CO_2 Capture Project (CCP) – Phase 3 Results

2015 CSLF Mid-Year Meeting – 16th June 2015

Presented by:
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BP Group Technology, UK

- CCP Overview
- CCP3 Capture Program
- CCP3 Storage Program
- CCP3 Comms/P&I Programs
- CCP4
- CCP Conclusions

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CCP – A brief history

The CCP was founded in 2000. As a partnership of several major energy companies, it provides a unique, collaborative forum for those companies to develop practical CCS knowledge and solutions that relate specifically to the oil and gas industry.

Since 2000 the CCP's expert Technical Teams, made up of engineers, scientists and geologists from member companies, have undertaken well over 150 projects to increase understanding of the science, economics and engineering applications of CCS.

In that time, the CCP has worked closely with government organizations - including the US Department of Energy and the European Commission – and more than 60 academic bodies and global research institutes. It has been recognised by the Carbon Sequestration Leadership Forum (CSLF) for its contribution to the advancement of CCS.

Its activities are monitored and reviewed by an independent Technical Advisory Board made up of CCS industry experts.

CCP3 “Demonstrate technologies that will reduce the cost and accelerate deployment of CCS”

CCP

*“Field/plant **access** for pilot/demo’s”*

*“Project **Delivery** Focus”*

*“**Mid TRL** level technology development”*

*“Company **Expert** Collaboration”*

CCP1
2000-2004
Screening/proof of concept

CCP2
2004-2009
Intensive development

CCP3
2009-2014
Demonstration phase

*“Independent **Verification** of Cost and Performance”*

*“**Global** network of external partners”*

*“Technology **Agnostic”***

*“**Effectivel**y managed and run”*

CCP3 Team Overview

The project consists of four work teams, supported by Economic Modeling to build a fuller picture of the integrated costs for CCS:

1. **Capture**: aiming to reduce the cost of CO_2 capture from a range of refinery, in-situ extraction of bitumen and natural gas power generation sources
2. **Storage Monitoring & Verification (SMV)**: increasing understanding and developing methods for safely storing and monitoring CO_2 in the subsurface
3. **Policy & Incentives**: providing technical and economic insights needed by stakeholders, to inform the development of legal and policy frameworks
4. **Communications**: taking rich content from the ongoing work of the other teams and delivering it to diverse audiences including: government, industry, NGOs and the general public

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Refinery Scenario

Image courtesy of Petrobras

- Field demonstration of Fluid Catalytic Cracking (FCC) oxy-firing capture technology at Petrobras, Brazil
- FCC is one of the main sources of oil refinery CO_2 emissions (20-30%)
- Aim: to evaluate operability, test start-up, shut down procedures and obtain data for scale-up

Heavy Oil Production – Steam Generation

Image courtesy of Cenovus Energy Inc.

Oxy-fired – Once Through Steam Generation

Image courtesy of Cenovus Energy Inc.

