CCP

2018 ANNUAL REPORT

CO_2 Capture Project

Innovating to deliver safe and lower-cost CCS

PARTICIPANT ORGANIZATIONS

bp Chevron BR PETROBRAS

ABOUT THE CCP

The CO_2 Capture Project (CCP) was formed in 2000 to advance technologies for CO_2 capture and geological storage to help make CCS a viable option for CO_2 mitigation.

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

Today, this group is focused on delivering further progress in CO_2 capture and geological storage technology through research, development and demonstration.

This 2018 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 CO_2 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 CO_2 trapping
- Adapting subsurface monitoring technologies to track CO_2 underground and developing approaches to respond to out-of-zone migration of CO_2
- Providing technical and economic insights needed by a range of stakeholders, most notably governments and regulators, to inform the development of legal and policy frameworks.

CHAIRMAN'S INTRODUCTION

Jonathan Forsyth
BP, CCP Chairman

I am pleased to introduce this report, which presents achievements from a successful year for CCP and highlights some of the key areas of work that will be completed in the coming year.

The following pages will provide you with an informative overview of some of the main projects being carried out by our Storage, Capture, Policy and Communications Teams, as we continue to advance the development of CCS technologies and understanding.

From a global policy perspective, 2018 may well have been a pivotal year for CCS development, with numerous positive signals emerging. However, there still lies ahead the challenge of bringing CCS into widespread commercial use. Reflecting on the achievements of CCP itself, the project continues to support innovation and field-testing of exciting new technologies. Evaluations and analyses, research, development and demonstrations have created results that can support improved CCS applications. The collaborative nature of CCP's participant organizations, developed over nearly 20 years, offers a way ahead providing expert guidance, resources and support at the scale required.

Outside of the scope of CCP, our member organizations are using their expertise to develop CCS across a number of their own projects. CCP's founding member, BP, announced in late November its participation in the Clean Gas Project – the world's first large-scale commercial facility for capturing CO_2 from gas-fired power generation; Chevron's Gorgon project aims to become the largest commercial-scale CO_2 injection project to date, reducing the emissions of the project by approximately 40%; finally, Petrobras, continues a CO_2 injection rate of 2.5Mt annually across its 10 floating production storage and offloading units in the Santos Basin.

As we near the end of CCP4, which is our fourth and final phase, most of our current projects should be completed in 2019, with a few projects drawing to a close in 2020. We are planning for a comprehensive presentation and publication of the project results next year, when we will be looking forward to connecting with those with a firm interest in CCS – whether within the industry or academic sector – to help us successfully deploy CCS as a climate change mitigation technology.

CCP4 CAPTURE PROGRAM 2018 OVERVIEW

The CCP4 Capture Team, led by Raja Jadhav, has worked alongside a number of partners in 2018 to drive forward projects agreed earlier in CCP4. There is potential for further projects to be agreed upon during 2019, for completion that year and in 2020.

Work on evaluating novel capture technologies included the completion of techno-economic assessments and commencement of pilot stage testing of a novel solvent, while the project to use 3D printing technologies to create sorbent structures for pre- and post-combustion applications saw a number of milestones achieved. The Capture Team also selected and contracted three new projects towards the end of 2018.

CCP4 Scenarios

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.

Refinery
Identify and develop technologies for pre-combustion capture from steam methane reformer (SMR) H_2 plants

NGCC
Seek and develop breakthrough capture technologies with less than \$50/tonne CO_2 avoided cost

Natural gas extraction
Understand landscape and potential for CO_2 capture from offshore gas production and support pilot testing of a promising technology

Heavy oil
Seek and develop breakthrough capture technologies with less than \$50/tonne CO_2 avoided cost

PROJECT: NOVEL CAPTURE TECHNOLOGY ASSESSMENTS

STATUS: WP3, WP4 COMPLETED

During 2016 and 2017, Work Packages (WP) 1 and 2 of the CCP research theme of novel capture technologies saw Laboratorio Energia e Ambiente Piacenza, Milan (LEAP), undertake a techno-economic assessment of five novel capture technologies, and detailed analysis of one of these – a molten carbonate fuel cell (MCFC) option for post-combustion capture from natural gas-fired processes. In 2018, the theme of novel capture technologies was carried forward with the completion of a number of projects under WP3 and WP4.

