-scale geological heterogeneity on multiphase flow and carbon trapping in sedimentary rocks. Delegates from BHP, our funding partner, and our research partners from Stanford University (USA), Cambridge University (UK) and the CO2CRC came together to present and discuss research progress thus far and to plan data integration and researcher visits at partner institutions. The GeoCquest team also visited the CO2CRC Otway site near Port Campbell (Victoria) and inspected rock cores at Geoscience Australia (Canberra).

The announcement of the Hydrogen Energy Supply Chain (HESC) project in April was an exciting moment for the community in the Latrobe Valley here in Victoria and for CCS in Australia. Hydrogen will be produced from brown coal in a pilot plant and shipped to Japan to demonstrate the full supply chain. Should the project progress to commercial scale a CO_2 solution will be necessary to achieve a carbon-neutral future fuel. The CarbonNet project, funded by the Australian and Victorian governments, is developing a CCS network to meet the needs of new industries in the Latrobe Valley such as the HESC. Later in the year, Prof. Alan Finkel, Chief Scientist, expressed his enthusiasm for Australia's opportunities for hydrogen production and the development of a National Hydrogen Strategy is currently underway.

It is great to see that our own researchers including Prof. Webley, Prof Kentish, Dr Scholes and Assoc. Prof. Mumford are already involved in hydrogen research through the Future Fuels CRC, a long-term research program signed at the end of last year. I have no doubt this will lead to important and complementary outcomes to the HESC project.

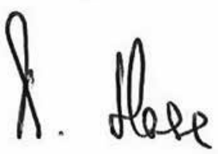
Now in it's third year, an intensive one-week course on geological carbon storage was given by Dr George Carman to professionals and post-graduate students in June. Once again, the course was fully booked. Dr Carman is a highly experienced petroleum geologist who also served as the Subsurface Storage Director for the Victorian CarbonNet project. The course covered a large range of technical and scientific aspects pertinent to geological carbon storage.

The highlight of the year was our participation at the largest CCS conference worldwide, the Greenhouse Gas Technologies conference, GHGT-14, held in Melbourne in October. Over 1000 delegates from industry, governments and academia presented and discussed recent research results and developments of the emerging CCS industry. In preparation for this event, The Peter Cook Centre updated its web site, made a professional film featuring the Centre and ended up with 25 scientific contributions. The response was overwhelming. Our booth at the conference was well attended and various international connections were made. International delegates and research groups asked for tours through our laboratories and meetings to explore opportunities for collaborations. I am confident we will hear more about the flow-on effects of this event very soon.

Our researchers and research leaders are at the heart of our Centre. Their recognition is a reflection of the quality of their work and the Peter Cook Centre has seen several awards and recognitions received by our researchers over the last year: Our student Yue Wu was a member of the winning group at the IEAGHG International CCS Summer School (Norway, June 2018). Dr. Colin Scholes was recognized in the 2018 Class of Influential Researchers by Industrial & Engineering Chemistry Research (I&ECR), an award recognizing influential early-career researchers on the basis of the quality and impact of their research. Dr Kathryn Mumford, Deputy Director of the Peter Cook Centre, and Dr John Moreau were promoted to Associate Professor. Last but not least, Prof. Sandra Kentish was listed as one of Australia's 100 Woman of Influence in the Australian Financial Review. Congratulations to all of them!

CCS continues to be discussed as part of the future energy technology mix and I have no doubt our research with the objectives to reduce the cost and remaining technical and scientific uncertainties of CCS will continue to be relevant and sought after here in Australia and overseas.

Sincerely,



Prof. Ralf Haese

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MEMBERS

PARTNERS

RESEARCH PROJECTS

CAPTURE PROGRAM

SOLVENT SYSTEMS

NOVEL PROMOTERS FOR CARBON DIOXIDE ABSOPTION IN POTASSIUM CARBONATE SOLUTIONS

Guoping Hu, Kathryn Smith, Sandra Kentish, Geoff Stevens

Carbon dioxide emissions to the atmosphere are major drivers for climate change. In this project, different promoters including carbonic anhydrase, amino acids and a carbonic anhydrase inspired polymer were examined in potassium carbonate solvents for enhancing the carbon dioxide absorption kinetics. Results indicate that the addition of effective promoters can significantly increase the carbon dioxide absorption rate by more than ten times and this can reduce the capital costs and operation costs of a carbon capture plant.

ENCAPSULATED SOLVENTS FOR POST-COMBUSTION CARBON CAPTURE

Thomas Moore, Kathryn Mumford, Geoff Stevens, Paul Webley

The separation of carbon dioxide from flue gases is typically the most expensive stage of a carbon capture and storage operation, and while many solvents and adsorbents could be used for this separation, at present no material is without significant disadvantages. This project aims to develop a new hybrid material, microencapsulated solvents (MECS), in which solvents are encapsulated in small (100-500 micron) polymer shells which are highly permeable to CO_2. Microencapsulation may allow corrosive, viscous or volatile solvents to be used in CCS operations. Further, the very high surface area of these particles enhances the kinetics of absorption, allowing the use of solvents with low regeneration energies, whose kinetics would otherwise be prohibitively slow. This project will investigate the industrial application of MECS for post-combustion capture of CO_2. Through a combination of large-scale process modelling, small-scale transport phenomena analysis and experimental measurements we hope to assess their industrial viability, analyse different process designs, and compare them with existing capture technologies.

INVESTIGATION AND MODELLING OF A PRECIPITATION ABSORBER USING CONCENTRATED POTASSIUM CARBONATE SOLVENTS FOR CARBON DIOXIDE CAPTURE

Yue Wu, Kathryn Mumford, Geoff Stevens

In this project, a precipitating CO_2 capture process using concentrated potassium carbonate (K_2CO_3) solvents is systematically investigated under post-combustion process conditions (approximately 1 bar and 20-60 °C) from three aspects:

1. thermodynamic properties of the solvent system;
2. precipitating kinetics;
3. process model (absorber) development.

Due to the strong electrolytes present in the concentrated K_2CO_3 solvent system, an electrolyte non-random two liquid (ENRTL) thermodynamic model is regressed through the Data Regression System (DRS) in Aspen Plus®. The model is successfully validated with experimental data, and used to predict the thermodynamic properties of the solvent system, such as CO_2 partial pressure, precipitate solubility, CO_2 reaction kinetics and CO_2 diffusivity etc.

The precipitation kinetics of the concentrated K_2CO_3 solvent system including primary nucleation, secondary nucleation and crystal growth is comprehensively studied in an unseeded batch cooling crystalliser using a focused beam reflectance measurement (FBRM®) probe and OptimaxTM workstation 1001. The supersaturation of the precipitates, a primary driving force for precipitation kinetics, is evaluated from the regressed ENRTL model.

A process model using the concentrated K_2CO_3 solvent system was developed in Aspen Custom Modeller to enable large scale system design.

ANIONIC AMINO ACIDS AS SUPERIOR ABSORBENTS FOR CO_2 CAPTURE: THE ROLE OF PRECIPITANTS AND NANOPARTICLES

Masood Sheikh Alivand, Colin Scholes, Kathryn Mumford

This project aims to develop highly cost-effective, environment-friendly and superior amino acid solvents for post-combustion CO_2 capture. To reach this objective, two novel approaches are followed; I) quasi-aqueous amino acid solvents (amino acid-nonaqueous solvent-water) with phase-changing behavior and II) amino acid based nanofluids. The liquid-liquid and solid-liquid-liquid phase separation of amino acid solvents after CO_2 absorption can easily accumulate the absorbed CO_2 molecules in liquid/solid phases while the upper liquid phase is CO_2-free and can be returned to the absorption column and reused. Thus, only a portion of the solvent has to be regenerated which can substantially decrease energy consumption during the regeneration step. Moreover, using both metal oxide and carbon-based nanoparticles suspended in amino acid solvents not only can improve absorption capacity and kinetics of absorption, but also can decrease the regeneration energy consumption. The improvements can be attributed to both physical and chemical aspects of nanoparticles. Especially, different oxygen groups located on the surface of Graphene Oxide (GrO), Graphene Quantum Dot (GQD), Carbon Quantum Dot (CQD) and their functionalized derivatives can make them extremely efficient carbocatalysts/promoters for superior absorption-desorption of CO_2 in amino acid/potassium carbonate solutions.

MEMBRANE SYSTEMS

IMPROVING MEMBRANE GAS-SOLVENT CONTACTOR SEPARATION PERFORMANCE UNDER OSCILLATING PHASE CONDITIONS.

