
ANNUAL REPORT 2016

CO₂ CAPTURE PROJECT
CREATING SOLUTIONS FOR
SUSTAINABLE OIL AND GAS



PARTICIPANT ORGANIZATIONS

ABOUT THE CCP

The CO₂ Capture Project (CCP) was formed in 2000 to advance technologies for CO₂ capture and geological storage to help make CCS a viable option for CO₂ mitigation.

CCP is now in its fourth phase of activity, which began in late 2014. The program is planned to last for five years and is driven by four of the world's leading energy companies – BP, Chevron, Petrobras and Suncor – supported by numerous experts.

Today, this group is focused on delivering further progress in CO₂ capture and geological storage technology through research, development and demonstration.

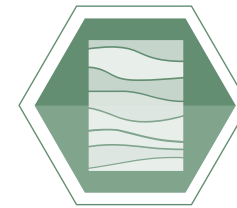
This 2016 Annual Report provides an update from the Teams that make up the CCP – Capture, Storage, Policy & Incentives and Communications.

CCP AIMS:

- To drive down the cost of existing CO₂ capture technologies for future use by the oil, gas and power generation industries, through further technology R&D as well as demonstrations of next-generation technology
- Advancing knowledge of well integrity, natural site characteristics amenable to containment and subsurface processes governing CO₂ trapping
- Adapting subsurface monitoring technologies to track CO₂ underground and developing approaches to respond to out of zone migration of CO₂



CAPTURE



STORAGE



POLICY & INCENTIVES



COMMUNICATIONS

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CHAIRMAN'S INTRODUCTION



Jonathan Forsyth
BP, CCP Chairman

“
As business faces the uncertainties of a changing world, it is encouraging to see how 2016 saw an upswing in interest around CCS.”

Welcome to the 2016 CCP Annual Report. It gives me great pleasure to provide the introduction to this year's Report, which marks the 16th year of CCP's continuing work.

We are now well into our stride on our fourth phase of activity – CCP4. I hope that the following pages will provide you with an interesting overview of some of the main projects being carried out by our Storage, Capture, Policy and Communications teams as we seek to advance the development of CCS technologies and understanding.

Our decision to switch to a digital/online report only last year has been welcomed by our readers so we are continuing with the format. More information about CCP and our projects can be found at www.co2captureproject.org, where registrants can also make requests and provide feedback on any aspect of CCP's work.

As business faces the uncertainties of a changing world, it is encouraging to see how 2016 saw an upswing in interest around CCS. This came off the back of renewed international commitment to tackling climate change, as witnessed in the ratification and coming into force during 2016 of the Paris Agreement. The energy transition to a lower carbon world is already well underway and certainly CCP member companies are looking closely at how CCS can be a part of their portfolios to support delivery against the increasing demand for low or zero carbon energy.

As CCP, our aim is to orientate our programme to provide our members with what they need in regard to future CCS development in the face of potential societal needs and legislative requirements.

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“

The ability to steer a steady course will be vital, and collaboration and partnership will also be very important.”

Of course, there remain many challenges for CCS, but we must hold true to our long-term vision. All players in the energy and CCS industries must work extremely hard, not only from a technology development perspective, but crucially with policy makers to help create the market structures that will incentivise investment. The ability to steer a steady course will be vital, and collaboration and partnership will also be very important. The emergence of new industry alliances will support that aim.

As far as CCP is concerned, our primary goal remains to drive down cost, particularly of capture. Renewables are making great strides in doing the same and we really have to step up to the mark. To this end, our Capture and Storage programmes delivered some important work and results in 2016.

This included insightful work into novel capture technologies and the completion of a natural gas treating study as well as a strong range of storage projects, from CO₂ leakage mitigation remediation technologies to cost analyses.

Another highlight of the year was CCP’s participation at the GHGT-13 conference in Lausanne, Switzerland. We were honoured to be among those selected to host a Technical Plenary Session on the achievements of CCP and were also involved in hosting a number of other technical and poster sessions and a site visit to our storage demonstration at Mont Terri.

