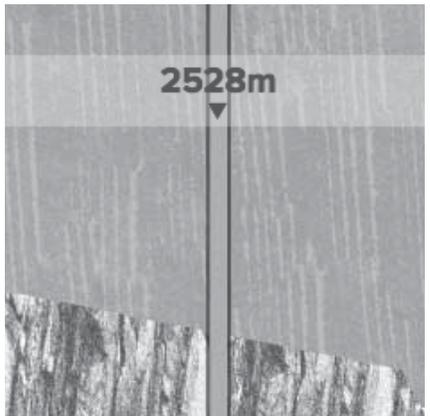
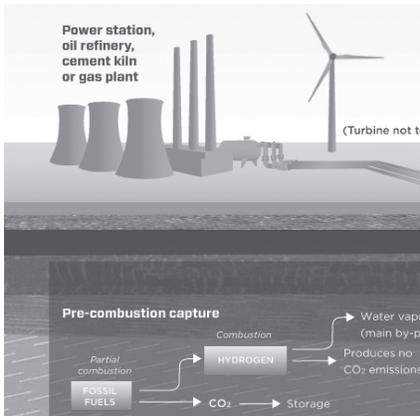
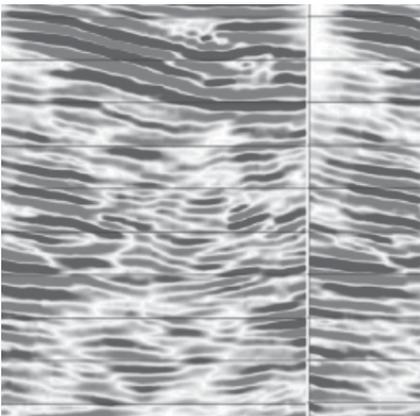


# ANNUAL REPORT 2011

## ADVANCING TO DELIVER RESULTS





# CONTENTS

The CO<sub>2</sub> Capture Project (CCP) is a partnership of several major energy companies working together to advance the technologies and to improve operational approaches in order to reduce costs and accelerate the deployment of CO<sub>2</sub> Capture and Storage (CCS). The CCP is dedicated to advancing and sharing the industry's knowledge to ensure that CCS can make a significant impact on CO<sub>2</sub> emissions. CCS has an important role to play in reducing emissions from power plants and heavy industrial processes such as heavy oil production, oil and gas refining, gas processing and cement manufacture.

Download further copies of the report from the CCP website [www.co2captureproject.com](http://www.co2captureproject.com)



- 04** Chairman's Introduction
- 06** Global Overview
- 08** Technical Advisory Board Review
- 09** Capture Program
  - 10** Refineries
  - 10** Heavy Oil Extraction
  - 11** Natural Gas Power Generation
  - 11** Other technologies
  - 11** Economic Baselines
- 12** Storage, Monitoring & Verification Program
  - 13** Storage Assurance
  - 14** Field Trials
  - 14** CCP Contingencies Program
- 15** Policy & Incentives Program
- 16** Stakeholder Issues Review
- 16** Risk Valuation Study
- 17** Communications Program

Front cover images:

*Top row left & top row middle:* Fluid Catalytic Cracking unit – Oxy-firing demonstration, Brazil. Images courtesy of Petrobras.

*Top row right:* OTSG Boiler. Cenovus Energy, Christina Lake, Canada. Image courtesy of Cenovus Energy.

*Middle row right:* PS InSAR feasibility study at Decatur site, Illinois. Image courtesy of TRE.

*Bottom row left:* Time lapse imaging of baseline and post injection 3D VSP with differencing. Image courtesy of CO2CRC.

*Bottom row middle & right:* Cut-through of interactive In Depth brochure.

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## INTRODUCTION

Brian Williams,  
BP CCP Chairman

### Welcome to the CO<sub>2</sub> Capture Project (CCP) 2011 Annual Report.

It has been a mixed year for the development of CO<sub>2</sub> Capture and Storage (CCS) but the CCP has continued to make progress towards delivering significant results.



### CCP3 Executive Board 2011

**Brian Williams, BP\***  
williadb@bp.com

**Gardiner Hill, BP\***  
gardiner.hill@uk.bp.com

**Vincent Kwong, Chevron**  
vkwo@chevron.com

**Sarah Edman, ConocoPhillips**  
sarah.edman@conocophillips.com

**Mario Vito Marchionna, eni**  
mario.vito.marchionna@eni.com

**Rodolfo Dino, Petrobras**  
dino@petrobras.com.br

**Ad Punt, Shell**  
a.punt@shell.com

**Stephen Kaufman, Suncor Energy**  
skaufman@suncor.com

\*Brian Williams replaced Gardiner Hill as CCP Chairman on 7th June 2011.

A number of significant global events have slowed the development of CCS during the past year. Wider geopolitical and economic concerns have taken center stage. Regime change, budget deficits and other economic factors in various parts of the world have come to dominate the agenda, while climate change issues have been given lower priority.

There have also been setbacks to some key projects that aimed to demonstrate the feasibility of CCS on an industrial scale. Planned demonstrations in the USA, UK and Germany, for example, have been shelved whilst others have stalled even where funding is available. However, there has been some progress with a number of large-scale projects proceeding through the development stage. There were eight large-scale projects in operation and six under construction by the end of 2011. These projects will have a critical role to play in demonstrating the viability of CCS on an industrial scale.

There remains an urgent need for proactive leadership in both the regulatory and policy arenas in order to create the stimulus to further business investment in CCS. There is a risk that a lack of clear direction and commitment will further reduce confidence, even in already planned projects.

Despite the setbacks, there have been some developments that bode well for the future. Policy changes and the advancement of a CCS regulatory framework in Canada and Australia during 2011 will enable the wider development of CCS in those countries. In addition, CO<sub>2</sub> injection has begun at some key demonstration sites in the USA.

Perhaps most significantly, towards the end of 2011, the UN Climate Change 'Conference of the Parties' (COP17) held in Durban, South Africa, saw a major breakthrough for CCS. Lengthy negotiations finally paved the way for CCS to be included as a greenhouse gas mitigation technology under the Clean Development Mechanism. This is an important step forward for CCS development, particularly in rapidly industrialising countries.

Against this backdrop, the work of the CCP's Capture, Storage, Monitoring & Verification, Policy & Incentives and Communications Teams continues, developing and demonstrating lower cost CO<sub>2</sub> capture technologies at scale, building knowledge of CO<sub>2</sub> geological storage and sharing insights from this work with a range of audiences.

## 2011 HIGHLIGHTS

2011 has seen the teams build the framework for the many demonstration activities that will deliver results and insights during 2012 and 2013. Partners have been identified, contracts put in place and preparatory work and studies completed during the course of the year.

