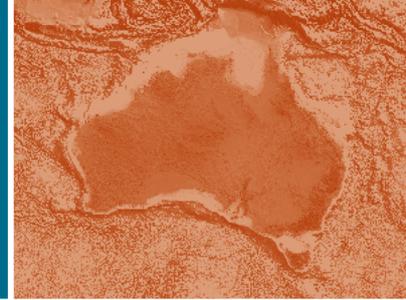




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China Australia Geological Storage of CO₂ Project Phase Two (CAGS2) Summary Report

Feitz, A., Gurney, J., Huang, L., Zhang, J. and Jia, L.

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Summary Report

GEOSCIENCE AUSTRALIA
RECORD 2015/06

Feitz, A.¹, Gurney, J.¹, Huang, L.¹, Zhang, J.² and Jia, L.²



Australian Government
Geoscience Australia



1. Geoscience Australia
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Executive Summary

Phase two of the China Australia Geological Storage of CO₂ (CAGS2) project aimed to build on the success of the previous CAGS project and promote capacity building, training opportunities and share expertise on the geological storage of CO₂. The project was led by Geoscience Australia (GA) and China's Ministry of Science and Technology (MOST) through the Administrative Centre for China's Agenda 21 (ACCA21).

CAGS2 has successfully completed all planned activities including three workshops, two carbon capture and storage (CCS) training schools, five research projects focusing on different aspects of the geological storage of CO₂, and ten researcher exchanges to China and Australia. The project received favourable feedback from project partners and participants in CAGS activities and there is a strong desire from the Chinese government and Chinese researchers to continue the collaboration. The project can be considered a highly successful demonstration of bi-lateral cooperation between the Australian and Chinese governments.

Through the technical workshops, training schools, exchange programs, and research projects, CAGS2 has facilitated and supported on-going collaboration between many research institutions and industry in Australia and China. More than 150 experts, young researchers and college students, from over 30 organisations, participated in CAGS2. The opportunity to interact with Australian and international experts at CAGS hosted workshops and schools was appreciated by the participants, many of whom do not get the opportunity to attend international conferences. Feedback from a CAGS impact survey found that the workshops and schools inspired many researchers and students to pursue geological storage research.

The scientific exchanges proved effective and often fostered further engagement between Chinese and Australian researchers and their host organisations. The research projects often acted as a catalyst for attracting additional CCS funding (at least A\$700,000), including two projects funded under the China Clean Development Mechanism Fund. CAGS sponsored research led to reports, international conference presentations, and Chinese and international journal papers.

CAGS has established a network of key CCS/CCUS (carbon capture, utilisation and storage) researchers in China and Australia. This is exemplified by the fact that 4 of the 6 experts that provided input on the "storage section" of the 12th Five-Year plan for Scientific and Technological Development of Carbon Capture, Utilization and Storage, which laid out the technical policy priorities for R&D and demonstration of CCUS technology in China, were CAGS affiliated researchers.

The substantial contribution of CAGS to China's capacity building and policy on CCUS has been gratefully acknowledged by the Chinese Government.

Recommendations

- There is an increasing willingness from China to provide co-funding towards a future CAGS program. There are a number of Chinese demonstration projects that could contribute significant in-kind and domestic cash funding. This provides an opportunity to leverage funding and expertise to further enhance Australian-Chinese cooperation on geological storage of CO₂.
- The application of geological storage of CO₂ in China will be mostly associated with enhanced oil recovery (EOR) and enhanced shale gas recovery (ESGR). While CCUS-EOR is not practical for Australia due to the type of oils and geological formations found in Australia, it is recommended to maintain cooperation with China in the research areas of CO₂-ESGR and enhanced water recovery. This could potentially benefit Australia's nascent shale gas industry. China has successfully started production of shale gas using ESGR in the Ordos Basin and there are opportunities for cooperation, especially in terms of monitoring technologies and geological modelling and assessment.
- Most of the research under CAGS has been conducted at a national, regional and provincial level but future work should focus on where concrete activities and projects are likely to happen. A key target area is the Xinjiang province and the planned CCUS demonstration project at the Zhundong oilfield in the Junggar Basin, but it is also recommended to link in with other active geological storage demonstration projects in China such as the Shenhua Ordos or Jilin oilfield projects.
- Focus on challenges facing both Australia and China, e.g. storage in arid environments, baseline mapping of groundwater resources, application of geological storage assessment workflows, development of shale gas resources, and tackling the challenge of developing cost-effective, near-surface, monitoring technologies that can monitor over large areas.
- The network established by CAGS is an invaluable asset, e.g. young researchers, experienced researchers, company representatives, and government officials. Further efforts should go into maintaining and strengthening the network, including the international partners. This could be achieved by combining capacity building with targeted research, which is often overlooked in the bilateral cooperation space. It is also recommended to expand the capacity building program to include key provincial government representatives.
- It is recommended to continue to engage in capacity building through workshops and schools. This was a very effective model and should be included in any future cooperative program. The workshops and schools had a number of important benefits beyond direct knowledge transfer including: increasing cooperation amongst Chinese institutions; inspiring students and researchers to pursue geological storage research; facilitating increased collaboration between international experts and Chinese participants; and increasing resource allocation and funding to CCS research within the participants' institutions.

1 Introduction

1.1 Background

The China Australia Geological Storage of CO₂ (CAGS) project (2009-2012) was established under the Asia-Pacific Partnership on Clean Development and Climate (APP). The project aimed to help accelerate the development and deployment of geological storage of carbon dioxide in both China and Australia. The project was led by Geoscience Australia (GA) and China's Ministry of Science and Technology (MOST) through the Administrative Centre for China's Agenda 21 (ACCA21).

Phase two of the China Australia Geological Storage of CO₂ (CAGS2) project was endorsed by the Australia-China Joint Coordination Group on Clean Coal Technology (JCG). The Department of Industry and Science provided total funding of up to \$1,389,000 (GST excluded) under the Project for a range of activities that support the ongoing collaboration between Australia and China in the geological storage of CO₂. GA managed the project jointly with ACCA21. CAGS2 commenced in mid 2012 and finished in March 2015.

1.2 Aim and objectives

CAGS2 was designed to build upon the cooperation established between Australia and China during the first phase of CAGS. The project aimed to further develop China and Australia's technical skills in the area of geological storage of carbon dioxide (CO₂) through a number of capacity building activities; training opportunities; sharing of expertise through scientific exchanges; and advancing geological storage science through sponsored research projects in China. The planned outcomes of the project were as follows:

- Enhance Australia's bilateral relationship with China through the successful implementation of project activities;
- Develop and expand ties of cooperation between Australia and China in the geological storage of CO₂;
- Identify areas where cooperation on the development and demonstration of the geological storage of CO₂ can be enhanced for mutual benefit; and
- Identify opportunities for new joint projects in the geological storage of CO₂.

1.3 Project outline

The project comprises four programs with three activity-based programs and an operational program to support the activities.

1.3.1 Program 1 – Workshops and Training Schools

The focus of Program 1 was on training, knowledge transfer and network building through technical workshops and training schools that were held in both Australia and China. Two workshops were held

with participants from Australia and China, and supported by international expert speakers. Two CCS training schools were held for more than 60 tertiary students and early career researchers. It was identified that an additional mini workshop would be helpful to wrap up the project and obtain recommendations for future programs and this was held in November 2014.

1.3.2 Program 2 – Exchange Programs

The aim of Program 2 was to provide and facilitate exchange and secondment opportunities in the field of geological storage of CO₂. By the end of November 2014, ten exchange programs (1-6 months) for Australian researchers to visit China and for Chinese researchers to visit Australia were completed.