In one of these, LEAP undertook a techno-economic assessment of 5 molal (5m) piperazine as a new potential baseline solvent for carbon capture from NGCC. This work was based on the most recent findings from University of Texas at Austin (UT) research activities.

Three different case studies were considered relevant from the preliminary literature analysis. The three evaluated configurations were (i) conventional F-class NGCC coupled with the conventional absorber configuration with a direct contact cooler (DCC), (ii) conventional F-class NGCC coupled with an advanced absorber configuration (no DCC – flue gas cooling integrated within the absorber) and (iii) high efficiency, state-of-the-art H-class NGCC, coupled with the advanced absorber configuration. The process flow diagram for a single CCS train for configuration (i) is shown on the next page.

At the end of the project, configuration iii) was found to be the best performing of the three options with a lower SPECCA (Specific Primary Energy Consumption for CO_2 Avoided) index, superior energy efficiency and lower capital cost, resulting in a minimum cost of CO_2 avoided of $59/tonne CO_2. Full details of the project and results were presented at the GHGT-14 conference – *Techno-economic assessment of novel vs. standard 5m piperazine CCS absorption processes for conventional and high-efficiency NGCC power plants* – and the paper is available at www.co2captureproject.org.

Also as part of the novel technologies theme during 2018, LEAP undertook a techno-economic assessment of MCFC for capturing CO_2 from a group of reciprocating gas engines. Here, the CO_2 from the flue gas is sent to the cathode of the MCFC, where it is transported across the electrolyte to the anode side in a concentrated form, which can be further purified relatively easily. In this process, the MCFC generates additional electricity, which can be sold to generate revenue.

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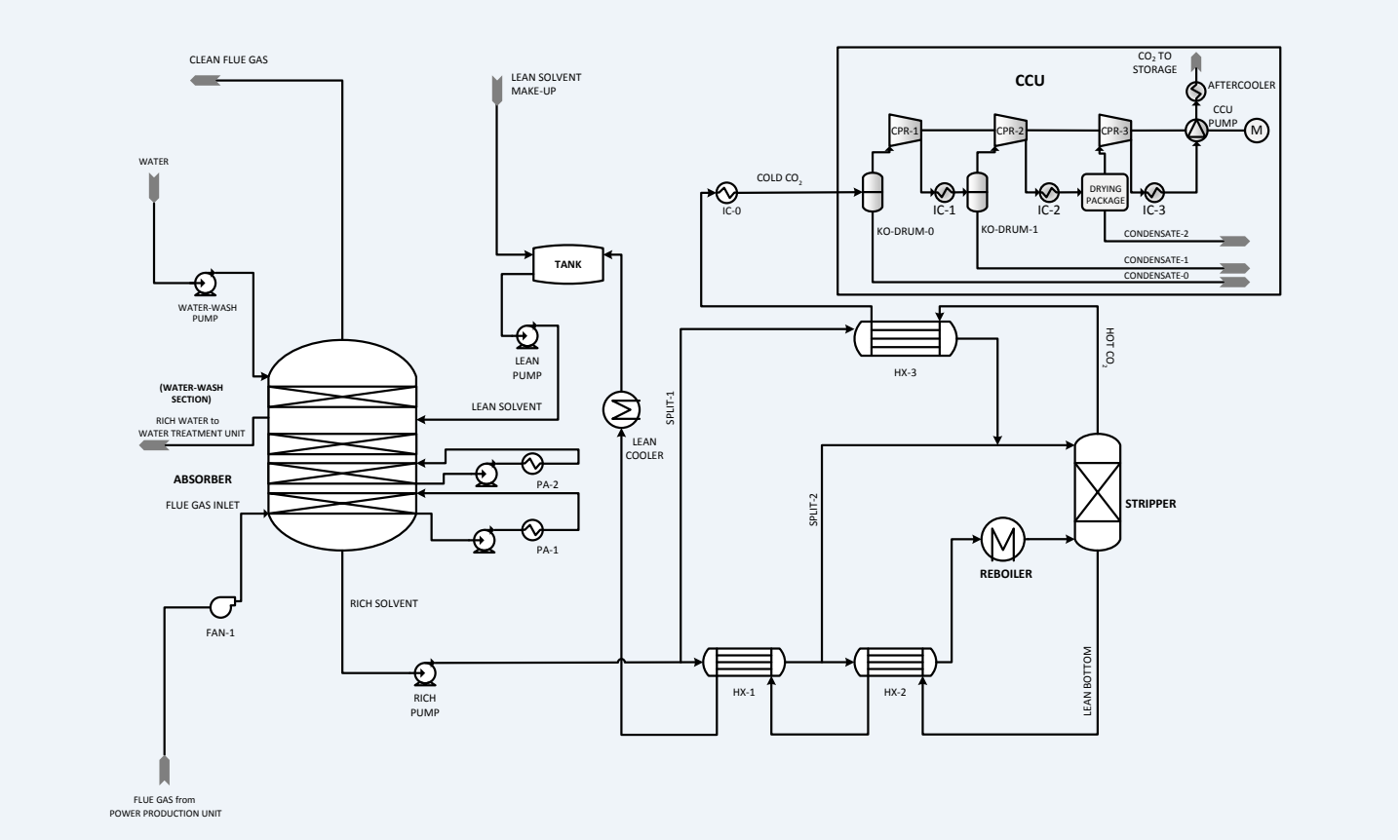
PROJECT:
NOVEL CAPTURE TECHNOLOGY ASSESSMENTS CONTINUED



