CO_2 Capture Project - phase 4

Advancing CCS technology deployment and knowledge for the oil and gas industry

CCP4 application for CSLF Recognition – 1st November 2015

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Contents

Contents

CCP3 Capture Program

Purpose: Move CCS towards commercial deployment by

- Increasing technical and cost knowledge
- Develop support for technologies to reduce CO_2 capture costs by 20-30%

Image courtesy of Petrobras

Approach:

- Deliver successful demonstrations at representative industrial scale of key technologies of interest
- Support a shortlist of new technologies to advance their development towards readiness for field-based pilot
- Scan the landscape for emerging new technologies and understand their potential.
- Evaluate the application of state of the art technology for specific applications

Image courtesy of John Zink Co.

Scenarios:

- Refinery: FCC, heaters and boilers (H&Bs), SMR
- Heavy Oil: Once-through steam generators (OTSGs)
- NGCC

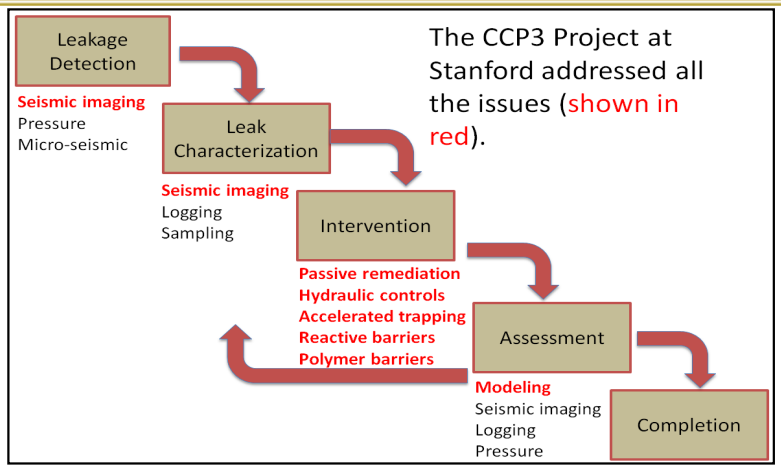
Results at a Glance:

- 21 Technical Studies by Foster Wheeler
- 2 Demonstrations (oxy-fired FCC, oxy-fired OTSG)
- 4 bench/pilot projects (oxy-burner testing, Pd membrane, CLC, enzyme post-C)
- 1 pilot test post-C solvent screening program (EERC)
- 5 preliminary evaluations of novel technologies
- 24 in-house economic evaluations

Image courtesy of Cenovus Energy Inc.

CCP3 Storage Program

Modeling and simulation topics covered for Stanford / CCP3 Contingencies study



D9-8 wellhead as completed with control lines penetrating through port collars and collar sleeves.

Purpose:

Verify Safe and Secure Storage by

- Quantifying subsurface processes
- Reliable, low cost surveillance
- Risk assessment & "contingency" planning

Approach:

- Support desk top, lab, bench and pilot scale studies
- Leverage top researchers and 3rd party field sites

Results at a glance:

- The Field Trialing effort laid out in 2009 was ambitious and accomplished all objectives with the exception of a microseismic trial (due to potential public sensitivities).
- CCP3 began the first systematic approach to "contingencies", ranging from modeling/ simulation to experiments and a detailed bench/field test design.
- Subsurface processes studies involving experiments revealed phenomena that may be worth further investigation:

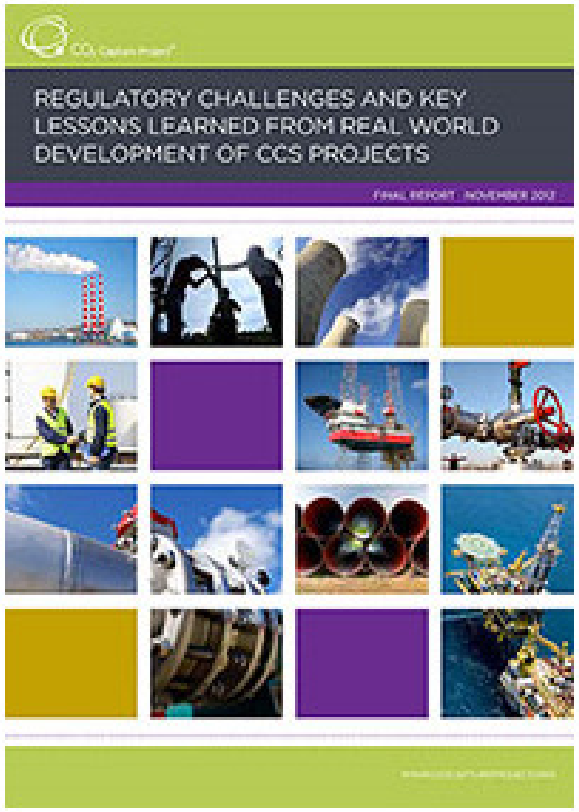
CCP3 Policy & Incentives (P&I) Program

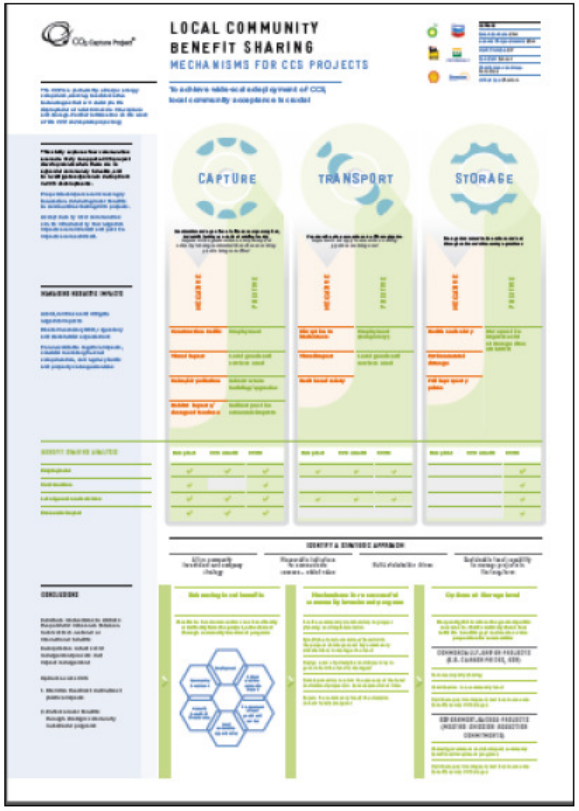
Purpose: Inform the development of legal and policy frameworks through

- Technical and economic insights
- Project experience of regulatory processes

Results at a Glance:

- Local community benefit sharing Study, 2011 - Local community benefit sharing can help to address the potential imbalance between **local costs** vs. **national or international benefits** associated with some major developments
- Regulatory Study, 2012 – Update of regulatory issues facing CCS projects, documented **lessons learned** and found that **pathways for approval do exist**