At the end of 2016, we said farewell to one of our long-standing members, Suncor, and I would like to take this opportunity to thank them for all of their support over the years. As CCP moves through 2017 and beyond,

I would like to encourage others with an interest in CCS – whether industry, academia or governmental – to engage with us and share in our work.

Apart from our member companies, a range of diverse organisations is partnering with us on various projects – including the United States Department of Energy (through Lawrence Berkeley National Laboratory); the Swiss Federal Office of Topography; the Politecnico di Milano; the University of Texas Bureau of Economic Geology; Stanford University; and the Petroleum Technology Research Centre of Saskatchewan. Valued collaborations like these will play a key role in ensuring a bright future for both CCP and CCS as a whole.

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CCP4 CAPTURE PROGRAM

2016 OVERVIEW

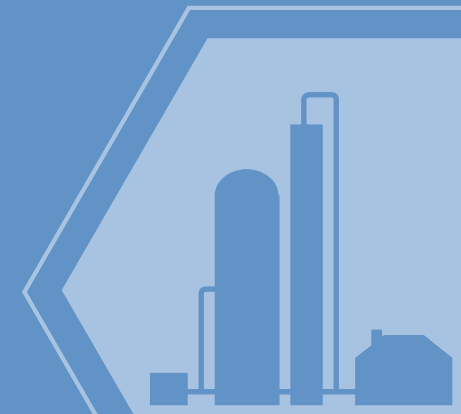
The CCP4 Capture program in 2016 saw the steady progression of a range of projects, including the completion of the first initiative in the newly defined CCP scenario of natural gas treating.

The potential of step-out novel capture technologies continues to be evaluated. The Capture Team is working towards developing a pilot project targeting CO₂ removal from either flue gas, syngas or natural gas streams.

“The CCP Capture Team was pleased to complete the landscaping study as the first piece of work in the natural gas treating scenario – this will provide a useful addition to current knowledge. As we move through CCP4, the aim is to progress existing initiatives and identify additional pilot/demo-scale opportunities to support their development and drive down the cost of CO₂ capture.”

Raja Jadhav,
Chevron, Capture Team Lead

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CCP4 SCENARIOS

2016 OVERVIEW

The Capture program consists of four key scenarios. Much of the work has focused on applications in refining operations, heavy oil extraction and natural gas combined cycle (NGCC) power generation. Capture from natural gas extraction is the latest scenario for CCP4.

Technical factsheets of previous work are available to download:



If you are unable to download the factsheets, they can be accessed from the **Brochures and Reports** page in the **Media & Resources** section at www.co2captureproject.org

▲ *Images courtesy of Shutterstock, BP and Suncor*

PROJECT: NOVEL CAPTURE TECHNOLOGIES

STATUS: WORK PACKAGE (WP) 1 COMPLETED
 WP2 COMPLETION EXPECTED MID-2017

The initial techno-economic assessment by LEAP (Laboratorio Energia e Ambiente, Milan) of five novel capture technologies for the NGCC scenario was completed early in 2016, bringing WP1 to a conclusion.

Two technologies were chosen for further development in WP2:

- Molten carbonate fuel cell (MCFC) was found to have the lowest CO₂ avoided costs, primarily because it produces additional power at higher efficiency compared to the NGCC plant, while also purifying the exhaust CO₂ stream.
- The high-pressure solvent absorption option (Pi-CO₂) with a novel hybrid membrane configuration showed economic potential.

The scope of work for WP2 included:

- A more detailed analysis of MCFC application to post-combustion CO₂ capture from natural gas fired processes, considering both integrated and non-integrated configurations. Perform sensitivity and optimization studies e.g. different CO₂ concentrations, capture levels, current densities, etc. Identify key feasibility challenges in the practical application of the HRSG design.
- Development of a High Pressure Aqueous Solvent CO₂ capture process (based on Pi-CO₂ concept) and membrane hybrid case.