Elaheh Hosseini, Geoff Stevens and Colin Scholes

Membrane gas-solvent contactors are a hybrid technology that combine the advantages for membrane gas separation and solvent absorption, for efficient CO_2 capture. This project is focused on improving the efficiency of the technology for CO_2 capture by enhancing mass transfer within the contactor module. This is achieved by adding oscillating flow conditions to the various phases within a membrane contactor involved in carbon capture. The pulsation conditions alter the diffusion and movement of chemical components within the membrane, compared to conventional flow. This enhances the mass transfer and therefore CO_2 capture efficiency

NON-IDEAL MODELLING OF MEMBRANE SEPARATION FOR CARBON CAPTURE APPLICATIONS.

Ehsan Soroodan Miandoab, Sandra Kentish, Colin Scholes

Conventional membrane gas separation models are often considered as "ideal" as they neglect "non-ideal effects" imposed by the nature of membrane materials and process conditions. Moreover, the majority of these models cannot be implemented for the process simulation of industrial applications. In this project, a rigorous model is developed for commercial hollow-fibre membrane modules assuming Joule-Thomson effect, real gas behaviour, pressure loss and concentration polarization as the non-ideal effects. The model is coded in Aspen Custom Modeller to be applied as a process simulator for the diverse range of membrane gas separation. The proposed non-ideal model has been successfully validated by the experimental works and its performance was tested for the isothermal separation of CO_2/ N_2 using various hollow-fibre polymeric membranes. Natural gas separation was simulated at non-isothermal condition using temperature-dependent permeability. The influence of Joule-Thomson effect over the flowrate and purity of penetrants was exclusively compared with the ideal model, as well as, the accumulated model taking all aforementioned non-ideal effects into account. This project is demonstrating significant deviation between the accumulated model and the conventional ideal model.

PILOT PLANT DEMONSTRATIONS OF MEMBRANE CONTACTOR TECHNOLOGY

Colin Scholes

This project is commercialising membrane contactor technology for both CO_2 absorption and solvent regeneration at a pilot plant located on a coal-fired power station in New South Wales. The project aims to evaluate and quantify the performance of membrane contactors undertaking carbon capture from flue gas, as well as determine the economics and lifecycle analysis of the process. Particularly, the pilot plant is to identify the most suited membranes for industrial capture and verify their performance over extended periods. This is achieved through two operational campaigns on-site.

EFFICIENT CO_2 DELIVERY FROM FLUE GAS TO MICROALGAE PONDS THROUGH A NOVEL MEMBRANE SYSTEM

Shirley Xu, Greg Martin, Sandra Kentish

During microalgae cultivation, carbon dioxide is supplied as the carbon source for photosynthesising microalgae. The traditional strategy is to directly bubble CO_2 gas into photobioreactors or microalgae ponds. However, most CO_2 is lost into the atmosphere. In the present work, a novel system, consisting of chemical absorption, membrane separation and microalgae cultivation, was demonstrated to capture and transport CO_2 from flue gas to microalgae. The novel approach can reduce energy requirements for the compression and transportation of CO_2 and avoid energy penalty for the regeneration of solvents as incurred in the conventional chemical absorption process.

Over the last year, we have scaled up this approach from 400 ml flasks to raceway ponds of 2.8 Litre capacity. We have also introduced pH control, which improves the CO_2 uptake efficiency and microalgal growth rates.

We are now investigating an alternate approach that allows direct capture of CO_2 from air. As we hope to patent this approach, further details cannot be disclosed here.

CAPTURING ANAESTHETIC GASES

Liang Liu, Sandra Kentish, Forbes McGain, Brendan Abrahams

General anaesthetic gases are unusual drugs, with approximately 95% of the inhaled gas exhaled by the patient. The exhaled anaesthetic is captured within the hospital scavenging system and ultimately exhausted to the atmosphere. These anaesthetic gases have high global warming potential (hundreds to thousands of times that of CO_2). The objective of this project is to develop a feasible means to capture an anaesthetic gas (sevoflurane) and release it back as a gas for reuse.

This is a multidisciplinary team formed from clinicians, chemists and chemical engineers. At the University of Melbourne, Prof. Sandra Kentish is lending her experience in membrane technologies to assist in the development of anaesthetic gas capturing devices. Dr. Forbes McGain, anaesthetist at Western Health has extensive experience in the field of anaesthetic environmental sustainability. In late 2017 he united the researchers to begin testing different chemistry and chemical engineering solutions to gas capture on actual anaesthetic machines. University of Melbourne School of Chemistry, A/Prof. Brendan Abrahams leads a team with extensive experience in the development of materials capable of adsorbing gas molecules. We are financially supported by the University of Melbourne, by Western Health and by the Australian and New Zealand College of Anaesthetists.

MATERIALS DEVELOPMENT

CONTINUOUS ASSEMBLY OF POLYMER ON METAL-ORGANIC FRAMEWORK (CAP ON MOF)

Ke Xie, Qiang Fu, Paul Webley, Greg Qiao

As estimated by the International Energy Agent (IEA), fossil fuels fulfilled 81% of the world energy demand in 2013. In order to limit the global temperature rise to <2°C, 95% of coal fired and 40% of gas fired power plants need to be equipped with carbon capture and storage (CCS) facilities. Among various CCS approaches, post-combustion CCS is the most urgent one since it can be directly retrofit to existing fossil fuel-fired power generators. Thin film composite membrane (TFCM) systems have been shown to be one of the best ways to achieve high separation permeance. Most of the TFCMs consist of a porous substrate, a gutter layer and an ultra-thin (< 100 nm) top layer. With such a configuration, the gutter layer has always been considered essential since it can provide a smooth surface and prevent the penetration of dilute solution substance into the porous substrate. The performance of such TFCMs can be understood by a well-established resistance model, wherein the gutter layers in these TFCMs will increase the CO_2 capture cost by >100%. Thus, the gutter layer has become a major obstruction that hampers further improvement for membrane performance. We have developed a novel method to overcome this technical barrier by using a continuous MOF layer instead of a polymeric gutter layer. Furthermore, we have developed a bottom-up approach to fabricate what is now the thinnest (~30 nm) polymeric gas separation membrane on a rough micro-scale MOF layer, pre-gown on a substrate. This membrane exhibits excellent gas separation performance for CO_2 capture applications.

ADSORBENT SYSTEMS

CO_2 CAPTURE FROM NATURAL GAS: DEVELOPMENT OF ADSORBENTS AND ACCOMPANYING PROCESSES

Lefu Tao, David Danaci, Ranjeet Singh, Penny Xiao, Paul Webley

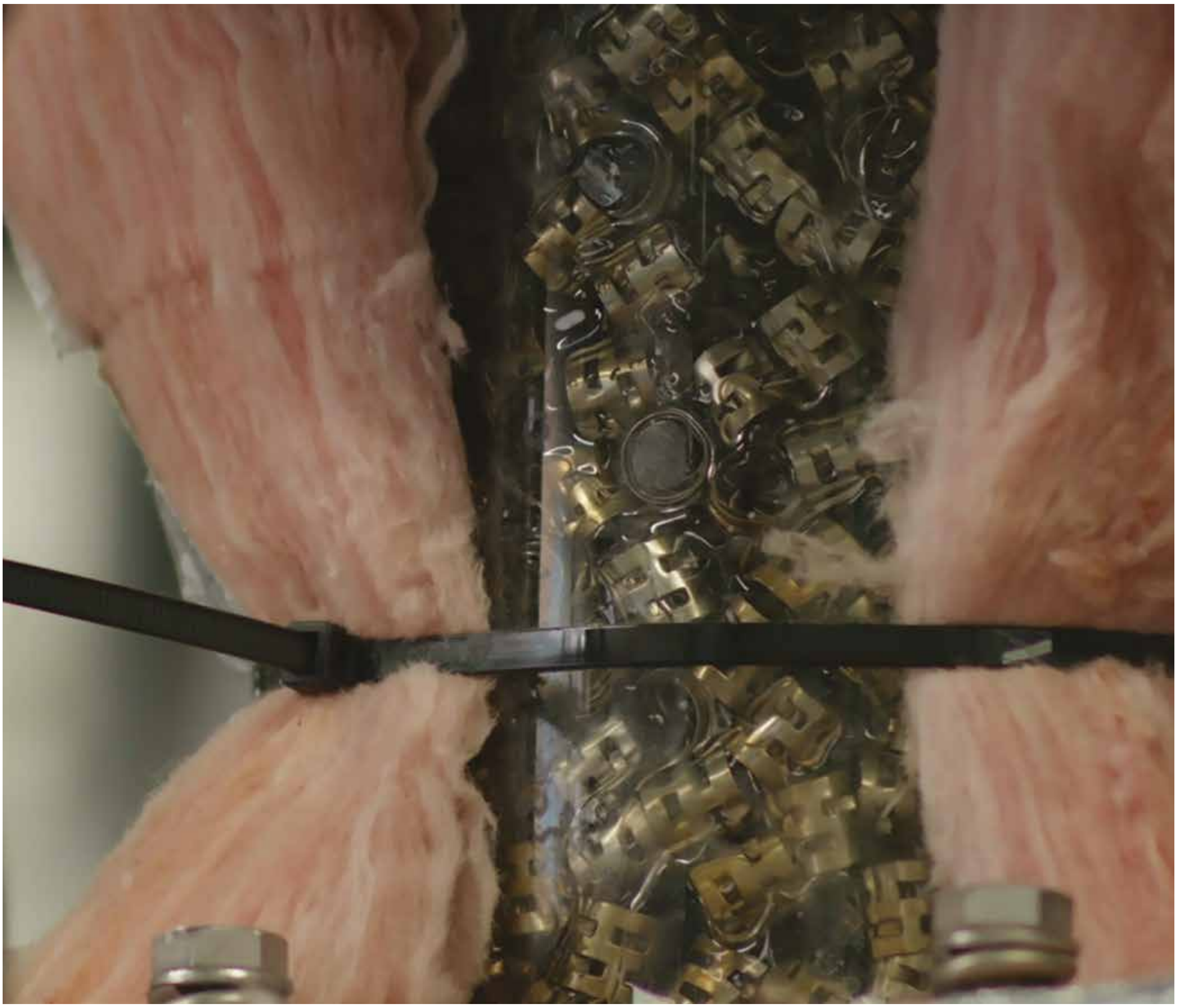
Work continued on zeolite, ZSM-25 as little work exists on this material and it initial works show it to be promising for CO_2/CH_4 separation. Our work has shown that additional efforts are required on the reproducible synthesis of the material and initial adsorption work has demonstrated that there may be an application in the kinetic separation of CO_2 from CH_4 as the diffusion of CH_4 appears to be slower than CO_2. In 2018 we successfully synthesized several ion exchange versions of this material and it is currently under study.