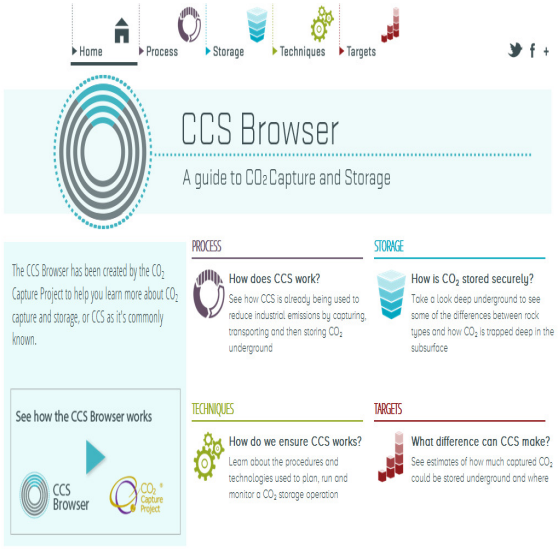
CCP3 Communications

Knowledge Sharing
www.co2captureproject.org

Conferences

- UNFCCC (Side events)
  - COP 16/17/18/19 in MX, ZA, QA, PL
- GHGT (Sponsor/Exhibitor/Presenter)
  - GHGT10/11/12 in USA, JP, NL
- CCUS Conference (Partner/Exhibitor/Presenter)
  - March 2009-2014 in Pittsburgh, PA
- CSLF (Recognized Project/Exhibitor/Presenter)
  - 4-7th November 2013 in Washington, DC
- CO_2 Conference Week (Sponsor/Presenter)
  - December 2012-2014 n Midland, TX

Public engagement
www.ccsbrowser.com



Contents

CCP4 - Advancing CCS technology deployment and knowledge for the oil and gas industry

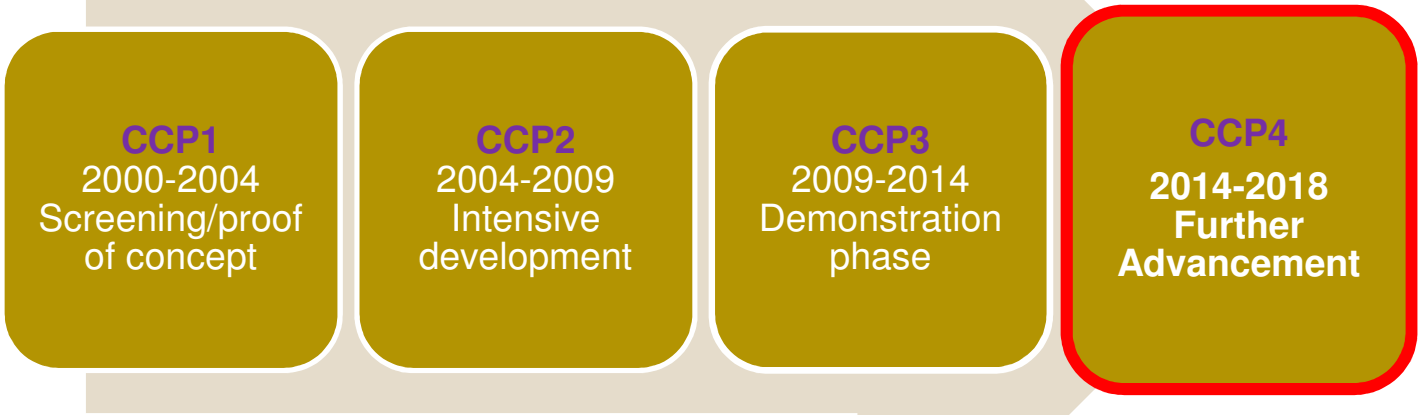
CCP4 "*Advancing CCS technology deployment and knowledge for the oil and gas industry*"

*"Project **Delivery** Focus"*

*"Field/plant **access** for pilot/demo's"*

*"Company **Expert** Collaboration"*

*"**Mid TRL** level technology development"*



*"Independent **Verification** of Cost and Performance"*

*"**Global** network of external partners"*

*"Technology **impartial**"*

*"**Effective**ly managed and run"*

CCP4 Draft Framework

Tactical Demonstration (applicable for short-medium term)

Capture: Development & field testing high-concentration CO_2 sources

SMV: Development & field testing Measurement Monitoring & Verification technologies

P&I: Regional Incentives & Global Regulations

Comms: Industry Knowledge Sharing

Strategic Deployment (applicable for medium-long term)