1.3.3 Program 3 – Research Projects

Program 3 included the following five research projects, focusing on different aspects of the geological storage of CO₂:

- Research Project 1: CO₂ Geological Storage: Target Area Selection and Evaluation Method
- Research Project 2: Possibility and Potential of CO₂ Enhanced Shale Gas Recovery in the Ordos Basin
- Research Project 3: Current Status and Gaps in Essential Technology, Equipment and Material for Implementing CO₂ Saline Aquifer Storage Projects in China
- Research Project 4: Key Parameters for Environmental Impact and Risk Assessment for CO₂ Geological Sequestration
- Research Project 5: Research on Carbon Dioxide Capture, Utilization and Storage Technology Roadmap in Xinjiang

1.3.4 Program 4 – Operations

This program covered the operational aspects of CAGS2. The major functions of this program were project management activities, staffing, travel costs, communications and networking activities (such as the website, project meetings, project publications) for both Geoscience Australia and the Administrative Centre for China's Agenda 21, Ministry of Science and Technology (ACCA21).

1.4 Report scope

This report provides a summary of the China Australia Geological Storage of CO₂ Project Phase Two (CAGS2) including a list of project activities, achievements, lessons learned, opportunities identified and recommendations.

2 Achievements against milestones

CAGS2 has achieved all project objectives and milestones over the past two and half years, building on the success of the first phase of the project.

CAGS2 organised three technical workshops and two training schools, with an aim to develop and expand ties between Australian and Chinese institutions in the area of CO₂ storage. The workshops and schools focussed on training, knowledge transfer and network building. More than 150 experts, young researchers and college students, from over 30 organisations, participated in the workshops and schools. They proved very successful and received favourable feedback. The majority of presentations, publications, and any other materials resulting from CAGS have been made publicly available through the CAGS bilingual website (www.cagsinfo.net).

CAGS2 coordinated five research projects, focusing on important gaps identified by Chinese researchers and administrators in China's CO₂ storage research program. The objective of these research projects was to assist China to build its capacity for geological storage of CO₂. The research projects increased collaboration between Chinese and Australian organisations and increased research outputs including research papers, publications and conference presentations. Some 29 journal papers and book chapters have been published to date based on CAGS funded research and scientific exchanges.

Ten scientific exchanges were sponsored through CAGS2. The exchanges proved very effective and often fostered further engagement between Chinese and Australian researchers and their host organisations. One of the exchanges represented a historic first ever placement of a Geoscience Australia government official with the Chinese government (China Geological Survey). This is a concrete demonstration of increasing cooperation between the two governments.

Through the technical workshops, training schools, exchange programs, and research projects, CAGS2 has facilitated and supported on-going collaboration between the following research institutions and industry in Australia and China:

Australian organisations:

- Geoscience Australia
- Department of Industry and Science
- CO2CRC
- Global CCS Institute
- CSIRO
- University of New South Wales
- University of Western Australia
- University of Adelaide
- University of Melbourne
- Monash University

- University of Queensland
- Queensland Geothermal Energy Centre of Excellence

Chinese organisations:

- Ministry of Science and Technology (MoST)
- The Administrative Centre for China's Agenda 21, MoST
- Chinese Academy of Sciences (CAS)
- Institute of Rock and Soil Mechanics, CAS
- Institute of Geology and Geophysics, CAS
- China Geological Survey (CGS)
- Centre for Hydrogeology and Environmental Geology Survey, CGS
- Center for Hydrogeology & Environmental Planning
- Ministry of Environmental Protection
- Chinese Academy of Environmental Planning
- China University of Geosciences (Wuhan)
- Tsinghua University
- China National Petroleum Corporation
- Sichuan Clean Development Mechanism Center
- Xinjiang University
- Productivity Centre of Jiangsu Province
- PetroChina
- Sinopec
- South China Sea Institute of Oceanology
- Chinese Academy of Sciences with the National Marine Monitoring Center
- State Oceanic Administration of China
- China University of Petroleum
- Beijing University
- China National Offshore Oil Corporation
- Qingdao Institute of Marine Geology
- Guangzhou Institute of Energy Conversion, CAS
- China University of Petroleum
- Sinopec Petroleum Research Institute
- Jilin University
- Shanghai Advanced Research Institute, CAS
- Chengdu University of Technology

GA undertook a bilingual online survey in mid 2014 to assess the effectiveness of the CAGS program. The survey results provided further evidence that CAGS2 has achieved its outcomes. Feedback from Chinese participants indicated a strong desire to continue the relationship with Australia. Participants valued the opportunity to learn from and interact with international CCS experts and to establish collaborations with Chinese organisations as well as with Australia. Participants also commented that participation in CAGS activities promoted CCS within Chinese institutions and initiated new research activities. The survey also sought ideas and suggestions from participants on research areas that could be explored for future cooperation between Australia and China. Detailed discussions were held at the final workshop on future collaborative opportunities and areas identified include: environmental monitoring, storage site selection, groundwater studies, CCS policy/regulation, and a research program centred on a demonstration project in Xinjiang Province.

2.1 Contribution to CCUS in China

CAGS2, building on the first phase of the project, continued to have impact on the research and development of geological storage in China. CAGS has been a catalyst for attracting additional CCS funding for research activities (at least A\$700,000) including two projects funded under the China Clean Development Mechanism Fund.

CAGS2 funded research projects have had a tangible impact on CCUS in China. The Ministry of Environmental Protection took the first steps to implement a national approach to environmental regulation of CCUS projects with the release of a Notice to strengthen the environmental protection requirements for CCUS pilot and demonstration projects, based on scientific input from Research Project 4 “Key parameters for environmental impact and risk assessment for CO₂ geological sequestration”. Another project investigated CO₂ enhanced shale gas recovery technology as an emerging technology providing an alternative for CO₂ storage and shale gas recovery. “Possibility and potential of CO₂-enhanced shale gas recovery in the Ordos Basin” is the first basin scale technology feasibility research of ESGR in China. With CAGS2 support, research has been conducted to develop a target scale evaluation and screening method for assessing CO₂ geological storage using a comprehensive index system, using the Sichuan Basin on CO₂ geological storage as a case study. CAGS2 supported preparation of the first preliminary CCUS roadmap for the Xinjiang province. Xinjiang is a priority area for developing western China and has large fossil fuel resources. Large-scale implementation of CCUS is considered one of the most promising solutions for maintaining economic development in the province while reducing carbon emissions.

Based on the feedback from ACCA21, CAGS has potentially helped accelerate the development and deployment of geological storage of CO₂ in China. The Chinese Government is keen to further develop CCUS and has adopted a series of steps in policy making, R&D, capacity building and international cooperation. Four CAGS affiliated researchers were among six experts that provided input on the “storage section” of the 12th Five-Year plan for Scientific and Technological Development of Carbon Capture, Utilization and Storage, which lays out the technical policy priorities for R&D and demonstration of CCUS technology. The plan was launched in July, 2012.

Dr Sun Chengyong, Deputy Director General of Department of Social Development, Ministry of Science and Technology, China expressed in a letter to the Deputy Secretary of the Department of Industry his thanks to the Australian Government for its support of the CAGS project and noted CAGS’s substantial contribution to China’s CCUS policy and capacity building. In the letter it stated that “The Chinese Government considers CAGS a successful bilateral cooperation” and “is one of the best International CCUS Project within MOST”.