Simplified process flow diagram for the 5 molal piperazine process
Diagram courtesy of LEAP

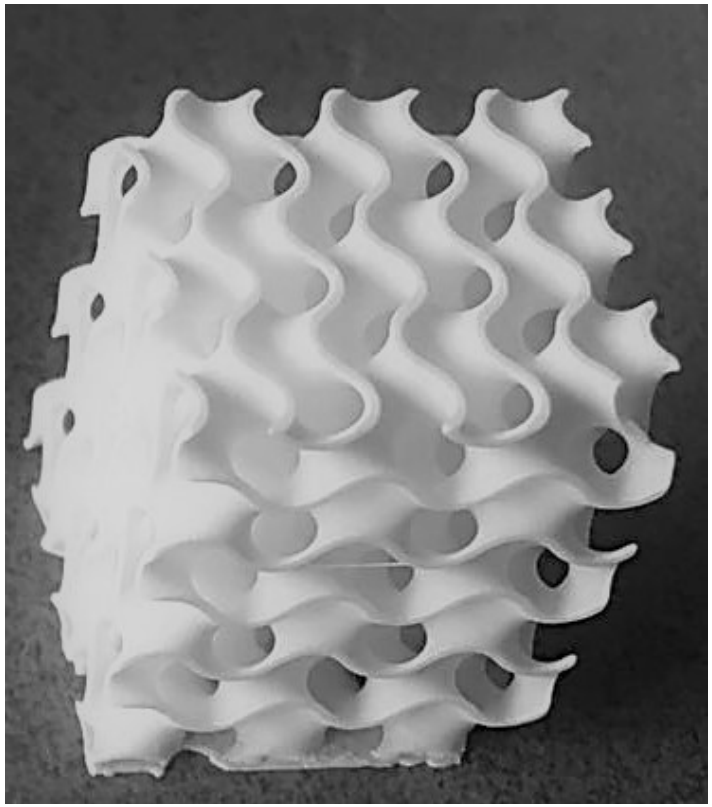
PROJECT: SORBENT-BASED CAPTURE USING NOVEL 3D PRINTING TECHNIQUE

STATUS:
ONGOING

The Capture Team and its project partners progressed the project to develop 3D-printed sorbent structures for pre- and post-combustion applications. The objectives of the 3D-CAPS project are twofold: first to achieve a tenfold productivity increase for two sorbent-based technologies in CCS; and secondly, to optimize sorbent shapes with Computational Fluid Dynamics (CFD) and other modeling tools, with direct realization in 3D-printed objects for testing under relevant conditions. Success in this project should also lead to a substantial decrease in overall equipment size and costs.

