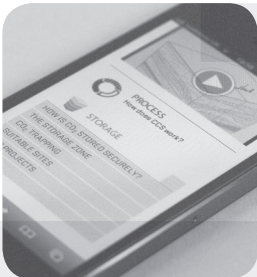
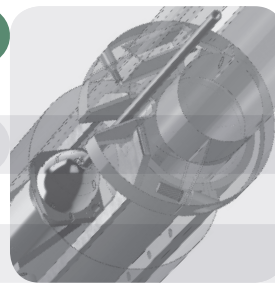


ANNUAL REPORT 2013

Advancing CCS
technology development
in oil and gas



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April 2014.

 WWW.CO2CAPTUREPROJECT.ORG

FRONT COVER

Top to bottom:

- Oxygen delivery skid for OTSG project. Image courtesy of Praxair and Cenovus
- MBM system. Image courtesy of LBNL
- CCS Browser
- *Local community benefit sharing mechanisms for CCS projects* report.

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

Today, this partnership of major energy companies is focused on delivering results from its demonstrations, field trials and studies. This Annual Report provides an update from the Teams that make up the CCP – Capture, Storage, Policy & Incentives and Communications.

CONTENTS

Chairman's Introduction	04
CCP 2013 Structure	06
CCP3 Partnerships and Collaborations	08
Capture Program	10
Storage, Monitoring & Verification Program	16
Policy & Incentives Program	22
Communications Program	26
CCP3 Milestones and Achievements	30

INFORMATION KEY



MORE INFORMATION ONLINE



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2013 HIGHLIGHTS

CAPTURE

Foster Wheeler completed technical studies of state-of-the-art capture technologies and initiated those for novel technologies
➔ [READ MORE ON PAGE 11](#)

Activities on the Chemical Looping Combustion technology completed
➔ [READ MORE ON PAGE 11](#)

CCP joined CO₂ Solutions development project, looking at novel post-combustion solutions
➔ [READ MORE ON PAGE 12](#)

Successful performance and durability tests completed for Membrane Water Gas Shift (MWGS) module
➔ [READ MORE ON PAGE 13](#)

Retrofit of the Cenovus OTSG unit in Christina Lake was completed and now ready for demonstration
➔ [READ MORE ON PAGE 14](#)

STORAGE, MONITORING & VERIFICATION

Geo-mechanical Hysteresis project completed
➔ [READ MORE ON PAGE 17](#)

Further work on Modular Borehole Monitoring project shows potential for cost-effective use of fibre optic sensors
➔ [READ MORE ON PAGE 18](#)

Certification Framework completed
➔ [READ MORE ON PAGE 18](#)

Contingencies study modeling completed with significant conclusions drawn
➔ [READ MORE ON PAGE 20](#)

POLICY & INCENTIVES

Study completed on *Local community benefit sharing mechanisms for CCS projects*
➔ [READ MORE ON PAGE 23](#)

Presented benefit sharing mechanism results at International Emissions Trading Association (IETA) side-event at UN Conference of the Parties (COP19, Poland) and at the Carbon Sequestration Leadership's Stakeholders Panel Discussion on Communications
➔ [READ MORE ON PAGE 23](#)

COMMUNICATIONS

Selected for CSLF technical showcase, Washington D.C., in November 2013
➔ [READ MORE ON PAGE 27](#)

CCS educational tool, the CCS Browser, launched in June - available on smartphone, tablet and PC
➔ [READ MORE ON PAGE 28](#)

CHAIRMAN'S INTRODUCTION

2013 MEMBERS OF THE CCP3 EXECUTIVE BOARD



CHAIRMAN
Nigel Jenvey
BP

- MEMBERS**
Rodolfo Dino
Petrobras
Stephen Kaufman
Suncor
Vincent Kwong
Chevron
John MacArthur
Shell
Mario Vito Marchionna
eni

During the course of the past year, a number of significant CCP projects were brought to conclusion. This work has continued to develop our understanding of how the oil & gas industry can safely deploy the most cost-effective CO₂ capture and storage technologies into its operations to reduce CO₂ emissions when needed in the future.

A small number of projects remain to be completed in 2014, and therefore we have decided to extend CCP3 by a further year to accommodate their full conclusion. Behind all of this work – and indeed the way in which CCP has evolved over the years – is collaboration. We have taken the opportunity in this Annual Report of highlighting the valued contribution of our member companies as well as academic, industry and government partners in bringing to fruition many of these projects. CCP is able to draw upon a global network of CCS expertise, without which many of our achievements would not have been possible.

One of the realities of the work carried out by a body such as CCP is that, by its very nature, it is experimental. This helps drive our understanding forward. But as a consequence of that, there is always a degree of uncertainty to the outcomes – most of the time they are what we expected or hoped for, occasionally they raise new questions. This was reflected in the results of some of our work which came to a conclusion in 2013. However, it is the value of the learning that we obtain from this work that is the definition of our true success. This ensures that the most appropriate decisions and solutions can be developed to advance CCS technologies in our industry.

Two of the largest projects ever undertaken by CCP reached important milestones during the year before their final planned phases in 2014. In terms of CO₂ capture, final preparations were made in setting up the second field demonstration to be carried out by CCP – testing oxy-fired capture from a Once Through Steam Generator. Retrofitting of the commercial boiler to be used in the demonstration was completed at a partner facility in Alberta, Canada. Results from the project should prove highly useful in informing ongoing development of CO₂ mitigation technologies at heavy oil extraction facilities.

Meanwhile, the Contingencies Study undertaken by the Storage Team produced some significant work and results by the end of the year. This project is, we believe, quite unique within the industry, building knowledge around CO₂ storage scenarios and identifying intervention strategies and technologies in the event of unexpected CO₂ migration. The first phases of this work have now been completed, culminating in results from a modeling-based approach to detection, characterization and intervention. The next phase of the project will see decisions made regarding the possibility of running large-scale testing.

The potential impact of CCS on local communities was the subject of a new study from the Policy & Incentives Team. The study was completed towards the end of 2013 and used real-life examples to show how the benefits from large-scale industrial projects can positively influence acceptance by local communities.

Sharing the insights gained from our work and the pool of knowledge that has accrued over time is a key objective of CCP. We have gradually built up a number of ways to do this, ranging from presence at industry conferences to the production of various digital and print materials. In what was our most ambitious project to date, the past year saw the launch of the CCS Browser (www.ccsbrowser.com) – an online educational resource which takes much of the learning and expertise gained by CCP over the years and translates it into understandable, accessible information for the wider public.

Finally, I cannot let the introduction to the Report pass without saying a big thank you to two people from within our membership, who have played major roles in furthering the aims of CCP. Both Ivano Miracca (eni, Capture Team Lead) and Scott Imbus (Chevron, Storage Team Lead) complete their tenures during 2014 after many years leading their Teams' work. Both have shown extraordinary levels of commitment, resilience and good humour and their deep subject knowledge has been invaluable. My best wishes go to both of them and to their successors, who will be announced in due course.

In previous years it was apparent that the global impetus for CCS had slowed down somewhat as economies around the world focused on other more immediate priorities, and demonstration projects tackled first-of-a-kind cost escalation. However, now, as the world's economies continue to recover and demonstration project learnings are dissected and understood for continued improvement, so we can expect to see CCS move gradually back up the political agenda. The oil & gas industry needs to be well placed for this potential eventuality and the work of CCP has been crucial in building vital knowledge thus far.

With CCP3 due for completion in 2014, a decision will be made shortly on continuation into a fourth phase to CCP's work. Further news on this will be announced in due course. In the meantime I do hope you enjoy reading our 2013 Annual Report.