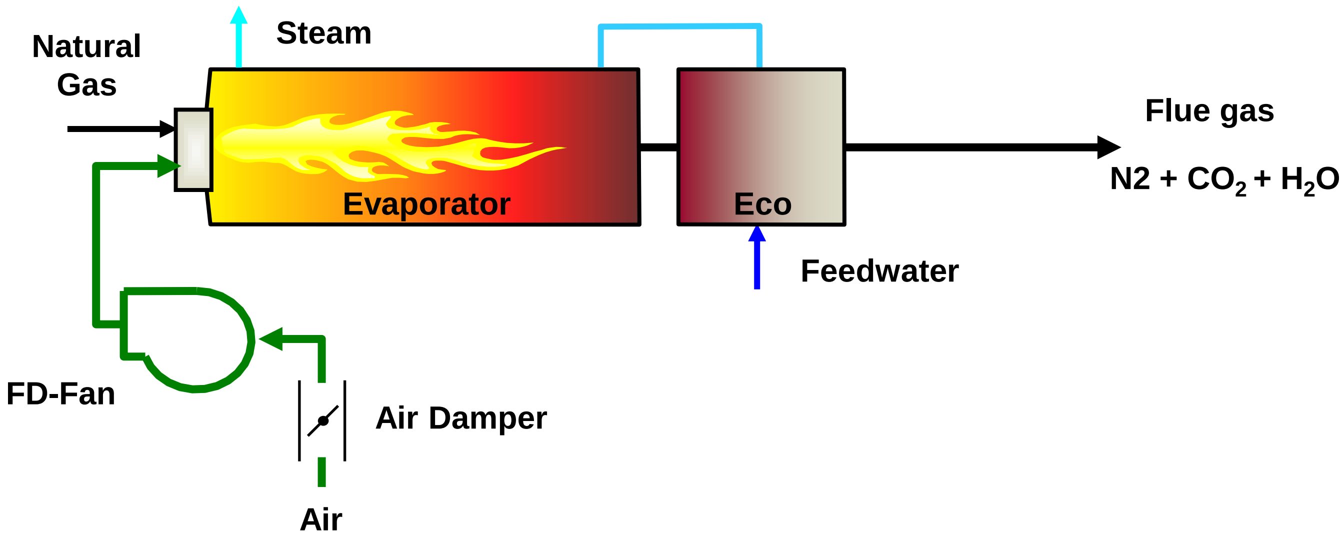
Oxy-OTSG demonstration project

- 50 MMBtu/h fuel input (~75 tpd CO_2 emission)
- Host: Cenovus Energy Inc, Canada
- The field demonstration run confirmed the technical viability of the process.
- Similar temperature and flux profiles in air and oxy-firing

- *Suncor – Project Administrator, Project Manager*
- *Cenovus Energy – Site Participant, Project Leader*
- *Praxair, Inc. – Site Participant, Project Leader*
- *Other project partners and co-funders: CCEMC, CCP3, MEG Energy, Devon and Statoil*

Oxy-fired – Once Through Steam Generation

- Existing commercial OTSG Boiler at Cenovus Energy Inc - Christina Lake
- Retrofit with flue gas recirculation
- Installation of oxygen supply and control integration



Project will demonstrate technical viability and safety of oxy-fuel combustion at operating in-situ site

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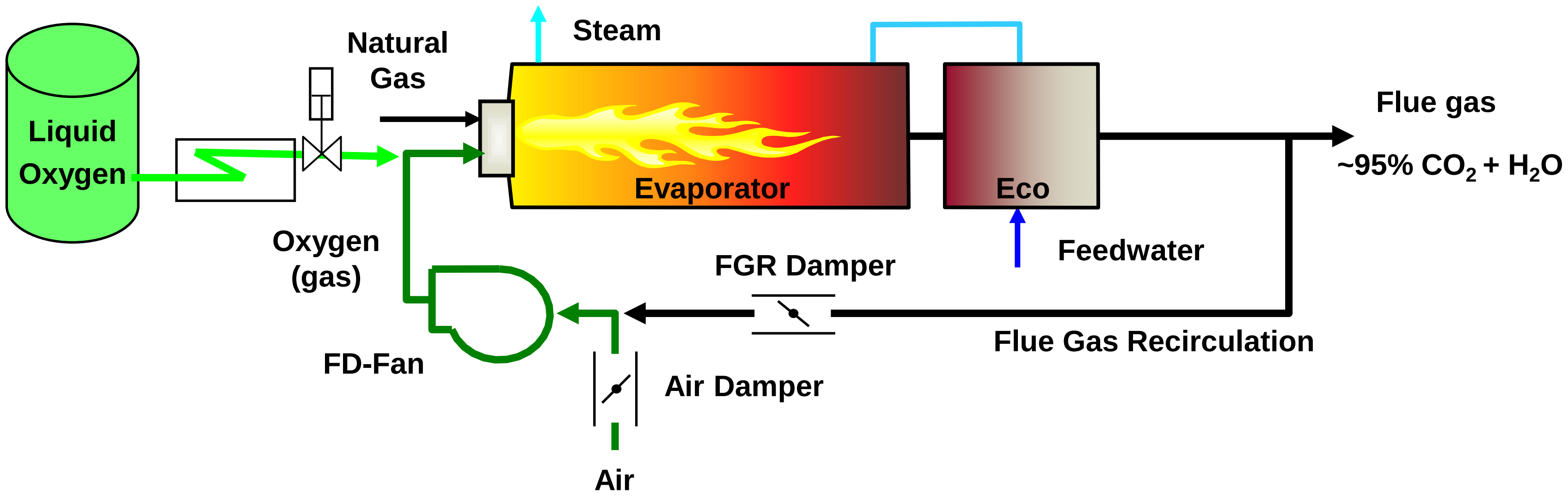

Project will demonstrate technical viability and safety of oxy-fuel combustion at operating in-situ site

Oxy-fired – Once Through Steam Generation

Air-fuel
70% load with small FGR flow

Oxy-fuel
70% load with 2.5% J Burner

- Hot refractory tile at burner provides stability for ignition
- Luminous flame over tile is a result of a desired recirculation pattern
- Oxy-fuel flame darker and more slender than air-fuel flame
- Boiler darker with oxy-fuel, tube hangers showing similar temperatures

Oxy-fired – Once Through Steam Generation

Image courtesy of TIW Western Inc.