The CCP's first major capture demonstration – an oxy-firing test at a pilot-scale Fluid Catalytic Cracking (FCC) unit (one of the highest CO<sub>2</sub> emitting units of a refinery) – has suffered some technical delays as anticipated, but is now underway. Results are expected during the first half of 2012. Experience from this demonstration will go a long way to determining the viability of this CO<sub>2</sub> capture technology in an oil refinery environment. Meanwhile, a lengthy process has brought together a range of partners to deliver the once-through steam generator oxy-fired capture demonstration in Canada during 2012 and 2013, with results due later in 2013. This will be of real use in understanding the viability of oxy-firing technology in reducing emissions from heavy oil and oil sands extraction processes.

On storage, a number of studies, tests and monitoring trials being undertaken by the Storage, Monitoring & Verification (SMV) Team, along with a broad range of industry partners, are at various stages of completion. Results from a Fault Seal Study and a CO<sub>2</sub> Impurities Study were delivered in 2010, while injection has now started on two different, innovative monitoring projects in the USA at Decatur and Citronelle. A CCP storage contingencies workstream has also been set up to provide stakeholder assurance in the ability of industry to assess potential storage containment issues and identify suitable remediation options before an event occurs.

Since taking over the chairmanship of the CCP in the latter part of 2011, I have been struck both by the commitment of the individual teams and by the clear sense of vision and purpose instilled in the CCP by my predecessor, Gardiner Hill, who led the CCP since its formation in 2000. Under Gardiner's leadership, and with the dedication of the Executive Board representatives from the member companies, the CCP has developed into one of the most important joint industry projects in the world of CCS technology. The CCP now has 11 years of history on its side, with established technical credibility.

Since taking on my new role I've felt the passion and dedication of CCP's team leaders and team members. I've also experienced at first hand the strong yet pragmatic guidance provided by the members of the Executive Board as well as the counsel offered by our independent Technical Advisory Board. This structure and our partner efforts have combined to create a powerful vehicle for advancing our technical understanding of CCS.

I was disappointed to see ConocoPhillips withdraw from the group at the end of 2011 due to internal restructuring. ConocoPhillips has contributed greatly to ensuring that the CCP has become a leading technical authority. While there will be some adjustment to CCP3 as a result, there should be no impact on the core focus and activities of the program.

It has been an important year for the CCP as we've passed the halfway point in Phase 3. The pieces are now all in place for the final push for demonstration across a range of technology areas. Without doubt, the next two years will be even more significant as CCP Phase 3 draws to a close at the end of 2013. Results from these planned storage and capture trials will become available during this period and, based on CCP's track record, will become key reference points for large-scale adoption and deployment of CCS in the years to come.

**Capture:** Oxy-combustion capture trial on a pilot-scale fluid catalytic cracking unit (one of the highest CO<sub>2</sub> emitting units of a refinery) began. Results available in 2012

Oxy-fired once-through steam generator project Phase 2 (demonstration) engineering work began. The demonstration run is scheduled in the Spring of 2013

Screening studies completed for novel natural gas combined cycle (NGCC) capture technologies, paving the way for potential future development and scale-up

New baselines (state-of-the-art technology and cost) established for refinery and heavy oil extraction using pre-combustion and oxy-firing technologies

**Storage, Monitoring & Verification:** First phase of CO<sub>2</sub> Impurities Study completed, showing impact of stream impurities on underground CO<sub>2</sub> plume behaviour

Modular Borehole Monitoring assembly at Citronelle in preparation for injection in early 2012

Injection started at Decatur, USA, with InSAR satellite technology deployed to detect surface deformation. Results expected by the end of 2012

CO<sub>2</sub> contingencies program launched with cross-industry and academic input

**Policy & Incentives:** Investigation conducted into various stakeholder issues at project and global level, with the P&I Team presenting the findings at the COP17 conference in Durban, South Africa

Progressed risk valuation study to determine a financial value for potential CCS-related risks and damages

**Communications:** Exhibited at US DoE NETL conference in Pittsburgh

Continued to provide resources to be used by NGOs, industry, media and policy makers – including first CCP Annual Report

## GLOBAL OVERVIEW

Harnessing the power of CO<sub>2</sub> Capture and Storage (CCS) to reduce global CO<sub>2</sub> emissions



The year ended with greater certainty about the continuation of carbon markets. The UN Conference of the Parties (COP17) resulted in a firm agreement for the first time since the Kyoto Protocol was signed in 1997. In the medium-term (2015-2020) world leaders agreed on continuing negotiations towards a legally binding agreement for all countries and in the short-term many countries, though not all, committed to an extension of the Kyoto Protocol.

The industry will continue to face pressure to reduce emissions and will need to go on developing technologies to protect core business and build competitive advantage. CCS remains of critical importance not just for coal power plants but also biomass, gas power plants, oil and gas operations, fertilizers, chemical industries and cement manufacturing. But of course, industry interest in CCS will be driven by a business case that includes an anticipation of longer-term climate policies and potential carbon offset markets. It is critical that government and industry work ever more closely, both at a national and international level, to respond to the challenges presented by climate change.

### CDM INCLUSION

The inclusion of CCS in UN-backed carbon offsetting schemes is a milestone decision. Although we are unlikely to see an immediate increase in CCS projects, within the next two decades the impact could be significant. Inclusion in CDM affords CCS a new international status and it now sits alongside mitigation technologies such as solar and wind. It is now recognized that CCS has a credible role to play in climate change mitigation. Critically, it can be expected that inclusion in the UN scheme will set a precedent for inclusion of CCS in other financing and technology support systems.

### LARGE-SCALE INTEGRATED PROJECTS

The annual Global CCS Institute (GCCSI) report showed that there was measured progress in 2011 with a number of large-scale integrated projects moving towards operation or reaching advanced development stage, and a cluster reaching advanced development planning. There are now eight large-scale projects in operation around the world and six under construction. GCCSI puts the total CO<sub>2</sub> storage capacity of all 14 projects in operation or under construction at over 33 million tonnes a year; the equivalent of taking more than 6 million cars off the road. However, to put this positive progress into perspective, we are reminded of the vision provided by the IEA CCS Technology Roadmap 2009, that 100 commercial-scale CCS projects must be operational worldwide by 2020 and 3,400 by 2050 if global warming is to stay below 2°C.



## STAKEHOLDER ENGAGEMENT

With an increasing number of projects moving towards the final stages of development, planning public engagement is critical. The CCS industry needs to effectively share experiences and knowledge from efforts to better understand the needs and concerns of the public, NGOs, politicians and other stakeholders.

In 2011, the CCP updated the 2007 study on stakeholder issues. The new study entitled *CCS Stakeholder Issues Review and Analysis* incorporated case studies including Quest (Canada), FutureGen 2.0 (USA), Barendrecht (Netherlands), In Salah (Algeria) and Gorgon (Australia) to give strong insights into local level engagement.