▲ Novel capture technology summary table

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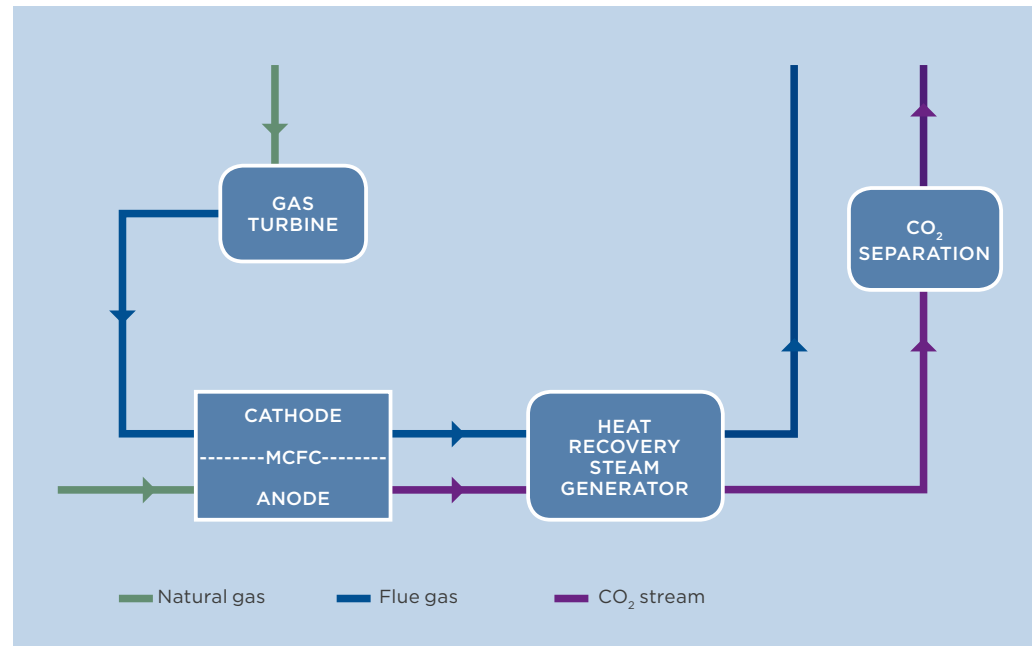
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PROJECT: NOVEL CAPTURE TECHNOLOGIES

WP2 CONTINUED

The membrane hybrid configuration of Pi-CO₂ technology was evaluated and the avoided cost was estimated to be lower than the non-hybrid configuration, but still higher than the base amine case.

Evaluation of a retrofit or non-integrated application for MCFC is underway. Four process configurations with different levels of syngas recycle have been evaluated, and the LEAP team is currently working on developing an optimized process configuration with CO₂ avoided cost as a parameter.



▲ Simplified look at capture scheme using molten carbonate fuel cells

PROJECT: NATURAL GAS TREATING STUDY

STATUS: COMPLETE

The first project under CCP4's newly introduced scenario of CO₂ removal from extracted natural gas was completed in 2016.

The objective of the natural gas treating landscape study was to gain fuller understanding of state-of-the-art technologies for separating CO₂ from natural gas in an offshore environment and to identify potential technology development projects.

An initial screening study identified numerous technologies – including solvents (physical and chemical), membranes, cryogenics, sorbents – which were then ranked by a number of criteria including technical applicability, Technology Readiness Level (TRL), Risks, Capex and Opex.

The main conclusions of the study were:

- Product specifications, product values and utility costs have a significant impact on the outcomes
- For 6% and 20% CO₂ feed natural gas streams, the relatively tight natural gas and CO₂ product specifications were shown to favour solvent-based processes over membranes – primarily due to the higher hydrocarbon recovery with solvent-based processes
- For the rich natural gas case with 60% CO₂, membranes had higher hydrocarbon recovery and superior estimated economic performance

A number of these technologies were then shortlisted for potential development into a future pilot study. Discussions are ongoing with potential partners to establish which of these might be a suitable choice for future development under the CCP program.