We have been operating on the Otway carbon capture rig. This field unit is in the Otway basin and uses high CO_2 concentration well gas as the feed. A two bed PSA system capable of operation to 100 bar has been designed. Initial tests with silica adsorbent have been promising and we are now in the process of synthesizing a more advanced adsorbent for further testing.

POLYMER METAL-ORGANIC FRAMEWORK COMPOSITE STRUCTURE FOR CO_2 CAPTURE APPLICATIONS

Ke Xie, Qiang Fu, Greg Qiao, Paul Webley

Metal-organic frameworks (MOF) are good candidates for gas separation due to their molecular sieving properties and high thermal stability. MOFs are cast into membranes (MOF membranes) or blended with polymer matrix to produce mixed matrix membranes (MMM). Neither of these techniques is optimal as the resultant membranes can have poor mechanical strength, defect-prone features and processing difficulties. In this study, the amino-functionalised MOF (NH2- UiO-66) and the bromide functionalised MOF (Br@MOF) nanometric crystals (30~50 nm) were successfully prepared and characterised by XPS, XRD, TGA, SEM and TEM. Br@MOF was used to initiate the polymerisation of polyethylene glycol acrylate (PEGA) via atom transfer radical polymerisation (ATRP), resulting in a polymer grafted MOF composite (P@MOF). P@MOF was firstly applied as the catalyst carrier by loading Pd nanoparticles. Owing to its absolute water dispersity and pH-sensitive aggregation-deaggregation nature, Pd loaded P@MOF integrated the advantage of both high homogeneous (high activity) and heterogeneous (good recyclability) catalysts. Furthermore, the unique core-shell structure of P@MOF implies its potential for gas separation MMM. Currently, CO_2 separation measurements (over light gases like CH_4 or N_2) are being performed to reveal the CO_2 capture capability of the membranes.



STORAGE PROGRAM

GEOCHEMISTRY

CHARACTERISTIC TRENDS IN THE EVOLUTION OF RESERVOIR WATER COMPOSITION DURING CO_2 STORAGE

Hong Vu, Ralf Haese

Site-specific characterisation, the prediction of CO_2 plume migration and changes in physical-chemical conditions over time are important elements during the exploration and appraisal of prospective CO_2 storage reservoirs. The formation water composition and lithologies can vary significantly between and within reservoirs. Consequently, the evolution of the formation water composition as a reflection of reactions between minerals and CO_2-enriched water will vary as well. For example, the presence of minor carbonate content will buffer the acidity of water and the dissolution of potassium feldspar leads to a characteristic enrichment in dissolved potassium.

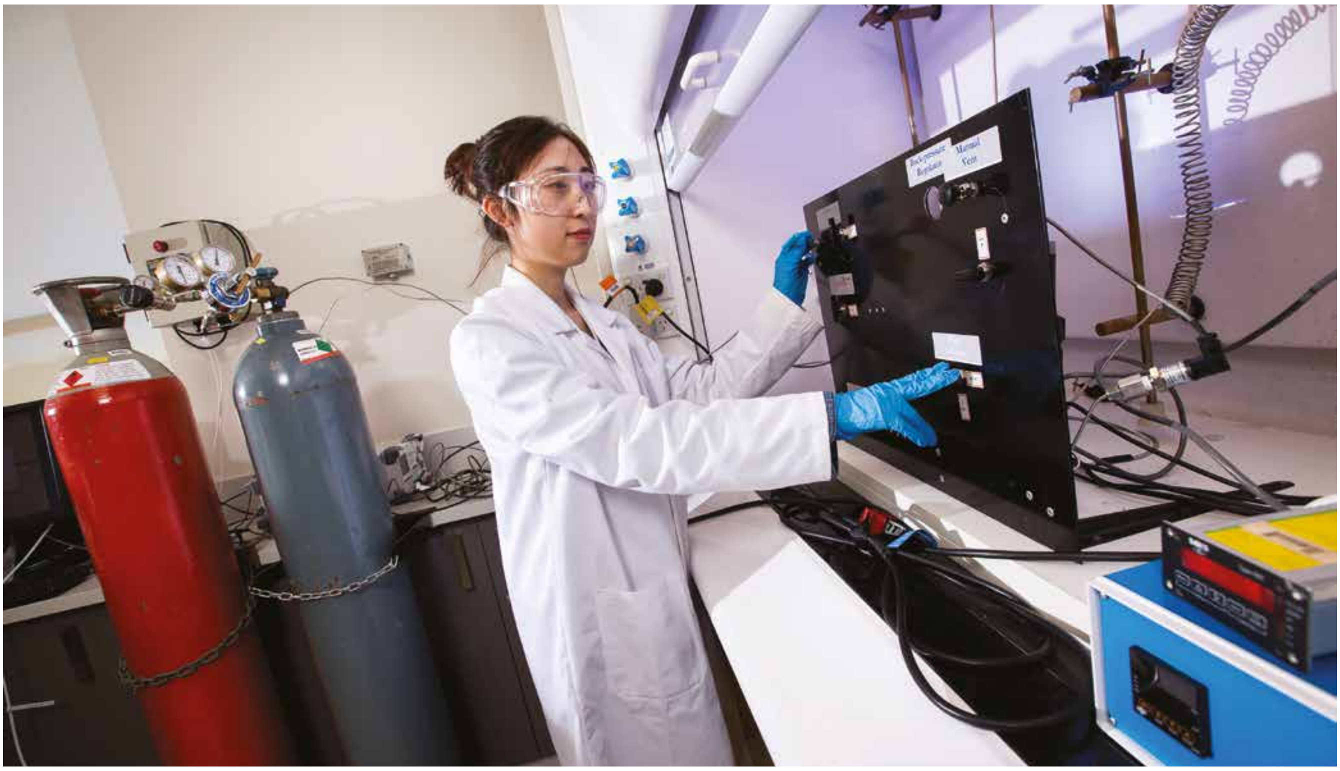
This project will compile relevant properties from national and international reservoirs with highly variable lithologies, formation water compositions, temperatures and rock/water-ratios (porosity), which are currently assessed for their CO_2 storage prospectivity. The data will be used to determine the evolution of fluid-rock reactions and the respective formation water composition over time through reaction path modelling. We expect to identify characteristic trends and water quality indicators for particular reservoir conditions. The latter could be used for the development of monitoring plans. Our studies will also estimate the capacity to permanently immobilise CO_2 through mineral (carbonate) precipitation.

The targeted CO_2 storage reservoir in the Gippsland Basin is the Latrobe Group, which will be used as a case study to determine variations in the evolution of formation water within one reservoir. The Latrobe Group sandstone is a relatively homogenous high-porosity / high-permeability reservoir rock, which makes it highly suitable for CO_2 storage. However, intraformational baffles in the form of coals, shales and carbonate (ankerite/siderite) cemented zones are found within and greensands at the top of the Latrobe Group. The reactivity of those lithologies are poorly understood and will be determined in support of CarbonNet's assessments of CO_2 reservoirs the Gippsland Basin.