Yours faithfully,



Nigel Jenvey
BP, CCP Chairman

CCP STRUCTURE 2013

Ever since the year 2000, CCP has been at the forefront of CCS development in the oil & gas industry worldwide. During that time it has brought together experts from its own member companies and worked with specialists from industry, technology providers and academia to share insights and expertise that can help CCS become a viable option for CO₂ mitigation for the industry.

CCP is made up of four Teams – Capture; Storage, Monitoring & Verification; Policy & Incentives; and Communications. The Teams comprise geologists and other subsurface specialists, engineers, policy and regulatory specialists and communications experts drawn from each of the member organizations.

Each member organization is represented on a CCP Executive Board that comes together quarterly. In 2013, the CCP members were: BP, Chevron, eni, Petrobras, Shell and Suncor.

The CCP is 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 resulting TAB recommendations help to ensure the Program remains true to its aims and shape its future direction. The TAB is comprised of eight independent assessors from industry and academia.

The CCP is in its third phase of activity – CCP3 – scheduled to finish in 2014.

CCP TEAM 2013

CCP3 EXECUTIVE BOARD

Nigel Jenvey (Chair)
BP
Rodolfo Dino
Petrobras
Stephen Kaufman
Suncor
Vincent Kwong
Chevron
John MacArthur
Shell
Mario Vito Marchionna
eni

PROGRAM MANAGER

Mark Crombie
BP

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Olav Bolland
Head of Department/
Professor, *NTNU, Norway*

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CAPTURE

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BP
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Suncor
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Shell
Raja Jadhav
Chevron
Jamal Jamaluddin
Shell
Leonardo de Mello
Petrobras
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eni
Gustavo Moure
Petrobras
Betty Pun
Chevron
Frank Wubbolts
Shell

STORAGE, MONITORING & VERIFICATION

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Shell
Marco Brignoli
eni
Andreas Busch
Shell
Mark Chan
Suncor
Walter Crow
BP
Rodolfo Dino
Petrobras
Kevin Dodds
BP
Bryan Dotson
BP
Grant Duncan
Suncor
Craig Gardner
Chevron
Scott Imbus
Chevron
Dan Kieke
Chevron
Josephina Schembre
Chevron

ECONOMIC MODELING

David Butler
David Butler & Associates

POLICY & INCENTIVES

Eric Beynon
Suncor
Dan Burt
Suncor
Mark Crombie
BP
Renato De Filippo
eni
Christiaan Greco
Petrobras
Arthur Lee
Chevron
Charles Samuda
Shell

COMMUNICATIONS

Rachel Barbour
BP
Mark Crombie
BP
Renato De Filippo
eni
Kurt Glaubitz
Chevron
Christiaan Greco
Petrobras
Tanis Shortt
Suncor
Peter Snowdon
Shell

CCP3 PARTNERSHIPS AND COLLABORATIONS

CCP3 has been characterized by many technical projects, studies and demonstrations conducted across the world.

The CCP Capture and Storage Teams have led these projects, frequently calling upon support and collaboration from many within the broader CCS, academic, governmental and engineering worlds.

This map is a summary of this truly international network of collaboration, showing some of the main projects and the key partners and contractors involved.

CANADA

OTSG Oxy-firing Demonstration

CCEMC funding: \$CAD 2.5m

Partners:

- Genovus
- Devon Canada
- MEG Energy
- Praxair
- Statoil

CANADA

CO₂ Solutions Enzymatic Technology

CCEMC Funding: \$CAD 500k
National Research Council
Funding: \$CAD 350k

Partners:

- CO₂ Solutions
- Procede Group
- Codexis
- Statoil
- + other undisclosed partner(s)

USA

PS InSar Satellite Surveys

Partners:

- TRE Canada
- MCGC
- ADM Decatur

USA

Modular Borehole Monitoring

Partners:

- LBNL (Lawrence Berkeley National Laboratories)
- Denbury Resources
- SECARB (Southeast Regional Carbon Sequestration Partnership)
- Advanced Resources International

EUROPE

INNOCUOUS CLC Project

EU funding: €2.7m

Partners:

- Chalmers University
- CSIC (Spanish National Research Institution)
- Technical University of Vienna (TUV)
- VITO (Flemish National Research Institution)
- Johnson Matthey
- Bertsch

USA

Partnership for CO₂ Capture

DoE funding: €2.2m

Partners:

- University of North Dakota EERC
- 25 companies, mostly in the power production business

USA

Contingencies Project

Partners:

- Stanford University
- Mont Terri Underground Lab, Switzerland
- GeoScience Ltd

USA

MWGS Reactor System for CO₂ Capture and H₂ Recovery

Partners:

- Pall Corporation

USA

CO₂ Impurities Study

Partners:

- University of Texas Bureau of Economic Geology

BRAZIL

FCC Oxy-firing Demonstration

Partners:

- Petrobras
- Linde Gas (contractor)
- TecnoProject Latina (contractor)

UK

Economic Baselines

Contractors:

- Foster Wheeler

AUSTRALIA

3D VSP Seismic Monitoring

Partners:

- CO₂ CRC Otway

KEY

CAPTURE

**STORAGE, MONITORING
& VERIFICATION**

CAPTURE PROGRAM

CAPTURE HIGHLIGHTS

Foster Wheeler completed technical studies of state-of-the-art capture technologies and initiated those for novel technologies

Activities on the Chemical Looping Combustion technology completed

CCP joined CO₂ Solutions development project, looking at novel post combustion solutions

Successful performance and durability tests completed for Membrane Water Gas Shift (MWGS) module

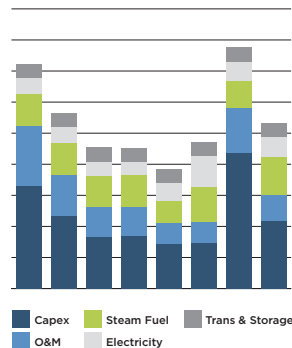
Retrofit of the Cenovus OTSG unit in Christina Lake completed and now ready for demonstration

PARTNERSHIPS COME TO FRUITION

Following the successful oil refinery oxy-firing demonstration carried out during 2011-12, much effort was spent in 2013 in progressing the second major capture demonstration project to be carried out in CCP3. Led by Suncor and with a number of partners, this collaborative project will test the effectiveness of oxy-firing in capturing CO₂ emissions from a Once Through Steam Generator (OTSG) used in oil sands production. One of the challenges in this method of extraction is the relatively high levels of CO₂ emitted in the process, so technical advancements in the field may potentially prove highly significant in the development of this sector.

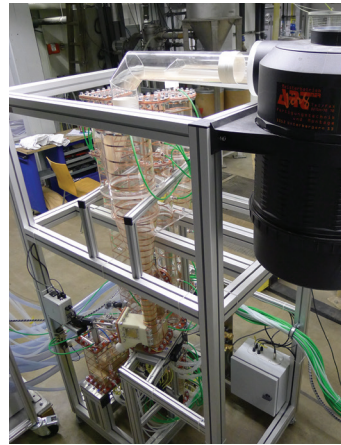
CCP worked with a range of partners during 2013 to complete a number of other projects focusing on the development and testing of novel capture technologies with the potential for use in refinery, NGCC and oil sands scenarios – with very interesting results. The outputs of this work have also been included in the final phase of economic evaluations, to assess the potential reduction in CO₂ across the main scenarios against the CCP economic baselines.

THE 2013 CAPTURE PROGRAM



Economic Baselines

Establishing economic baselines for each capture technique across all scenarios was completed in early 2013.