3 Summary of Project Funded Activities

3.1 Program 1: Workshops and Schools

3.1.1 Workshop 1, May 2013, Melbourne

The first technical workshop was on monitoring for the geological storage of CO₂ was held in Melbourne, Australia from 7 to 10 May 2013, and included a site visit to the CO2CRC Otway Project and Energy Australia's Iona Gas Plant. The workshop was organised and hosted by GA with assistance from ACCA21.

The workshop helped to facilitate the building of networks of researchers, government and industry within China and between China, Australia and international agencies to advance development and understanding of geological storage of CO₂. Moreover, it promoted exploration and discussion of technical issues associated with the monitoring and verification of geological storage.



Figure 1. CAGS2 workshop 1 participants.

More than 20 delegates from Australia and China participated in the workshop. Selected participants were invited to share their knowledge and experience through presentations. Following the three-day workshop, a group of Chinese delegates visited the CO2CRC Otway Project and Iona Gas Plant in south-western Victoria. Chinese researchers were impressed by the monitoring techniques and equipment used in the Otway Project, and appreciated the opportunity to visit both sites.

3.1.2 School 1, October 2013, Chengdu

The first geological storage of CO₂ training school was held in Chengdu, China from 14 to 17 October 2013. The school was hosted by the Sichuan Clean Development Mechanism Center, with assistance from ACCA21 and GA.

The training school was attended by 30 students and a total of 15 speakers from China, Australia, UK, USA and New Zealand presented at the training school.

The school was divided into five sessions covering aspects of CO₂ geological storage. Each session was followed by group discussions. The students actively engaged in discussing CCS related issues,

including social acceptance, technical difficulties, and safety concerns. Many students asked questions, shared their experience, and sometimes proposed innovative solutions.

Feedback received was positive and the training school was regarded as a great learning, knowledge sharing and networking opportunity for participating students and experts.



Figure 2. CAGS2 training school 1 participants

3.1.3 Workshop 2, May 2014, Shanghai

CAGS2 Workshop 2 was hosted by the Shanghai Advanced Research Institute in Shanghai from 11 to 13 May 2014. It was attended by approximately 50 delegates from China, Australia, USA and UK. The main participating organisations from China included: China's Ministry of Science and Technology, ACCA21, Shanghai Advanced Research Institute, Chinese Academy of Sciences, Center for Hydrogeology & Environmental Planning, China University of Geosciences (Wuhan), Institute of Rock and Soil Mechanics, China Academy of Sciences, and Xinjiang University. International organisations participating in the workshop included: Geoscience Australia, Global CCS Institute, CO2CRC, Australian National Low Emissions Coal Research and Development, British Geological Survey and the University of Texas at Austin.

The workshop covered various aspects of the geological storage of CO₂ and a session was dedicated to reporting on the five CAGS-funded research projects. The workshop was held in English and Chinese, with excellent simultaneous interpretation service. The participants were able to contribute to lively discussions in their native languages.



Figure 3. CAGS2 Workshop 2 participants.

Feedback from participants indicated that the event was successful in bringing together Chinese and international researchers and providing updates on storage projects (experimental as well as demonstration) being conducted around the world. The GCCSI presentation illustrated the difficulty of getting projects to final investment decision but remained optimistic about the potential for new

projects. The Gorgon CO₂ Injection Project is being watched with keen interest as it will be the world's largest storage project by annual injected volume once it commences.

3.1.4 School 2, May 2014, Nanjing

The second geological storage of CO₂ training school was held in Nanjing, China from 14 to 17 May 2014. The school was hosted by the Productivity Center of Jiangsu Province, with assistance from the ACCA21 and GA.

The training school was attended by 50 delegates, including 30 students and 20 experts. The 18 presentations given at the school were divided into 5 sessions covering a wide range of CO₂ geological storage topics, including:

- CCUS overview;
- onshore and offshore geological storage and capacity assessment;
- risk assessment and monitoring;
- CCS social and economic issues; and
- current CCS projects.

The school was conducted in English and the Chinese students demonstrated excellent English skills in the training school. Even though some students found expressing their ideas in English quite demanding, they embraced this challenge.

All attendees actively participated in the school. Several students expressed openly that they gained valuable knowledge from the school. One student commented the training school made her realise that CCS technology was no longer "pie in the sky". While the students appreciated this opportunity to learn directly from CCS experts, the presenters were impressed by the students' enthusiasm and innovative ideas. Formal evaluation conducted at the end of the school showed a high level of satisfaction at the content, structure and logistics of the school.

All workshops and schools programs and presentations can be found at www.cagsinfo.net.



Figure 4. CAGS2 training school 2 participants.

3.1.5 Workshop 3, November 2014, China

CAGS2 Workshop 3 was held in Wuhan from 18 to 20 November 2014 to wrap up the project and discuss opportunities for future Australia-China engagement in the geological storage of CO₂. The workshop was hosted by China University of Geosciences (Wuhan).

The workshop was attended by about 30 delegates from Australia and China. Selected participants were invited to share their knowledge and expertise during the workshop. Presenters from China included the ACCA21 (under MOST), Center for Hydrogeology & Environmental Geology Survey (under China Geological Survey), China University of Geosciences (Wuhan), Institute of Rock and Soil Mechanics (under Chinese Academy of Sciences), Xinjiang University, Shangxi Yangchang Petroleum Group, Sinopec Petroleum Engineering & Consulting Corporation, Institute of Huaneng Clean Energy Research and China CBM Group. Overseas participants included the Department of Industry, GA, and Global CCS Institute.

The workshop covered the current status of CCS and projects in China and Australia, final reporting from five research projects and CAGS achievements and impact. An open floor discussion was held at the end of the workshop on possible future collaborations between Australia and China. This was a lively discussion and many new opportunities for collaboration and ongoing engagement were identified.

Feedback from Chinese participants indicated a strong desire to continue the collaboration on capacity building in CCS with Australia and there appears a willingness for co-funding of future programs. Possible future collaboration areas include environmental monitoring, storage site selection, groundwater studies, CCS policy/regulation, and a research program centred on a demonstration project in Xinjiang Province. The workshop was highly successful in achieving its desired outcomes. In the words of Dr Peng, Deputy Director General of ACCA21, “CAGS – China Australia Great Success!”.

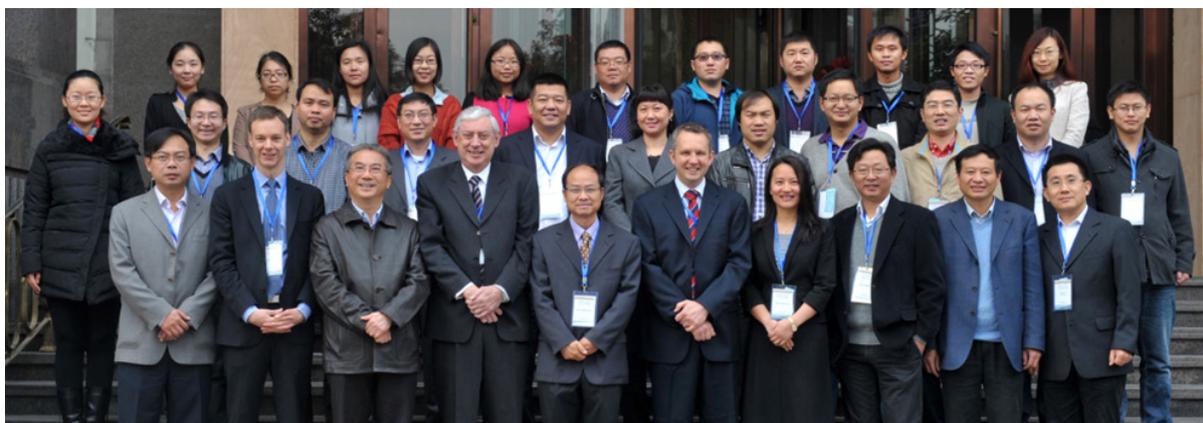


Figure 5. CAGS2 Workshop 3 participants.