ENHANCED CONTAINMENT THROUGH BARRIER FORMATION

Jay Black, Cesar Herrera, Angus Keillar, Ella Llanos, John Moreau, Ralf Haese

Long-term CO_2 containment is a key criteria for safe CO_2 storage, which is currently assessed through a range of seal integrity studies. While these site-specific studies will always be necessary, developing and testing the process of creating a flow barrier will help to understand how to manage and remediate undesired migration in future storage sites where containment is at an insufficient risk level. The only robust CO_2 leakage mitigation technology so far is pressure management as demonstrated in modelling studies so far. However, this approach requires permanent termination of the CO_2 injection and continued pumping as a means to stir the CO_2 plume away from the leakage point. Here, we propose the development of procedures leading to 'engineered' permanent mineral barriers a) as a remediation option in case of a CO_2 leakage and b) as a (precautionary} CO_2 leakage mitigation technology for areas where seal integrity is possibly at risk. In addition, this project will characterize reservoir microbial communities and will test whether high CO_2 conditions may lead to biofilm formation and/or biomineralisation reducing CO_2 mobility. The two activities on 'engineered' barrier formation are scoped to derive the required information for the design of a field experiment at the CO2CRC Otway Project site demonstrating effective barrier formation as a mitigation and/or remediation technology. The project will integrate desktop studies, laboratory experiments testing microbial metabolic behavior, mineral dissolution and precipitation experiments, and reactive-transport modelling predicting barrier formation and its effect on CO_2 migration.



EVOLUTION OF THE SOLUTE PLUME COMPOSITION AT THE GLENHAVEN SITE (QUEENSLAND)

Nicolas Spycher (Lawrence Berkeley National Laboratory, USA), Ralf Haese

The site-specific geological characterisation, the prediction of CO_2 plume migration and changes in physical-chemical conditions under CO_2 storage conditions are important elements during the exploration and appraisal of prospective CO_2 storage reservoirs. The formation water composition, the gas composition of the injectate and lithologies can vary significantly within reservoirs. Consequently, changes in the formation water composition as a reflection of reactions between the injectate and formation water and the gas-enriched formation water and minerals will be dynamic in space and time. For example, minor concentrations of SO_2 can be present in the injectate and will lead to sulfuric acid formation as it dissolves into formation water in the presence of (minor concentrations of) O_2. The additional acid, however, can be buffered through the dissolution of carbonate minerals.

This project will assess the chemical evolution of formation water using two complementary approaches: Firstly, the speciation of formation water following the dissolution of the injectate gas will be calculated and reaction path modelling will be carried out to identify the most relevant fluid-mineral reactions and trends in the formation water evolution for a range of conditions (mainly variations in mineral reactive surface area and injectate gas compositions). Secondly, a 2-dimensional reaction-transport model will be developed for selected transects using the ToughReact software with input from the reaction path modelling in order to observe the extent and concentration changes within the water plume affected by the mixing and reactions with the injectate gas and reservoir minerals.

The targeted CO_2 storage reservoir is the Precipice Sandstone and its overlying regional seal, the Evergreen Formation, at CTSCo's Glenhaven site (eastern Surat Basin). The modelling will be based on an up-to-date geological model of the region and well-constrained formation water and injection gas compositions.

ARE VERTICAL JOINTS AND FRACTURES SELF-SEALING DURING BUOYANCY-DRIVEN CO_2 MIGRATION IN CONTINENTAL FLOOD BASALTS?

Meghalim Phukan, Hong Vu, Ralf Haese

The permanent disposal of carbon dioxide in the subsurface has been considered a viable mitigation option to reduce global warming. Sedimentary basins have been studied over years as a conventional storage reservoir for CO_2 due to presence of caprock, but the mineralisation of CO_2 might take thousands of years to occur. Continental flood basalts are considered unconventional CO_2 storage reservoirs where interbedded massive basalt zones serve as barriers for upward CO_2 migration. However, vertical joints and sub vertical fractures in those massive basalt zones may serve as conduits for buoyancy-driven CO_2 migration and thereby pose a risk to CO_2 containment. Basalts have high concentrations in Ca-, Mg- and Fe-bearing silica minerals and basaltic glass, which are known to dissolve in low pH, CO_2-enriched water. The dissolution of basalt phases consumes protons and leads to an enrichment in dissolved silica and di-valent cations to the point when secondary minerals precipitate. Mineral precipitation in joints and fractures may be sufficient to reduce or fully block fluid flow. This research project will investigate the conditions and capacity of self-sealing of these joints.

Batch reactor and core flood experiments are used to determine the rate of dissolution and precipitation reactions and the required fluid residence time for self-sealing. The kinetics of mineral dissolution is studied in batch reactor experiments, using basalt wafers as the reactive sample immersed in CO_2-saturated fluid. Results from fluid analysis shows a rapid increase in cation (e.g., Ca and Mg) concentrations, followed by a significant reduction in those cations suggesting precipitation of secondary minerals. Further, geochemical modelling suggests the formation of clay minerals and zeolites, which could be potential sealants under the conditions of the experiments.

Future experimental work involves core flood experiments to better understand the reactive-transport of CO_2-saturated fluid and associated dissolution and precipitation reactions in basalt cores with artificial fractures.

LOSS OF INJECTIVITY CAUSED BY DRY-OUT AT THE AQUISTORE SITE

Ralf Haese, Jay Black, Nicolas Spycher (Lawrence Berkeley National Laboratory, USA)

Salt precipitation from water uptake into supercritical CO_2 ($scCO_2$) at injection wells where the salinity of formation water is extremely high is in-principle well understood. Other minerals including oxides and amorphous silica may precipitate near the well-bore of injection wells from the introduction of reagents such as oxygen or (mildly) acidic solutions, respectively. Reconstructing and predicting conditions and the type of precipitation will, however, require site specific details such as brine composition under reservoir P-T conditions as well as an accurate representation of two-phase flow conditions in the injection interval. Both data requirements are inherently complex at the Aquistore site: Firstly, temperature and the respective aqueous speciation is temporally and spatially dynamic given CO_2 is injected cold and intermittently. Secondly, CO_2 is injected into a lithologically heterogenous interval with a thickness of more than 170 m. Brine will flow towards the well by capillary forces when residual water is taken up into $scCO_2$. The latter provides a continuous supply of ions to the near-wellbore zone. The impact of salt precipitation on permeability has been shown not to obey theoretical porosity-permeability relationships, such as the Kozeny-Carman equation, and should therefore be derived from core flood experiments.

The Aquistore site has experienced a reduction in injectivity presumably related to mineral precipitation in the past. The nature and conditions of precipitation, however, remain poorly understood, which is a technical and possibly financial risk to the operation of the Aquistore CO_2 storage site. Apart from a better understanding of the principle conditions leading to precipitation and associated reduction in permeability it is desirable to develop a strategy to mitigate precipitation in the future and to remediate any loss of injectivity at the Aquistore site.

GEOCQUEST: QUANTIFYING CO_2 TRAPPING MECHANISMS AND CAPACITY IN OPEN SALINE AQUIFERS -THE ROLE OF RESERVOIR HETEROGENEITY

Peter Cook, Ralf Haese, Kuncho Kurtev, Stephan Matthai, Achyut Mishra

A major international research programme based at the Centre funded by BHP is underway, with Melbourne, Cambridge and Stanford as partners and in close collaboration with CO2CRC Ltd. CO_2 trapping mechanisms in geological reservoirs are highly dependent on the nature of structural and lithological heterogeneities. However, important mm- to meter scale heterogeneities are not incorporated into storage complex models because they can neither be seismically imaged nor represented by grid cells. The GeoCquest Project is evaluating capillary, dissolution and mineral trapping over time, taking into account the impact of heterogeneity at a range of scales. A series of coordinated process studies are now progressing at Cambridge, Stanford and Melbourne Universities, using experimental, analytical and numeric approaches, to better quantify variations in the proportion of CO_2 trapping by the different mechanisms over time. Particular attention is being paid to residual trapping. Data from the CO2CRC Otway site is being used as the case study. The GeoCquest participants met in Melbourne in 2018 and will be holding the annual workshop in Cambridge UK in March 2019.

CO2CRC Otway site. Photo courtesy of CO2CRC Limited.

RESEVOIR ENGINEERING

CONSTRUCTION OF AN ALTERNATIVE SIMULATION MODEL OF THE OTWAY SITE

Kuncho Kurtev, Chloe Burney, Junchul Kim, Stephan Matthai

Over the past year, in close collaboration with the Peter Cook Centre and the CO2CRC, a new alternative geomodel of the Otway site has been constructed, starting with the reprocessed seismic data and now available well logs. Additional regional scale data on the geologic context of the site were incorporated. To perform the geologic interpretation, an advanced attribute analysis of the seismic data was performed, yielding the input for the new interpretation of horizons and faults. The new model is being developed in the SKUA-GOCAD software by Emerson-Paradigm. Construction objectives include a higher resolution of the structural detail as compared to the existing models for Otway, and a more geologically realistic interpretation of the faults, circumventing the limitations of more conventional geomodelling software.