ECN TNO printed and evaluated small structures from silica pastes, while the first hydrotalcite (HTC) pastes were prepared and tested. The SINTEF Team grafted amine components onto powdered silica and performed characterization of the sorption properties. UBB (Babeș-Bolyai University, Cluj-Napoca) selected two different structures for modeling: honeycomb (iso-reticular foams) and monolith.

CCP is presently involved in the development of the techno-economic assessment. Completion of the project is expected in late 2019.



3D-printed structured silica adsorbent.
Image courtesy of ECN, part of TNO.

The ACT 3D-CAPS project #271503 has received funding from RVO (NL), RCN (NO), UEFISCDI (RO), and is co-funded by the CO_2 Capture Project (CCP) and the European Commission under the Horizon 2020 programme ACT, Grant Agreement No. 691712

PROJECT: PILOT-SCALE TESTING OF PZ SOLVENT

STATUS:
ONGOING

Piperazine technology – advanced flash stripper skid installed at the National Carbon Capture Center (NCCC), Alabama, USA. *Image courtesy of UT*

After a successful pilot campaign in 2017 in collaboration with University of Texas at Austin (UT), a larger-scale pilot of the piperazine solvent is being undertaken. The pilot plant will be operated for three weeks with factorial testing and six additional weeks to get results on oxidation with and without mitigation measures.

The aim of the project is to demonstrate the application of an aqueous piperazine solution – a second-generation solvent – in a pilot plant (~2.5-4 tpd CO_2). This would test CO_2 separation from synthetic flue gas representative of the exhausts from natural gas-fired combined cycle power plants, where low concentrations of CO_2 (~3.5 mol%) are typically considered to be a challenge for many capture technologies. The performance of 5m piperazine will be evaluated at a range of operating conditions (solvent loadings, gas and liquid flow) and in two different absorber configurations.

These pilot tests are designed to supplement the model evaluation data set for NGCC flue gas as well as to address questions related to oxidation/corrosion and cooling scheme optimization for NGCC applications. The pilot is expected to be operational in early 2019.

PROJECT:
DEVELOPMENT OF NOVEL C-CAPTURE SOLVENT AND PILOT TESTING

STATUS:
ONGOING

Progress was made in 2018 on the project undertaken by CCP as part of a UK government-funded project under the Energy Entrepreneurs 5 (EEF5) program to develop and evaluate a novel low-energy solvent family for post-combustion CO_2 capture. Additional funding has been received through C-Capture and CLIMIT (Norwegian RD&D CCS program) and other partners involved in the additional project are SINTEF AS and Biobe AS.

Solvent optimization work was completed for use in 4 and 8 mol% CO_2 streams. Construction of a 0.2 tonne/day pilot plant was completed and initial results have been obtained. The pilot plant features an absorber with eight individual column sections, and a total 16m packing height. A stripper is used to regenerate solvents by electrical heater or natural gas boiler.

The goal is to evaluate the solvents at 0.2 tonne/day scale and perform pilot tests of promising solvents – and ultimately to optimize and validate the process at 1 tonne/day scale, and demonstrate an energy consumption of less than 2.1 GJ/tonne for solvent regeneration.

NEW CONTRACTS

Towards the end of 2018, three new contracts were executed including – a graphene oxide membrane project with GTI; a turboexpander pilot project for CO_2 capture from small gas engines with NextStream; and a sorbent-based technology project with Inventys.

CCP4 STORAGE, MONITORING & VERIFICATION PROGRAM – 2018 OVERVIEW

During 2018, good progress was made on a number of the projects related to the Contingencies theme, with one project completed and two more seeing important milestones achieved during the year.

Work also continued in the areas of field trialing and storage assurance although some projects have been delayed due to a combination of funding, contractual and operational issues. These have been largely resolved, and – thanks to the diligence and commitment of the CCP Storage, Monitoring & Verification (SMV) Team, led by Scott Imbus – delivery of these projects is expected in 2019 and 2020.

A number of other projects are also under consideration for implementation during the remaining two years of CCP4 and decisions on whether to progress with these projects will be taken early in 2019.