3.2 Program 2: Scientific Exchanges

3.2.1 Mr Guodong Yang: 7 May – 9 August 2013

Mr Guodong Yang, a PhD student from China University of Geosciences (Wuhan), worked with staff from the Queensland Geothermal Energy Centre of Excellence at the University of Queensland on the advanced technologies of CO₂ geological sequestration and geothermal utilization. His study aimed to address climate change and improve the economic and environmental delivery of geothermal energy.

Before embarking on his exchange, he participated at CAGS2 Workshop 1 in Melbourne and visited the CO2CRC Otway Project demonstration site. Yang also attended the Queensland Geothermal

Workshop in Brisbane. He presented his findings and shared his exchange experience at CAGS2 School 1 in Chengdu.



Figure 6. Guodong Yang (left) with researchers from the Queensland Geothermal Energy Centre of Excellence.

3.2.2 Ms Hui Zhang: 26 August – 29 November 2013

Hui Zhang, a researcher from the Center for Hydrogeology and Environmental Geology Survey, China Geological Survey, worked with the staff from the Geoscience Australia to study monitoring technologies and the impact of high concentrations of CO₂ on plant health. Ms Zhang collected plant samples from the GA-CO2CRC Ginninderra greenhouse gas controlled release facility in Canberra and analysed the effects of artificial CO₂ release on plants.

During her exchange, Ms Zhang also attended the IEAGHG Combined Monitoring and Environmental Research Network Meeting in Canberra and attended meetings with researchers from the University of New South Wales in Sydney.



Figure 7. Hui Zhang working at Geoscience Australia.

3.2.3 Dr Keyu Liu: 31 August – 30 December 2013

Dr Keyu Liu, a senior research scientist from the CSIRO Earth Science and Resource Engineering Division, worked with staff from the Research Institute of Petroleum Exploration and Development (RIPED) in Beijing on the physical and numerical simulations of CO₂-rock interaction under reservoir conditions with specific reference to CO₂ storage.

During his visit, he also chaired a discussion session at the AAPG/SEPM/PetroChina/CUP Joint Research Symposium in Beijing in September 2013. Dr Liu's exchange resulted in ongoing collaboration between CSIRO and RIPED.



Figure 8. Dr Keyu Liu giving a conference presentation.

3.2.4 Ms Le Zhang: 21 October –5 December 2013

Le Zhang, a postgraduate student from the Institute of Engineering Thermal Physics at Tsinghua University, undertook her exchange at the Department of Civil Engineering at Monash University. During her exchange, she explored the thermo-hydro-mechanical model of rocks and created the fundamental simulation methods using COMSOL Multiphysics software (i.e. the numerical simulations of uniaxial compression test, triaxial compression test, HM coupling, TM coupling, THM coupling of rocks).

Her final report presented numerous numerical simulation models implemented with COMSOL Multiphysics software, which should be very useful in the field of Carbon Capture and Storage (CCS), Enhanced Geothermal System (EGS).



Figure 9. Le Zhang in front of Monash University's Civil Engineering Department.

3.2.5 Dr Ning Wei: 21 October – 20 November 2013

Ning Wei, a researcher from the Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, worked at CSIRO Earth Science and Resource Engineering on numerical modelling and performance evaluation based on site monitoring data. He focused specifically on data collected from the U-tube sampling system. During his visit, Wei met and shared knowledge with other experts at CSIRO. He also attended the 7th JCG meeting in Melbourne in October 2013.

Dr Wei investigated the preliminary simulations on the migration process of N_2/CO_2 mixture in an aquifer and summarised his results of the co-injection in his report.



Figure 10. Ning Wei with staff at CSIRO.

3.2.6 Dr Lancui Liu: 23 October – 29 November 2013

Lancui Liu, a researcher from the Chinese Academy of Environmental Planning, worked with staff from the Energy Advice Group at Geoscience Australia on evaluation range, rank or risk assessment level of environmental impact assessment, and environmental risk management for CO_2 geological storage.

During her exchange, she undertook research to identify the key parameters for environmental risk assessment for CO_2 geological storage, reviewed the regulations for these parameters, and developed suggestions for environmental risk assessment of CO_2 geological storage in China.



Figure 11. Dr Liu working at Geoscience Australia.

3.2.7 Ms Shu Wang: 7 April – 4 July 2014

Shu Wang, a post-doctoral researcher from the Institute of Geology and Geophysics, Chinese Academy of Sciences, worked at the Peter Cook Centre for CCS Research at the University of Melbourne. Due to the unavailability of the X-ray computed tomography (CT) laboratory at the centre, her original plan to experiment on the cores of Ravensdale Group of the Darling Basin in NSW was changed to studying the relationship between the mineral composition and other properties of the rocks, which contributed to a larger research project led by Professor Haese.



Figure 12. Shu Wang.

3.2.8 Mr Xiaocheng Wei: 7 April – 4 July 2014

Xiaocheng Wei, a PhD student from the Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, undertook training at the Earth Systems Science Computational Centre at the University of Queensland. He analysed the risk of induced seismicity due to CO₂ injection, studying data from the Ordos Basin in China. He also examined the effects of a variety of controlling factors for fault reactivity and relative magnitude of seismicity.

His findings are being prepared for a paper, investigating the numerical simulation of fault reactivation and induced seismicity in the Ordos Basin.



Figure 13. Xiaocheng Wei at the University of Queensland.

3.2.9 Dr Yinxiang Cui: 1 June - 30 July 2014

Dr. Yinxiang Cui, a researcher from the Institute of Rock and Soil Mechanics, worked with Dr Linlin Ge at The University of New South Wales on the application of InSAR techniques to monitoring ground deformation due to CO₂ storage. He targeted the CCS Project in the Ordos Basin and an iron mine in Hainan in China for his analysis of the advantages and disadvantages of the different monitoring techniques, evaluating the precision of the InSAR monitoring technique in the different working conditions.



Figure 14. Dr. Yinxiang Cui enjoying his time in Sydney and the University of New South Wales.

3.2.10 Mr Ivan Schroder: 22 September – 21 October 2014

Ivan Schroder, a geoscientist from Geoscience Australia, worked at the Center for Hydrogeology and Environmental Geology Survey, China Geological Survey. The objective of his exchange was to engage with the researchers and agencies conducting CCS monitoring research and pilot projects within China, and investigate monitoring techniques used at Chinese projects. He also tested the feasibility and suitability of additional monitoring techniques at Chinese sites and explored opportunities for future collaborative research.



Figure 15. Ivan Schroder undertaking CO₂ soil flux monitoring at the Qinghai research centre in China.

3.3 Program 3: Research Projects

3.3.1 Research Project 1: CO₂ geological storage: Target area selection and evaluation method

Organisation: Centre for Hydrogeology and Environmental Geology Survey, China Geological Survey

Objectives: The aim of this project was to investigate the screening methods and the selection criteria for ranking target areas for CO₂ geological storage by evaluating a number of favourable regions in the Sichuan Basin. The study aimed to provide one or two case studies for typical target areas using the key evaluation criteria.

Project summary: An evaluation of the suitability of different target areas for geological storage of CO₂ within the Sichuan Basin was conducted. The Sichuan basin is the fourth largest sedimentary basin in China and is an important shale gas and, potentially, CO₂ storage resource.