It also highlights the importance of the industry building understanding of global level stakeholder concerns. It showed that there is considerable work to do to set the scene for CCS and to raise public awareness of climate change as a problem which requires immediate action. And, of course, local and global issues are interlinked. Global discussions have significance for the management of local issues as they will determine whether CCS will be commercially viable in the future. Without effective industry-wide local and global stakeholder engagement, it is clear that industrial-scale CCS will not be possible.

## THE CHALLENGES AHEAD

In 2011, CCS laws and regulations have continued to grow – with several jurisdictions completing framework legislation and beginning to implement secondary legislation and other guidance documents. The GCCSI has identified the European Union, Australia and Canada as leaders in this area.

However, significant uncertainty remains and urgent work is needed to address incomplete or delayed regulation. For example, the GCCSI pointed to the failure to ratify CO<sub>2</sub> related amendments to the London Protocol as posing uncertainty and barriers to CCS projects with transboundary transportation elements.

The challenge ahead is for industry and government to work together to build the foundations for an industry that offers the world huge potential to make a major impact on reducing CO<sub>2</sub> emissions.

# TECHNICAL ADVISORY BOARD

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## 2011 Members of the CCP3 Technical Advisory Board

**Vello Kuuskraa**, Chairman CCP3 Advisory Board, President, Advanced Resources International, Inc., Arlington, VA, USA

**Olav Bolland**, Head of Department/ Professor, NTNU - Norwegian University of Science and Technology, Department of Energy and Process Engineering, Trondheim, Norway

**Michael Celia**, Professor and Chair, Civil and Environmental Engineering, Princeton University, Princeton, NJ, USA

**David Coleman**, Business Development Leader, Carbon Capture and Storage, DNV Energy North America, Katy, TX, USA

**Pierpaolo Garibaldi**, independent consultant, Peschiera, Borromeo, Italy

**Christopher Higman**, independent consultant, Schwalbach, Germany

**Larry Myer**, independent consultant, Benicia, CA, USA

**Dale Simbeck**, Vice President Technology, SFA Pacific, Inc., Mountain View, CA, USA

The Technical Advisory Board (TAB) is responsible for peer reviewing the activities of the CCP team, providing recommendations to strengthen the program. The Capture Team met with the TAB in March 2011 to assess and complete the proposed work program (2011-2013) on capture technologies for natural-gas combined cycle power stations. The work of the Storage, Monitoring & Verification Team is also guided by the TAB; with the independent group helping shape the scope of the contingencies program and the forward well strategy.

### Storage, Monitoring & Verification Team:

With an increased budget and a focus on wellbore integrity work, the TAB believes that the activities of the SMV program will remain valuable. The TAB supports and recommends an increased focus on CO<sub>2</sub> transport and storage, particularly within saline formations such as studying the capacity of 'closed' saline formations and the composition of saline reservoir seals.

### Capture Team:

The TAB supports the Capture Team's focus on the CO<sub>2</sub> emission areas of major concern such as the fluid catalytic cracking (FCC) unit of a refinery and once-through steam generators (OTSG) used in heavy oil production. The TAB recommends to:

- Identify alternative CO<sub>2</sub> capture options in oil refining by comparing low cost options for refineries heaters and low cost options for refinery hydrogen plants
- Maintain involvement with post-combustion CO<sub>2</sub> capture in natural gas combined cycle (NGCC) power generation through monitoring and evaluation
- Re-evaluate pursuing long-term CO<sub>2</sub> capture technologies from CCP Phase 2 (CCP2) such as chemical looping combustion that holds promise for reducing emissions from the production of heavy oil

### Communications Team:

The TAB recommends increased engagement with government decision makers, NGOs and industry, especially educating those involved with electric power generators who may have limited knowledge of CCP's work.

CCP 2011

# THE CCP CAPTURE PROGRAM

Ivano Miracca, eni  
CCP Capture Team Lead



## CONSOLIDATION AND PROGRESS

2011 has been a year of consolidation and progress in the development of industrial scale CO<sub>2</sub> capture technologies for the three scenarios, critical for the oil and gas industry i.e. refining operations, steam production for heavy oil extraction and natural gas power generation.

## CONTRACTS AWARDED

Following the award of contracts for demonstrations of oxy-firing capture technologies on a fluid cracking catalytic (FCC) unit in Brazil and on a once-through steam generator (OTSG) for heavy oil extraction in Canada, work has progressed in bringing these to reality. As for the natural gas combined cycle (NGCC) plant scenario, partners have been identified and work has progressed on emerging and novel technologies that could be applied to CO<sub>2</sub> capture.

## COST BASELINES ADVANCED

Work has also continued on establishing cost baselines for the three scenarios, with results delivered on oxy-firing and pre-combustion technologies in the refinery and OTSG scenarios. These complement the work on post-combustion baselines carried out in 2010 to better understand and deliver cost reductions for CO<sub>2</sub> capture technologies.

For the Capture Team 2011 has been a year in which huge preparation work has come to a conclusion. Several projects were kicked off, including the demonstrations (fluid catalytic cracking and once-through steam generator) as well as most big R&D projects. The screening projects for the power generation scenario were also completed by the end of the year, so that within a few months the team will be able to finalize the CCP3 work program for capture. We are now in transition to an implementation phase covering the last two years of CCP3 in which we expect to achieve all of our targets, preparing the ground for a further step towards large scale application of CCS.”

**Ivano Miracca, eni, CCP Capture Team Lead**

## 2011 HIGHLIGHTS

Oxy-combustion capture trial on a pilot-scale fluid catalytic cracking unit (one of the highest CO<sub>2</sub> emitting units of a refinery) began, results available in 2012

Oxy-fired once-through steam generator project Phase 2 (demonstration) engineering work began. The demonstration run is scheduled in the Spring of 2013

Screening studies completed for novel natural gas combined cycle (NGCC) capture technologies, paving the way for potential future development and scale-up

New baselines (state-of-the-art technology and cost) established for refinery and heavy oil extraction using pre-combustion and oxy-firing technologies

Fluid Catalytic Cracking unit – Oxy-firing demonstration, Brazil. Image courtesy of Petrobras

THE 2011 CAPTURE PROGRAM

**1. REFINERIES**

**Fluid catalytic cracking (FCC) unit**

**Project Overview:** Oil refineries are significant emitters of CO<sub>2</sub> and the FCC unit is a key source of those emissions, typically equating to some 20-30% of CO<sub>2</sub> emissions from a typical refinery. Developing a capture technology to effectively reduce these emissions has been a major focus of the Capture Team. Oxy-firing was established early on as a preferred technology route and development has now reached the demonstration stage.

**Progress in 2011:** During 2011 operation began on the oxy-firing demonstration at a large pilot-scale FCC unit at a Petrobras research complex in Parana State, Brazil. The demonstration is expected to confirm the technical and economic viability of retrofitting a FCC unit to enable CO<sub>2</sub> capture through oxy-combustion.