Chemical Looping Combustion

Cold flow model of a 10MW CLC demo plant. Image courtesy of Institute of Chemical Engineering, Vienna University of Technology.

ECONOMIC BASELINES

The final phase of Foster Wheeler's work in establishing economic baselines for each capture technique (post-combustion, pre-combustion, oxy-firing) across all scenarios was completed in early 2013.

It has proved difficult to challenge post-combustion as a capture technology given current state-of-the-art alternatives, with a few notable exceptions (oxy-firing for FCC units in the refinery, pre-combustion in a hydrogen-fired refinery).

The project then moved into evaluating the novel technologies developed in CCP3, in particular:

- Chemical Looping Combustion in the oil sands scenario
- Ion Engineering post-combustion technology in the NGCC scenario
- CO₂ Solutions post-combustion technology in the NGCC scenario.

This phase will be concluded within the first quarter of 2014.

HEAVY OIL/OIL SANDS PRODUCTION

Demonstration: OTSG oxy-firing

The demonstration unit is a commercial boiler with a capacity of 50 Million BTU/hour, which is owned by Cenovus and located in its extraction facilities at Christina Lake, Alberta, Canada. Retrofit to oxy-firing is now complete, as is the commissioning of the oxygen supply system and the boiler. Testing will begin in early 2014, with results expected in the Spring. See page 14 for more detail.

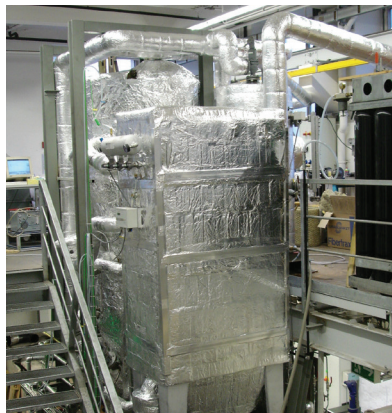
Novel Technology: Chemical Looping Combustion (CLC)

Development and testing of CLC has progressed during 2013 and techno-economic evaluation undertaken. CCP's work has been carried out in collaboration with the EU-funded INNOCUOUS R&D project, which reached completion in September 2013.

CLC is an oxy-firing technology based on using a solid carrier that alternately adsorbs oxygen from air and releases it for flameless combustion of a gaseous fuel. It is suited for potential use in the capture of CO₂ from steam production in oil sands extraction by SAGD (Steam Assisted Gravity Drainage).

The three-year, €3.9m part-EU funded INNOCUOUS project finished with interesting results. The main success of the project was in developing and testing a range of effective alternatives to the expensive Ni-based carriers developed in the previous phases of CCP.

THE 2013 CAPTURE PROGRAM



Chemical Looping Combustion

The 140kW chemical looping pilot at Vienna University of Technology. Image courtesy of Institute of Chemical Engineering, Vienna University of Technology.

Sizing of the next scale demonstration unit (10MW) and of a commercial cluster of boilers (4x80MW) for deployment in a typical oil sands field in Alberta was also jointly carried out by Bertsch in collaboration with the Technical University of Vienna (TUV). Results have been implemented into the ongoing evaluation of this technology.

From these results, manganese-based perovskitic materials showed a similar reactivity to nickel, but with some clear benefits – potentially much reduced manufacturing costs and complete combustion without hydrogen or CO₂ impurities, at the expense of a higher consumption rate due to lower resistance to attrition.

These carriers may be the subject of further development to achieve a cheaper CLC technology. INNOCUOUS has also provided useful information to CCP about carrier price and attrition rate for use in the economic evaluation of this technology.

The main partners in this project included: Chalmers University; CSIC (Spanish National Research Institution); Technical University of Vienna (TUV); VITO (Flemish National Research Institution); Johnson Matthey; and Bertsch.

Novel technology: CO₂ Solutions

CCP joined a development project run by a Canadian company, CO₂ Solutions, looking at solvent and enzyme-based post-combustion. The project focuses on application for oil sands extraction, but the technology may be applied to any capture scenario and CCP is also investigating its application to Natural Gas Power Generation.

CCP joined Phase One of this nearly four-year project at the start of 2013. Phase One has a budget of \$1.8m, of which \$0.85m is governmental funding.

The application of enzymes to accelerate the absorption rate of CO₂ may enable the use of solvents with low energy consumption in the regeneration phase. Without enzymes these solvents would react too slowly for commercial application.

This phase of the project includes solvent screening, process simulations and enzyme management, screening and selection – and ends with large-scale bench testing and a techno-economic analysis.

So far, interesting results have been achieved in terms of energy consumption and enzyme management. Enzymes could accelerate the reaction rate to the same level as MEA for solvents, but with much lower regeneration energy. Since enzymes can be damaged by high temperature, particular care must be used in their management during plant operation. The project was successful in devising ways for proper management either by immobilizing the enzyme in specific positions or by letting them flowing freely in the system. Results from tests in a large bench scale unit are due in early 2014.

CO₂ Solutions

Left: Large bench prototype.

Right: Enzyme characterization work. Images courtesy of CO₂ Solutions Inc.



REFINERIES

Novel technology: Membrane Water Gas Shift (MWGS)

CCP has been working with Pall Corporation to gain a better understanding of the potential of this membrane-based capture technology which could have potential in the refinery scenario. This pre-combustion technology uses metallic membranes permeable to hydrogen to separate hydrogen from CO₂ in the syngas produced by the reforming of a fossil fuel.

In 2013, this work moved into the final testing and techno-economic evaluation phase. Pall had developed palladium alloy-coated steel membrane modules during 2012 and these underwent testing during the past year. Performance and durability tests were concluded with positive technical results. The membranes were tested in a real syngas environment for more than 1,000 hours without undergoing any significant decay.

Membrane modules were designed by Pall, based on available tubes, taking into account both test results and 'concentration polarization' effects. The economic evaluation of this technology has been based on adoption of these modules in a pre-combustion scheme for supply of hydrogen fuel to clusters of boilers and crude heaters in an oil refinery. However, the results in terms of CO₂ avoidance costs are challenging due to hardware complications caused by the concentration polarization and to the increased cost of palladium.

NATURAL GAS POWER GENERATION

Novel Technology: Ion

Working alongside the Energy and Environment Research Centre (EERC), University of North Dakota, USA, CCP has been involved in the screening and comparative testing of novel solvents which could be used to support capture of CO₂ in the NGCC scenario.

In 2013, extended pilot-scale testing at EERC was carried out on a non-aqueous solvent provided by Ion Engineering. The development of non-aqueous solvents may result in consistent energy savings avoiding water evaporation in the regeneration phase.

Test results have been elaborated in collaboration with the technology provider to achieve heat and mass balances and equipment sizing to be used in the ongoing technical study and economic evaluation of the technology.

IN FOCUS: ONCE THROUGH STEAM GENERATOR (OTSG) OXY-FIRING DEMONSTRATION

OTSG oxy-firing

Oxygen delivery skid for OTSG project. Image courtesy of Praxair and Cenovus.



OVERVIEW

Once Through Steam Generators (OTSGs) burn large amounts of natural gas, and are the primary source of GHG emissions from the in-situ production of bitumen from Canada's Athabasca oil sands. OTSGs are used in steam-assisted gravity drainage (SAGD) operations; these types of operation will be the primary source of growth in heavy oil activities for the foreseeable future, as upwards of 85% of bitumen resources in Canada can only be extracted through in-situ production methods. This is an important area of development which could help significantly reduce the greenhouse gas emissions of these operations.