The evaluation method used an analytic hierarchy process (AHP) to assist with the decision making processes. The first step identified four broad relevant categories: safety; reservoir quality; social-economic and environmental factors; and economic factors. Within each of the broad categories there were multiple indicators (e.g. caprock depth, population density, reservoir thickness, transport distances) and these were assigned a qualitative ranking of good, medium or poor. In total, 44 different indicators were used. The method then used expert scorings to weight the different indices.

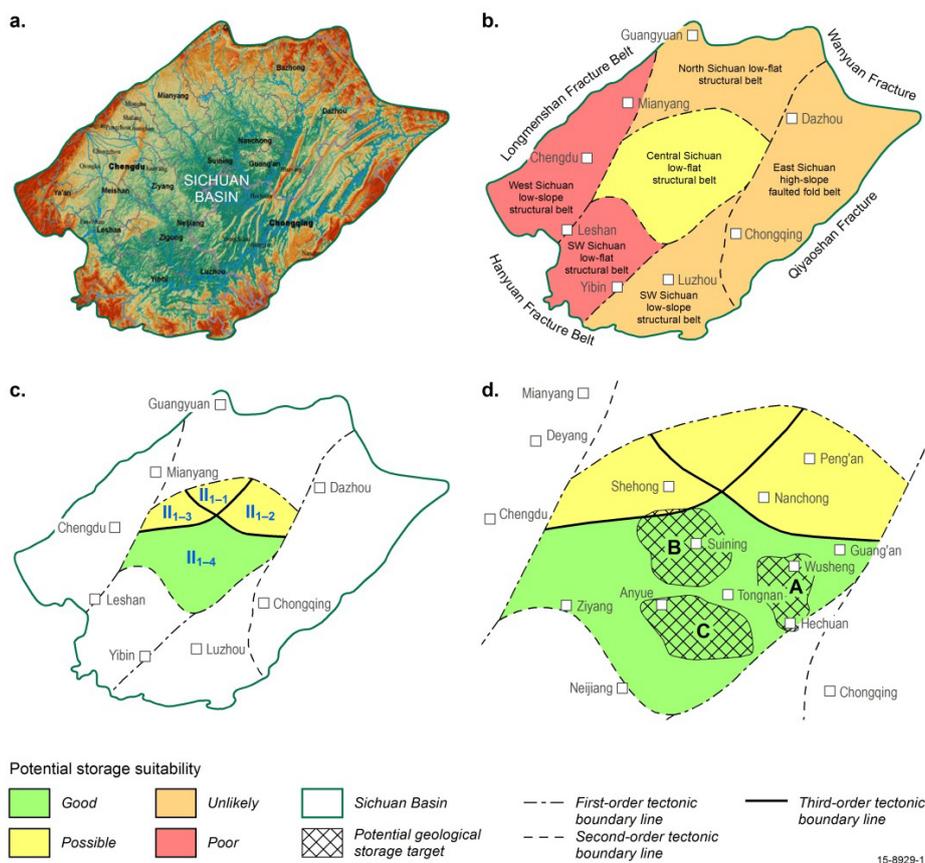


Figure 16. Potential geological storage targets within the Sichuan Basin. A: Sichuan Basin; B: Geotectonic Units within the Sichuan Basin; C: Suitability assessment within the most prospective geotectonic unit; D: Potential targets for geological storage (A: Hechuan-Wusheng-Target; B: Suining Target; C: Anyue-Tongnan Target).

Key findings: The Suining target, within the Central Sichuan tectonic unit, was identified as the most suitable target for CO₂ geological storage within the Sichuan Basin, followed by Hechuan-Wusheng target, and then the Anyue-Tongnan target. The preliminary screening study concluded that the Sichuan Basin has a medium level suitability for geological storage of CO₂, but additional societal considerations (such as high population centres) make the storage at the identified target areas potentially infeasible.

3.3.2 Research Project 2: Possibility and potential of CO₂ enhanced shale gas recovery in the Ordos Basin

Organisations: China University of Geosciences (Wuhan) and Tsinghua University.

Objectives: CO₂ enhanced shale gas recovery (ESGR) is receiving increasing interest, but the feasibility of this new concept has not been established. The aim of this activity is to assess the feasibility, potential and suitability of applying ESGR in the Ordos Basin by studying the interaction between CO₂ and shale formations, taking into account the geological conditions of the basin. The outcome of this study aimed to provide a basis to assist government policy makers and industry investors.

Project Summary: This project assessed the potential for CO₂ enhanced shale gas recovery in the Ordos Basin through a combination of laboratory tests, modelling and desktop assessments. China

has recently started exploration drilling for shale gas in the Ordos Basin and has obtained good gas production recoveries from the Chang 7 shale interval of the Yanchang Formation in Ganquan, in the southern part of the Basin. A sample of the Chang 7 interval was used to evaluate enhanced shale gas recovery potential in the laboratory studies.

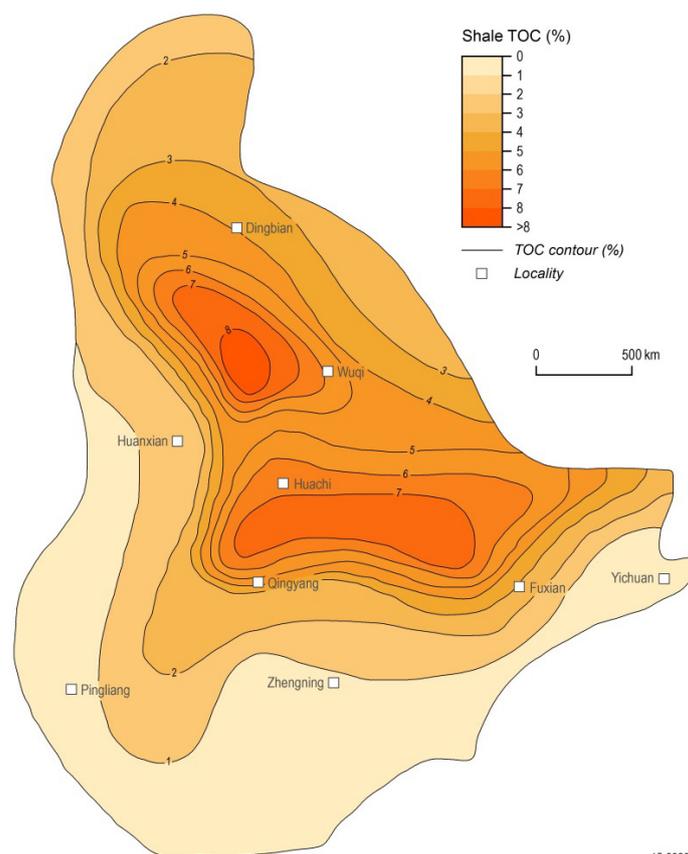


Figure 17. A percentage shale total organic carbon (TOC) contour map of the Yanchang formation in the Ordos Basin, a target for CO₂ enhanced shale gas recovery.

The laboratory tests were used to generate adsorption isotherms for CH₄, CO₂ and N₂ and to investigate the degree of enhanced recovery using CO₂. Numerical modelling suggests that CO₂ injection can result in a modest increase in the shale gas recovery through competitive adsorption processes (CO₂ adsorbs more readily than CH₄); however, the major benefit of using CO₂ for enhanced shale gas recovery appears to be replacing water with CO₂ as the fracturing fluid. This has a number of advantages including: lower consumption of water resources, particularly in arid environments; increase drilling efficiency; lowering the environmental impacts of drilling; lower induced seismicity; and storage of CO₂ for climate mitigation purposes. For example, the high levels of water consumption typically required for shale gas recovery may not be feasible for the water scarce Ningxia and Gansu provinces, making gas recovery using CO₂ attractive. Given the co-existence of large CO₂ fossil fuel sources and shale gas resources in the Ordos Basin, enhanced shale gas (ESG) recovery appears to be an attractive option for China. Preliminary analysis suggest that the total shale gas resource of the Ordos Basin is $9.0 \times 10^{12} \text{ m}^3$ and the effective CO₂ storage capacity in the Yanchang formation is $2.1 \times 10^{11} \text{ m}^3$. The Yanchang Oil Company conducted the first ESGR tests in 2013 with great success.