Installation of the process skids was completed in March and pre-start-up tests took place during the early part of April. Pre-operation ran through April and May and the full oxy-firing test program began in mid-June.

The program is based on the testing of operating variables in daily runs, including different feedstocks, feed flow-rate and heat removal rate. A longer run in constant conditions will be carried out to verify any ageing effects on catalyst activity and reaction yields.

There have been some delays in the testing, caused by acid corrosion to the flue gas recycle compressor. This has necessitated the replacement and repair of some parts as well as adjustment of the operating conditions. Full results will be available by the second quarter of 2012.



Fluid catalytic cracking unit – Oxy-firing demonstration, Brazil. Image courtesy of Petrobras

**Process Heaters**

Work also began during 2011 on CO<sub>2</sub> capture in a complementary area – oil refinery process heaters. Standard burners for combustion with air, produced by the vendor, will be tested in oxy-firing mode at the pilot-scale to verify the option of shifting operational mode with minimal

or no modifications. Tests are scheduled in June 2012, with a final report during 3Q, 2012. If the results are positive, a demonstration run at a refinery might be planned, as part of an overall scale-up program.

**2. HEAVY OIL EXTRACTION**

**Once-through steam generators**

**Project Overview:** Heavy oil and, in particular, oil sands-based petroleum are increasingly important sources of energy and there is an increasing need to manage CO<sub>2</sub> emissions from the production process. Once-through steam generators (OTSGs) are used for steam production in the in-situ extraction of heavy oils and bitumen using the steam assisted gravity drainage (SAGD) technique and are the main source of CO<sub>2</sub> emissions in this Canada-based production process.

The aim of the CCP's work in this area is to evaluate the integration of oxy-firing in the operation of an OTSG boiler to significantly reduce those CO<sub>2</sub> emissions, providing design and cost estimates for a commercial scale unit with CO<sub>2</sub> capture, purification and compression. The program includes a demonstration run, scheduled in the Spring of 2013.

The project is led by Suncor and the CCP is joined by Cenovus Energy, Devon Canada, MEG Energy, Praxair (main technology provider) and Statoil.

Funding (\$2.5m) was secured in 2010 from the Climate Change and Emissions Management Corporation (Alberta) and finalization of the work program has been taking place during 2011. The project has a schedule of 24 months, following a feasibility study carried out in 2009.



OTSG Boiler. Cenovus Energy, Christina Lake, Canada. Image courtesy of Cenovus Energy

**Progress in 2011:** Important groundwork has been carried out including a site study and revisions to the scope of burner testing during the run. The demonstration run will take place at the Christina Lake (Canada) site managed by Cenovus on a 50 millions BTU/hr (British Thermal Units) unit. 2012 will see detailed engineering taking place along with installation of gas

supply systems for the demonstration, which will be at a size of about 1/5 world scale for these boilers.

### 3. NATURAL GAS POWER GENERATION

The low concentration of CO<sub>2</sub> in natural gas-fired power station's flue gas makes capture a challenging but important area for technology development. The CCP has identified post-combustion as the preferred technology for natural gas-fired power generation in the short-to-medium-term. A screening for novel technologies that may result in a breakthrough, started in 2009 and is now close to completion.

Progress in 2011: Progress was made in 2011 on two of the novel technologies for further development, with the aim of assessing their suitability for natural gas combined cycle (NGCC) power stations.

During 2011 the CCP became a member of the Partnership for CO<sub>2</sub> Capture (PCO<sub>2</sub>C) organized by the Energy and Environment Research Centre (EERC) of the University of North Dakota. The PCO<sub>2</sub>C is composed of about 20 partners, including solvent and technology providers as well as utility producers and enjoys 1.5 million of US\$ co-funding by the Department Of Energy of the United States (DoE). Comparative testing of novel solvents in a pilot scale facility at EERC is one of the main tasks of PCO<sub>2</sub>C and will be a powerful tool for assessing the potential of novel solvents. This project is scheduled for completion by the third quarter of 2012.

A screening project, funded by the CCP, on an adsorption technology has been completed. The results from this and from a cost feasibility study early in 2012 will determine whether further development is viable in CCP3 to assess its potential, reliability and performance. The aim would be a scale-up of the technology using a continuous rotary adsorption machine, in order to prove that the concept can be used at a commercial scale.

A second technology, based on a novel amine solvent used in a solution of ionic liquids has also been screened, with positive results. Avoidance of water evaporation in the amine stripper would be the major advantage of this approach. The plan is then to test the solvent at EERC in the frame of the PCO<sub>2</sub>C partnership.

### 4. OTHER TECHNOLOGIES

#### Membrane Water Gas Shift

Testing of hydrogen membranes for membrane water gas shift (MGWS) modules is planned to start in 2012. MGWS is a pre-combustion technology that uses metallic membranes permeable to hydrogen to achieve efficient separation between CO<sub>2</sub> and hydrogen. It has shown particular potential for use in the refinery scenario and the plan is to develop membrane modules for use in a field pilot unit.

#### Chemical Looping Combustion

This is an oxy-firing technology that may represent a breakthrough in the area of heavy oil extraction, because of the ease with which this approach could be deployed for steam generation. It is characterised by a solid carrier that alternately adsorbs oxygen from the air and releases it for combustion of a gaseous fuel.

The CCP has been supporting development of this technology since 2001 and is now addressing some specific key issues in a project which started in 2011 and is scheduled for conclusion in 2013. This project is running in parallel with a R&D project funded by the European Union (INNOCUOUS) with mutual exchange of information. INNOCUOUS is run by a partnership including Chalmers University of Technology, CSIC, VITO, Vienna University of Technology, Johnson Matthey, Bertsch and Shell.

The main targets of the CCP scope of work are:

- Optimization of the solid carrier, both in performance and in environmental impact.
- New design for a commercial scale unit in the heavy oil scenario with technical/economical evaluation.

The program includes bench and pilot scale testing, as well as hydrodynamic optimization in a dedicated cold model unit.

### 5. ECONOMIC BASELINES

Work continued on establishing cost baselines for the three CCP scenarios. Having completed the post-combustion work in 2010, state of the art oxy-firing and pre-combustion cases for the refinery and OTSG scenarios were developed by Foster Wheeler (Phase 2). This work is vital to the CCP's mission to better understand and deliver cost reductions in CO<sub>2</sub> capture technology. Phase 3 of the economic modelling will be completed during 2012 and will include additional pre-combustion and oxy-firing cases.