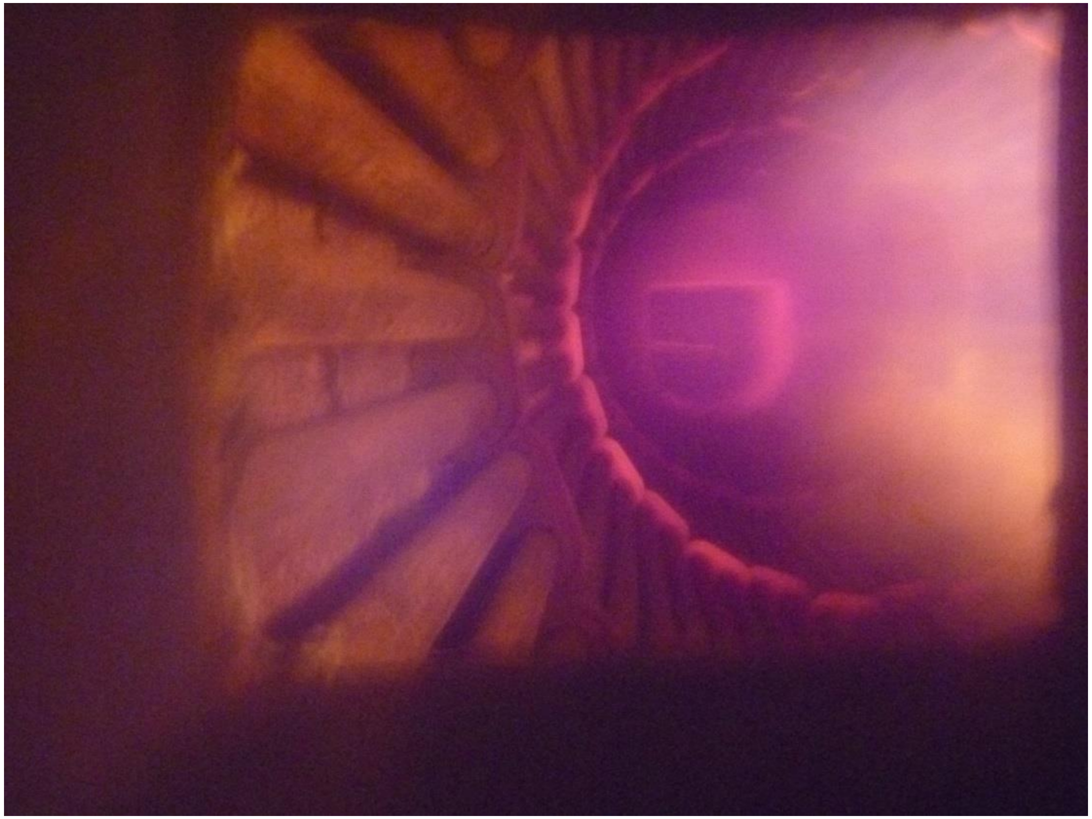

Image courtesy of Cenovus Energy Inc.

Capture Team – Other Key Projects

CCP

Development projects

- Capture of CO_2 from refinery heaters using oxy-fired technology
- Chemical Looping Combustion (CLC)
- Membrane Water Gas Shift (MWGS)

Economic evaluation

A detailed study by Foster Wheeler on state-of-the-art technologies for the capture of CO_2

- Refinery process heaters (4 x 150 MMBTU/hr) – US location
- Regenerator of FCC unit (60,000 bpd) – US location
- Hydrogen production for chemical (Steam reforming) or fuel use (Autothermal reforming) – US location
- Natural Gas Combined Cycle (NGCC) power station (400 MW) – European location
- OTSG for Steam Assisted Gravity Drainage (SAGD) oil extraction – Alberta location

Economic Evaluation – Key Assumptions

Calculated capture and avoidance costs include transportation and storage

Base Assumptions	Units	Value	Source
Fuel Gas Price – US	USD/GJ	4.50	Gulf Coast Public Data
Electricity Price - US	USD/MWh	70.00	Gulf Coast Public Data
Fuel Gas Price – AB	USD/GJ	4.50	
Electricity Price - AB	USD/MWh	60.50	
Time Horizon	Years	25	CCP Assumption
Power Intensity	tCO_2 /MWh	0.60	Gulf Coast Public Data
Steam Intensity for WHB FCC	tCO_2 /t	0.19	CCP Generated Figure
Heat to Produce Steam for FCC	GJ/t	3.13	CCP Generated Figure
CO_2 Transportation and Storage *	$/t	9.1	CCP Generated From Published Data