Key findings: Enhanced shale gas (ESG) recovery is receiving increasing attention in China and the first injection trials have started in the Ordos Basin. The results of this study suggest that the Taiyuan group in the north east and middle west parts of the Yanchang group within the Ordos Basin is an optimal CO₂-ESG target.

Please see Appendix 14 for the final report.

3.3.3 Research Project 3: Current status and gaps in essential technology, equipment and material for implementing CO₂ saline aquifer storage projects in China

Organisation: Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

Objectives: The aim of this project was to investigate the current status and to identify the gaps in technology, equipment and material (TEM) required for implementing CO₂ saline aquifer storage projects in China.

Project summary: An evaluation of the status and gaps of China's technology and equipment supplies for implementing CO₂ aquifer storage projects (excluding capture and transportation) was conducted. A systematic process for evaluating technology gaps was developed and applied to a hypothetical 1 Mtpa CO₂, 20 year injection, aquifer storage project in the Ordos Basin. The evaluation involved a review of reports, papers and interviews with experts and key people involved in CCUS projects both in China and internationally. A list of key Chinese enterprises to provide equipment for CO₂ aquifer storage, and a preliminary assessment of their technology readiness, was compiled. Technologies associated with traditional oil and gas activities were identified as mature and there were no major technological barriers to large-scale deployment for CO₂ aquifer storage. Technical gaps in current technology and required performance do exist in other areas however, particularly in monitoring and verification, site evaluation and wellbore integrity. It was identified through a technology readiness level (TRL) assessment that Chinese technology suppliers are not as advanced as other international firms in these key technology areas. Consequently, to support the deployment of CO₂ aquifer storage in China it is recommended that research and development be prioritised to support improvement in the following technologies:

- Geological modelling and prediction tools for managing risk and evaluating storage performance;
- Monitoring, verification and assessment (MVA) technologies for near surface and sub-surface monitoring. More cost effective and reliable large-scale near surface technologies are required and the increasing the long-term reliability and sensitivity of sensors for sub-surface monitoring is a priority;
- Remediation technologies to detect and repair leaks, including intelligent well drilling and advanced cementation technologies.

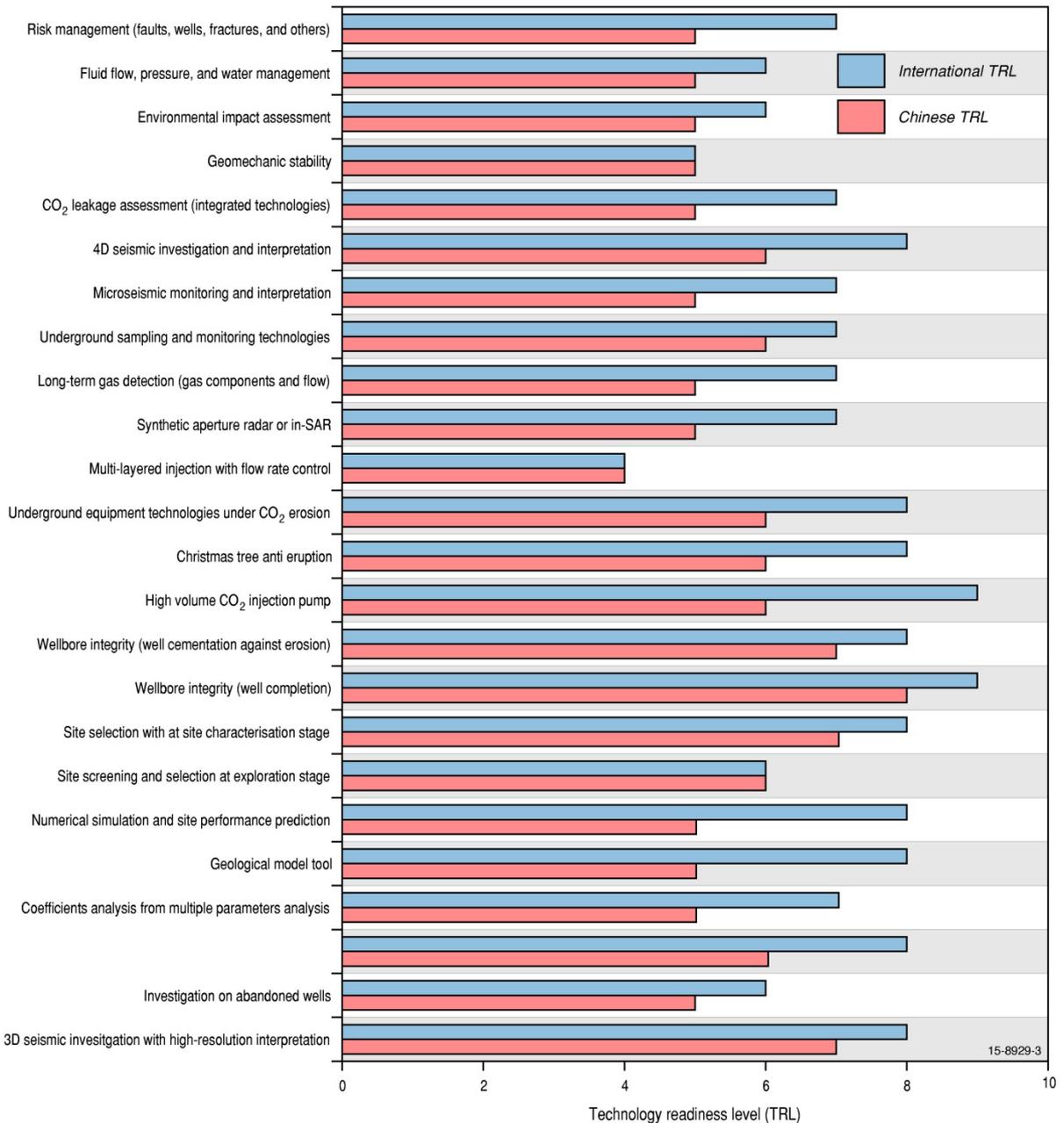


Figure 18. An evaluation of the current Technology Readiness Level (TRL) of key technologies in China and internationally using the US Department of Energy Storage Technology TRL Framework. A TRL of 1 indicates basic research whereas a TRL of 10 indicates commercial deployment.

Key Findings: The evaluation identified gaps in existing technology capability needed to support deployment of CO₂ aquifer storage in China. It has been identified that China lags behind in technology readiness in some areas, particularly geological modelling, monitoring, remediation and integration of technologies. It is recommended to attract more China domestic enterprises to participate in key priority research and development activities and work with international groups to further technology development.

3.3.4 Research Project 4: Key parameters for environmental impact and risk assessment for CO₂ geological storage

Organisations: Chinese Academy for Environmental Planning and the Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

Objectives: The aim of the project, based on the output of CAGS Phase I Research Project 3, was to investigate the key parameters for the assessment of the risk of CO₂ geological storage to the environment. The study aimed to provide a scientific basis for the formulation of strong operational regulations and guidelines to manage CO₂ geological storage risks to health, safety and the environment in China.