PILOT-SCALE TESTING STATUS: Ongoing

The Capture Team is working towards developing a pilot project targeting CO₂ removal from either flue gas, syngas or natural gas streams. A number of technologies have been identified and the discussions are progressing on finalizing the scope and obtaining additional co-funding from external parties.

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CCP4 STORAGE, MONITORING & VERIFICATION PROGRAM

2016 OVERVIEW

A series of technical and logistical challenges was managed by the CCP Storage, Monitoring & Verification (SMV) Team in 2016. Delays from external factors and the inherent novelty of project work, however, did not prevent progress from continuing on a range of projects aimed at building knowledge, developing technologies and mitigating risk around the storage of CO₂.

Several project developments were accomplished with notable results over the course of the year. In addition, a number of new initiatives have been identified which will be fully underway during 2017.

“

We have a robust and wide-ranging portfolio of projects in play, from CO₂ leakage mitigation technologies to cost analyses. Over the course of the next three years, these will come to fruition and provide us with rich learnings and insights to support our understanding of secure CO₂ storage.”

Scott Imbus,
Chevron, SMV Team Lead

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CCP4 STORAGE THEMES

2016 OVERVIEW

The Storage program involves activity from fundamental and applied R&D to field deployment of instrumentation. The three themes of work focus on security of storage, field trialing and storage assurance.

Technical factsheets of previous work are available to download:



If you are unable to download the factsheets, they can be accessed from the **Brochures and Reports** page in the **Media & Resources** section at www.co2captureproject.org

▲ *Image courtesy of The University of Texas Bureau of Economic Geology*

PROJECT: WELL SEALING EXPERIMENT

STATUS: COMPLETION EXPECTED 2017

CCP's involvement with the well sealing experiment at Mont Terri, Switzerland continued during 2016, following well installation and pressure testing. The overall objective is to test novel sealants for their ability to treat unexpected, small but persistent migration of CO₂ from wells. The Mont Terri rock laboratory is an underground research facility where such experiments can be carried out in-situ in the Opalinus Clay formation.

The main focus in the last year was on inducing fractures (via heat stimulation) and tracer tests to characterize fracture volume and geometry. Three novel sealants, capable of reaching small voids otherwise not accessible in wells, have been selected for testing. Two of these sealants can be triggered by the chemistry of water already present (or injected) and one sets over a period of time.

Detailed tracer testing was a key intervention proposed by CCP4 for the overall project and has been instrumental in establishing a better understanding by the team of the fracture paths created by the heat stimulation. However, some issues around the integrity of the upper part of the well have been identified, and final tracer testing and analysis is underway that will help identify routes forward. The project has been slowed as a result of this and sealant testing is therefore not envisaged until the first half of 2017.

This important work continues to receive wider attention. A visit to the Mont Terri site took place to coincide with the GHGT-13 conference in November and was attended by invitees from IEAGHG, US DoE and Norwegian CCS (SINTEF). A technical poster session on the progress of the project was also given at the same conference.