Oxy-firing combustion is a natural candidate for OTSG boilers and uses nearly pure O₂ instead of air for combustion. By eliminating N₂, a gas with concentrated CO₂ is produced, which requires minimal clean-up prior to compression and transport to long-term geological storage.

A logical next step for CCP3 was to develop a practical demonstration project to test viability. CCP entered a demonstration project, with member company Suncor acting as project manager, jointly with Cenovus Energy (owner of the demonstration plant and site), Devon Canada, MEG Energy, Praxair and, Statoil. The project is financially supported by the Climate Change Emission Management Corporation (CCEMC) of the province of Alberta.

THE PROJECT

The main goals of the project are:

- To evaluate the integration of oxy-fuel combustion and CO₂ capture technology into the operation of an OTSG boiler to enable CO₂ sequestration
- To provide design and cost estimates for a commercial-scale OTSG boiler with CO₂ capture, and compression.

Oxy-fuel combustion in OTSG is expected to have several advantages over post-combustion capture, including:

- The ability to capture up to 99% of the CO₂ emissions
- Significant reductions in emissions of air contaminants
- Recovery of water from the gas, thus reducing or eliminating the need for boiler make-up water
- No requirements for amine or ammonia solvents, which may pose operational and environmental challenges
- The potential for improved boiler efficiency as there is no nitrogen present in the combustion process.

PROJECT DEVELOPMENT TO 2013

Phase I, at an approximate cost of CAD\$1 million, was completed in 2010 and optimized the design and costs of both a pilot-scale and commercial-scale boiler. This phase included the establishment of the design basis for a commercial-scale boiler system as well as a test-sized boiler.

Phase II of the project, at an approximate cost of CAD \$5 million, will test oxy-fuel combustion on a 50 MMBTU/hr OTSG unit at Cenovus Energy's Christina Lake (Alberta, Canada) in-situ site. In 2010, the project participants were awarded a \$2.5 million grant from the Alberta CCEMC to partially offset the costs of the pilot program.

During 2013, construction was completed including installation of liquid oxygen equipment and control skid, and work on blower dimensions and modelling.

During 2014, the modified OTSG will operate (without capture and compression) to demonstrate feasibility and full-scale design implication. The oxygen for the test will be provided by trucking and storing liquid oxygen.

[OTSG factsheet available](#)

 CO2CAPTUREPROJECT.ORG/REPORTS/FACTSHEET_OTSG.PDF

CAPTURE PROGRAM CONCLUSIONS

2013 MEMBERS OF THE CCP3 CAPTURE TEAM

TEAM LEAD

Ivano Miracca
eni

MEMBERS

Dan Burt
Suncor

Jonathan Forsyth
BP

Iftikhar Huq
Suncor

Mahesh Iyer
Shell

Raja Jadhav
Chevron

Jamal Jamaluddin
Shell

Leonardo de Mello
Petrobras

Gustavo Moure
Petrobras

Betty Pun
Chevron

Frank Wubbolts
Shell

"This past year has been one where we have been able to draw together the findings of some highly important tests and assessments to better understand the most realistic options for CO₂ capture in the oil & gas environment. Bringing our second large-scale demonstration to the point of testing has been a major achievement and is the culmination of a number of years' hard work. I would like to thank the many partners involved – Suncor, Cenovus Energy, Devon Canada, MEG Energy, Praxair and Statoil – for their engagement in this venture.

"I leave the CCP after 13 years, with a great sense of satisfaction in the progress that has been made in identifying, screening and developing next generation CO₂ capture technologies. Much work remains to be done, but the work of the CCP members and our many partners to date have helped lay very solid foundations."

Ivano Miracca, *eni*, CCP Capture Team Lead

STORAGE, MONITORING & VERIFICATION PROGRAM

SMV HIGHLIGHTS

Geo-mechanical Hysteresis project completed

Further work on Modular Borehole Monitoring project shows potential for cost-effective use of fibre optic sensors

Certification Framework completed

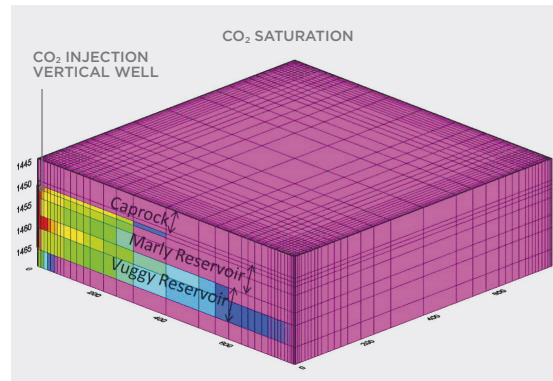
Contingencies study modeling completed with significant conclusions drawn

DRAWING CONCLUSIONS

The focus of the CCP Storage program during 2013 was to complete remaining projects. Some particularly significant conclusions have been drawn from CCP's work around Modular Borehole Monitoring while, late in the year, the CO₂ Storage Contingencies program produced novel modeling simulation findings and practical field project experiment design concepts.

Storage Assurance and Field Trialing continued to be the focus for the majority of the work carried out during the year. A new project looking at Geomechanical Hysteresis (to better understand the impact of E&P activities on containment) was commissioned and completed during the year, while a number of projects were closed out, including the *Site-Specific Optimization for Selection of Monitoring Technologies* and *Value of Information (VOI) for Monitoring* studies. A field baseline monitoring deployment of a new electro-magnetics (EM) source-receiver configuration was conducted ahead of anticipated CO₂ injection at the Aquistore site in Saskatchewan, Canada.

THE 2013 STORAGE, MONITORING & VERIFICATION PROGRAM



Geo-mechanical Hysteresis

CO₂ distribution in dynamically fractured (in-situ and induced) reservoir showing minimal impact on caprock seal integrity. Image courtesy of Taurus Reservoir Solutions Ltd.

STORAGE ASSURANCE

Subsurface Process

As referenced in the 2012 CCP Annual Report, two subsurface process studies conducted in 2012 provided interesting results which demanded further investigation in 2013.

The Capillary Entry Pressure (P_c) study had been run with the RTWH-University of Aachen, Germany and provided initial diverging results, despite homogeneity of the rock examined. The study was an approach to predicting the CO₂ column height that a caprock can safely retain prior to plume migration. The conclusion from further analysis in 2013 is that micro-fracture formation (either in-situ from excavation or de-stressing from removal to surface conditions) may have impacted experimental results, and thus limits the general applicability of this technique for assessing seal competence to CO₂ accumulation.

A separate Relative Permeability (K_{rel}) study was designed to better understand the variance in pore scale processes using variable experimental conditions and to assess the suitability of commercial laboratories to conduct such experiments routinely. Preliminary results differed significantly in terms of potential storage capacity from those in the literature. Further experiments were carried out in 2013 and will continue into 2014. These aim to understand the effects and implications of experimental conditions and testing on those results.

Geo-mechanical Hysteresis

A new study on geo-mechanical hysteresis was commissioned through Taurus Reservoir Solutions with the objective of better understanding system containment vulnerabilities which are induced by field development and production operations prior to CO₂ injection for storage.

The study looked at cumulative reservoir/seal system stress changes that may impact seal resilience during CO₂ injection for storage. It involved compiling a set of input data suitable for a numerical modeling study on hysteresis effects. This was achieved first by assembling a set of publicly available data on rock properties, initial stress distribution, PVT, production history, initial pressure and temperature and relative permeability.

This served as the basis for building a model using a Taurus proprietary GEOSIM simulator and the Weyburn field, Saskatchewan, Canada was used as a case study. This study showed that thermo-elasticity dominates during the early stage of the waterflood, which resulted in tensile fracturing of the reservoir and partial growth of the fracture into the caprock without violating the seal of the caprock.