Project summary: An evaluation of the suitability of existing technical guidelines for environmental impact assessments for CO₂ geological storage projects in China was undertaken. The EIA procedures applied to the Shenhua Ordos CTL and PetroChina Jilin Oil Field EOR demonstration projects were reviewed and a site visit was conducted at the Shenhua Ordos project. A gap analysis of the appropriate technical guidelines was undertaken and it was concluded that it is difficult, and possibly infeasible, to undertake a comprehensive environmental impact assessment of a CO₂ storage project in China based on the current guidelines. The lack of suitable guidelines for the environmental management of CCUS leads to two main problems: an overestimation or underestimation of the environmental risk (on the enterprise side); and a lack of regulations to supervise the CCUS project (on the government sector side). A list of environmental risk assessment approaches used by different agencies for CO₂ storage was compiled and a comprehensive baseline monitoring framework is presented. Based on recommendations from the project about environmental risk identification and evaluation at CO₂ saline aquifer storage projects, the Ministry of Environmental Protection (MEP) has issued a Notice on Strengthening the Environmental Protection of Pilot and Demonstration Projects for Carbon Capture, Utilization and Storage (HB[2013] No. 101). This seeks to fill the gaps in current technical guidelines.

Key Findings: There is a lack of suitable technical guidelines for environmental management of CCUS projects in China. Based on recommendations from the project, the Ministry of Environmental Protection (MEP) has issued a Notice on Strengthening the Environmental Protection of Pilot and Demonstration Projects for Carbon Capture, Utilization and Storage.

3.3.5 Research Project 5: Study the carbon dioxide capture, utilisation and storage technology and design a roadmap for Xinjiang Province in China

Organisations: Xinjiang University and the Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

Objectives: This research project planned to develop a CCUS roadmap for Xinjiang province by focusing on the local conditions and situations. The Xinjiang roadmap planned to include development vision, stage goals, key directions, priority actions and implementation pathways. This could provide guidance to cover all aspects of CCUS and enhance system integration and demonstration process in Xinjiang.

Project Summary: The Xinjiang Province, located in western China, has the largest reserves of crude oil, natural gas and coal among the provinces in China. It is a key area for the implementation of the western development strategy for China. Economic development in the province has been rapid but is largely based on fossil fuels and has been accompanied by significant environmental pollution. The

main CO₂ emission sources are coal-fired power plants, coal chemical plants, cement plants, fertiliser plants, steel plants, and other industrial sources. As a large number of chemical and coal-fired power plants are in the pipeline, Xinjiang faces the issue of large and increasing CO₂ emissions despite carbon emissions for the province already exceeding the national average. As an autonomous region, Xinjiang has a responsibility and obligation to meet Chinese emission reduction targets. At Conference of Parties (COP 15) to the United Nations Framework Convention on Climate Change meeting in Copenhagen in December 2009, the Chinese government made a commitment to reduce CO₂ emission intensity in 2020 by 40-45% from 2005 levels. As a rapidly developing and fossil fuel intensive region, this commitment is seen as a major challenge for the future development of Xinjiang. Large-scale implementation of CCUS technology is considered one of the most promising solutions to reduce CO₂ emissions while maintaining economic development for the province.

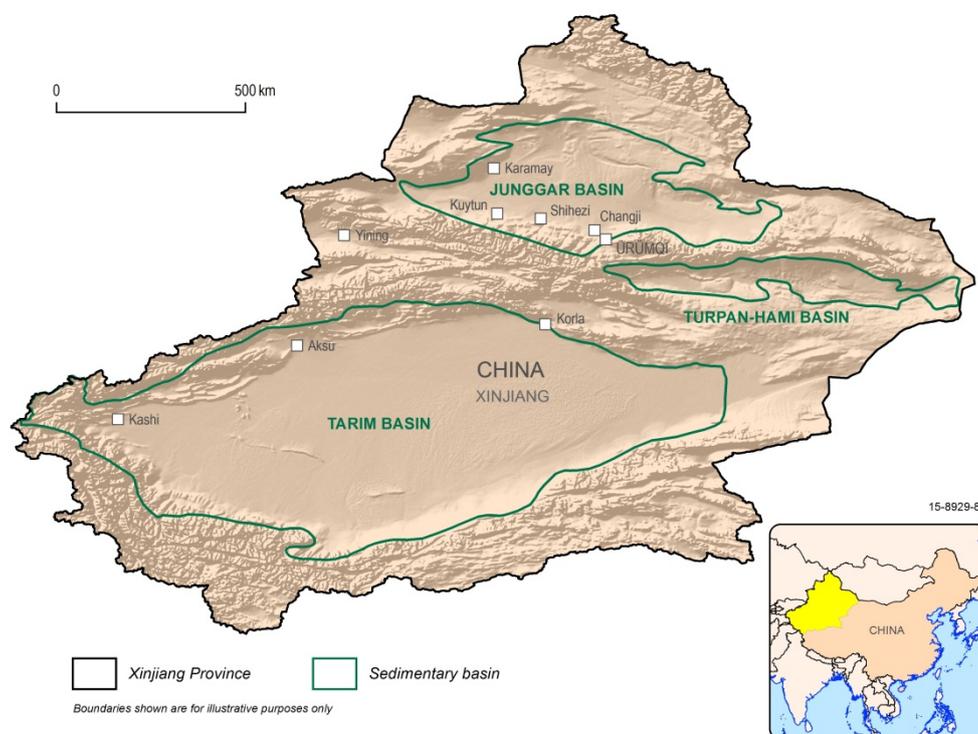


Figure 19. A map of the Xinjiang Province showing the location of Junggar, Tarim and Turpan-Hami sedimentary basins.

Compared with other provinces in China, Xinjiang has a number of advantages for implementing CCUS projects: its vast territory is sparsely populated; CO₂ capture sites are generally concentrated and close to the CO₂ storage sites; the province has experience with oil and gas pipeline infrastructure; and transportation costs are likely to be lower. There are also three large sedimentary basins in the Xinjiang region: the Junggar Basin in the north; the Tarim Basin in the south; and the Turpan-Hami Basin to the east. The Jurassic reservoirs appear to be the most suitable for CO₂ storage in the Junggar and Turpan-Hami basins. The province has a dry climate and freshwater and industrial water resources are scarce; however, there are large saline groundwater resources.

A preliminary recommendation is to conduct CCUS projects in Xinjiang coupled with enhanced water recovery (i.e. desalination of the saline groundwater) to produce potable drinking water and support further industry and agricultural development. Further assessments of the CO₂ storage potential and storage security in Xinjiang are required. It is also recommended that a large CCUS demonstration

project be supported in Xinjiang, near the Zhundong oilfield in the Junggar Basin. This plant would use concentrated CO₂ from nearby chemical industries is planned to begin operation in 2020. The Zhundong site is well characterised, enhanced oil recovery will bring economic benefits and transportation distances are short. The study suggests policies to enhance development of CCUS in Xinjiang, including: making use of the high concentration CO₂ streams from the chemical plants to support a demonstration CCUS-EOR project; better coordination across government departments; incentives to attract capital and business investment; and support of research and development.

Key findings: Xinjiang is a priority area for developing western China. It has large coal, gas and oil reserves and there has been rapid development over the last decade. Commitments by the Chinese government to significantly reduce CO₂ emission intensity by 2020 present a pressing challenge for this province. Large-scale implementation of CCUS is considered one of the most promising solutions for maintaining economic development. Assessment of storage potential is still at an early stage and a more detailed geological storage assessment is urgently required.

3.4 Program 4 – Operations

CAGS2 maintained a strong project management team in Australia and China (GA and ACCA21). The team worked closely to ensure the successful implementation of all project activities. The project team released periodical newsletters to keep stakeholders informed of project progress.