The model construction is aimed at both, resolving the detailed patterns of sedimentary and structural heterogeneities as well as compositional variations among the sedimentary rocks at the site. The former are important because of their influence on permeability distribution and storage capacity. The latter provide decisive constraints for the modelling of reactive flow and fluid rock reactions that depend on the spatial distribution of minerals. The goal is to predict CO_2 migration, dissolution and mineral trapping, which will be accompanied by changes in the pore geometry and permeability.

SIMULATION OF PLUME MIGRATION AND GEOPHYSICAL MONITORING

Qi Shao, Junchul Kim, Stephan Matthai

Major progress was made in the Federal Government CCS-RD fund sponsored research project that the PCC runs in collaboration with the University of Queensland and CNRS, ISTERRE, Chambery, France. This project entitled "*Simulation-Based Forecasting and Monitoring of Subsurface Behaviour of Carbon Dioxide*", focuses on improving the understanding of how CO_2 behaves during geo-sequestration in the Australian subsurface and how this behaviour can be monitored. A further aim of the project is to generate state-of-the-art software tools and workflows for performance assessment of storage sites and these will be tested by application to the Otway site. In 2018, the project team delivered its prototype of the integrated Australian CO_2 Geo-Sequestration Simulator (ACGSS), forecasted a range of geophysical signatures of a plume spreading in a heuristic model of a fluviatile sand-shale sequence, and applied geophysical inverse modelling to establish how much of the simulated plume would actually be visible by means of geophysical imaging.

IMPACT OF MESOSCALE HETEROGENEITY ON CO_2 SWEEP AND STORAGE EFFICIENCY

Chloe Burney, Stephan Matthai,

The high displacement efficiency of supercritical CO_2 (≥30%) seen in core-flooding experiments, is in stark contrast with its sporadic infiltration of the available pore volume in field-scale injection pilots (e.g., ≤5%) in the Sleipner plume. One potential reason for this discrepancy is that geologic heterogeneity on the 0.1 to 100-meter scale is not captured by lab experiments. Such heterogeneity is determined by the geologic environment of sediment deposition, sediment facies, bedforms and composition as well as overprint (cementation, fractures etc.). These factors give rise to complex geologic features and order of magnitude variations of permeability and capillary pressure. It also gives rise to intricate flow geometries that control the spreading of CO_2 after injection. Although similar lab-field differences have long been recognised in Enhanced Oil Recovery (EOR) studies, they have remained underexplored because the underpinning geologic complexity is difficult and time-consuming to characterize. Its model representation is even more difficult. .

Yet, the dramatic implications of this heterogeneity for plume spreading, storage efficiency and capacity make it imperative to overcome these difficulties.

To better understand the impact of nested intermediate scale heterogeneities, we implemented simulation models of outcrops of fluvial deposits in Germany and intertidal sandstones in Wyoming, and conducted high-resolution numeric multiphase flow simulations. For both outcrops, porosity and permeability has been measured either directly or in the laboratory. In the Wyoming field case, the local precipitation of calcite has consumed all porosity. To elucidate the effect of this diagenetic overprint on storage performance, simulations with and without the nodules were performed.

ENGINEERING NEGATIVE EMISSIONS

BIOENERGY AND CCS

Nasim Pour, Paul Webley, Peter Cook

To avoid irreversible climate changes, the atmospheric CO_2 concentration should be stabilized in the range of 350-450 ppm by 2100. To achieve this target some of the historical CO_2 would need to be removed from the atmosphere. Bioenergy with carbon capture and storage (BECCS) is a CO_2 removal technology, in which CO_2 absorbed from the atmosphere during photosynthesis is released when biomass is used for energy production. This CO_2 is then captured, transported and stored in geological formations and a “negative flow” of CO_2 emissions i.e. from the atmosphere to subsurface is established.

The methodology involves a three-step approach:

1. Firstly, The technical feasibility of different BECCS routes is assessed with the focus on BECCS for power production.
2. Secondly, Life cycle assessments (LCA) has been conducted to compare the environmental impacts of the BECCS options outlined in the first step.
3. Third step of the project, elements for an optimization sink and source matching model have been investigated in the context of BECCS, to produce a decision making tool that optimises biomass resource collection, conversion plants and CO_2 storage locations.

SEISMOLOGY

OPTIMISATION OF EARTHQUAKE MONITORING FOR CCS APPLICATIONS ON LOCAL AND MICROEARTHQUAKE SCALES

Mike Sandiford, Januka Attanayake, Gary Gibson, Abraham Jones

This project focuses on earthquake monitoring in CO_2 storage sites in the Australian context. Seismic monitoring is relatively difficult for proposed CarbonNet storage sites in the Gippsland Basin because of soft near-surface rocks and unconsolidated sediments, together with the offshore location. In these environments, seismic data is subject to rapid attenuation of signal amplitudes with distance, strong surface wave noise from ocean waves and wind, high transitory noise from anthropogenic sources, and site response issues whereby near surface soft rock and/or unconsolidated sediments significantly alter the seismic wave motion measured at the surface compared with that at bedrock. For these reasons, seismic monitoring in coastal sedimentary basins is rarely done.

To conduct successful monitoring within this challenging environment, elements of network design and operation have been considered, including careful selection of instruments. The network utilises new high-frequency seismometers and accelerometers with flat response to 100 or 200 Hz, which record motion from small nearby earthquakes at frequencies above most of the ongoing surface wave noise, while still recording the long period motion from larger earthquakes required for focal mechanisms. These instruments are installed in postholes (~2 to 4 metres deep) or shallow boreholes (10 to 100 metres) to reduce both transitory and ongoing surface wave amplitudes. Offshore ocean bottom seismometers (OBS) are used to provide monitoring closer to potential offshore storage site than possible with the onshore instruments.

The installation and operation of this high-density seismic network in the target area reduces the distance from earthquakes to the nearest seismographs, increasing signal to noise ratio and enabling smaller magnitude earthquakes to be detected than previously possibly. The network improves epicentral location accuracy for local earthquakes and enables more and smaller magnitude earthquakes to be detected. It also facilitates research into the stress state of the Gippsland Basin and provides the input data for the development of local velocity and attenuation models.