Capture: Breakthrough Technologies, NG Power/Cogen

SMV: Basin Scale Development and Operation

P&I: FOAK to NOAK Pathway

Comms: External Stakeholder Engagement

Advancing CCS

Contents

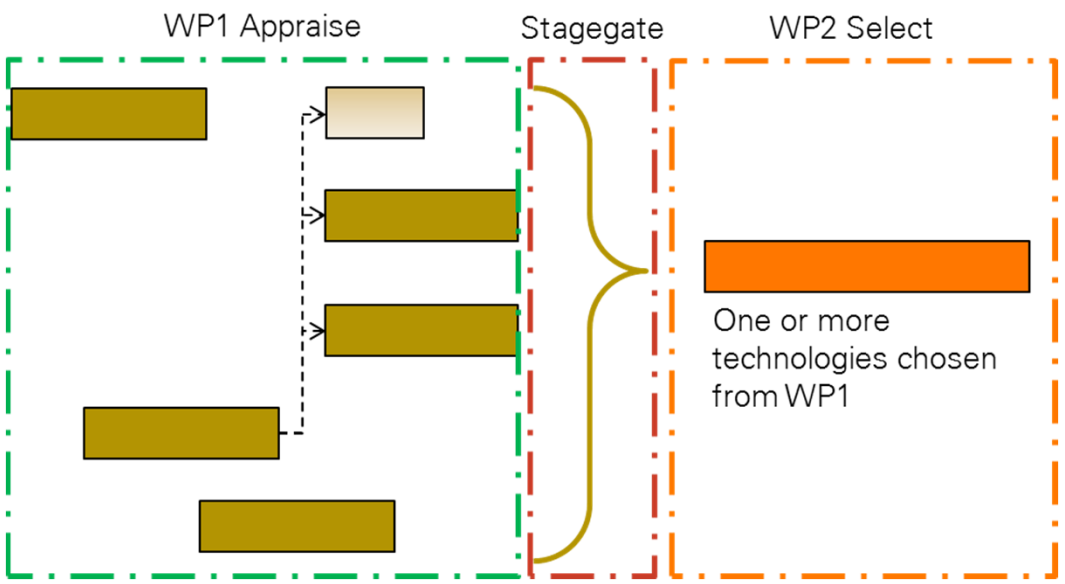
Step-out Novel Capture Technologies Assessment

Study Purpose:

- The purpose of the work is to undertake objective expert analysis of five innovative CO_2 capture technologies and to provide quantified feedback and guidance to innovators from a technology-impartial stand-point
- Target is >50% reduction in the CO_2 capture cost for NGCC application

Study Approach:

- Internally screen novel technologies based on the available information to short-list potential step-out technologies
  - I. CO_2 selective membranes,
  - II. Molten Carbonate Fuel Cells,
  - III. High-Pressure Solvent Absorption (integrated and non-integrated with power generation)
  - IV. Low-Temperature CO_2 Freeze-Out
- Work with a consultant to perform an independent techno-economic assessment of the selected technologies



Development of High Concentration CO_2 Sources

1. CO_2 Capture from SMR H_2 Plants

Study Purpose:

- Evaluate various CO_2 removal process schemes in a SMR hydrogen plant and estimate the cost of CO_2 capture

Study Approach:

- Develop Reference and Base cases for CO_2 capture - *Location*: Northern Europe; *Scale*: 100,000 Nm^3/h
- Reference Case: SMR without CO_2 capture
- Five Cases studied