CAGS2 continued disseminating information through the publicly accessible bilingual CAGS website. All CAGS2 activities have been uploaded and essential CAGS1 materials have been archived. Please refer to the CAGS website www.cagsinfo.net for further details.

4 Lessons Learned

Throughout the project implementation, observations have been made on what worked well and what could be improved. The CAGS impact survey provided additional insights from the participants. A list of some of the key lessons learned during the implementation of CAGS is given below:

- Establishing a collaborative working relationship with the project partner is the key to success. Over the past five years, GA and ACCA21 have worked as a team and built a strong cooperative relationship. This relationship has provided a solid foundation for the project implementation. The trust and good will from both sides enabled Australian and Chinese project teams to work together through issues and reach agreements.
- There was a deliberate effort in CAGS2 to be more “hands off” with the research projects and exchanges, compared to CAGS1. We received comments that some of the research projects or exchanges were not well organised by the host. It is recommended that future exchanges or projects maintain a strong central coordination team to ensure projects run smoothly.
- The workshops and schools continue to be an effective mechanism for knowledge exchange and networking. In feedback compiled through the CAGS impact survey, Chinese researchers commented that they are able to deepen their understanding in the latest research and developments in China and overseas and expand their professional networks. The opportunity to interact with Australia and international experts at the CAGS hosted workshops and schools was appreciated by the participants, many of whom do not get the opportunity to attend international conferences and therefore are not exposed to the latest international research developments. The international experts in turn found the workshops and schools valuable because it enabled them to expand their network in China and form new research collaborations. This is an excellent model and should form the basis of any future cooperative program.
- Simultaneous translation services during the workshops were greatly appreciated by the participants and fostered a more collaborative environment and open discussion.
- All surveyed Chinese workshop participants considered that their involvement led to an increased awareness and priority placed on CCS within their organisations, which in some organisations, led to increased funding and resources allocated to CCS research. For Australian and international participants, the capacity building events provided a great opportunity to learn more about Chinese CCS research, often not presented at international conferences, and provided an opportunity to engage with a greater number of Chinese institutions.
- We received feedback that the level of research funding for the projects was fairly modest and could only support non-core activities. There could be greater impact if larger research projects were co-funded that supported active demonstration projects. Nevertheless, the research projects often acted as a catalyst for attracting additional CCS funding.
- The exchanges were generally very successful and led to lectures, publications and sometimes significant new Chinese funding for ongoing collaborative research. Most participants have continued collaboration with their hosts after their exchange.

5 Opportunities

Among many emission reduction technology options, CCS/CCUS is regarded by the Chinese Government as an important new technology that can contribute to achieving low-carbon utilisation of fossil fuels at a large scale, and as a result, the Chinese government has been increasing funding for research and development of CCUS technology.

The CAGS projects have assisted many Australian (and some international) organisations to establish closer ties with the Chinese CCS research community, and future collaborative partnerships to utilise each country's strengths and infrastructure will be of great advantage to advance CCS in each country. CAGS has also facilitated research and policy cooperation between Chinese institutions, drawing on Australian expertise.

Opportunities for further engagement have been identified through the CAGS impact survey results, recommendations from the research projects, contributions from ACCA21, and the final workshop, where an open floor discussion was held on possible future collaborations between Australia and China.

5.1 Research opportunities

A large number of Chinese, international and Australian participants expressed a strong desire to participate in a future Australia-China geological storage of CO₂ collaboration, in both technical research projects and capacity building. There was considerable overlap in the research topics identified for further research, including:

- CCS/CCUS site selection and geological assessments;
- Improving near surface monitoring techniques (i.e. InSAR monitoring system);
- Geological modelling (e.g. reactive transport, geomechanics);
- CCS technical readiness and environmental regulations;
- CCS risk assessments, including evaluation of technical risk and environmental, economic and social impacts; and
- CO₂ geological utilisation (i.e. enhanced shale gas recovery; unconventional gas fracking; mineral extraction; water extraction in dry areas; or geothermal).

A key recommendation from the Chinese partners is that future research should support active CCS projects. A key target area is the Xinjiang province and the planned CCUS demonstration project at the Zhundong oilfield in the Junggar Basin. This could provide Australian researchers the opportunity to work on a fully integrated demonstration project.

5.2 Capacity building opportunities

5.2.1 Public:

CCUS capacity building activities can be organised for the wider public, i.e. CCUS week, teaching CCUS in schools or colleges, producing educational videos for media or online, to create public awareness and acceptance of CCUS. This could be potentially conducted in collaboration with the Global CCS Institute's outreach program.

5.2.2 Policy makers:

Study tours and seminars can be organised for policy makers, to provide a basic knowledge of CCUS and issues related to CCUS, including environmental, regulatory and technology issues. This would also provide an opportunity for policy makers to gain firsthand experience of CCS deployment from successful and advanced CCS projects and technologies.

5.2.3 Stakeholders and business:

Site visits and workshops can be organised to improve stakeholder's engagement with CCUS, i.e. to encourage their early adoption of CCUS technology, to discuss business models, to improve communication, and to eventually establish successful demonstration projects.

5.2.4 Experts:

Workshops and exchanges can be organised for experts to analyse the outcomes of CCUS projects, to share knowledge and to improve technical knowledge of CCUS, to gain international working experience, and to develop new understanding.

5.2.5 Young researchers:

CCUS training schools and site visits can be organised to invite experts to present on CCS technologies, environmental and risk assessment, monitoring technologies, and case studies summarising experience from existing CCUS projects.

5.3 Wider international opportunities

One major factor that has contributed to CAGS's success is the support and contribution received from various international organisations in the UK, USA and New Zealand to share their expertise with Chinese researchers and students. Many international participants understand the sustainability of projects such as CAGS may require co-funding from the Chinese and international partners. A majority of the international participants are willing to contribute financially for their future involvement with Australia-China CCS collaboration activities and this could include salary, in-kind contribution, travel costs, other associated costs. Co-funding opportunities may also be available by engaging with organisations such as the US Department of Energy. In addition to cooperation on research projects, the international partners were willing to assist with capacity building through giving presentations, hosting discussions, and facilitating possible exchange visitors.

6 Conclusions

- CAGS has been a very successful program and there is a strong desire from China to continue the collaboration. There is also a strong desire from Australian researchers to continue the engagement, with a greater willingness to undertake research activities based in China.
- During the course of CAGS1 and CAGS2, China has changed from being a minor player in CCS research to becoming a leader. CAGS can take some credit for this change by facilitating the communication and cooperation between Chinese researchers and government departments. We are starting to see Chinese CCS/CCUS policy undergo similar transformations.
- CAGS has provided Chinese scientists with largely unfettered access to current Australian (and international) CCS research and policy, with opportunities to take home to China learnings and insights for immediate application.
- CAGS has increased the impact and influence of Australian CCS research by influencing the course of China's CCS research and policy. The future actions of China (being a much larger economy than Australia), should, in turn, influence the progress of CCS in other countries.

7 Acknowledgements

The success of CAGS has been due to the generous contributions from many researchers, students and administrators in Australia, China and internationally. We would like to acknowledge, in particular, the contribution by Dr Sizhen Peng from ACCA21 for his support and advice during the project. We would also like to thank the CO2CRC, Energy Australia, the Sichuan Clean Development Center, the Shanghai Advanced Research Institute, the Productivity Center of Jiangsu Province, and the China University of Sciences (Wuhan) for generously hosting the field trips, schools and workshops.

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8 Appendix

8.1 List of publications from CAGS supported research

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