- Post-combustion steam consumption for solvent regeneration in the range of 2.7- 3.0 GJ/ton of CO_2
- *Storage costs – based on the WASP Study – Porous brine-filled aquifer http://www.ucalgary.ca/wasp/reports.html
- Transport costs based on capital costs factored from NETL data

CCP3 Economic Results

Application Scenario and Case Description	Fuel	CO_2 captured	CO_2 capture	CO_2 avoided	CO_2 capture cost	CO_2 avoided cost
Units		t/h	%	%	$/t	$/t
Refinery - US Gulf Coast						
FCC - Post Combustion	Carbon	55.5	85.5	65.5	94.2	112.9
FCC Oxyfuel Retrofit	Carbon	64.8	100.0	83.5	108.3	129.7
Fired Heater - Post Combustion	Fuel gas	26.6	85.0	65.0	118.6	156.5
Fired Heaters Pre-Combustion	Fuel gas	284.0	90.0	76.0	111.1	160.1
Refinery SMR with Post-Combustion	Nat gas	58.4	85.5	65.5	95.9	123.3
Oil Sands Steam Generation - Fort McMurray						
OTSGs - Post-Combustion	Nat gas	67.4	90.0	76.0	170.7	237.9
OTSGs CLC	Nat gas	63.3	100.0	86.0	195.7	236.4
Gas-Fired Power Generation - US Gulf Coast						
NGCC - Post-Combustion	Nat gas	126.1	85.5	73.7	97.9	113.6

- Post-combustion solvent-based technology is still the most economic (or close second).
- CO_2 avoidance costs are very high, especially for the Heavy Oil (oil sands) scenario due to the Alberta location.
- The economic assumptions, such as, fuel cost, location factor, imported power cost/CO_2 footprint, process scale/configuration all have an impact on the cost numbers.

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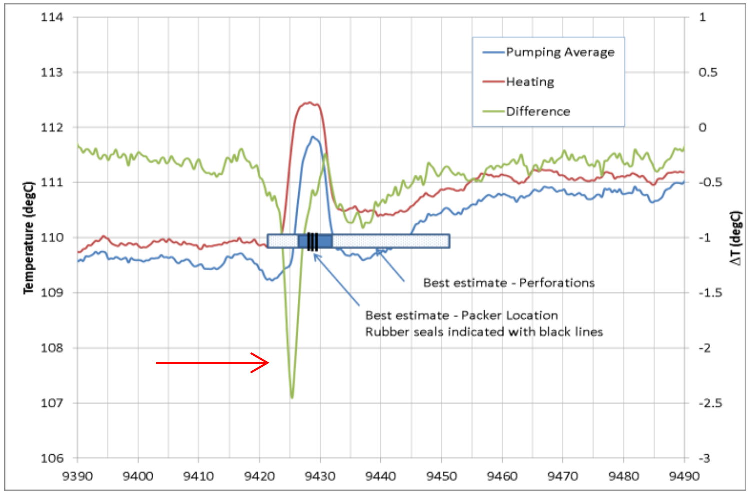
SMV Program – Themes

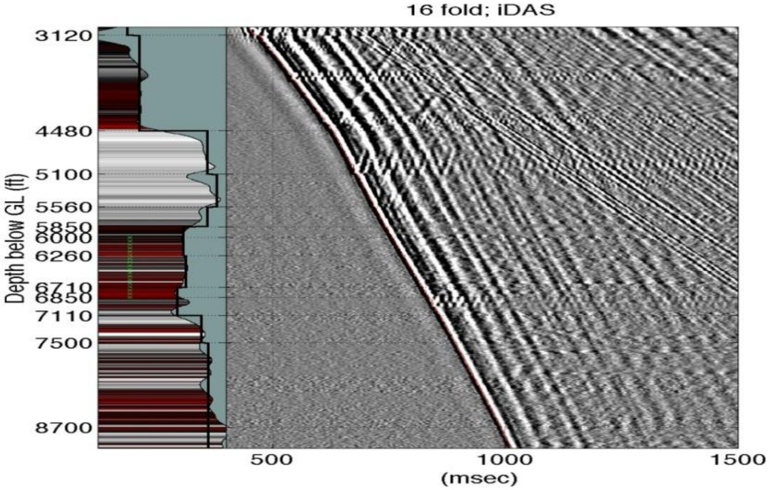
- **Well Integrity** – Stability of well barrier function with geomechanical and geochemical alteration
- **Subsurface Processes** – Physicochemical interactions that affect storage assurance
- **Monitoring & Verification** – Retrospective performance of past deployments and decision support; Technology development
- **Optimization** – Risk-based analysis of storage program development, economics of CO_2 EOR/storage and EGR utilization challenges in unconventionals
- **Field Trialing** – Deployment and performance analysis of new and adapted monitoring technologies at third party field sites
- **Contingencies** – Detection, characterization and intervention in unexpected CO_2 migration through top/fault seals