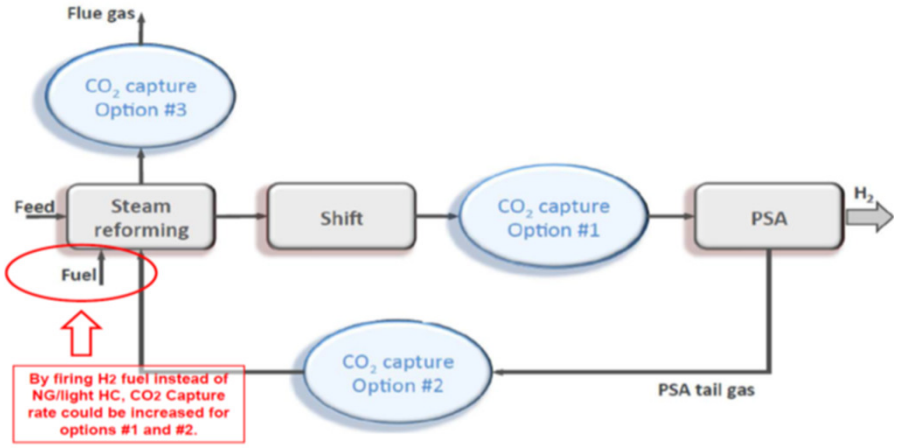


Image courtesy of Amec Foster Wheeler

2. Offshore NG Treating

Study Purpose:

- To inform and align CCP on the state of the art in *offshore* CO_2 removal and identify potential technology development projects and provide a basis for deciding whether to invest in one or more of them

Study Approach:

- Expert informed opinion: each technology – which is best for certain scenarios
- High-level performance, energy consumption and cost estimates
- Current technology readiness level (and barriers to commercialization)
- Qualitative comparison of technologies based on desired characteristics

CCP4 Capture Program – Future Field Testing Projects

Purpose:

Participate in field testing projects to advance CCS technology deployment in oil and gas scenarios

Field testing options:

- **Novel capture technology** – post combustion capture - NGCC flue gas, >50% capture cost reduction potential
  - Following the completion of WP2 a decision will be made on the viability of undertaking a pilot / demonstration on the assessed technology
- **CO_2 removal from SMR syngas streams** – pilot/demo of a novel technology with cost advantage over MDEA
  - CCP will look for opportunities to work with OEM vendors on a pilot / demonstration project if a clear cost benefit has been identified by the study work
- **CO_2 removal from natural gas streams** – potentially a membrane technology demonstration
  - After the completion of the landscape study CCP will approach the most favourable assessed technology provider and other interested parties to evaluate the option of a pilot / demonstration project

Image courtesy of Petrobras

Contents

Well-Sealing Experiment at Mont Terri

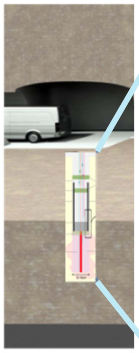
Study Purpose:

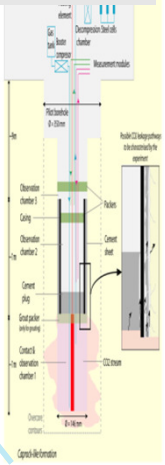
- Determine ability to intervene in difficult to mitigate, small aperture CO_2 leaks in annular space or cement sheath using novel materials

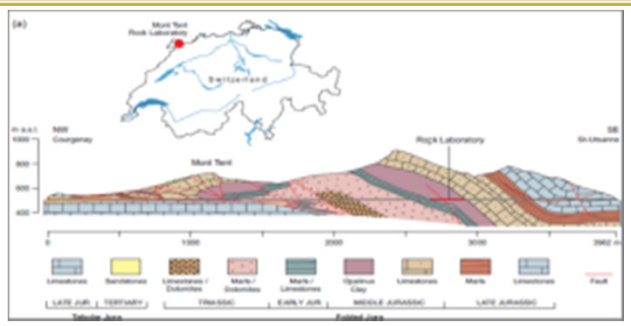
Study Approach:

- Utilize a scale well installed in a tight shale with deliberately damaged, multi-zonal completion design to test ability of multiple sealants to treat gas leakage
- Develop leakage remediation capability using novel sealant technologies to restore containment at the test site. Develop path forward for field-scale demonstration (potential application to reservoir permeability control or top seal fracture mitigation)

Defective CO_2 well exposure and sealing experiment







6m investigation interval
• 6 independent casing/cement/rock pressure monitoring & sealant placement access sites.