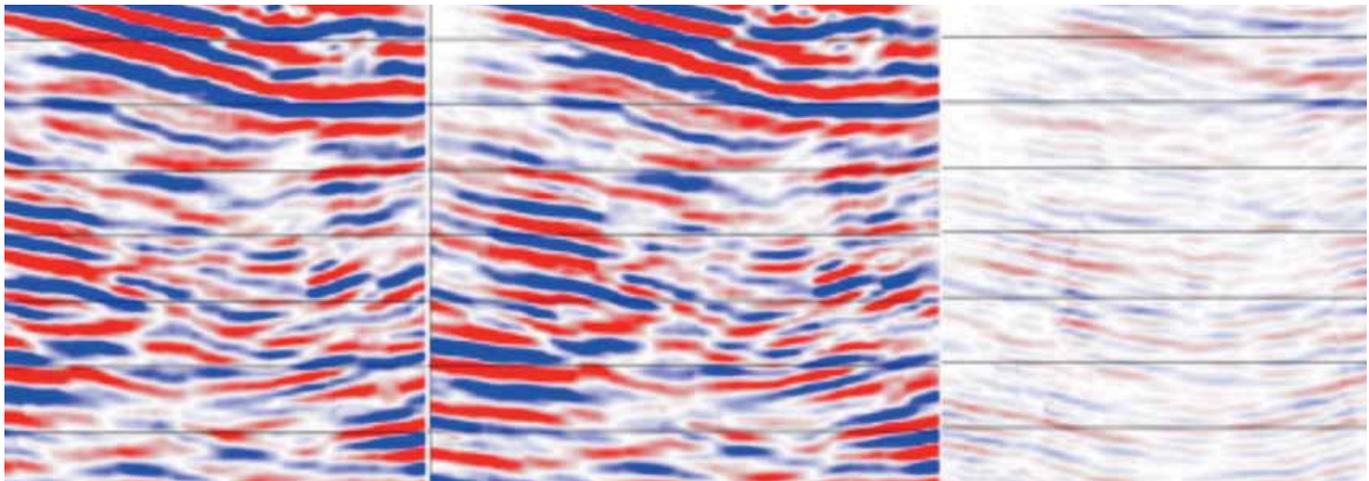
The scenarios include:

- Oil Refinery
  - Set of three fired heaters with a duty of 100 million BTU/hr each
  - Fluid catalytic cracking unit with a capacity of 60,000 barrels per day of feed
  - Steam methane reformer (SMR) producing 50,000 NM<sup>3</sup>/hr of hydrogen (approx 44.8 million standard cubic feet/day (MMSCFD))
  - Refinery-wide fired heaters with a total fired duty of 5,000 million BTU/hr LHV
- Heavy Oil Production
  - Set of four once-through steam generators each with a firing duty of 250 millions BTU/hr, producing steam for steam-assisted gravity drainage oil extraction
- Natural Gas Power Generation
  - 400 MW natural gas combined cycle power station

## CCP 2011

# THE CCP STORAGE, MONITORING & VERIFICATION PROGRAM

Scott Imbus, Chevron  
CCP SMV Team Lead



### 2011 HIGHLIGHTS

First phase of CO<sub>2</sub> Impurities Study completed, showing impact of stream impurities on underground CO<sub>2</sub> plume behaviour

Modular Borehole Monitoring (MBM) assembly readied for deployment at Citronelle Field prior to injection in early 2012

Injection started at Decatur, USA, with InSAR satellite technology deployed to detect surface deformation. Initial results are expected by the end of 2012

CO<sub>2</sub> Contingencies program (detection and intervention of unexpected migration) launched with cross-industry and academic input

Time lapse imaging of baseline and post-injection 3D VSP with differencing. Image courtesy of CO2CRC

### A YEAR OF PROGRESS

The Storage, Monitoring & Verification (SMV) Team continued its work in storage assurance and field trialling in 2011, securing some notable achievements during the course of the year. A number of studies have been completed or are underway and several field trials of innovative monitoring technologies have reached significant milestones. In addition, a new work stream was begun – the CCP contingencies program – which aims to increase public and regulatory confidence around storage integrity.

The oil industry has a unique understanding of managing underground production and injection of gases, gained from more than 100 years of oil and gas exploration. Since the CCP was formed in 2000, the SMV Team has been working to close gaps in existing knowledge and has played a significant role in building and deploying the science and technology of CO<sub>2</sub> storage through systematic research and development (R&D) efforts. The CCP3 SMV program includes technical studies and field deployments aimed at improving understanding of the subsurface behavior of CO<sub>2</sub> and its fate over time.

In 2011 the SMV Team achieved key milestones on R&D projects and was active in deploying technologies in the field and analyzing data from earlier deployments. Major R&D accomplishments included completion of a simulation study on subsurface impacts of CO<sub>2</sub> stream impurities and a geochemical-geomechanical alteration model of a previously surveyed CO<sub>2</sub>-exposed well. Assessment of results from previous field deployments shows promise both for through casing resistivity (TCR) and for borehole gravity as approaches to detection of CO<sub>2</sub> without well perforations. The team is currently managing ongoing and new R&D projects and proposals, whilst preparing to deploy a multi-sensor tool at the Citronelle Field demonstration in Alabama.

**Scott Imbus, Chevron, CCP SMV Team Lead**

## THE 2011 SMV PROGRAM

### 1. STORAGE ASSURANCE

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The Storage Assurance R&D projects aim to address key remaining geological uncertainties around CO<sub>2</sub> storage, through a mix of experiments, analysis and modelling.

**Well Integrity:** Properly designed and constructed wells will act as a barrier to deep fluids (gases and water), preventing them from migrating into formations containing potable groundwater or to the land surface, thus protecting natural resources, human health and the environment. It is recognized that the wells are a potentially vulnerable part of the CO<sub>2</sub> storage system, particularly those completed before modern standards were in place and the CCP's work in this area seeks to understand the conditions, mechanisms and extent of alterations resulting in degradation of barrier performance in a well exposed to CO<sub>2</sub>. This work will help in improving well design and developing detection and remediation technologies for well leakage.

Well surveys carried out by the CCP in recent years in the USA (Colorado) and Brazil illustrated that good well installation practices are more essential to long-term barrier performance than is the use of CO<sub>2</sub>-resistant well materials. The SMV Team continues to assess new opportunities for well prospects.

2011 has also seen extensive post-survey work carried out on the CCP's Colorado producer well survey. Carried out by Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL), the work included modeling and experiments focused on simulating the type and extent of alteration observed in the well cements. Among the key findings of this study is the role of geomechanical processes in well integrity.

**Subsurface Processes:** A diverse set of studies that aim to better understand subsurface physico-chemical phenomena and their impact upon formation injectivity and CO<sub>2</sub> plume migration, trapping and containment.