▲ Technical poster of the project presented at GHGT-13

PROJECT: EOR AS DE FACTO STORAGE

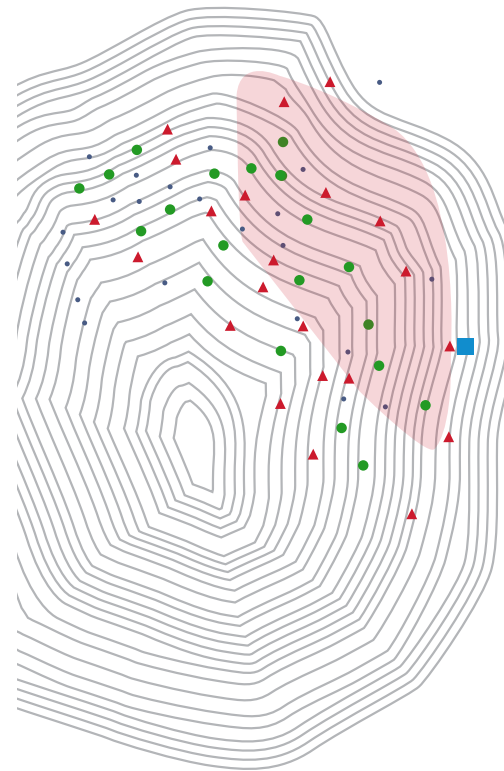
STATUS: COMPLETION EXPECTED MID-2017

The CCP4 project to quantify the extent to which CO₂ EOR constitutes de facto CO₂ storage got fully underway in 2016, with the University of Texas Bureau of Economic Geology (UT-BEG) conducting initial modelling using newly acquired relative permeability (Krel) data.

The Cranfield field site in Mississippi (USA) is being used as the test case to ultimately estimate how much CO₂ is trapped over the course of the CO₂ EOR process. The study includes a 'history match' simulation, incorporating an earlier water flood, followed by analysis of the CO₂ EOR flood. Additional funding has been secured by UT-BEG from the US DoE, which will allow the work to be enhanced with rock/fluid analyses, with enhancements including

relative permeability measurements, improved history match through possible addition of 4D seismic data and longer term simulations.

The results of the first stage of relative permeability experiments suggests high levels of super-critical CO₂, possibly related to channelling of CO₂. Re-testing is required in order to gain better understanding and the completion date for the project has been extended into 2017 as a result.



- ▲ Injection wells
- Sample wells
- Abandoned wells
- Observation well
- ▲ Area of study (shaded in red) of testing CO₂ EOR as de facto storage at Cranfield site, Mississippi, USA.

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SELECTED PROJECTS AND NEW INITIATIVES

AQUISTORE ELECTROMAGNETIC MONITORING CAPABILITY STUDY

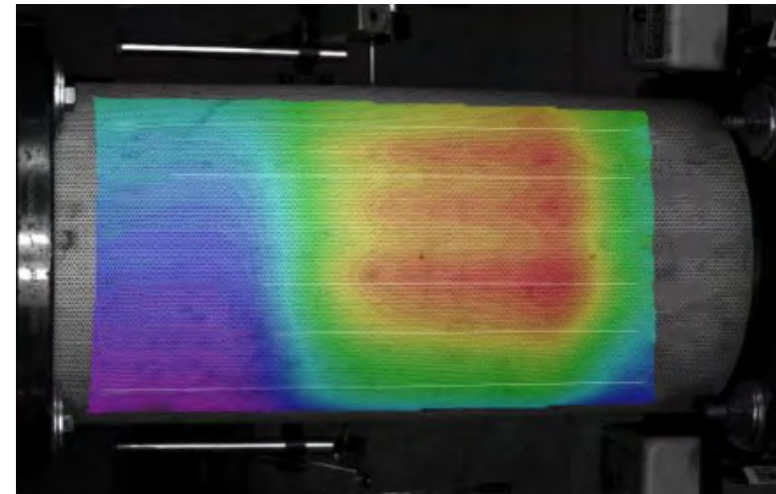
STATUS: Completion expected mid-2017

After an initial baseline study by CCP3 in 2013, a repeat CCP4 EM survey is planned following injection of ~100 Kt CO₂ by the operators at the Aquistore site in Saskatchewan, to better assess the viability of electromagnetics as a monitoring technology. However, issues with the morphology of the plume following injection mean that further modelling to determine EM sensitivity is needed and the survey has now been put back to mid-2017.