Images courtesy of Mont Terri Consortium / Solexperts AG

Demonstration of de-facto CO_2 storage at a CO_2-EOR site

Study Purpose:

- Utilize results from simulations and experiments to characterize and quantify the different trapping mechanisms that contribute to retention of CO_2 in a reservoir during the course of a CO_2 EOR flood.

Study Approach:

- Numerical modeling study using data from Cranfield CO_2 flood to quantify amounts of CO_2 trapped by different mechanisms during a CO_2 EOR flood over time.
- Amounts of CO_2 stored under each of the trapping mechanisms (residual trapping, dissolution in oil and brine, and mineralization) will be reported separately and sensitivity of the history matching process to each of the trapping mechanisms will be demonstrated.

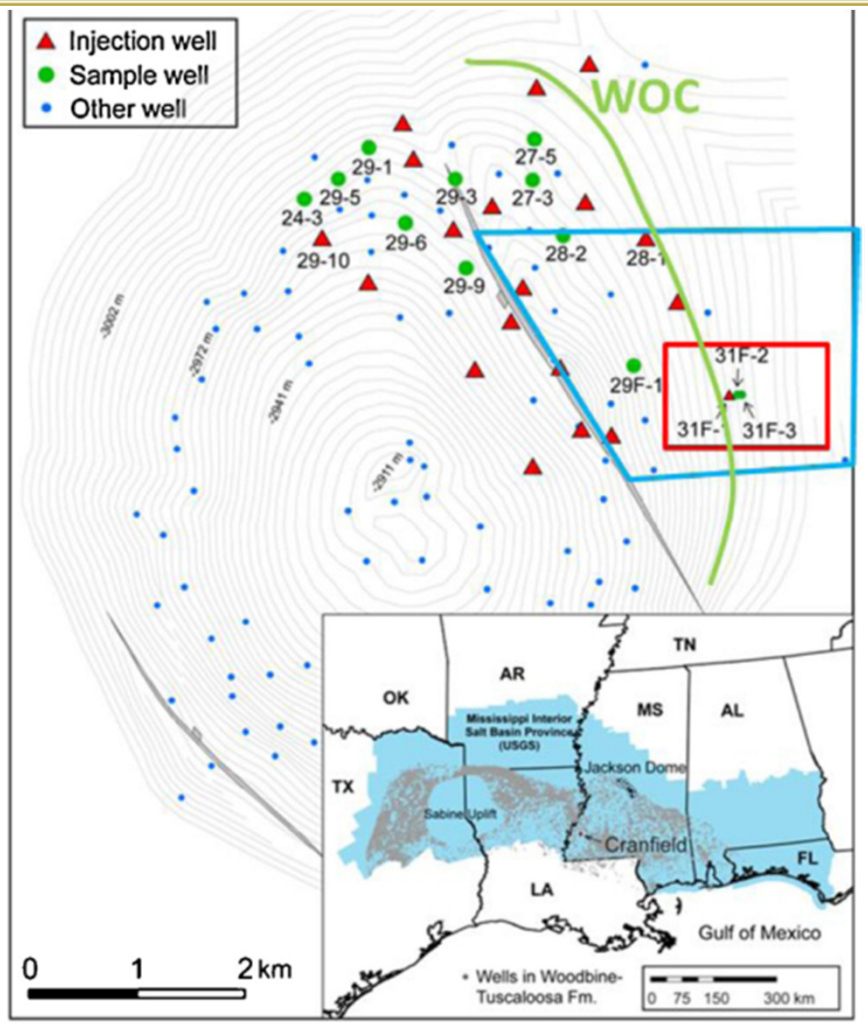


Image courtesy of UT-BEG

CCP4 SMV Program –Future Field Testing Projects

1. Contingencies:

- **Fracture-sealing experiment at Mont Terri** - novel well design used to introduce multiple sealants into the fracture network of a tight shale. Project objective is to test CO_2 leakage intervention strategies by demonstrating ability of sealants to reduce flow through fractures in a reservoir seal (leverages Well Sealing experiment)
- **Intervention in failed P&A wells** – Approaches to detecting, locating and mitigating CO_2 / brine leaks in "inaccessible" sections of P&A wells undergoing CO_2 injection for storage or EOR