SMV Program – Field Trialing

- Time-Lapse TCR and RST – comparability of pre-flood, open hole resistivity and post-flood TCR logs to infer saturation [T. Dance, CO2CRC/CSIRO; A. Datey, Schlumberger]
- Borehole Gravity – Resolution and reproducibility at Cranfield [SECARB; CSM, LBNL]
- Decatur – Remote detection capability
  - InSAR [G. Falorni, TRE-Canada]
  - GPS [T. Dixon, U Florida]
- Modular Borehole Monitoring system
  - Design (Design) [T. Daley et al., LBNL]
  - Deployment (Citronelle) [SECARB, LBNL, EPRI, ARI]
- Downhole to surface EM evaluation at Aquistore [LBNL, Groundmetrics,]
- Soil Gas Monitoring Method [K. Romanak, UT-BEG]



Successful diagnosis of pressure bleed off issue – i.e., DTS showed fluid influx above packer due to off depth perforations, not the MBM assembly (B Freifeld, LBNL & R Trautz, EPRI)

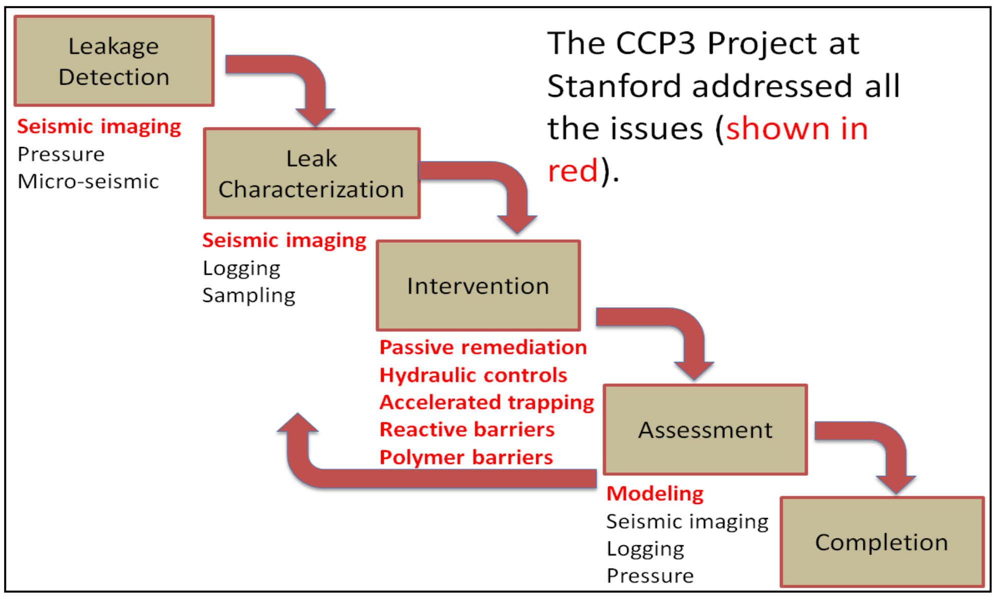


Fiber Optic DAS VSP quality (T Daley, LBNL & D Miller Silixa)

SMV Program – Contingencies

Projects

- Detection, characterization and intervention in top or fault seal CO_2 leakage (Stanford) [S. Benson & A. Agarwal et al., Stanford]
- Feasibility and design for a “fracture-sealing experiment at Mont Terri Underground Lab. [P. Ledingham, GeoScience Ltd., et al.]