MICRO-ANNULUS SEALING

STATUS: Completion TBC

A project being run with Suncor to test a non-cement based sealing approach to micro-annuli (SMART) saw the tool designed and constructed at bench scale. A patent was applied for and external laboratory tests carried out in the early part of 2016. Results were positive and field testing was due to take place in Canada. However, wildfires in the Mackay River area where the tests were due to take place mean that the testing has been postponed until new wells can be identified.



▲ SMART tool showing a stereoscopic picture of expanded casing. *Image courtesy of Suncor*

SELECTED PROJECTS AND NEW INITIATIVES

CONTINUED

MODULAR BOREHOLE MODELLING

STATUS: Ongoing

A new CCP project has been initiated that links the CCP MBM and well contingencies projects into a single, staged program where modified MBM technology ('mini'-MBM) is used with selected sensors to provide a less expensive above-zone surveillance tool and a means to locate, characterize and mitigate plugged and abandoned well migrations.

Stanford and Lawrence Berkeley National Labs will deliver the project jointly - the first step is to understand the range of well leakage scenarios and how they may be mitigated, particularly with the mini-MBM approach, which in turn could inform the viability of using this technology for routine surveillance of reservoir CO₂ injection and migration. The project could ultimately progress to field testing.

FIRST OF A KIND/NTH OF A KIND (FOAK/NOAK) COST ANALYSIS

STATUS: Ongoing

This new CCP study aims to bring together the learnings from past CO₂ storage and EOR projects and demonstrations to understand what cost reductions might be expected as commercial CO₂ storage projects evolve from early, expensive 'FOAK' to later 'NOAK' projects, the latter of which would have the benefit of advances in SMV technologies and practice.

Advanced Resources International (ARI) conducted base cases for onshore CO₂ storage and CO₂ EOR with storage. A workshop held in late 2016 reviewed the findings with industry experts to identify the most promising routes to reduce future costs, including project scale, limiting injection and monitoring infrastructure and taking advantage of recent technology developments.



▲ 'Learning by Doing' for energy industries as an analogue for CC(U)S cost reduction
Based on original source: Advanced Resources International

SELECTED PROJECTS AND NEW INITIATIVES

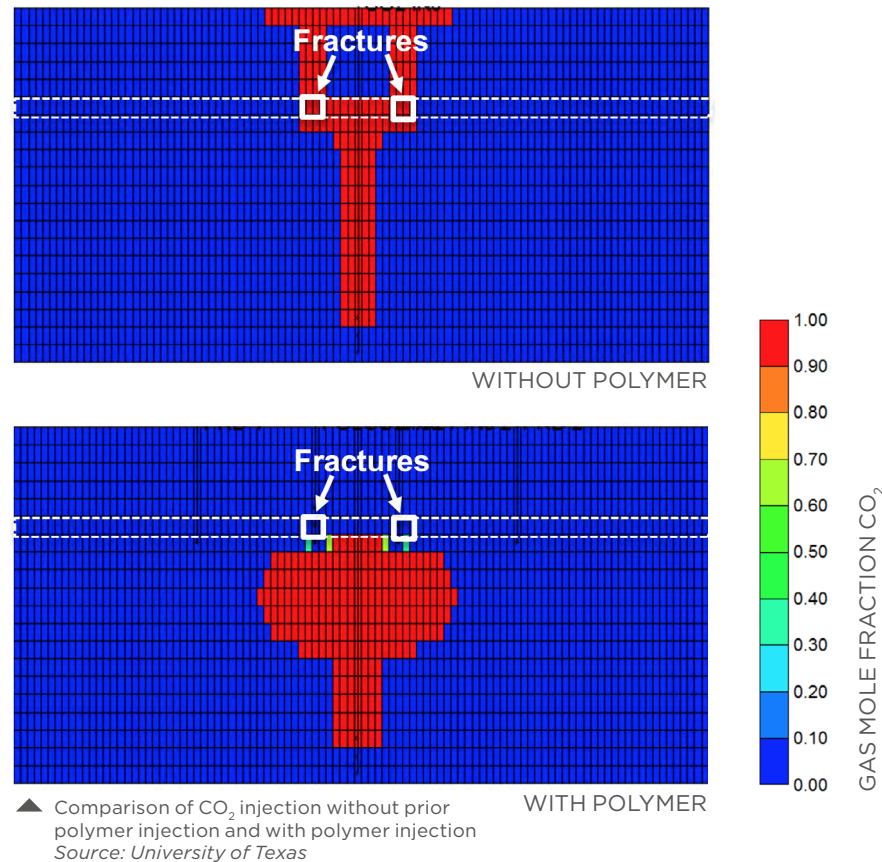
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AGENTS FOR TOP SEAL ENHANCEMENT AND REPAIR