Monitoring & Verification

The University of Texas Bureau of Economic Geology (UT-BEG) helped CCP deliver two important studies to further the effective use of CO₂ monitoring technologies.

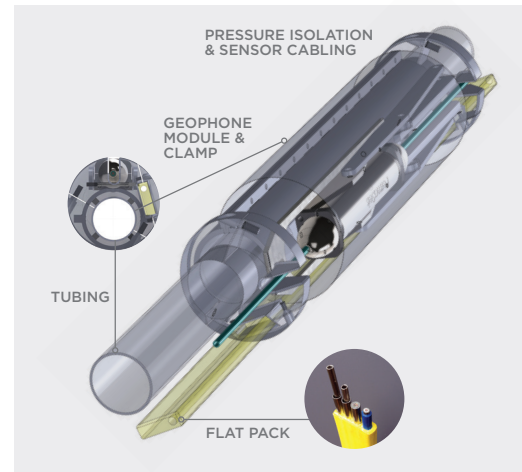
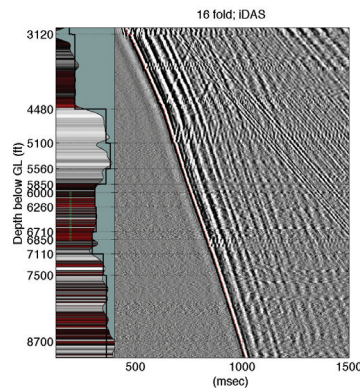
The *Site-Specific Optimization for Selection of Monitoring Technologies* study was conducted with CCP3 input by UT-BEG with majority funding from the US Environmental Protection Agency to assess the relative utility of CO₂ storage monitoring technologies, individually and collectively, based on experience and theory.

THE 2013 STORAGE, MONITORING & VERIFICATION PROGRAM

Modular Borehole Monitoring

Left: A profile from the deepest 6400ft section of the Citronelle D-9-8 well that was recorded on Silixa's iDAS system. Image courtesy of Silixa Ltd, LBNL.

Right: MBM system. Image courtesy of LBNL.



A report was delivered which focused upon time-lapse 3D seismic, above zone pressure, above zone temperature and ground-water field geo-chemistry. These technologies were forward modelled to show the response in a monitoring deployment, varying the elements of the geological setting to illustrate the sensitivity of the technology to the environment.

The other M&V study with UT-BEG was the *Value of Information (VOI) for Monitoring*. A procedure was developed to quantify the benefit of monitoring technologies in CO₂ storage projects and applied to a real-life injection case study - in this case, the In Salah storage project in Algeria.

The resulting work has provided useful concepts on the value of seismic monitoring at In Salah, as well as a creating a template to (i) identify activities or technologies that could provide information regarding important uncertainties (ii) quantify the accuracy of this information (iii) understand and quantify how this information would alter the operator's decision making and (iv) determine if the likely improvement in this decision making is worth the additional cost of the information.

Storage Optimization

Final reports were submitted for each of the outstanding sub-projects led by LBNL and UT-BEG, bringing this initiative to a conclusion. These studies - which included induced seismicity, native gas exsolution, injection-induced fracture propagation and storage capacity - contribute to the completion of the Certification Framework, initiated in CCP2 (2006). This provides a consistent means of site assessment as well as informing monitoring technology selection.

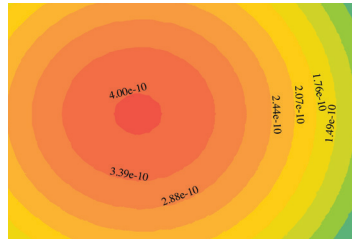
FIELD TRIALING

Modular Borehole Monitoring

The CCP3-LBNL Modular Borehole Monitoring (MBM) system was deployed at the Citronelle field (Alabama, USA) in 2012. Initial tests of the downhole monitoring capability of the MBM system established that off-depth perforations were the source of pressure bleed-off. With this evidence that the deployment was robust, the installation was transferred to the field operator as functional. At the same time, an opportunity was taken to use the fiber optic lines as a distributed acoustic sensor, using Silixa Ltd's laser-based FO-iDAS. This was carried out at the same time as a 2D VSP test using the MBM's conventional permanent geophones. The initial test was repeated at a later date due to source timing issues and this later test showed that the FO-iDAS data was highly comparable to 2D VSP data, demonstrating a method that would have significant logistical and hardware economies for seismic monitoring. Overall reporting of the FO-iDAS deployment was completed by LBNL with the following key conclusions:

1. A high degree of repeatability was observed
2. A signal was achieved that was comparable to the geophones, providing six times the number of shots used
3. The fibre optic cable was in the flatpack (single completion assembly) and hence not in the most ideal coupling position - yet it worked well.

THE 2013 STORAGE, MONITORING & VERIFICATION PROGRAM



Electromagnetics Monitoring

Borehole to Surface EM Model at Aquistore: Anomalous Surface horizontal electric field (Eh) due to 10 kt CO₂ with 360 amp-m, 1 Hz downhole source at 3+ km. Image courtesy of LBNL.



Soil Gas Monitoring

Transect of UT-BEG soil-gas monitoring stations in Gulf Coast, US. Image courtesy of The University of Texas Bureau of Economic Geology.

The implications of this test are particularly significant not only for CO₂ monitoring but also for other E&P monitoring tasks. The potential exists to replace downhole geophones with simpler and less costly FO-iDAS to obtain similar quality 2D and 3D VSP images.

MBM factsheet available

 CO2CAPTUREPROJECT.ORG/REPORTS/FACTSHEET_MBM.PDF

Electromagnetics (EM) Monitoring

A feasibility modeling study was completed for electromagnetics (EM) deployment at Aquistore (a deep storage facility for the Boundary Dam utility capture project in Saskatchewan, Canada) using current sources. This showed that this EM approach would be feasible to detect the mass of CO₂ planned for injection.

However, rig availability and timing issues meant this configuration could not be deployed. Fortunately CCP3 was able to engage a new company, GroundMetrics Inc., to run a field study with a novel approach involving well casings as EM current returns, using a surface source and receiver array. This configuration provided an equivalent method to deploying source downhole, but removing the need to intervene in the well bore.

GroundMetrics deployed a pre-injection baseline survey which was also the deepest EM acquisition attempted (~3,000m), recovering good signal to noise. Despite some initial deployment issues, the survey was conducted providing the predicted signal level. Plans are being agreed to provide the repeat survey after injection occurs in Q1 2014.

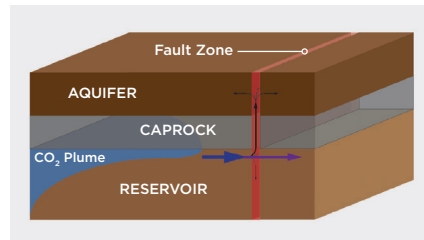
Soil Gas Monitoring

A process-based approach to soil gas monitoring at geologic carbon storage sites may provide an accurate, simple, and cost-effective alternative to other soil gas methods that require complex background data collection and analysis. The technology for economical, field-deployable smart data collection of all gas parameters (important for a process-based analysis, especially N₂) is lacking, thus limiting the ability to use this approach on an industrial scale.

Twelve continuous monitoring tests were conducted over a two week period at two localized sites within a typical Gulf Coast oil field (Denbury Resources' West Hastings EOR project in Texas, USA). The aim was to assess commercially-available automated sensors that measure CO₂, CH₄, O₂, temperature, relative humidity (RH), and pressure, followed by derivation of N₂ by mass balance.

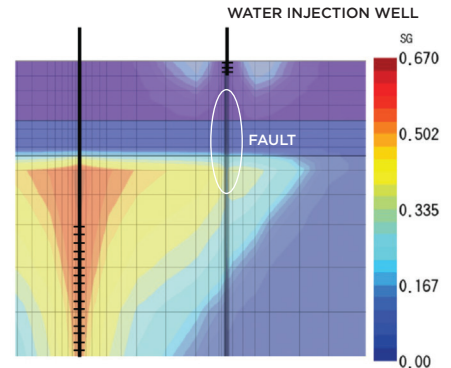
However, neither NDIR (non-dispersive infrared) nor galvanic cell technologies consistently produced data in the field with the necessary quality to perform process-based monitoring at geologic carbon storage sites. The principle conclusion was that commercially-available sensors for CO₂, CH₄, O₂ and RH were found to possess factory-derived accuracies that meet the desired specifications for implementing the process-based method in the field. However, field testing of sensors yielded data with insufficient accuracy and precision to match the current GC method.

IN FOCUS: CONTINGENCIES MODELING AND FIELD EXPERIMENT



Contingencies Study

Remediation scenario of potential CO₂ migration through fault zones. Image courtesy of C. Zahasky and S. Benson, Stanford Univ.



Contingencies Study

Above-seal water injection was one of the scenarios simulated. Image courtesy of C. Zahasky and S. Benson, Stanford Univ.

OVERVIEW

The CCP Contingencies initiative aims to identify anomalies that may lead to containment failure at a CO₂ storage site and formulate an intervention plan using existing (or developing new) technologies. Developing the capability to detect, characterize and intervene in unanticipated CO₂ or displaced brine migration will add an additional layer of stakeholder reassurance around CO₂ storage.

THE PROGRAM IN DETAIL

Defining the Scope (Phase 1)

An initial scoping workshop was held in 2011, attracting 35 experts from the oil & gas field services industry, national laboratories and universities. The workshop looked at the vulnerabilities of natural and engineered systems to out of zone CO₂ and brine migration and the potential impacts on a project's effectiveness and compliance, as well as on health, safety and the environment (HSE). From this, a plan for the project was produced, encompassing modeling and technology development.

Modeling and Simulation of Potential CO₂ Migration Scenarios (Phase 2)

Stanford University was selected to conduct Phase 2 of the Program – a modeling-based approach to the detection, characterization and intervention of unexpected CO₂/fluid migration. This involved using a geologic model with simulation of CO₂ injection, with and without features that would allow CO₂ to migrate out of zone via conduits (e.g. undetected faults).

For the migration cases, sensitivity to detecting CO₂ migration was estimated and intervention techniques simulated. Injection profile management, above-seal water injection and below-seal CO₂ extraction were carried out as was simulation of injection of sealants

into the top seal breaches. Other specialized studies were carried out, including simulations of sealant efficacy (for a commercial well sealant and novel chemical agents) with respect to fault zone geomechanics/permeability characteristics.

The significant results of this work were presented at the end of 2013. They include:

- Surface seismic detection and characterization of unexpected CO₂ migration is limited but could be improved using above-seal pressure monitoring and borehole (e.g. cross-well) seismic. Ceasing CO₂ injection stops the bulk of future unexpected CO₂ migration in most cases. Additional hydraulic controls are effective for further reducing or eliminating CO₂ flow but such operations would need to be maintained as long as CO₂ is injected
- Injection of sealants could be highly effective and perhaps allow continued injection of CO₂. More development work would be needed, however, to extend the setting time under subsurface conditions
- Conduit 'self-healing' via salt and other mineral precipitation may occur under some circumstances.

Intervention Technology Development (Phases 3 and 4)

The last two stages of the project aim to identify a suitable site to test an intervention technology with the development of a detailed characterization, engineering, surveillance and analytical plan (Phase 3), then potentially to deploy it (Phase 4). Work is ongoing with GeoScience Ltd on Phase 3 resulting in the delivery of practical field project experiment design concepts. A decision on further development and the identification of a suitable test site will be made in 2014.

Contingencies factsheet available

 CO2CAPTUREPROJECT.ORG

STORAGE, MONITORING & VERIFICATION PROGRAM CONCLUSIONS

2013 MEMBERS OF THE CCP3 SMV TEAM

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MEMBERS

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Chevron

Josephina Schembre
Chevron

"This past year has seen a number of important projects draw to a conclusion, the results of which provide a clear path for our forward program in CO₂ storage assurance and effectiveness. Perhaps our most significant CCP3 project is the work into contingency planning for unexpected CO₂ migration from storage zones. Extensive modeling-simulation has provided unique perspectives on unexpected migration mechanisms and their mitigation, which could be tested at the bench to field scale.

"Thanks are due to our many research partners in the range of Storage, Monitoring & Verification projects. Without them, we could not have built the considerable body of knowledge around CO₂ storage during CCP3. As I leave the CCP during 2014, I am particularly proud of what we have achieved together – work which will help the future advancement of CCS as a whole, both within and outside of the oil & gas industry."

Scott Imbus, *Chevron*, CCP SMV Team Lead

POLICY & INCENTIVES PROGRAM

P&I HIGHLIGHTS

Study completed on *Local community benefit sharing mechanisms for CCS projects*

Presented benefit sharing mechanism results at International Emissions Trading Association (IETA) side-event at UN Conference of the Parties (COP19, Poland) and at the Carbon Sequestration Leadership's Stakeholder Panel Discussion on Communications

STEADY PROGRESS FOR CCS POLICIES

There have been notable CCS regulatory developments in some countries but extensive policy efforts toward the long-term deployment of CCS projects are slowing down. These efforts are still reliant on global policy makers but it is also becoming increasingly important to gain support at the local level.

In 2013, the Policy & Incentives (P&I) Team undertook a study into benefits to the local community of CCS and the likely effects on the success or failure of CCS projects. Findings from the study were analysed to explore how community benefit sharing might apply in the context of CCS development.

THE 2013 POLICY & INCENTIVES PROGRAM

P&I reports

The *Local community benefit sharing mechanisms for CCS projects* report.



LOCAL COMMUNITY BENEFIT SHARING MECHANISMS FOR CCS PROJECTS

Back in 2011, the Team produced an updated *CCS stakeholder issues review and analysis* report that identified and analysed a number of issues raised by different stakeholders, including the local community, in relation to the development of CCS projects, which can have significant influence on the success or failure of these CCS projects. One of the key findings from that study was that local communities are more likely to become actively involved and oppose project developments when there are no apparent benefits to the local community itself.

As a follow-up to this report, the Team undertook a further study in 2013 which looked into community benefit sharing. The *Local community benefit sharing mechanisms for CCS projects* report aimed to explore further and investigate experiences and options for how local communities can reap tangible advantages from CCS projects being sited in their area. Results from the study were showcased at the IETA side-event of the UN Conference of the Parties (COP19, Warsaw, Poland) and at the Carbon Sequestration Leadership's Stakeholder Panel Discussion on Communications (Washington D.C.).

A desk-based review of local community benefit sharing experiences across the energy, mining and waste sectors was conducted. Following this, four projects in the energy sector (including one CCS project) were explored in greater detail and interviews were conducted in order to gain 'on-the-ground' insights and the specific mechanisms employed. Findings from the review were subsequently analysed in order to explore how community benefit sharing might apply in the context of CCS development.