Highlights include:

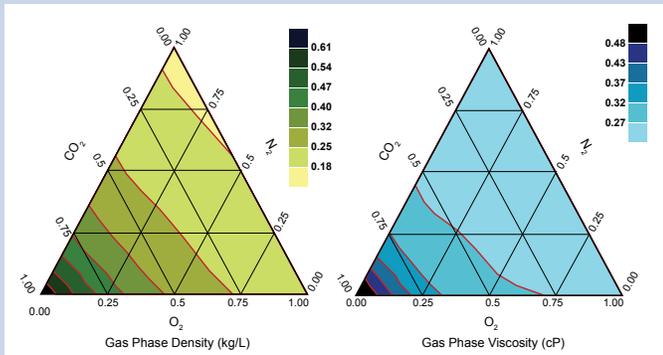
- **Fault Seal Study** – completed in 2011, this study by Washington University of St Louis examined natural CO<sub>2</sub> leakage through a known fault and natural long-term storage in the Paradox Basin, Utah, USA, looking at the effects that faults have on the containment of CO<sub>2</sub> and potential discharge to the surface. The work includes fieldwork, measurements and the generation of a physical model representing the geochemical and structural systems, identifying the factors that allow some faults to seal while other adjacent faults allow CO<sub>2</sub>-charged fluids to reach the surface.
- **Relative Permeability and Capillary Entry Pressure** – laboratory protocols developed by the CCP3 for measuring relative permeability (Krel) of reservoir rocks and capillary entry pressures (Pc) of caprocks using CO<sub>2</sub> are underway, although both have encountered temporary technical delays during 2011. Relative permeability influences the rate at which CO<sub>2</sub> moves through the reservoir, pressures required to inject and how far the plume might move in the subsurface. Capillary entry pressure represents a threshold which, if exceeded by pressure due to CO<sub>2</sub> injection and buoyant flow, will result in CO<sub>2</sub> potentially entering the pores of the caprock and possible seepage to shallower formations.
- **3D Geomechanical Modeling** – in collaboration with the CO2CRC (Australian Joint Industry Project) program, data acquired from the Otway Basin (Australia) pilot project was used to generate a 3D geomechanical model of very similar neighboring field (Iona) which described the physical evolution of the depleted natural gas reservoir since it was converted into a gas storage facility in 2000. This study has important implications for well integrity, fault stability, caprock integrity and surface deformation in CO<sub>2</sub> storage scenarios.

Other work on the Storage Assurance theme includes the ongoing evaluation of established oil and gas monitoring and verification technologies in the CO<sub>2</sub> storage setting, including performance and cost-effectiveness of existing technologies and the development of new ones. Work continued in 2011 on the development of a new multi-sensor tool that can be used to monitor a variety of conditions in a single borehole. Work also continued in storage optimization, with the intention of developing simulation approaches to minimize risk from pressure increases.

### KEY STUDY FINDINGS

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**CO<sub>2</sub> Impurities Study – Phase 1 Reservoir Simulation.** The CCP is supporting the University of Texas Bureau of Economic Geology (UT-BEG) in its reservoir simulations and experiments to understand the impact of CO<sub>2</sub> impurities on CO<sub>2</sub> injection, migration and pressure evolution. Phase One, completed in 2011, involved the development of reservoir models to simulate injection and plume migration of CO<sub>2</sub> streams with binary and complex non-compressible gas impurities. The key finding is that although significant levels of CO<sub>2</sub> impurities will impact the behavior of the CO<sub>2</sub> plume, the important tradeoffs in capture cost reduction vs. increased storage project management needed may make this worthwhile. Phase 2 (static experiments to understand CO<sub>2</sub>-impurity, particularly oxygen, effects on minerals) and Phase 3 (integration) will complete the study by late 2012. Visit the CCP website to register for updates and to download a factsheet on the CO<sub>2</sub> Impurities Study.



**FIG1: CO<sub>2</sub> impurities impact on mixed gas plume density and viscosity**  
 In all cases, viscosity and density of the mixtures are lower than that of neat CO<sub>2</sub> (only SO<sub>2</sub> would have the opposite impact). Figure 1 displays mixture density (left) and viscosity (right) properties expected at ~1.5 km (~5000 ft) deep U.S. Gulf Coast reservoir at 58°C (135°F) and 17 MPa (2500 psi)

Diagram courtesy of University of Texas Bureau of Economic Geology

## 2. FIELD TRIALS

Deployment and assessment of emerging and integrated monitoring technologies at third party field sites.

### A. Well Logging:

1. Borehole Gravity (SECARB - Cranfield Field EOR project). Work has continued on analyzing the borehole data acquired during 2009 and 2010, in order to prove that the borehole gravity approach is a viable non-invasive monitoring option. Colorado School of Mines is responsible for this analysis work and the results have been positive thus far, although there are significant operational issues that need to be overcome, such as well size and deviation and time to acquire the logs, which call for a change in technology.

2. Through Casing Resistivity (CO2CRC Otway Phase 1). During 2011, the CCP worked with CO2CRC to resolve ambiguous data from CO<sub>2</sub> injection in late 2010. A back-up saturation log was run in July 2011 to be compared to the initial baseline from 2007. Interesting results are already becoming apparent and the work will be completed in 2012.

3. Modular Borehole Monitoring (MBM) (SECARB – Citronelle Field). The CCP prepared for a field test of the Modular Borehole Monitoring technology referenced earlier in this report. This will take place at the Citronelle Field, Alabama, USA. A permit was issued in November 2011, with deployment planned for early 2012. The MBM will integrate pressure and temperature sensors, distributed temperature and temperature perturbation sensors, seismic geophones and a fluid sampling U-Tube.

### B. Well-based Seismic:

3D VSP (CO2CRC Otway Phase 1). The CCP has been working with CO2CRC to evaluate the imaging and detectability of CO<sub>2</sub> using 3D vertical seismic profile (4D VSP including the repeat survey) surveys in comparison with 4D surface seismic surveys

conducted at the Otway demonstration site. Conclusions drawn in 2011 are that both technologies can overcome the differences of varying sources, line differences and near surface effects to provide high quality imaging. The 4D VSP approach has proved to be much more robust in terms of repeatability, primarily due to its proximity to the reservoir and avoidance of near surface irregularities.

### C. Remote Methods:

PS InSAR (MGSC Decatur). 2011 saw important steps forward with the beginning of injection at the Decatur, Illinois, USA site, after some delays due to permitting. A series of baseline satellite passes began early in 2011 and will be completed in early 2012, with repeat passes due in 2012-2013. The aim is to prove the viability of InSAR satellite imagery on CO<sub>2</sub> injection-induced deformations in variable terrain (i.e. vegetated and commercially developed land). Preliminary geomechanical analysis suggest that detection is possible from the end of 2012 onwards.

## 3. CCP CONTINGENCIES PROGRAM

A new SMV work stream was begun in 2011 – the CCP contingencies program. This aims to increase public and regulatory confidence around storage integrity by understanding current versus needed capabilities to manage unexpected migration of CO<sub>2</sub>.