CCP4 Themes

The SMV Team's CCP4 work has the overarching objective of ensuring the long-term security of geologic CO_2 storage approached through the following themes:

Storage assurance
Subsurface processes: clarification and understanding of complex processes impacting storage security

Well integrity: solutions to identify and mitigate CO_2 leakage

Monitoring & Verification: modeling the cost-effectiveness of emerging and integrated sensors

Contingencies
Models for detection, characterization and mitigation of out-of-zone fluid migration (CO_2, brine) through wells and natural or induced geologic conduits

Field trialing
Deployment and integrated assessment of emerging monitoring technologies at third-party sites with research and operator partners

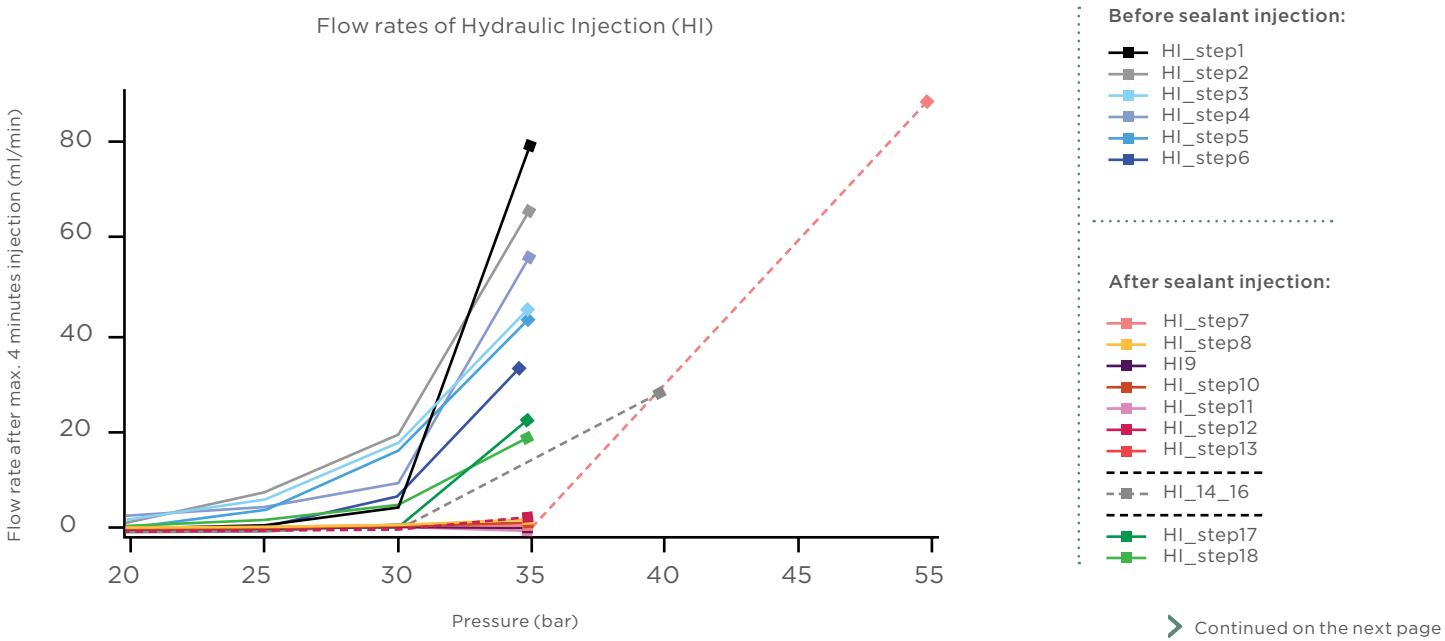
PROJECT: WELL SEALING EXPERIMENT AT MONT TERRI UNDERGROUND LABORATORY (MT-UGL)

STATUS:
ONGOING

The overall objective of this project (Mont Terri CS-A), which is being carried out at the Mont Terri underground rock laboratory in Switzerland, is to test novel sealants for their ability to treat small but persistent behind-casing migration of CO_2 from wells.

An experimental-scale well has been designed and installed at the underground test site that mimics CO_2 containment loss through various conduits (which were deliberately induced in this well) that occur in various well system interfaces, e.g. cement/casing, cement/rock and fractures within the cement and caprock systems. The experiment has progressed from characterizing induced defects (using hydraulic and tracer tests) to the injection program getting fully underway.

Good progress continued to be made in the well sealant testing program during 2018. The target of testing four sealants in this series of experiments is now well advanced, with two tested and results made available – the third and likely, the fourth sealant will be tested in 2019.



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PROJECT: WELL SEALING EXPERIMENT AT MONT TERRI UNDERGROUND LABORATORY (MT-UGL) CONTINUED

The first sealant, a nanoparticle (hydrogel) that massively expands in volume when triggered by low pH conditions, had been injected in 2017 into low and higher permeability zones followed by exposure to CO_2 (carbonated water). Pressure test results made available in 2018 across the input/output ports indicate very good sealing at less than 30 bar. Increased flow rates above 30 bar may indicate pressure-induced activation of new flow pathways and/or displacement of the sealant.

A second sealant was injected and successfully tested during the year. Final reporting on the performance of this polymer gel sealant are imminent. A third sealant test using a novel silicate gel sealant was also identified and is being readied for testing in mid-2019. A low viscosity resin is under evaluation for injection in two stages: 1) as the fourth sealant test restricted to a segment of the well in late 2019 and 2) in pervasive flooding to preserve the well/rock system prior to its exhumation (overcoring) in late 2019. A post-overcoring program, which entails imaging and rock/fluid analysis to characterize induced defects and corresponding sealant emplacements, is under development.

A collaboration has been established with the Mont Terri CS-D experiment operators. The project applies sensitive surveillance tools to monitor flow of CO_2-rich brine through a fault with results expected in early-mid 2020. The SMV Team is also looking into participating in the related Mont Terri FS-B experiment which entails inducing fault slip with monitoring of resultant seismicity and changes in permeability which could increase fluid flow. Drilling and instrumentation began during the second half of the year and results are expected in 2020–21. Both experiments may deploy one of the CS-A sealants to determine if fluid migration through a fault can be stopped.

PROJECT:
PERMEABILITY MODIFIERS FOR SEAL ENHANCEMENT, WELL MITIGATION & FLOOD CONFORMANCE

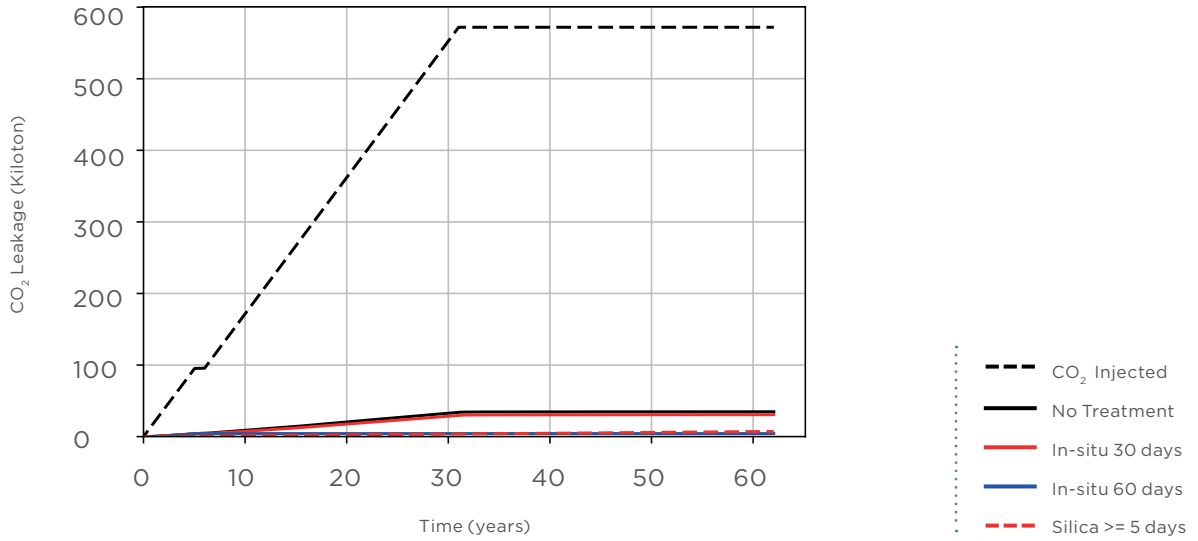
STATUS:
ONGOING

CCP is working alongside the University of Texas on this important contingency project. Well and top seal integrity are often difficult to accurately assess prior to CO_2 injection, as are changes to barrier status from geo-mechanical stress changes and chemical reactions over the course of a CO_2 storage project.