The overall key findings show that:

- Project developers increasingly focus on maximizing direct and indirect positive local impacts associated with a development (such as employment and the procurement of local goods and services), and also through specific community investment programs
- It is widely recognized that the sharing of benefits with local communities can help to address the potential imbalance of local costs and national or global benefits that can arise with many projects in the energy, mining and waste sectors
- Whilst projects in these sectors can have national or even (in the case of CCS) global benefits, the negative impacts or 'costs' of the development (such as noise, visual impacts, pollution, and perceived or actual health and safety risks) are often concentrated at the local level
- Benefit sharing allows benefits to be transferred to local communities and can help projects be more acceptable at the local level.

THE 2013 POLICY & INCENTIVES PROGRAM

P&I reports

Community benefit sharing measures. Image taken from the *Local community benefit sharing mechanisms for CCS projects* report.



The report also identified some barriers to be overcome which include:

- The need to address the imbalance of positive and negative impacts across the CCS chain. There may be a number of ways to ensure benefits are distributed across each stage of the CCS chain but they require careful appraisal
- Potential for consultation ‘burn-out’. Communities without experience of major developments may need guidance, specialist support and expertise in order to participate effectively in the community benefit sharing process. Project operators need to ensure that effective communication with the local community is maintained throughout the project life
- Determining what constitutes the ‘local’ community to receive the benefits to ensure that an overall sense of fairness applies throughout the process
- Ensuring benefit sharing at the community hosting the storage site. The storage site is frequently perceived to have the greatest public concerns around perceived health, safety and environmental risk and yet activities at this stage offer no real ‘value proposition’ to local communities in terms of direct or indirect local benefits stemming from project activities. A potential exception to this is where a new CCUS project creates jobs, procurement opportunities, and indirect economic benefits at the storage stage in association with the Enhanced Oil Recovery (EOR) activities being undertaken
- Thinking creatively about how to fill this ‘benefits gap’, creating a value proposition for the community hosting the CO₂ storage site.

The study found that a variety of benefit sharing approaches could be used to increase the attractiveness of a proposed CCS project to these communities. If a project is commercially driven, revenue sharing may be an option. Alternatively, project developers could explore options to ensure the distribution of direct and indirect project benefits such as employment, procurement of local goods and services and infrastructure enhancements (normally encountered at the capture stage of the project) across the whole CCS chain, so that such benefits are not purely concentrated at the capture stage. Another option for enhancing local community benefits at the storage site is through community investment.

P&I reports available

 [CO2CAPTUREPROJECT.ORG/REPORTS.HTML](https://co2captureproject.org/reports.html)

POLICY & INCENTIVES PROGRAM CONCLUSIONS

2013 MEMBERS OF THE CCP3 P&I TEAM

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Dan Burt
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Renato De Filippo
eni

Christhiaan Greco
Petrobras

Charles Samuda
Shell

"In order to advance CCS projects, there is a growing need to understand the various stakeholder relationships surrounding these projects and the local community is no exception. In 2011, the P&I Team had examined the roles of different groups of stakeholders, their roles and influence in the discussion about CCS and development of CCS projects.

"One of the issues identified at that time but not yet in scope was the critical role of the local community in determining the permission to develop a CCS project. With the P&I Team's 2013 study into local community benefit sharing mechanisms, the findings have shed new light on identification of community benefits, community engagement and social impact management."

Arthur Lee, *Chevron*, CCP Policy & Incentives Team Lead

COMMUNICATIONS PROGRAM

COMMUNICATIONS HIGHLIGHTS

CCS educational tool, the CCS Browser, launched in June - available on smartphone, tablet and PC

Selected for CSLF technical showcase, Washington D.C., in November

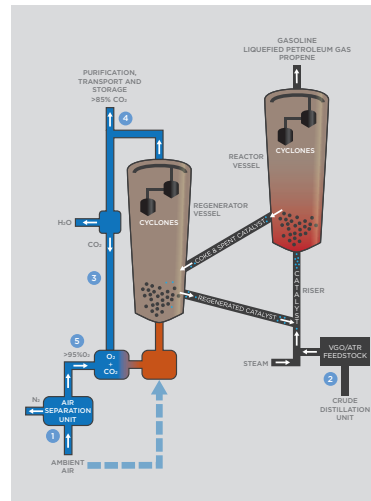
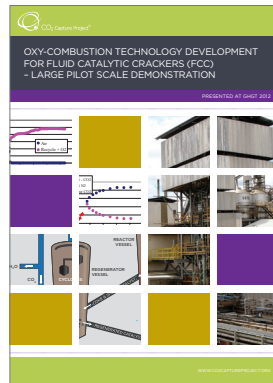
ENGAGING TO PROGRESS

The year saw the culmination of the CCP's most ambitious communications program to date.

The focus has remained on keeping the oil & gas industry and wider CCS world informed of the latest technical insights delivered by the Capture and Storage Teams. In particular the Communications Team has worked hard to share the rich insights gained from a series of important storage field trials and from the Fluid Catalytic Cracking oxy-firing capture demonstration in Brazil.

However, the progress of CCS is not dependent only on meeting technical challenges. As the Global CCS Institute highlighted in its 2013 status report: "Insufficient policy support, exacerbated by poor public understanding" is acting as a drag weight on progress. So it is significant that in 2013, the CCP launched the industry's first multi-platform digital tool to explain CCS to a non-technical audience. The CCS Browser (www.ccsbrowser.com) draws on the expertise of the CCP technical Teams to explain the science of CCS in an engaging and accessible way. It has been heartening to have received positive feedback from many industry groups. Our ambition is for the CCS Browser to be widely used by the industry in its outreach to the public.

THE 2013 COMMUNICATIONS PROGRAM



Fluid catalytic cracking
Left: The Oxy-combustion technology development for fluid catalytic crackers (FCC) - Large pilot scale demonstration detailed report.
Right: This infographic is a simplified representation of oxy-firing in an FCC unit.

LITERATURE DEVELOPMENT

In 2013, CCP issued a number of new and updated materials which included the 2012 Annual Report, updated factsheets on the Fluid Catalytic Cracking (FCC) and Once Through Steam Generator demonstrations and a new factsheet on the Contingencies Study (due for publication in 2014).

CCP's GHGT11 presentation on the FCC demonstration and the P&I report on local community benefit sharing mechanisms for CCS projects were both made available on the CCP website. Alerts were sent to website registrants (including NGOs, industry groups, academics and the media).

Infographics have been used across communications materials to make complex technical information accessible to a wider audience. The infographic above provides an overview of the CCP's first demonstration held in 2012 - an oxy-firing test at a pilot-scale Fluid Catalytic Cracking unit.

FCC detailed report available

 CO2CAPTUREPROJECT.ORG/REPORTS

FCC factsheet available

 CO2CAPTUREPROJECT.ORG/REPORTS/FACTSHEET_FCC.PDF

STAKEHOLDER OUTREACH

Web

CCP raised awareness of its work by issuing updates to the 4,500 people registered for updates on the website (www.co2captureproject.org). The website received on average nearly 2,000 visitors a month in 2013.

CCP website

 CO2CAPTUREPROJECT.ORG

Media

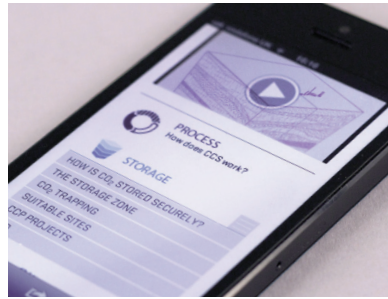
CCP articles appeared in a number of publications including the IEA Greenhouse Gas, ZEP and CCSA newsletters, *Carbon Capture Journal*, and *Oil & Gas Journal*.

Exhibitions & Conferences

CCP attended the Carbon Sequestration Leadership Forum (CSLF) Ministerial Meeting in Washington D.C. It was selected to exhibit in the technical showcase where it shared materials with country delegates and other stakeholders visiting the stand. CCP also exhibited and presented papers at the 12th Annual Carbon Capture, Utilization and Sequestration Conference (CCUS Conference, May 2013).

CCP made further presentations at a number of key forums in 2013, including the Platts 7th Annual European Carbon Capture & Storage Conference (February 2013), the Carbon Capture & Storage Workshop hosted by The High Commission of Canada (March 2013) and the Carbon Capture Journal conference - Keeping the momentum with CCS (November 2013).

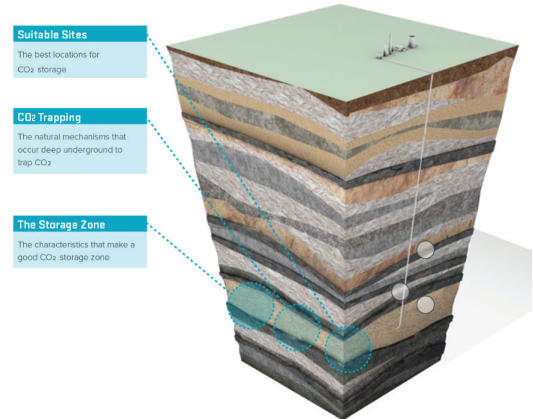
IN FOCUS: THE CCS BROWSER



CCS Browser

Above: CCS Browser – a multi-platform digital tool to explain CCS.

Right: Animations are used to explain topics on CCS.



The successful delivery of CCS projects relies partly on gaining public understanding and acceptance. As the number of CCS projects around the world increases, so will the demand from the general public for accessible information on CCS. In 2013 the CCP launched its most significant communications tool to date. The CCS Browser is the industry's first multi-platform digital tool to explain CCS comprehensively to a non-technical audience.

News of the CCS Browser was widely reported across industry publications and online sources, including *Carbon Capture Journal*, *Oil & Gas Journal*, *Carbon Offsets Daily*, *The Energy Daily*, ZEP newsletter and the CCSA newsletter. The news also attracted tweets from groups including the IEA, Shell and the Carbon Sequestration Leadership Forum (CSLF).

CCS Browser

 CCSBROWSER.COM

Engaging

The CCS Browser has been designed to allow people to explore the topic in the way best suited to them – by watching animations, listening to audio clips or by interacting with maps and diagrams. People can watch animations of CO₂ being trapped in rock pores at the scale of less than a millimetre.

Adaptable

It provides a high-quality experience whether accessed by smartphone, tablet or PC. With the number of people accessing the internet via smartphone and tablet rapidly increasing, ensuring the Browser works across platforms has been an important element of the project.

Focused

It is essential to assure the public of the security of CO₂ storage. Detailed animations are used to explain topics such as geological trapping, capacity and containment as well as storage site operation and CO₂ monitoring and verification.

Accessible

The language of the Browser is precise but deliberately non-technical. A hover-over glossary is provided to explain key terminology for those requiring more in-depth information.

Transparent

The site acts as a portal to other CCP and CCS resources to allow the exploration of topics in even greater depth, if required.

COMMUNICATIONS PROGRAM CONCLUSIONS

2013 MEMBERS OF THE CCP3 COMMUNICATIONS TEAM

TEAM LEAD

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MEMBERS

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Kurt Glaubitz
Chevron

Christhiaan Greco
Petrobras

Tanis Shortt
Suncor

Peter Snowdon
Shell

"It's been a demanding year as the CCP3 enters its final phase, with technical Teams and the Executive Board working flat out to deliver projects. It is a credit to all that the commitment to sharing knowledge has not waned. Extensive sharing of technical insights has demanded the energy of everyone; with technical experts working alongside communications specialists to make sure the information delivered is relevant and understandable to a range of important audiences. Nowhere was this collaboration more clearly seen than on the creation of the CCS Browser. Many hours were spent on working out the detail of animations and copy to ensure technical accuracy, while remaining accessible to non-technical audiences.

"We are very proud to have delivered the industry's first dedicated digital resource focused on explaining CCS. We hope the industry finds it a useful tool in its own efforts to help the public understand more about CCS and its potential."

Mark Crombie, *BP*, CCP Communications Team Lead

CCP3 MILESTONES AND ACHIEVEMENTS

The CCP is nearing the end of its third phase of activity, CCP3. This period has seen significant progress resulting in an array of demonstrations, field trials and studies.

While the broader world of CCS has lately witnessed something of a slowdown, CCP's commitment has remained constant in advancing technologies and improving operational approaches to help CCS become a viable option for the oil & gas industry. The main milestones from its work are outlined below:

2010 YEAR 1

➤ CCS first recognized in the Clean Development Mechanism at UNFCCC COP16

➤ Secured up to \$CAD 2.5million in funding from the Climate Change and Emissions Management Corporation (Alberta) for OTSG demonstration

➤ Co-funded acquisition and interpretation of time-lapse 3D VSP data and correlation to surface seismic 4D survey at Otway Basin, Australia

➤ Independent survey of regulatory issues commissioned

2011 YEAR 2

➤ Elaboration of rules in the Clean Development Mechanism to include CCS projects at UNFCCC COP17

➤ Contracts awarded for oxy-firing capture technology demonstration projects (FCC and OTSG)

➤ InSAR satellite technology deployed to detect surface deformation from CO₂ storage at Decatur, USA

➤ Updated study on stakeholder issues published - *CCS stakeholder issues review and analysis*

➤ Developed digital version of In Depth brochure as an education tool

2012 YEAR 3

➤ Phase III Economic Baselines for oil refinery, heavy oil and natural gas scenarios finalized

➤ Demonstration completed of oxy-firing capture technology in a pilot-scale FCC unit at a Petrobras research facility in Parana, Brazil

➤ Modular Borehole Monitoring system successfully deployed at Citronelle site

➤ CO₂ Impurities study concluded examining the effects of impurities in injected CO₂ on injection, migration and pressure evolution

➤ Latest CCS Regulatory Study published - *Challenges and key lessons learned from real-world development of projects*

2013 YEAR 4

➤ Chemical Looping Combustion project completed

➤ Testing of Membrane Water Gas Shift (MWGS) module completed

➤ OTSG oxy-firing facility constructed in Alberta, Canada and ready for demonstration

➤ Contingencies study modeling completed with significant conclusions drawn

➤ Certification Framework completed providing a consistent means of site assessment and monitoring technology selection

➤ Study concluded on *Local community benefit sharing mechanisms for CCS projects*

➤ Launched CCS Browser; an interactive, educational website for non-technical audiences

2014 TO BE CONCLUDED

➤ Testing at the OTSG demonstration facility due for completion

➤ Technical studies for novel technologies

➤ Economic evaluations

➤ CO₂ Solutions project due to complete trialing of novel solvents and enzymes for post-combustion

➤ Assessment due of practicality of the Contingencies study demonstration

KEY

➤ GENERAL

➤ CAPTURE

➤ STORAGE, MONITORING & VERIFICATION

➤ POLICY & INCENTIVES

➤ COMMUNICATIONS

"Behind all of this work – and indeed of the way in which CCP has evolved over the years – is collaboration. We have taken the opportunity in this Annual Report of highlighting the valued contribution of our member companies as well as academic, industry and government partners in bringing to fruition many of these projects."

Nigel Jenvey, *BP*, CCP Chairman