Modeling and simulation topics covered for Stanford / CCP3 Contingencies study

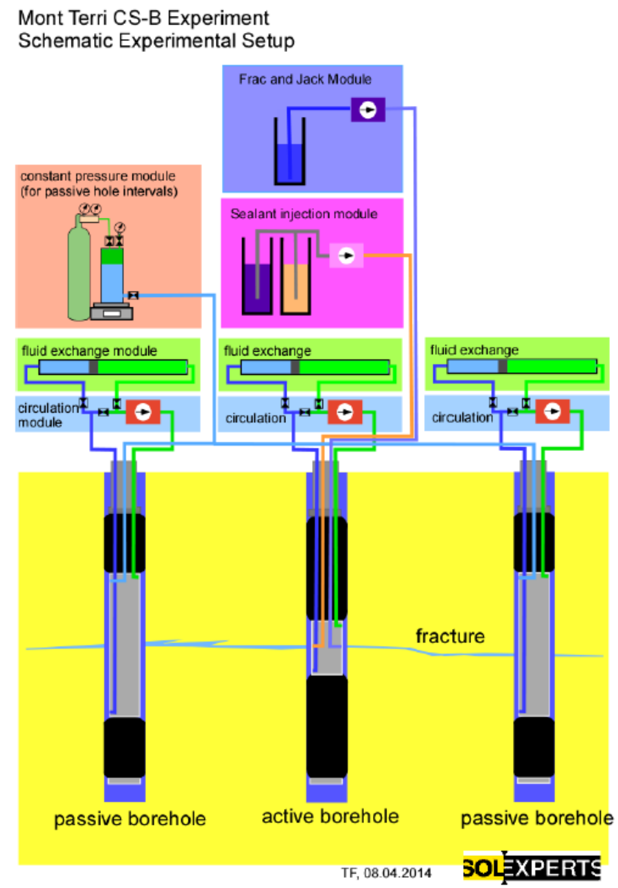


Figure 11: Schematic experimental setup

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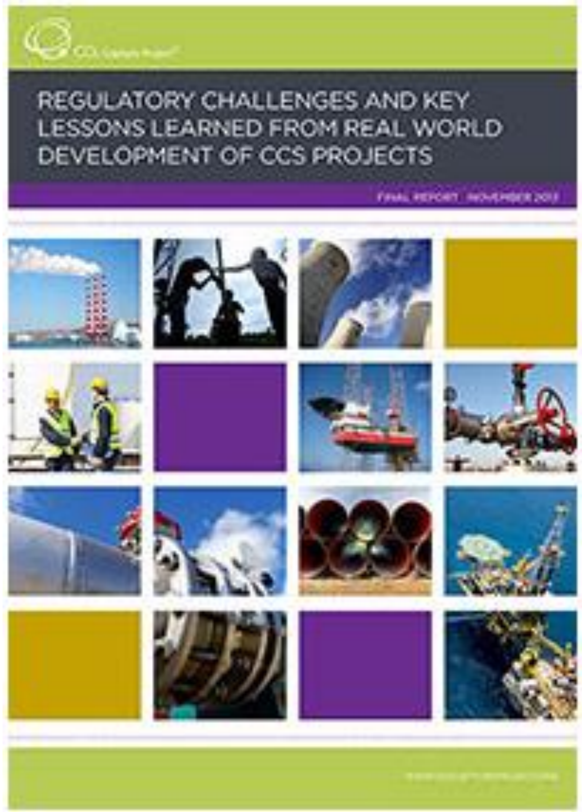
CCP3 Policy & Incentives Program

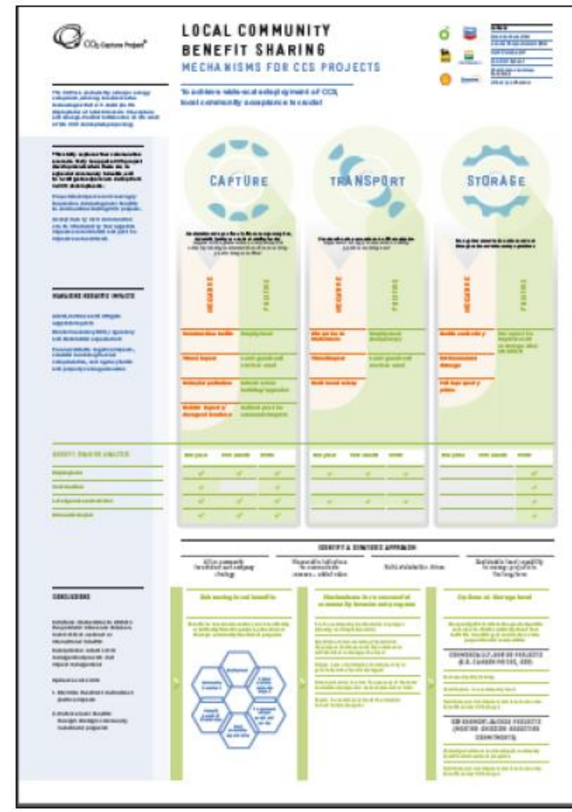
Program Objective: Inform the development of legal and policy frameworks through