Phase 1 had included a survey of prior R&D, ranking of permeability modifiers based on specific criteria and simulation of core scale experiments to understand fluid behavior before and after activation or triggering. Preliminary results using both a generic and actual reservoir/seal (Pembina, Canada) model indicated the rheological and setting time feasibility of sealant flooding with selected sealants.

2018 saw Phase 2 get fully underway, with completion due in late 2019. This phase involves bench-scale core flood tests of selected sealants in a CO_2-rich environment followed by modeling and history matching of the most interesting modifiers identified in phase 1. These will include silicate gels, where the plan is to determine bulk silica gel time, conduct core flooding experiments and numerical simulation.

Comparison of In-situ Gel and Silica Gel in Pembina model



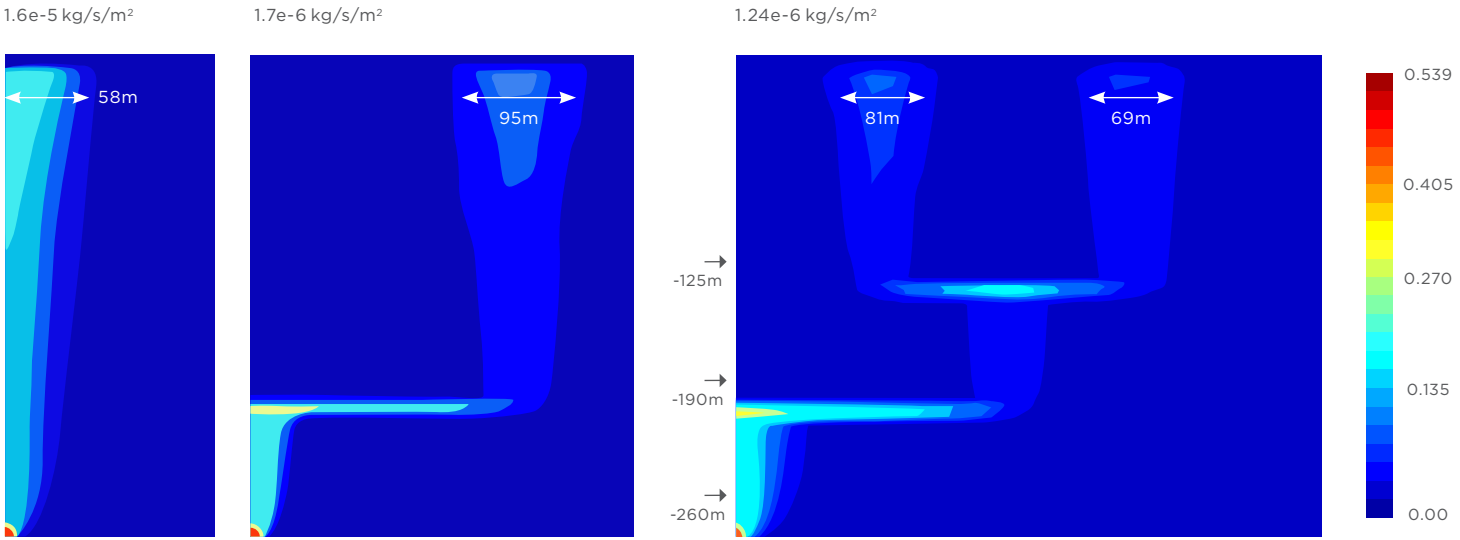
PROJECT: PLUGGED AND ABANDONED (P&A) WELL CONTINGENCIES

STATUS:
COMPLETED

The project initiated in 2017 to address leakage issues that can occur with older plugged and abandoned (P&A) wells was completed in 2018. CCP worked with Lawrence Berkeley National Lab (LBNL) and Stanford University on this study.

Following earlier documentation of vintage well types and P&A leakage reports vs. production history, detailed simulations were developed and run for deep and shallow segments of fluid migration towards the surface. A modeling strategy was developed to assess the resolution of electromagnetic monitoring strategies to localize, characterize and thus mitigate a leak.

Plume movement for scenarios with no barriers, a single barrier and two barriers.



No Sealing Layer, time = 10 years

One Sealing Layer, time = 50 years

Two Sealing Layer, time = 50 years

Click above image to see animation.
To close animation, click on the cross on top-right of window

Source: Anshul Agarwal, Stanford University

PROJECT:
AQUISTORE CO_2 STORAGE PROJECT COLLABORATION

STATUS:
ONGOING

Progress on a number of monitoring projects at the Aquistore storage site in Saskatchewan, Canada has not progressed as quickly as planned due to a number of partner funding and contractual issues. These have now been largely resolved and the various projects should be underway shortly with results due later in 2019 and early 2020.

The aim is to assess non-seismic geophysical techniques for their potential to offer cost savings with sufficient resolution and/or to enhance to surface seismic. To date, electromagnetic monitoring resolution has been modeled for downhole source/surface receiver configurations and processing strategies with the aim of conducting a repeat EM survey from the baseline survey that CCP3 conducted in 2014.

A borehole microgravity instrument to quantify CO_2 saturation (via density contrast with brine) has also been deemed feasible and a field test is planned for 2019. A field test of this technology was initially planned at a CO_2-EOR site to assess its ability to detect water-alternating-gas (WAG cycle fronts) but cancelled due to a change in field ownership.

Finally, the Aquistore Integration Project, comprised of joint inversions of available surveillance data using a common reservoir flow model, is underway with results expected in early to mid-2020.

CCP4 POLICY & INCENTIVES PROGRAM 2018 OVERVIEW

With society increasingly involved in finding ways to advance the energy transition to a lower CO_2 emissions world, 2018 was a timely moment for CCP's Policy & Incentives Team, led by Arthur Lee, to publish a new study looking at the current role of CCS in this approach.

Entitled *The role of CCS in the Energy Transition*, the report addresses four key questions:

- What is the scale of emissions reductions needed to achieve the long-term goals of the Paris Agreement?
- What is the projected magnitude of emissions reductions achieved by CCS deployment in the leading scenarios of low carbon energy transition?
- To what extent do government plans and policies serve to support the role of CCS in the energy transition (or downplay the role of CCS)?
- What sorts of actions could help CCS achieve its long-term potential to contribute to the energy transition and the Paris Agreement ambition?

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2018 OVERVIEW CONTINUED

The report finds that there is a fundamental gap between the ambitious goals of the Paris Agreement and the reality of CCS deployment. Very few countries have submitted Nationally Determined Contributions (NDC) or Mid Century Strategies (MCS) that feature CCS. Many of those do cite barriers to investments in CCS projects including cost, lack of finance and lack of implementation of government policies and incentives.

This is despite recognition from a number of respected organizations that the contribution of CCS to scenarios that could successfully achieve the Paris Agreement goals ranges from 10 to 25% of the total GHG emissions reduction.

However, the report also notes that, even if nations did not mention CCS in their NDCs or MCSs, they could still, as part of the every-five-year global stocktake, analyze and plan for the conditions that would help in the future deployment of CCS in order to reduce emissions significantly.

P&I activity

The 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.

CCP4 COMMUNICATIONS PROGRAM

The Communications Team continued to spread the word about the work of CCP during 2018, publicizing the ongoing activity of the technical teams and reaching a range of audiences through various channels.

CCP was represented and gave presentations at industry events including the European Geosciences Union General Assembly (Vienna, Austria) in April and the bi-annual GHGT conference in October (Melbourne, Australia).

Collateral was produced for members and press releases were issued on key CCP milestones during the year – resulting in coverage in industry media. The CCP website continued to provide up-to-date information on all key projects and developments.

Communications activity

The Team is responsible for supporting the work of the SMV, Capture and P&I teams and ensuring it is seen by relevant interested audiences. This typically involves a mixture of online, print and face-to-face communications routes.

STRUCTURE
CCP TEAMS 2018

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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