BASIN ANALYSIS

DISTRIBUTION AND GEOMETRY OF LATROBE GROUP INTRAFORMATIONAL SEALS, GIPPSLAND BASIN

Julie Dickinson, Guy Holdgate, Malcolm Wallace

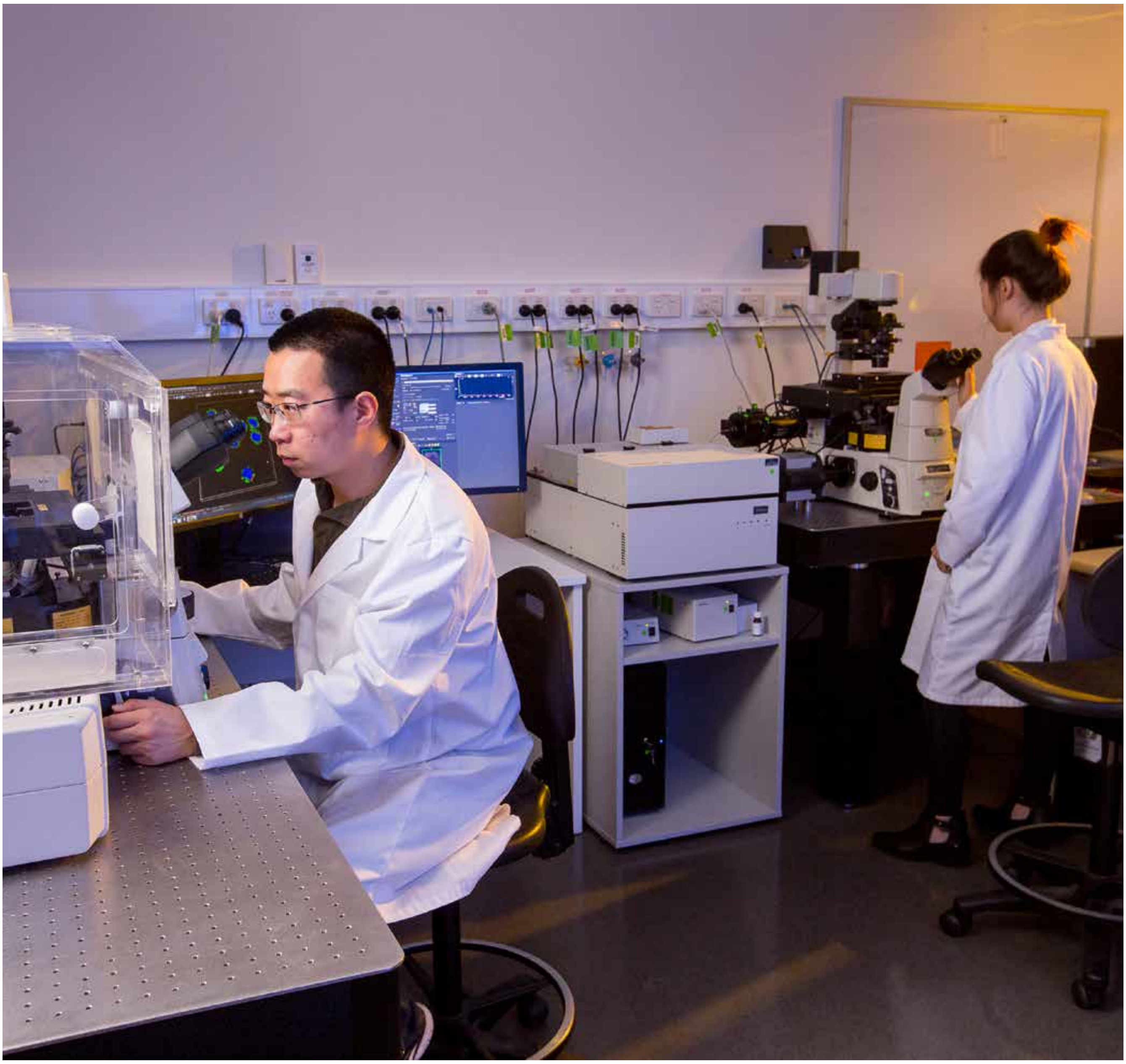
This project will provide a detailed understanding of the stratigraphy and structure of the Latrobe Group, with particular emphasis on the seal lithologies within the unit (largely coal and shale). The project will synthesize seismic, well log, core and lithological data onshore and offshore in order to produce a 3D map of seals within the unit. This will provide important information for the assessment of CO_2 storage sites in near- and off-shore areas of the Gippsland Basin. To date there is limited published work integrating the offshore to the onshore seismic coverage where there is more abundant well log and core data and extensive 2D seismic surveys. This project will therefore provide a better understanding of the way in which CO_2 will migrate and be stored within the Latrobe Group sediments. It will also provide a facies model for the Latrobe Group coals and sands that may be applied to other coal successions globally.

ATMOSPHERIC MONITORING

AN ATMOSPHERIC ASSURANCE SYSTEM FOR THE GIPPSLAND NEAR-SHORE ENVIRONMENT

Nicholas Deutscher (The University of Wollongong), Peter Rayner

This project establishes fit-for-purpose atmospheric monitoring methods and technologies to discriminate between detected environmental signals at geological storage locations. This project achieves these goals by developing and testing a passive, area-integrated measurement network that can detect anomalous sources by triangulation with high probability. It does this by combining the integrating effects of atmospheric flow with path-integrating measurements. The project addresses what the optimal instrument combination and configuration that might be effective for CCS application within the Gippsland environment.



AWARDS AND ACHIEVEMENTS

AWARDS BY POST-GRADUATE STUDENTS

YUE WU was a member of the winning group at the IEAGHG International Interdisciplinary CCS Summer School, The Norwegian CCS Centre, Norway, June 2018.

AWARDS BY ACADEMIC STAFF

COLIN SCHOLES was recognised in 2018 Class of Influential Researchers by Industrial & Engineering Chemistry Research (I&ECR). This award recognises researchers of influential, early-career researchers on the basis of the quality and impact of their research.

SANDRA KENTISH was listed as one of Australia's 100 Women of Influence in the Australian Financial Review.

Dr Colin Scholes

Prof Sandra Kentish

ROLES AND APPOINTMENTS OF ACADEMIC STAFF

PETER COOK

- Member of the Technical Working Group, Coal Innovation NSW
- Principal Adviser for CO2CRC Ltd
- Member of the CarbonNet Project Steering Committee, Victorian Government
- Chair, Expert Panel for Water, NSW Dept of Planning and Environment to advise on the Narrabri Gas Project
- Member, GHGT-14 Committee
- Speaker, Mexican Petroleum Institute – Stanford University Workshop

MALCOLM GARRETT

- Chair of the Centre Advisory Board, Peter Cook Centre for CCS Research

RALF HAESE

- Member of the Science Advisory Committee of the European CarbFix2 project
- Director, Peter Cook Centre for CCS Research
- Science Leader Geochemistry, ANLEC R&D
- Member of the Melbourne Energy Institute Executive Committee

SANDRA KENTISH

- Head of School, Chemical and Biomedical Engineering
- Technical Advisory Group for the Technical Programme Committee, International Conference on Greenhouse Gas Control Technologies (GHGT-14)
- Associate Editor, Clean Energy
- Editorial Board, International Journal of Greenhouse Gas Control
- Editorial Committee, Chinese Journal of Chemical Engineering
- Invited Professor, Centre for Water, Earth and the Environment, INRS, Canada
- Editorial Board. Industrial and Engineering Chemistry Research
- Editorial Board, Journal of Advanced Manufacturing and Processing
- Editorial Board, Journal of Membrane Science
- Fellow of the Vincent Fairfax Foundation
- Fellow of the Royal Australian Chemical Institute (RACI)
- Fellow of Engineers Australia

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STEPHAN MATTHAI

- Science Leader Reservoir Engineering, ANLEC R&D
- Board member, lead software developer, CSMP++ Originators Group of Universities
- Steering committee and review panel member, EAGE ECMOR – European Conference on the Mathematics of Oil Recovery
- Member of the Melbourne Energy Institute Executive Committee

KATHRYN MUMFORD

- Deputy Director, Peter Cook Centre for CCS Research
- Associate Professor, Department of Chemical and Biomolecular Engineering, The University of Melbourne

GEOFF STEVENS

- Associate Editor-in Chief of the Chinese Journal of Chemical Engineering (CJChE)
- Editorial Board of the International Journal Solvent Extraction and Ion Exchange
- Fellow of the Australian Academy of Technological Sciences and Engineering (FTSE)
- Fellow of the Institute of Chemical Engineers

GREG QIAO

- Assistant Dean (Research), Melbourne School of Engineering, The University of Melbourne

PAUL WEBLEY

- Head of Department, Chemical Engineering
- Editor, Separation and Purification Technology
- Board Member and Vice President, International Adsorption Society

INTERNATIONAL ENGAGEMENT

Prof. Sandra Kentish continues to collaborate with the Centre for Water, Earth and the Environment (INRS) in Quebec, Canada, to develop a process for the sequestration of carbon dioxide into a mineral form. Most recently, she has been assisting a PhD student to assess the opportunities for energy integration within their process. This student visited the University of Melbourne laboratories in February 2018. Sandra has been appointed as an invited Professor of the INRS since 2011 in recognition of her contribution to this work. Prof. Sandra Kentish continues to collaborate with Meiji University in Japan. In 2018, a student, Shuhei, visited and will stay for a year.

Prof. Peter Cook visited the Mexican Petroleum Institute in May 2018 to attend and speak at the Stanford University Workshop Sustainability of the Hydrocarbon Value Chain in Mexico.

The Workshop which was jointly sponsored by the Mexican Government and Stanford University was focussed on how to ensure the sustainability of Mexico's energy sector in a carbon -constrained world. Particular emphasis was placed on the role of CCS in decarbonisation of the Mexican economy

Prof. Ralf Haese, Prof Peter Cook and Prof. Stephan Matthai met with Dr Anthony Ku, Director for Advanced Technologies, National Institute of Clean-and-Low-Carbon Energy (NICE) in June 2018 at The University of Melbourne and participated in a technical workshop on CO_2 Storage.

Prof. Ralf Haese met with Prof. Song Yongchen, Vice President, Dalian University of Technology (China) in Oct 2018 at The University of Melbourne to provide an overview of expertise and capabilities of the Peter Cook Centre. In the same month, Prof Ralf Haese also met with Gianni Serra, Sotacarbo (Italy) at The University of Melbourne to discuss collaboration opportunities.

GeoCquest

GeoCquest is a major international research programme on geological carbon storage funded by BHP. Researchers from The University of Melbourne, the University of Cambridge (UK) and Stanford University (USA)met in Melbourne in March 2018. Data from the CO2CRC Subsurface Laboratory site is used for experimental and modelling studies. The GeoCquest team will be holding their next annual workshop in Cambridge (UK) in March 2019.