An initial scoping workshop was held in May, which included 35 experts from the oil and gas field services industry, national laboratories and academia. The workshop considered vulnerabilities of natural and engineered systems to anomalous CO<sub>2</sub> migration and its potential impacts on project effectiveness and compliance as well as potential impacts on health, safety and the environment. A White Paper will be produced in 2012 to detail the current state of knowledge and subsequent workshops set up to address realistic scenarios, current technical capability and development of a road map to develop needed technologies.

# CCP 2011

## THE CCP POLICY & INCENTIVES PROGRAM

Arthur Lee, Chevron; CCP Policy & Incentives Team Lead  
Mark Bohm, Suncor; CCP Acting Policy & Incentives Lead (September to December 2011)



### PROVIDING ECONOMIC, TECHNICAL AND SOCIAL INSIGHTS

There have been significant regulatory and policy developments in 2011. An important milestone was reached with the acceptance of CCS into the UN carbon offsetting scheme, the Clean Development Mechanism (CDM).

Inclusion in the CDM affords CCS a new international status. It has now been established that CCS has a credible role to play in climate change mitigation. Critically it can be expected that a precedent has been set for inclusion of CCS in other financing and technology support systems.

In this changing landscape the P&I Team has continued to provide critical insights needed by a range of stakeholders, most notably governments and regulators, to inform them of technical, economic and social developments which are so vital for the deployment of CCS. A highlight has been the completion of a study of stakeholder issues to understand better the concerns of people who are involved in the development of CCS – whether it is a member of a local community, a regulator or a policy maker.

It has been heartening to see CCS gain international recognition as an important climate mitigation technology, with its inclusion in the CDM. CCS has an important role to play alongside other technologies in the transition to a lower carbon economy. Getting UN recognition is one thing. But we certainly cannot afford to forget the importance of gaining the trust of the public and other important groups. Without acceptance from communities, industrial-scale CCS will not be possible. The CCS industry needs to work together more effectively to really listen and respond to the concerns of communities, NGOs, policymakers and elected officials. **Arthur Lee**, *Chevron, P&I Team Lead*

### 2011 HIGHLIGHTS

Investigation of various stakeholder issues at project and global level conducted, with the P&I Team presenting the findings at the COP17 conference in Durban, South Africa

Progression of risk valuation study to determine a financial value for potential CCS-related risks and damages

## THE 2011 POLICY & INCENTIVES PROGRAM

In 2011 the P&I Team undertook two major projects; studies into Stakeholder Issues and into Risk Valuation. The CCP shared the conclusions of the Stakeholder Issues study with delegates at a side event co-organized with the International Emissions Trading Association at the COP17 in Durban.

### 1. STAKEHOLDER ISSUES REVIEW & ANALYSIS

In 2007 the P&I Team undertook its own Public Perception of CO<sub>2</sub> and Storage: a Prioritised Assessment of Concerns which identified a range of stakeholder issues on the basis of type of stakeholder and geological region. The team looked to extend knowledge of this topic further by undertaking an up to date review of CCS stakeholder issues. The aim was to identify and evaluate the issues most strongly held and gain a greater understanding of what drives their sensitivity.

The study included a review of existing surveys and studies associated with CCS issues and developed a number of selected case studies. The following projects were focused on: Quest (Canada), FutureGen 2.0 (USA), Barendrecht (Netherlands), In Salah (Algeria) and Gorgon (Australia). The study looked at identifying the priority issues affecting stakeholder decision-making and attitudes towards CCS. Each case study also discussed what worked and what did not in how the project was developed, to help understand the lessons learned. The stakeholders studied were NGOs, the general public, politicians, policy makers; industry, thought leaders, regulators and investors.

The CCP shared the study's conclusions with delegates, at a side-event co-organized with the International Emissions Trading Association at the COP17 in Durban. A summary of the report is available on [www.co2captureproject.com](http://www.co2captureproject.com)

### 2. RISK VALUATION STUDY

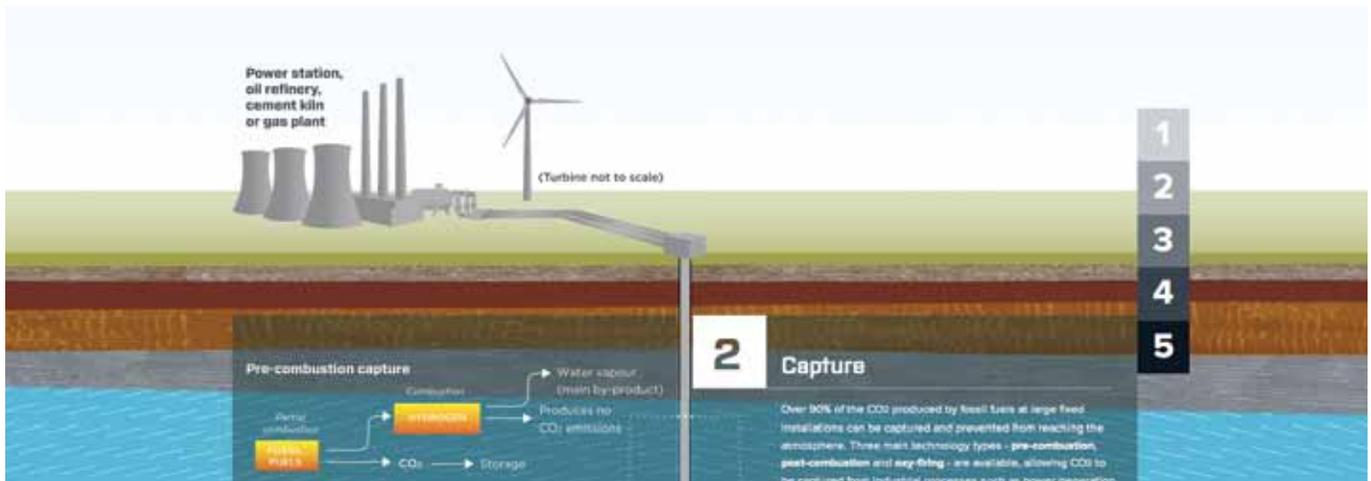
The CCP continued its work as part of a consortium on putting a financial value on the potential risks and damages associated with CCS. The consulting firm Industrial Economics, which has expertise in studying damage assessments for the insurance industry, produced the final report entitled *Valuation of Potential Risks Arising from a Model, Commercial-Scale CCS Project Site*.



CCP 2011

# THE CCP COMMUNICATIONS PROGRAM

Mark Crombie, BP  
CCP Program Manager & Communications Team Lead



## WORKING FOR GREATER UNDERSTANDING OF CCS

Stakeholder understanding and acceptance is critical to the success of CO<sub>2</sub> Capture and Storage (CCS) projects. There still remains significant work to do in raising public awareness of climate change as a problem which requires immediate action. Against this backdrop there is a long way to go to establish a robust dialogue with industry, regulators and the public about the opportunities presented by CCS.

To this end the Communications Team continued to take the content from the ongoing work of the CCP Team programs and deliver it to both technical and non-technical audiences.

“ In 2011 the Communications Team has looked to the power of digital technology to more widely share information. In response to popular demand we worked to produce the In Depth brochure in a scrollable, digital format, taking care not to lose the spatial perspectives that the paper version offers. It is hoped that making it available online will significantly expand its reach as an educational resource. **Mark Crombie, BP, CCP Program Manager & Communications Team Lead** ”

## 2011 HIGHLIGHTS

Exhibited at US DoE NETL conference in Pittsburgh

Continued to provide resources to be used by NGOs, industry, media and policy makers – including first CCP Annual Report

Developed digital version of In Depth brochure as an educational tool – to be launched in 2012

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Cut-through of interactive In Depth brochure

## THE 2011 COMMUNICATIONS PROGRAM

### 1. INDUSTRY CONFERENCES

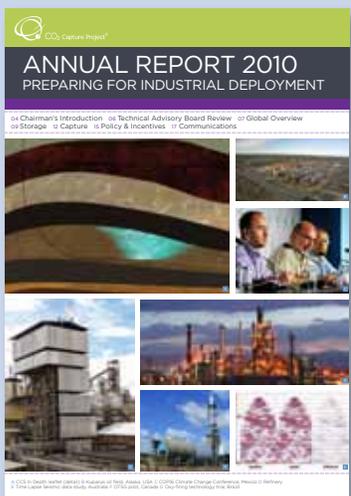
The CCP had a significant presence at the US Department of Energy's National Energy Technology Laboratory Conference (NETL 2011, Pittsburgh, May).

### 2. LITERATURE

The CCP continued efforts to keep key stakeholder groups updated on projects by disseminating a range of communications materials. For example the team worked closely with the P&I Team to circulate the *Update on Selected Regulatory Issues for CCS*.

A highlight of 2011 was the publication of the first CCP Annual Report, providing a full account of the group's work in 2010. The Annual Report was distributed to 200+ stakeholders, to national energy laboratories, to environmental NGOs and to CCS industry groups.

All literature has been made available on the CCP website at [www.co2captureproject.com](http://www.co2captureproject.com).



### 3. WEBSITE

The CCP has continued efforts to improve the user experience of the CCP website. Work was undertaken to improve the searchability of the website by popular search engines such as Google and Bing.

The groundwork was also laid to develop more interactive content to enable increased understanding of the fundamental principles of the CCS through the website. One such example has been bringing the In Depth brochure to life in a digital format. This will be available on the website in 2012.

During the year the CCP has continued to attract a high number of people registering for updates, with the number of registered users increasing from 3,500 in 2010 to over 4,800 by the end of 2011.

### 4. MEDIA

The CCP contributed articles to industry journals, sharing technical information on projects that are underway. Articles on the CO<sub>2</sub> capture demonstrations and the SMV program have been featured in: *Carbon Capture Journal*, *Petroleum Review* and *Hydrocarbon World*.

The CCP has also reached out to industry bodies to share project information, with articles featured in the IEA Greenhouse Gas newsletter, the CCSA newsletter and a technical blog post on the GCCSI website.

### 5. MEMBER COMMUNICATIONS

Member communications has continued to be an important part of the program, with materials prepared for management and the Communications Team to keep them informed of CCP work and important CCS developments.

### FOCUS FOR 2012

The CCP Communications Team will be focusing on keeping industry audiences updated on the results of demonstrations and field trials, helping to share knowledge gained. This will be done through attending key industry conferences, via the website and proactive outreach via mail-outs and email bulletins.

The CCP will also continue to work on projects that deliver digital resources for industry use, to help a broader audience understand the potential of CCS as an important climate change mitigation technology.

# CCP3 ORGANIZATIONAL STRUCTURE 2011



CO<sub>2</sub> Capture Project®

## CCP3 ADVISORY BOARD

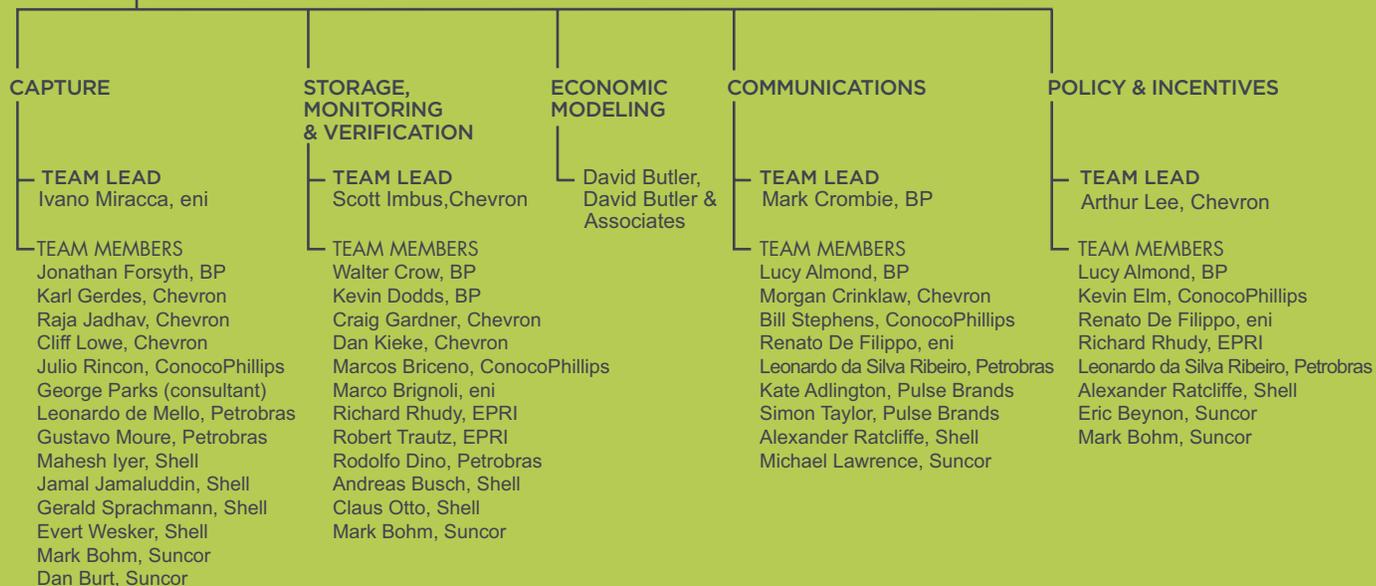
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 Stephen Kaufman, Suncor

### PROGRAM MANAGER

Mark Crombie, BP



Download further copies of the report from the CCP website  
[www.co2captureproject.com](http://www.co2captureproject.com)

CO<sub>2</sub> Capture Project Phase Three participating organizations, 2011