- 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**





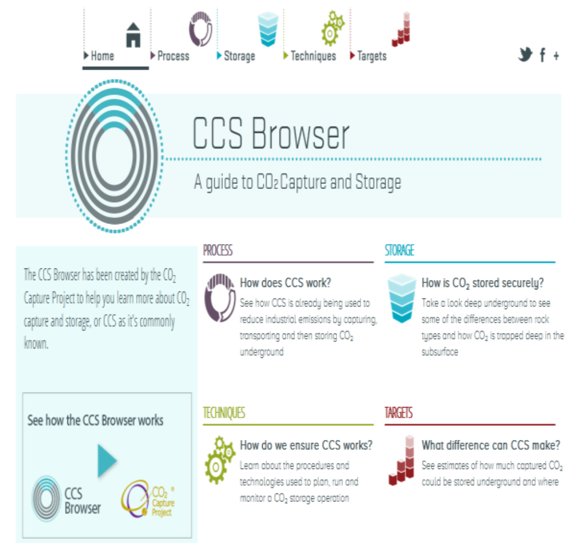
CCP3 Communications

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
- CO2 Conference Week (Sponsor/Presenter)
  - December 2012-2014 n Midland, TX

Public engagement
www.ccsbrowser.com



Acknowledging...

Our teams:

SMV:

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Environmental Resources Management (ERM)

Communications:

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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"*

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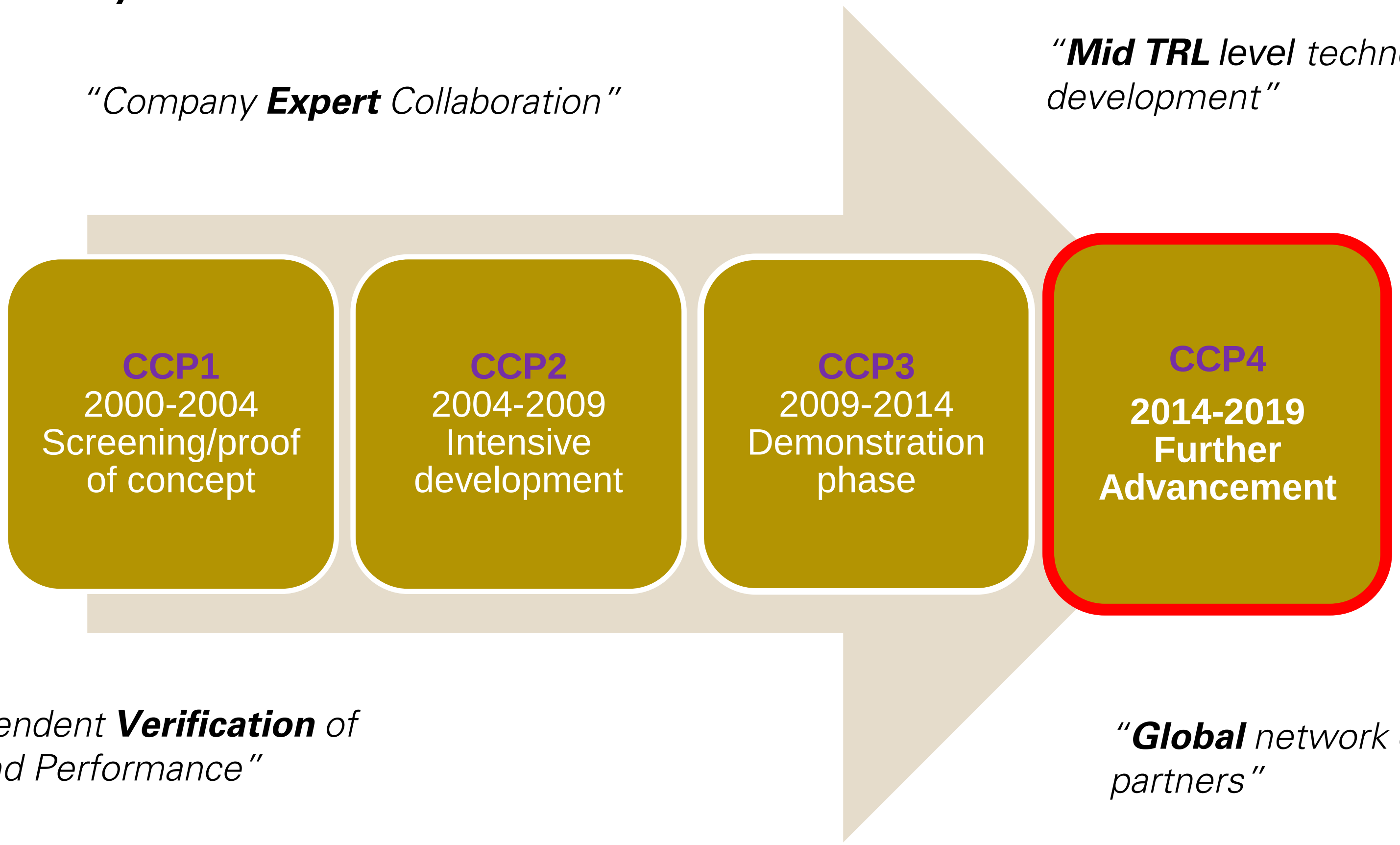