Prof Ralf Haese, Dr Anthony Ku (NICE), Prof Peter Cook, Prof Stephan Matthai, A/Prof Kathryn Mumford and Prof Robin Batterham (from left to right)

Prof Ralf Haese giving a lab tour to Prof Yongchen Song, Vice President of Dalian University of Technology (DUT), and his research group

The GeoCquest workshop in March 2018

NATIONAL ENGAGEMENT

Research collaboration with CSIRO to deploy an ocean bottom seismometer apx. 5km offshore from the Gippsland Lakes

In November 2018 in collaboration with CSIRO and Australian Maritime College (AMC), Abraham Jones travelled to Beauty Point, TAS and oversaw loading and configuration of a University of Melbourne ocean bottom seismometer (OBS) onto the deck of the AMC ship, the MV Bluefin. The OBS was deployed onto the ocean floor by CSIRO and AMC staff apx. 5km offshore from the Gippsland Lakes. The OBS is equipment funded through the EIF GipNet program (CO2CRC and the Australian Government) and will passively monitor local earthquakes occurring in the Gippsland Basin for up to 6 months.

BHP WORKSHOP ON THE DEPLOYMENT OF CCS

In October 2018, Prof. Peter Cook and Prof. Ralf Haese participated in a one-day discussion workshop at BHP on requirements for an accelerated deployment of CCS. This was held in Melbourne which brought together a number of CCS experts from China, USA, UK, Australia and Canada working with BHP.

Deployment of a University of Melbourne ocean bottom seismometer (OBS) from the deck of the Australian Maritime College ship, the MV Bluefin, in November 2018. Copywrite CSIRO.

A COURSE FOR PROFESSIONALS AND POST-GRADUATE STUDENTS

FUNDAMENTALS OF GEOLOGICAL CARBON STORAGE

The Peter Cook Centre for CCS Research together with the School of Earth Sciences at The University of Melbourne is offering an intensive course on geological carbon storage. The course is open to professionals as well as to post-graduate students and was given in the last week of June 2018. The lecturer is Dr. George Carman, who has worked as a petroleum geologist throughout his career; he served the Victorian CarbonNet Project as Exploration and Development Manager and Subsurface Storage Director for more than 3 years.

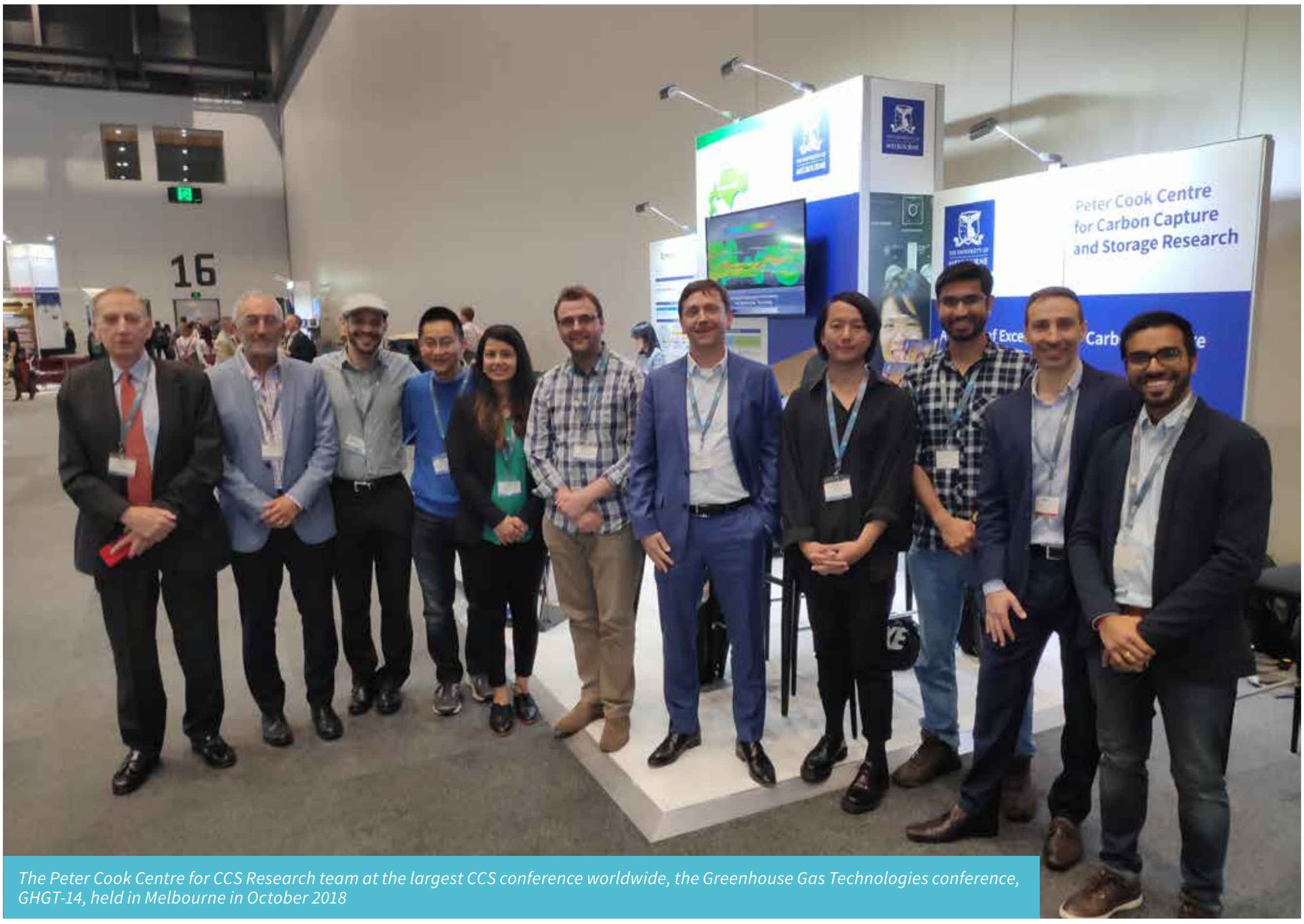
The course covers a large range of technical and scientific aspects pertinent to geological carbon storage. It commences with basin and play scale analyses and rapidly focus onto portfolio management for storage site screening, storage site selection and site analysis for future appraisal and development operations. Whilst a sound basic knowledge of geosciences and/or reservoir engineering is required, the application of those skills sets is reviewed and applied in hands-on group exercises.

The course is supported by the Global CCS Institute and offers participation at no cost to their member organisations.

Dr George Carman with class participants

THE GHGT-14 CONFERENCE

The world's largest CCS conference, the 14th international Greenhouse Gas Technology Conference (GHGT-14) was hosted by Melbourne in October and exceeded our highest expectations. It was a memorable week with over 1000 national and international delegates from industry, governments and academia, plenary and technical presentations, an exhibition floor and plenty of networking events. The Peter Cook Centre prepared for this event long in advance: A booth was designed, our web site updated, a professional 5-minute film produced and, last but not least, our researchers prepared and presented over 25 oral and poster contributions. Many international researchers and research groups approached us to discuss our research and to find out about collaboration opportunities. Richard Bolt, Victorian Secretary of the Department of Economic Development, Jobs, Transport and Resources, presented Victoria as a CCS focal point in his plenary talk. – A highlight of the year.



The Peter Cook Centre for CCS Research team at the largest CCS conference worldwide, the Greenhouse Gas Technologies conference, GHGT-14, held in Melbourne in October 2018

PRESENTATIONS

Agheshlui, H., Matthai, S.K. (2018). Simulation of Ground Deflection in Response to CO_2 Pressure and Buoyancy. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia 21-26 October. (Poster)

Benson, S.M., Bickle, M., Boon, M., Cook, P.J., Haese, R.R., Kurtev, K., Matthai, S.K., Neufeld, J., Watson, M., Winkelman, G. (2018). Quantifying the Impact of Heterogeneity on CO2 Migration and Trapping in Saline Aquifers. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Oral)

Black, J.R. , Castañeda-Herrera, C., Llanos, E.M., Stevens, G.W., Haese, R.R. (2018). Performance of Silica-gel as a Geochemical Barrier under CO2 Storage Conditions. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Oral)

Burney, C., Matthai, S.K. (2018). Scale-Transgressive Simulation of the Impact of Heterogeneity on CO2 Migration Using High-Resolution Outcrop-Analog Models. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia 21-26 October. (Poster)

Cook, P.J. (2018). CCUS: Retrospective and Prospective. CCUS2018-Applied Energy Symposium and Forum 2018: Carbon capture, utilization and storage, Perth, Australia, 27-29 June. (Oral)

Cook, P.J. (2018). Negative Emissions Conference: Integrating Industry, Technology and Society for Carbon Drawdown. Australian National University, Canberra, Australia October. (Oral)

Cook, P.J. (2018). The GeoCquest Project: Quantifying the impact of heterogeneity on CO2 migtation and trapping in saline aquifers. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Oral)