Image courtesy of Mont Terri Consortium

2. Field-based monitoring:

- **Modular Borehole Monitoring (MBM) tool** - build on successful CCP3 development and deployment of MBM tool at Citronelle by designing and testing a tool that incorporates novel and/or more resilient sensors
- **Repeat EM survey at Aquistore** - repeat of 2013 CCP3 baseline EM survey conducted on the Aquistore reservoir to verify modeling predictions that predict signal due to CO_2 migration could be seen laterally from wells

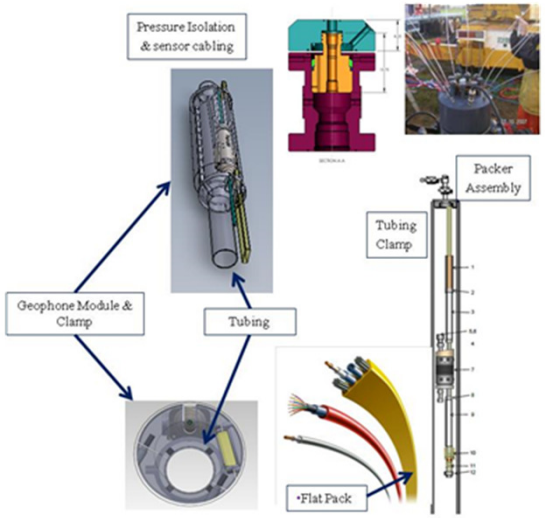
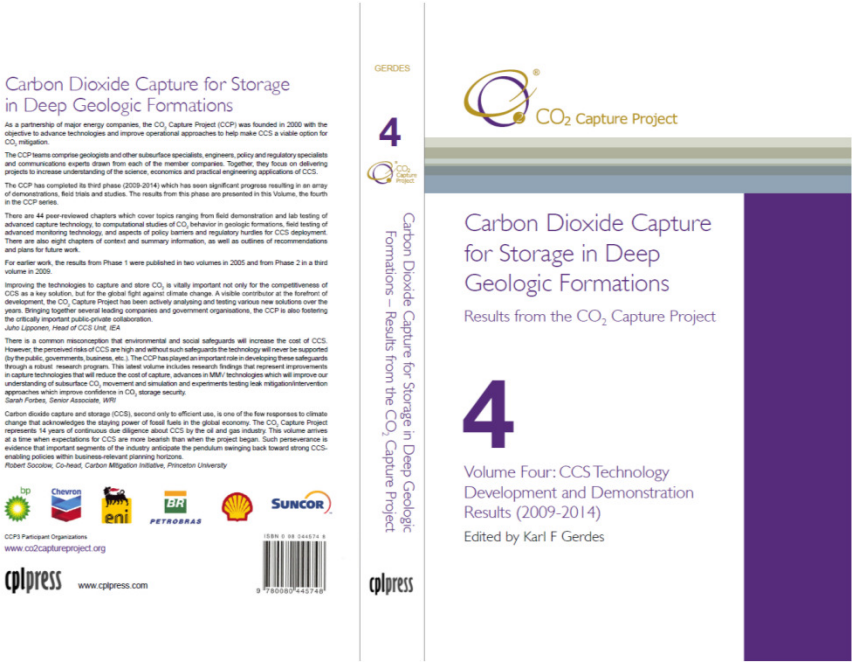


Image courtesy of LBNL

Contents

CCP4 P&I and Comms Program

CCP will continue to share knowledge and inform on CCS



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Contents

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