*"Independent **Verification** of Cost and Performance"*

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

*"Technology **Agnostic"***

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

CCP4 participating organizations

CCP4 Capture Program – Breakthrough Focus

CCP4 Focus

- Preference for technologies with <$50/tonne CO_2 avoided cost (e.g., SMR syngas capture, ECM technology, other "breakthrough" technologies)
- Low priority for "incremental" improvement technologies (e.g., current post-C technologies with costs >$100/tonne)

CCP4 Projects Under Consideration (partial list)

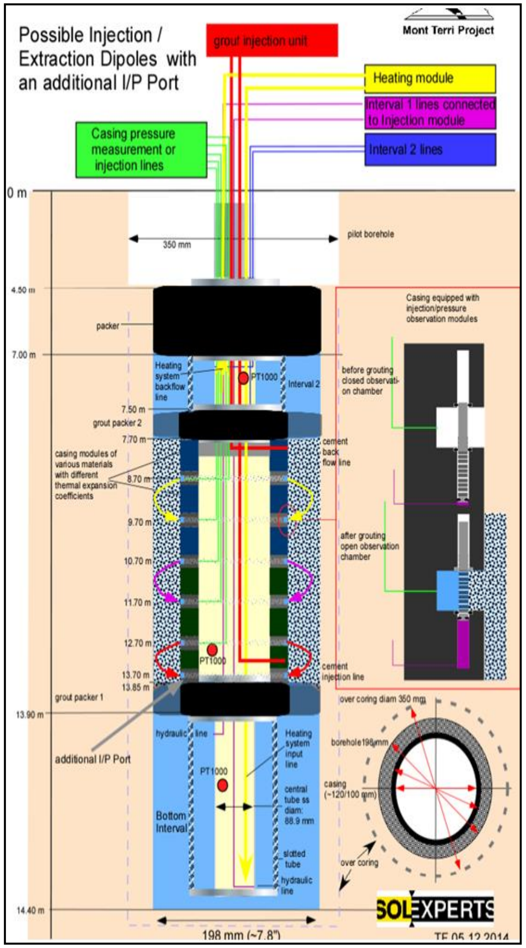
Scenario	Project/Study	SoW	Reasoning
Refinery	SMR pre-C baseline study	Develop cost for a base case (i.e., aMDEA) technology	Low-cost CO_2 capture from SMR is a priority in CCP4
Refinery	SMR pre-C capture technology	Economic assessment of a novel capture technology	Incremental cost reduction over the base case
Refinery	ITM O_2 evaluation	Evaluate ITM O_2 technology for oxy-FCC application	May reduce the cost of oxy-FCC technology
Heavy Oil	FuelCell Energy's ECM technology	Make an assessment and possibly participate in pilot	Potential of <$50/tonne CO_2 avoided cost
Heavy Oil	ATK's supersonic solid CO_2 formation technology	Techno-economic evaluation	Breakthrough technology for post-C
NG Treating	Pilot test of near-commercial membrane	Design, manufacture and evaluate membrane modules	Reduces cost and weight for offshore application

CCP4 Storage Program – Well Integrity

Well Integrity

- Well survey with logging, through casing sampling & VIT <u>or</u> bench+ scale well experiments (e.g., Chevron's Mont Terri CS-A experiment)
- MBM-based in-situ sensors for well integrity
- Approaches to mitigating P&A'ed wells

Figure 2: Test location in Gallery 04 looking from DR Niche



Chevron's proposed Mont Terri CS-A experiment (schematic)

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CCP Conclusions

- Post combustion capture technologies have seen some recent improvements, but what does the future look like versus alternatives, and will this achieve the end goal?
- There are some promising technology solutions to dramatically reduce capture costs & cost effectively verify safe/secure storage at scale, so R&D needs to continue
- CCP looks to build on its experience & expertise, welcome new partners and collaborate with others to ensure success

Questions?