Fang, X., Men, Y., Wu, F., Xiao, P., Webley, P.A., Du., T. (2018). Experimental Study of Cu-ZnO-ZrO2/Hydrotalcite Catalyst for Sorption-Enhanced Hydrogenation of CO2 to Methanol. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Jyoti, A., Haese, R.R. (2018). Geochemical reactions at lithological boundaries controlled by downward advection of CO2 -enriched brine – A reactive-transport modelling study at pore scale. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Kentish, S.E. (2018). Emerging Applications for Polymers in Membrane Technology. The 12th SPSJ International Polymer Conference (IPC2018), Hiroshima, Japan, 4-7 December. (Keynote)

Kentish, S.E. (2018). Polymeric Membranes for Carbon Dioxide Capture – What is needed? PolymerVic 2018, Melbourne, Australia, 21-22 November. (Oral)

Kentish, S.E. (2018). The Fundamentals of Membrane Separation Technology and The Current Applications. The University of Tokyo, Tokyo, Japan, 3 December. (Oral)

Kentish, S.E. (2018). The Use of Polymeric Membranes for Carbon Capture and Storage. Hiroshima University, Hiroshima, Japan, 5 December. (Oral)

Kentish, S.E. (2018). The Use of Polymeric Membranes for Carbon Capture and Utilization. CSIR National Chemical Laboratory, Pune, India, 14-15 December. (Keynote)

Knowles, G., Sher, J., Xiao, P., Webley, P.A., Chaffee, A. (2018). Novel Adsorption Process Technologies for CO2 Post Combustion Capture via Amine Type Adsorbents. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Kurtev, K., Matthai, S.K. (2018). Characterization and Impact of Seal Heterogeneity on its Sealing Capacity for a CO2 Storage. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Kurtev, K., Matthai, S.K. (2018). Modelling of Geological and Flow properties of Otway CO2 Storage. Peter Cook CO2 Centre, Parkville, Australia, 17 September.

Kurtev, K., Matthai, S.K. (2018). Update 2 on Project: Alternative Otway CO2 Storage. CO2CRC Office, Melbourne, Australia 18 November.

Kurtev, K., Matthai, S.K. (2018). Update on Project: Alternative Otway CO2 Storage. CO2CRC Office, Melbourne, Australia, 22 August.

Matthai, S. K. (2018). Modelling and simulation of CO2 geo-sequestration in heterogeneous geologic media. Centre for Coal Seam Gas Technologies, The University of Queensland, Brisbane, Australia 19 November.

Matthai, S. K. (2018). Space-Time Adaptive THMC Simulation with Hybrid FEM-FVM Methods Applied to CO2 Geo-Sequestration. RING Consortium Meeting, ENSG, Nancy, France, 19 September.

Matthai, S. K. (2018). Space-Time Adaptive THMC Simulation with Hybrid FEM-FVM Methods Applied to CO2 Geo-Sequestration. The Laboratory for Modeling and Scientific Computing (MOX), Politecnico di Milano with participation by ENI, Milan, Italy, 27 September.

Matthai, S. K. (2018). Upscaling CO2 relative permeability in heterogeneous sandstones. Australian InterPore Conference, Melbourne, Australia 2 November. (Keynote)

Men, Y., Fang, X., Wu, F., Zhao, Q., Xiao, P., Webley, P.A. (2018). CO2 Hydrogenation to Methanol by Ni-Ga Alloy Catalysts via Hydrotalcite-Like Precursors. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Mishra, A., Haese, R.R. (2018). Determining conditions of CO2 entry into intraformational baffles: A prerequisite to estimate carbon mineralisation at reservoir scale. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Oral)

Moore, T., Biviano, M., Mumford, K.A., Stevens, G.W., Webley, P.A. (2018). Immobilisation of Liquid Solvents inside PDMS for Carbon Capture. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Moore, T., Biviano, M., Mumford, K.A., Stevens, G.W., Webley, P.A. (2018). Immobilised Solvents Systems for Large-Scale Gas Separations. The American Institute of Chemical Engineers (AIChE) Annual Meeting 2018, Pittsburgh, USA, 28 October - 2 November. (Oral)

Moore, T., Biviano, M., Mumford, K.A., Stevens, G.W., Webley, P.A. (2018). Solvent Impregnated Polymers for Carbon Capture. Melbourne Energy Institute Energy Research Symposium, Melbourne, Australia, 12 December. (Poster)

Moore, T., Mumford, K.A., Stevens, G.W., Webley, P.A. (2018). Immobilised Solvent Systems: Evaluating the Potential of High Surface Area Membrane/Solvent Hybrid Sorbent Materials The American Institute of Chemical Engineers (AIChE) Annual Meeting 2018, Pittsburgh, USA, 28 October - 2 November. (Oral)

Nyunt, P., Haese, R.R. (2018). Towards a realistic representation of lithological heterogeneity at the South West Hub through high-resolution 3D static modelling. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Pandit, J.K., Qiao, G., Fu, Q., Kentish, S.E., Scholes, C.A., Chen, V., Lia, H., Xiao, P., Tao, L., Webley, P.A., Qader, A. (2018). An overview of CO2CRC's Capture Program. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Phukan, M., Vu, H.P., Haese, R.R. (2018). Mineral precipitation from CO2 saturated water in basalts and its potential for self-sealing of fractures and joints. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Pour, N., Webley, P.A., Cook, P.J. (2018). An Adaptive Management System for Sustainable BECCS Implementation. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Qiao, G.G. (2018). Towards Extremely High Gas Permeance in Ultra-thin Composite Membranes. Current and Future Challenges of Energy Efficient Separation, CFCEES2018, Cairns, Australia, 27-29 June. (Oral)

Scholes, C. A. (2018). BECCS from decentralised agricultural waste. Energy Transition Hub Symposium, Melbourne, Australia, 14 November. (Oral)

Scholes, C.A. (2018). Carbon, Clean Energy, Climate and how Chemistry is the Solution. RACI Victorian Branch Public Lecture, Melbourne, Australia, 14 August. (Oral)

Shao, Q., Matthai, S.K., Gross, L. (2018). Efficient modelling of CO2 injection and plume spreading with discrete event simulation (DES). The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia 21-26 October. (Poster)

Sin, I., Corvisier. J., Matthai, S.K. (2018). Impact of co-injected impurities on hydrodynamics of CO2 injection problems. Studying interplayed chromatographic partitioning and density driven flow and fate of the injected mixed gases: numerical and experimental results. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia 21-26 October. (Poster)

Spycher, N.F., Llanos, E.M., Vu, H.P., Haese, R.R. (2018). Reactive-transport modelling of CO2 with impurities (SO2, NO2, O_2) at reservoir scale to determine zones of fluid-rock reactions and the fate of impurities. The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Poster)

Stevens, G.W. (2018). Global Warming and What You Can Do About It: An Engineering Perspective. 6th International Conference on CO2 Emission Control and Utilisation, Hangzhou, China, 15-18 June. (Oral)

Tao, L., Xiao, P., Qader, A.Q., Webley, P.A. (2018). CO2 capture from high concentration CO2 natural gases by pressure swing adsorption in CO2CRC Otway site, Australia. CHEMECA 2018, Queenstown, New Zealand, 30 September – 3 October (Oral)

Tao, L., Xiao, P., Qader, A.Q., Webley, P.A. (2018). High Silica adsorbents for CO2 separation from high pressure natural gas via selective adsorption. CHEMECA 2018, Queenstown, New Zealand, 30 September – 3 October. (Poster)

Vu, H.P., Haese, R.R. (2018). Changes in formation water and mineral composition under CO2 storage conditions in the Latrobe Group reservoir, Gippsland Basin (Australia). The 14th Greenhouse Gas Technology Conference (GHGT 14), Melbourne, Australia, 21-26 October. (Oral)

Webley, P.A. (2018). Advances in Materials and Processes for CO2 Capture from Natural Gas. 30th German Zeolite Conference, Kiel, Germany, February. (Oral)

Webley, P.A. (2018). Next Generation: membrane materials. Carbon Capture & Storage (CCS) Forum 2018, Cetraro, Italy, 4-8 June. (Oral)

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2018 BUDGET

THE PETER COOK CENTRE RESEARCH BUDGET

Revenue generated by research projects	**$3,097,400**
Scholarships provided by The University of Melbourne	**$759,000**
Salaries provided by The University of Melbourne	**$690,167**

THE PETER COOK CENTRE OPERATING BUDGET

REVENUE

Project management support through research projects	$142,710
Membership (Vic Government)	$75,000
Admin support (Melbourne Energy Institute, The University of Melbourne)	$25,000
Total Revenue	**$212,710**

EXPENDITURE

Salaries	$125,988
Consulting services	$63,467
Operating expenses	$ 109,426*
Total Expenditure	**$298,881**

* This includes one-off expenses of sponsorship of the GHGT-14 conference as well as the production of the PCC short film.

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