STATUS: Ongoing

In late 2016, CCP4 launched a project with UT to assess the suitability of various sealants and permeability modifiers for use in CO₂ storage projects where top seals were naturally thin, or relatively permeable, or had been damaged through prior activity (e.g. drilling / completions, or geo-mechanical stress).

Potentially applicable agents were gathered from the literature and classified with respect to various properties, particularly compatibility for use in the presence of CO₂ or carbonated water. Among these prospective agents, one was selected for basic flow simulation to assess feasibility of flooding near the top of a reservoir and indeed into defects (e.g. faults) with a top seal.



CCP4 POLICY & INCENTIVES PROGRAM

2016 OVERVIEW

The P&I Team provides technical and economic insights needed by a range of stakeholders, most notably governments and regulators, to inform the development of legal and policy frameworks which are so vital for the deployment of CCS.

In 2016, the Team, led by Arthur Lee, focused on sharing the findings from its recent research-based study on the transitioning of EOR projects to CO₂ storage, and then progressed with evaluating real-world projects.

“

Presenting our Team’s work at the recent COP22 Marrakech side event, it was encouraging to see participation and engagement from the audience – a sign that CCS is gaining recognition. The more we discuss the issues and concerns with policymakers, communities and other stakeholders, the better for CCS to remain a viable option for reducing CO₂ emissions at an industrial scale.”

**Arthur Lee,
Chevron, P&I Team Lead**

IN THIS SECTION:



PROJECTS: TRANSITIONING CO₂ EOR TO CO₂ STORAGE

STATUS: STUDY PUBLISHED IN Q2 2016;
DEEP-DIVE STUDY ONGOING

Though much of the project's research was completed in 2015, the final report and results were presented in Q2 2016. The project's objective was to understand regulatory frameworks in the context of CO₂ EOR and how EOR operations could later transition to CO₂ storage.

Conclusions of the research were as follows:

- There is a clear regulatory framework for CO₂ EOR and for CCS in most regions but there are insufficient provisions to allow a CO₂ EOR operator to follow a clear transition pathway for legal and regulatory approval of a CO₂ EOR project to be a CCS project
- CO₂ EOR projects present a special case with particular circumstances for long-term underground CO₂ storage and provisions unique to this special case may be required

- Specific guidance or regulation should be provided, setting out the specific requirements for new and existing CO₂ EOR projects which may wish to transition to CCS
- A clear pathway for legal and regulatory approval of CO₂ EOR to become CCS could be elusive until regulatory and legal gaps that have been identified are resolved
- Given the relatively high costs of CCS today, coupling CCS with CO₂ EOR could provide a critical financial incentive to facilitate development of CCS projects in the near term.

Following publication of this research in 2016, the P&I Team commissioned Environmental Resources Management (ERM) Ltd to study in significantly greater detail any relevant real-world

projects where such a transition has occurred. ERM has since begun a deep-dive study of two jurisdictions, Texas (USA) and Alberta (Canada), focusing on CO₂ EOR projects possibly transitioning to CO₂ capture and storage projects in the context of existing regulatory frameworks.

The final report will broaden out the lessons learned from the Texas project to a potential regulatory pathway. As Alberta does not have an equivalent CO₂ EOR case, the ERM report will extrapolate lessons learned based on the current level of regulations in Alberta. Results from the deep-dive study are expected to be complete in early 2017.

CCP4 COMMUNICATIONS PROGRAM

2016 OVERVIEW

Insights and knowledge gained from the CCP4 technical programmes continued to be shared during 2016 through a number of channels.

The Communications Team, led by Mark Crombie, disseminated information to industry, influencers, members and academia via project factsheets, website registrant updates and exhibiting at important CCS conferences.

“

The highlight in 2016 was certainly attending and actively participating in the GHGT-13 conference. As we progress with the technical programs through CCP4, the Team will be closely following the availability of new results and findings to share with the industry and the general public.”

Mark Crombie,
BP, Communications Team Lead

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PROJECTS: COMMUNICATIONS HIGHLIGHTS

INDUSTRY CONFERENCES

The CCP was present at two major CCS conferences in 2016: the CCUS conference held in Washington D.C., US, in mid-June; and the GHGT-13 conference at Lausanne, Switzerland, in mid-November. The CCP shared materials, held poster sessions and participated in technical presentations at both events.

The GHGT-13 conference was the key event of the year for CCP and well attended by almost 1000 delegates. CCP participated as a bronze sponsor, which included an exhibit booth to showcase the Technical Teams' progress across the programs.

Delegates were invited to a site visit to the Mont Terri research laboratory, where presentations were given by the facility's team and a tour undertaken of the underground laboratory. This provided CCP with the opportunity to introduce the well sealing experiment site to delegates from IEAGHG, SINTEF and the US Department of Energy.

LITERATURE DEVELOPMENT

A range of communications material was produced and issued throughout the year, which included:

- The publication of the 2015 Annual Report covering the group's activity for that calendar year. The report was produced for the first time as a fully interactive pdf for onscreen use
- The Once Through Steam Generator technical factsheet was substantially revised to reflect the completion of the pilot testing of oxy-fuel combustion technology and full results. The latest factsheet was made available on the CCP website and shared at events such as the conferences
- The P&I Team's study of Best Practice in Transitioning from CO₂ EOR to CO₂ Storage was completed and published in November
- Media coverage was achieved on CCP activities across a number of channels including industry newsletters and social media.

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COLLABORATION

A NETWORK OF SUPPORT AND INFLUENCE

TECHNICAL EXPERTS

The CCP teams comprise technical experts from the member companies and include engineers and scientists

PARTNERSHIPS

CCP has worked closely with government organizations - including the US Department of Energy, the European Commission, CCEMC in Canada and the Norwegian government - and more than 60 academic bodies and global research institutes

FUNDING

CCP is being funded mainly by the member companies and with further support from governments

INDUSTRY INFLUENCE

Access to leading policymakers, NGOs and technology developers on all aspects of CCS. Provides a platform for members to help shape future policy and regulation

RESEARCH & DEVELOPMENT

Member companies have contributed results through research as well as data obtained from existing CO₂ capture and storage operations

SHARING PROJECT INSIGHTS

CCP has conducted over 150 projects and shared insights to help increase understanding of the science, economics and practical engineering applications of CCS



A like-minded group of industry experts, working together to identify the most cost-effective application of CCS technologies

STRUCTURE

CCP TEAMS 2016

The CCP is made up of four Teams
 - Capture; Storage, Monitoring & Verification; Policy & Incentives; and Communications.

The Teams consist of experts drawn from each of the member organizations.

Each participating member is represented on a CCP Executive Board that comes together quarterly.

The CCP is also supported by a Technical Advisory Board (TAB) responsible for conducting independent peer reviews on the activities of the CCP Teams and their respective programs. The TAB comprises independent assessors from industry and academia.

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**FRONT PAGE IMAGES
COURTESY OF CCS BROWSER,
PETROBRAS AND LBNL**

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AND ITS PROJECTS, PLEASE VISIT:

