CO_2 Capture Project - phase 4

Advancing CCS technology deployment and knowledge for the oil and gas industry – CCP4 Capture Program

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Section One
CCP Overview

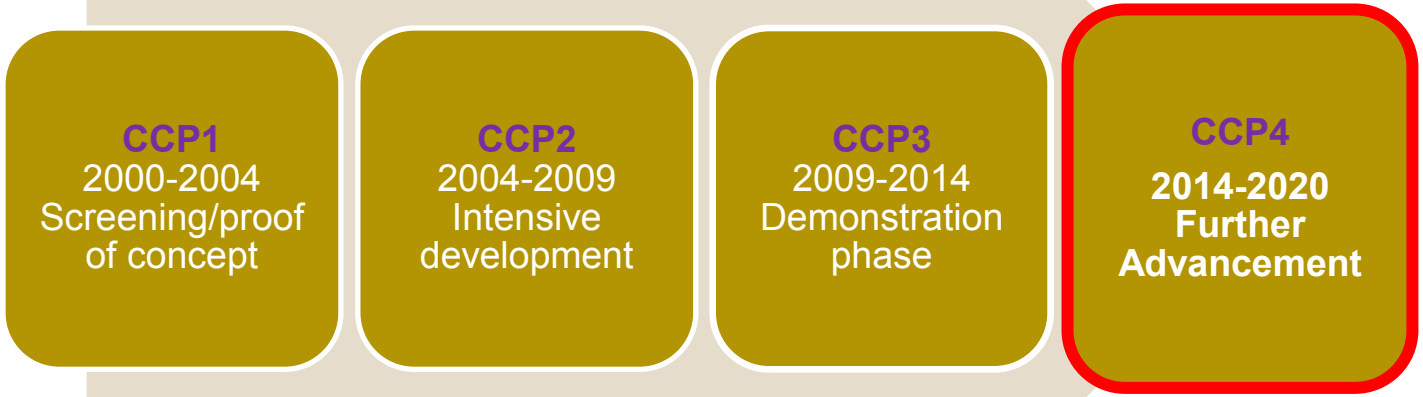
CCP4 "*Advancing CCS technology deployment and knowledge for the oil and gas industry*"

"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"

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Section Two
CCP4 Capture Program

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CCP4 Capture Program – results to date

CCP4 Capture Team – results to date

CO_2 capture from SMR H_2 plants

- Performed a techno-economic assessment (TEA) of CO_2 capture from SMR H_2 plants in collaboration with IEAGHG and Amec Foster Wheeler

Technology screening study for offshore CO_2 removal from NG

- Carried out a detailed techno-economic study of CO_2 removal from NG in offshore production in collaboration with Trimeric

Step-out novel capture technologies assessment

- In collaboration with LEAP, carried out preliminary TEA studies of several step-out novel CO_2 capture technologies

Pilot testing of advanced piperazine (PZ) solvent

- Carried out pilot testing of the PZ solvent in advanced flash stripper (AFS) configuration at University of Texas, Austin campus

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CCP4 Capture Program – current

CCP4 Capture Program

Purpose: **Increase the understanding** of existing, emerging, and breakthrough CO_2 capture technologies and target a reduction in the CO_2 capture cost by >50%

Approach:

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

Image courtesy of BP

Scenarios:

- Refinery Production
- Natural Gas Combined Cycle
- Natural gas extraction
- Heavy oil

Research activities in 2018 & beyond:

- **Novel technologies** – Continue carrying out TEA's of novel capture technologies, identify and support development of novel capture technologies at the pilot scale and participate in development and pilot testing of a technology to removal CO_2 from NG

Step-out Novel Capture Technologies Assessment

Study Purpose:

- The purpose of the work is to undertake an objective expert analysis of CO_2 capture technologies to increase the understanding of the potential of new technologies to exceed the performance of the current state of the art

Approach:

- The study was divided into the following areas:
- **Advanced solvents:** two advanced solvent processes, in different stages of process development, are included. These are:
  - **C-Capture process** – a process based on a low regeneration energy non-amine organic solvent and
  - **Piperazine process** – based on 5 m piperazine solution, an innovative absorber design and the advanced flash stripper being developed by Gary Rochelle's team at the University of Texas
- **High efficiency NGCC with advanced solvent CO_2 capture:** This study will investigate the impact of combining the currently reported record case for NGCC efficiency with an advanced solvent CO_2 capture technology
- **Non-solvent CO_2 capture:** CO_2 capture and electricity generation from small scale gas engines coupled with molten carbonate fuel cells

Piperazine / Advanced Flash Stripper Testing under Natural Gas Conditions

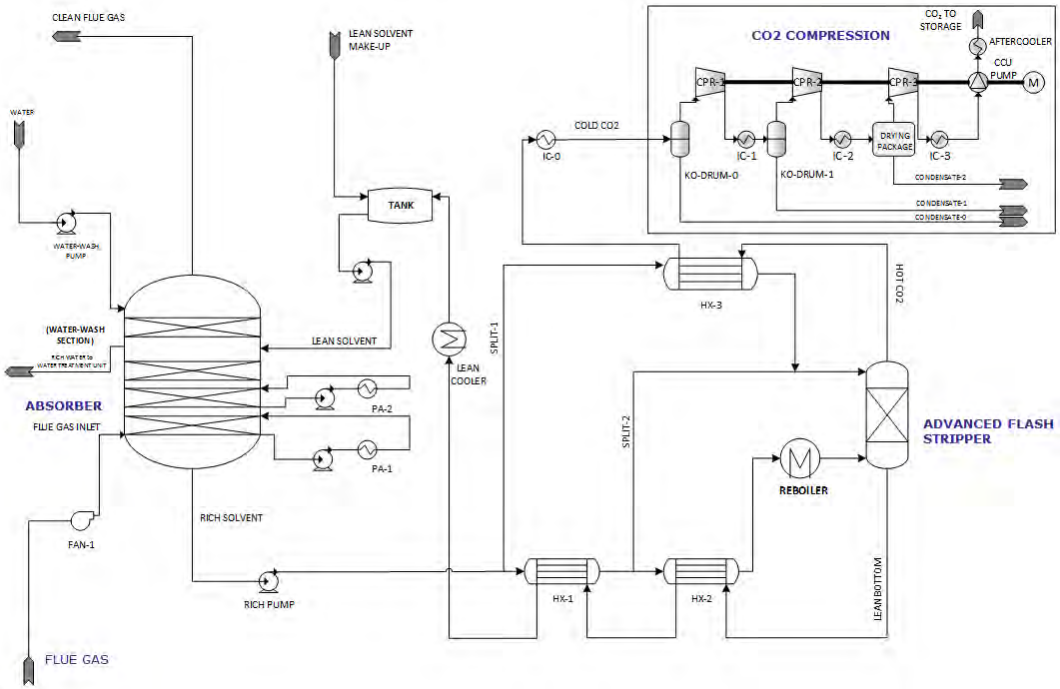
- In collaboration with Professor Gary Rochelle, University of Texas at Austin, pilot testing next generation solvent with advanced flash stripper
- At UT Separation Research Program pilot plant (Spring 2017)
  - Confirmed that PZ can be used to achieve high % capture even at 3.5% CO_2 in air.
  - Under an experimental design with varying liquid rates, gas rates, and lean loadings
  - Verified model performance at low CO_2 conditions
- At National Carbon Capture Center (ongoing)
  - Diluted flue gas conditions
  - Test several absorber intercooling configurations
  - Longer term testing to study oxidative degradation and potential mitigation

AFS Skid installed at NCCC Photograph courtesy of UT, NCCC

Piperazine-based CO_2 Capture Technology Assessment

Study Purpose:

- The purpose of the work is to undertake a techno-economic assessment of a 5 molal (5m) piperazine CO_2 capture process with advanced absorber and stripper designs, developed by the University of Texas



A simplified process flow diagram (PFD) for the 5 molal piperazine process (courtesy: LEAP)

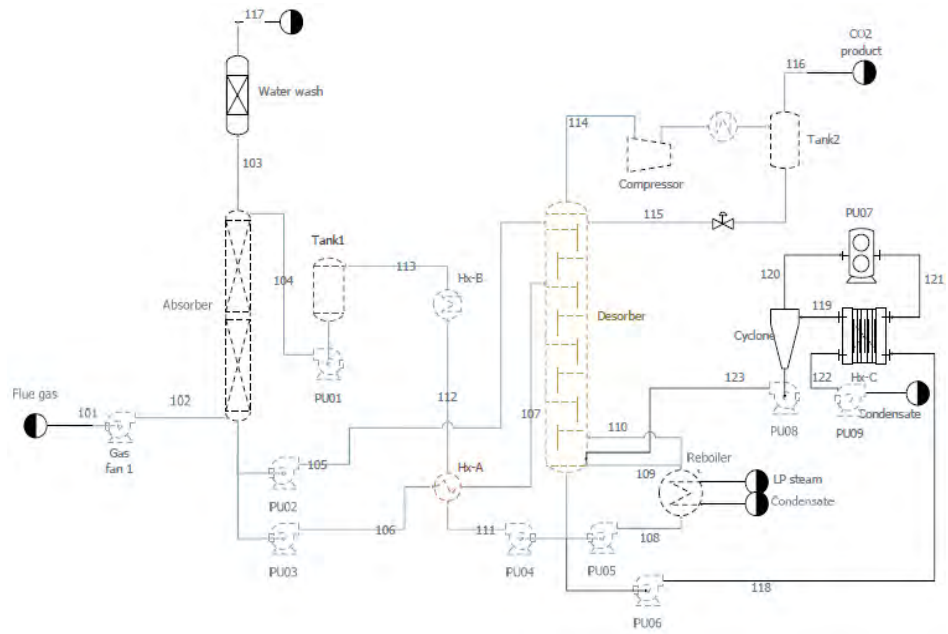
Key results

- **Energy performance** – the 5m piperazine process shows energy performance improvement compared to the benchmark (**7.0 % point** LHV efficiency penalty vs **8.5 % point** for benchmark)
- **CAPEX** – CAPEX estimation is on-going. We anticipate savings relative to the benchmark due to the shorter absorber and the elimination of the direct contact cooler

C-Capture Technology Assessment

Study Purpose:

- The purpose of the work is to undertake develop a preliminary techno-economic assessment on the C-Capture process for NGCC application, based on data supplied by C-Capture Ltd, to help direct further technology development work on the process



A simplified process flow diagram (PFD) for the C-Capture Process (C-Capture Ltd)

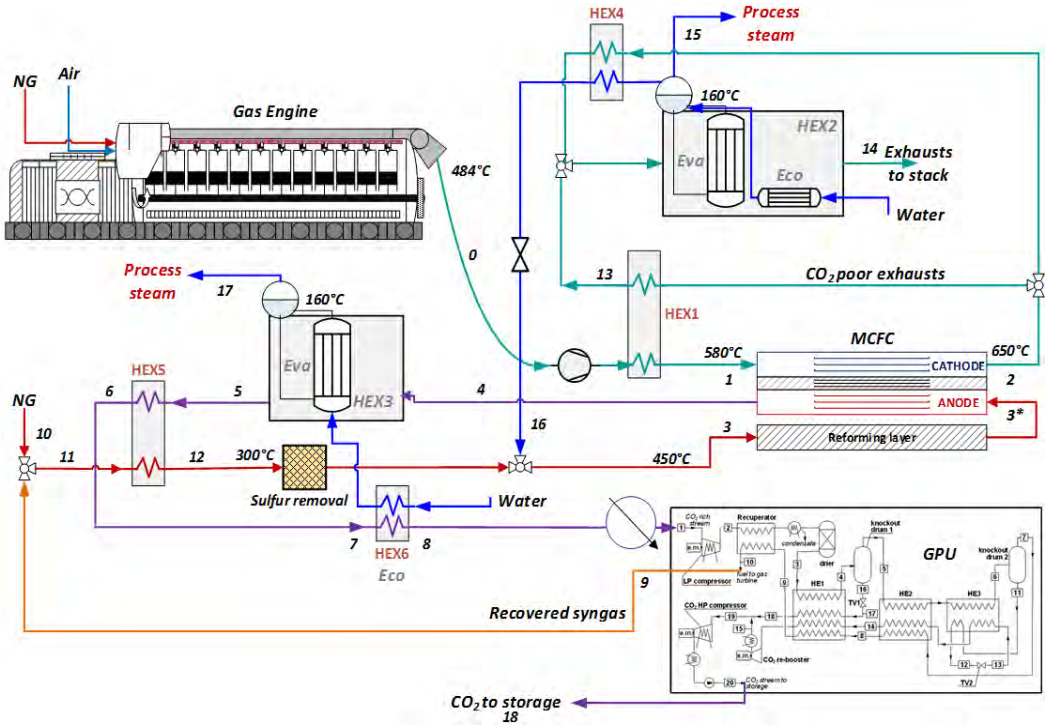
Key results

- **Energy performance** – the C-Capture process shows marked energy performance improvement compared to the benchmark (**6.5 % point** LHV efficiency penalty vs **8.5 % point** for benchmark)
- **Capital cost** – the CAPEX for the process is **marginally lower** than the benchmark with a lot of areas for improvement highlighted
- **Cost of CO_2 avoided** – the cost of CO_2 avoided was about **11% lower** than the benchmark
- Areas identified for further improvement include the mechanical vapour compression, absorber material of construction, lean/rich solvent heat exchangers and the stripper

Techno-economics of CO_2 capture – gas engines using MCFC technology

Study Purpose:

- The purpose of the work is to study post-combustion capture from small-scale gas engines (~ 5 MW_e, 60 t_{CO2}/day) coupled with a molten carbonate fuel cell (MCFC)

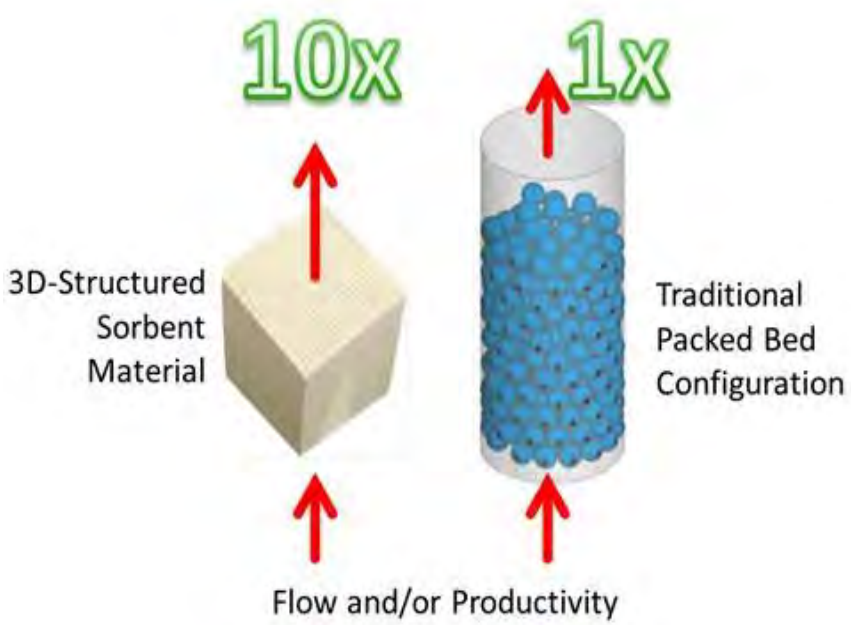


A simplified PFD of a gas engine with MCFC and cryogenic CO_2 capture (courtesy: LEAP)

Key results

- **Energy performance** – the results showed that it is possible to capture 90% of the CO_2 generated with **no net penalty** on LHV efficiency
- The scheme still produces a large amount of high temperature waste heat – LP steam is generated from the heat
- CO_2 recovery is by a cryogenic separation unit
- **CAPEX** - CAPEX estimation and economic analysis is on-going

Headline results



- Overall objective:
  - Productivity (kg CO_2/m^3hr) increase by a factor 10 of sorbent based capture technologies
- Means:
  - Additive manufacturing (3D-printing), sorption enhanced water gas shift (SEWGS)
- Materials:
  - Hydrotalcite (pre-combustion, 350 – 550^{o}C, up to 30 bar)
  - Amine functionalised silica (post-combustion & pre-combustion, 40 – 130^{o}C)

Three Dimensional Printed Capture Materials for Productivity Step-Change

3D-CAPS Acknowledgements

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

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Section Three

CCP4 Storage Monitoring & Verification (SMV) Program

CCP4 SMV Program Overview

Objective: Ensure safe and effective long-term CO_2 storage

- Conduct desktop to field deployment level RD&D to address key CO_2 storage uncertainties and risks
- Leverage O&G industry subsurface expertise to build a technical basis CO_2 storage assurance

Strategy:

- Identify key gaps in CO_2 storage assurance
- Develop projects with key 3rd party researchers with member company personnel as TPCs
- Progress projects through TRLs with an aim towards field testing of selected technologies
- Negotiate access to 3rd party field sites
- Rapid publication of results

Images courtesy of Mont Terri Consortium / Solexperts AG

Mont Terri Underground Laboratory (Switzerland) – Site of well sealing experiment

Themes:

- **Well Integrity** – Active & P&A
- **Field Trialing** – M&V, Intervention
- **M&V** – Cost-effectiveness
- **Subsurface Processes** – Coupled models
- **Optimisation** – Enhanced recovery
- **Contingencies** – Integrity event characterization & reversal

Deliverables:

- Results of models, experiments and field test via reports, presentations and articles
- Insights into status of technical basis for long term assurance of CO_2 storage
- Lessons learned applicable to improved O&G reservoir management and subsurface integrity

CCP4-SMV – Featured Projects
Well Sealing Experiment at Mont Terri*

Objective

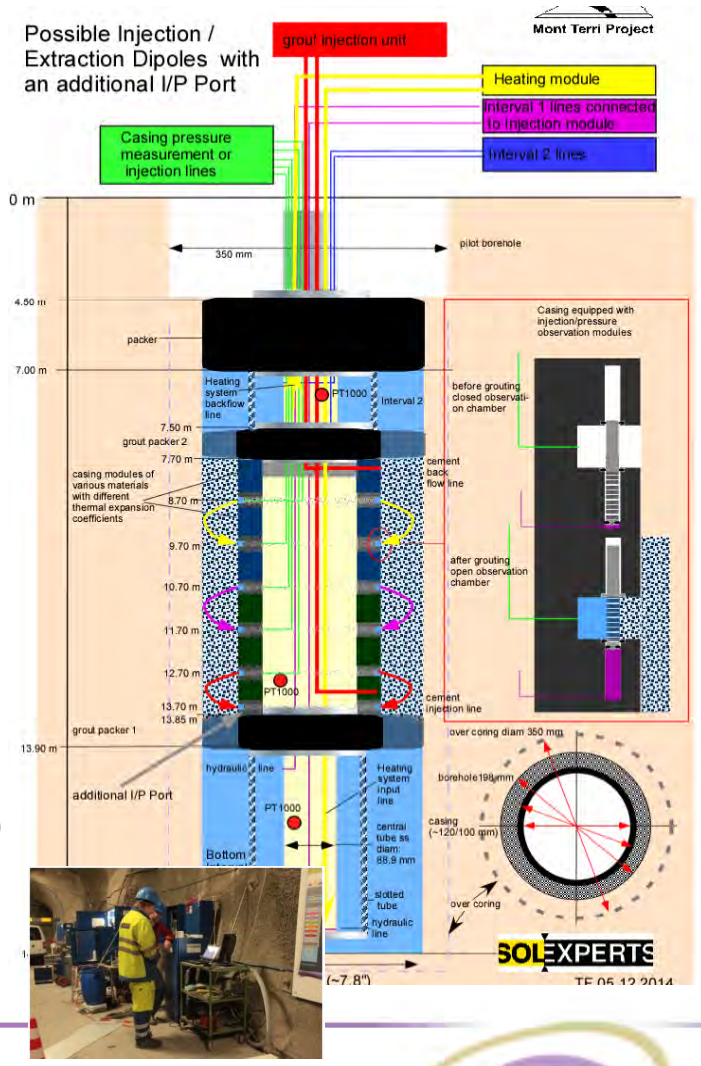
- Test effectiveness of novel sealants to treat small but persistent micro-annular CO_2 leaks in wells

Methods & Results

- Scale well (15m) installed at MTUGL with multiple sets of inlet/outlet modules and pressure monitoring instrumentation
- Thermal stimulation to achieve casing / cement micro-annular space (via de-bonding) likely created cement cracks and a cement / rock micro-annulus. Considerable effort to characterize defects (path, volume and permeability) and artifacts (pH increase, mineral precipitation, casing corrosion) prior to 1st sealant injection.
- First sealant trial (low pH-triggered) has achieved sealing to 35 bar in the upper module. This is deemed as a successful test of the sealant in the MT well setting and has the potential for providing a successful seal in a reservoir environment.

Status & Plans

- Injection and performance assessment of second sealant (high pH-triggered); Possible test of a third sealant (e.g., commercial product)
- Over-coring of well system with petrophysical, chemical and imaging analyses to characterize location and state of sealants
- Assessment of complications experienced reflection on real well integrity & whether sealants may be suitable for O&G well mitigation



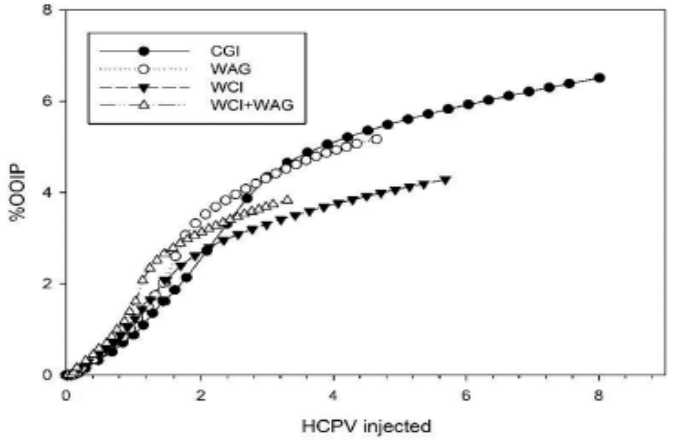
*Swisstopo, SolExperts

CCP4-SMV – Featured Project
Waterflood-EOR "*de facto* CO_2 storage"*

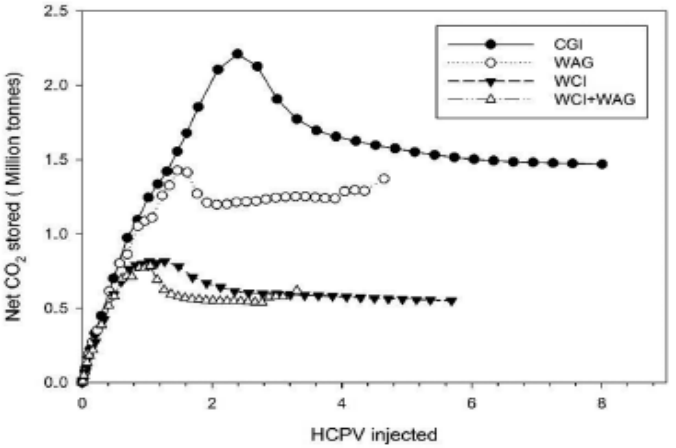
Objectives
- Demonstrate through numerical history matching simulation, calibrated with operational surveillance data, that CO_2 EOR delivers "de facto" storage whether 1) converting a waterflood to a CO_2 EOR flood or 2) converting a CO_2 EOR flood to CO_2 storage only.

Methods & Results
- Simulation using CMG-GEM is complete for four types of injection methods: 1) WAG (water alternating gas), WCI (water curtain injection), CGI (continuous gas injection) and hybrid WAG+WCI. Output illustrates tradeoffs among these methods in terms of oil production and CO_2 storage and associated utilization factors.
- Overall, CGI maximizes oil recovery and CO_2 storage in absolute volume terms, but WAG offers a more balanced approach (per utilization ratio).

Status & Plans - Complete
- CO_2-brine relative permeability & capillary pressure measurements were problematic although existing data was deemed suitable for the model (subsequent experiments run at another lab will be used to validate this assumption).
- Economics were not considered in this study but a basis for such work has been established



Cumulative oil produced by method (2010-33)



Net, cumulative CO_2 stored by method (2010-33)

*University of Texas Bureau of Economic Geology

CCP4-SMV – Key Projects
Geomechanical Hysteresis in a Clastic Oil Field*

Objective

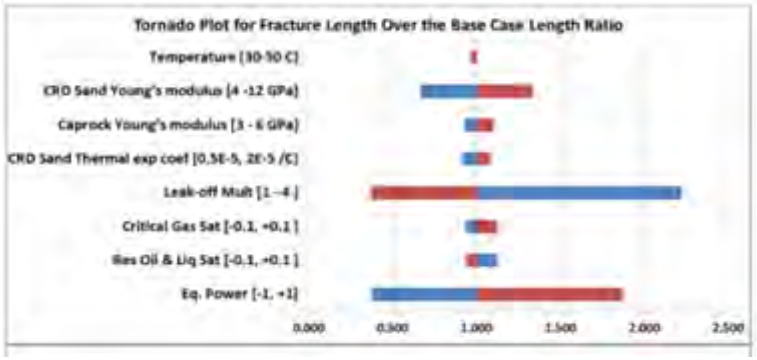
- Evaluate the hysteretic effects that oil fields experience through multiple development phases (primary through tertiary) that may impact their suitability to store CO_2
- An Alberta clastic system was selected as a follow on case to CCP3 Weyburn carbonate case

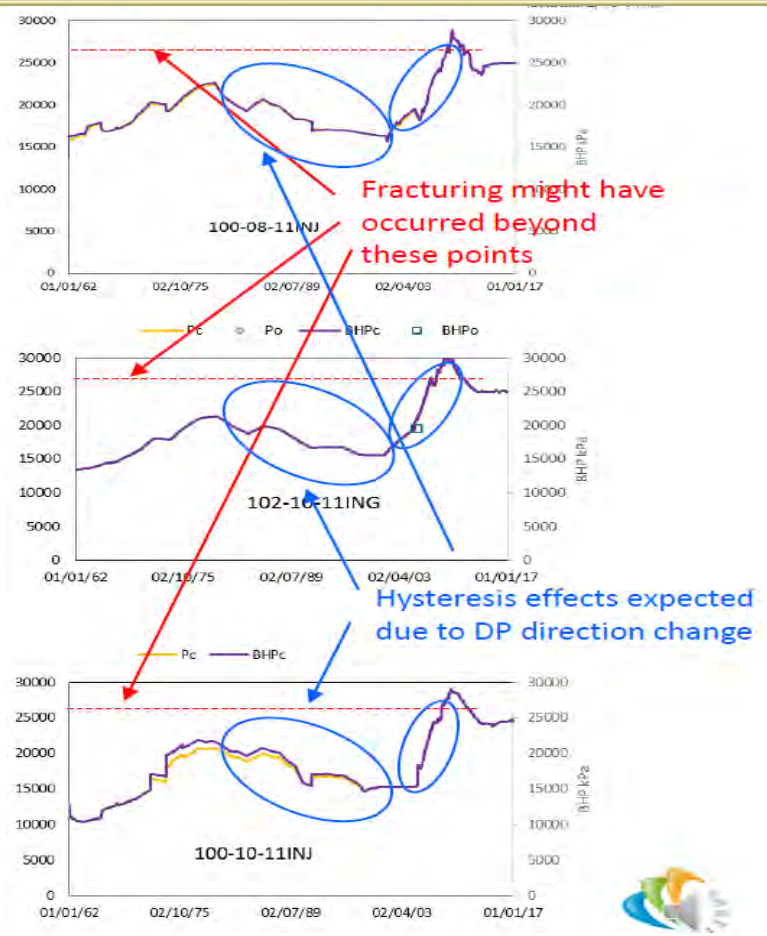
Methods & Results

- 50 yrs. of production (1-3^o) was modelled with analysis of stress changes that could have impacted caprock integrity investigated
- A parametric study identifies relative sensitivity to key seal integrity risk factors (e.g., fracture length, illustrated below)

Status & Plans

- Complete, no further work anticipated presently





Field production activity and bottom hole pressure with time vs. modeled stress path changes that may have led to exceeding fracture gradient.

*CGG Services (Canada), Ltd.

CCP4-SMV – Other Projects

Complete

- **FOAK to NOAK** - Characterize CO_2 storage costs for "first vs. nth of-a-kind" project for saline vs. CO_2 EOR field conversion and taking into account regulatory requirements and risk. *Key cost drivers include number of wells needed and monitoring requirements. [Advanced Resources International]*
- **CO_2 injection start-up / early operations** – review and analysis CO_2 storage pilots, demos and "commercial" project outcomes. Low side outcomes were typically attributed to insufficient characterization. *[Advanced Resources International]*

Ongoing

- **Contingencies: Leaking P&A well** – Model ability to detect, localize, characterize and access to treat a P&A well leaking CO_2. [Lawrence Berkeley NL & Stanford University]
- **Contingencies: Fractured top seal** – Simulate application of injected sealants to improve integrity of top seal prior to injection. [University of Texas]

Developing

- Repeat EM survey at Aquistore (vs. 2013 CCP3 baseline)

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Section Four
CCP4 Comms/P&I Programs

CCP4 Policy & Incentives Program

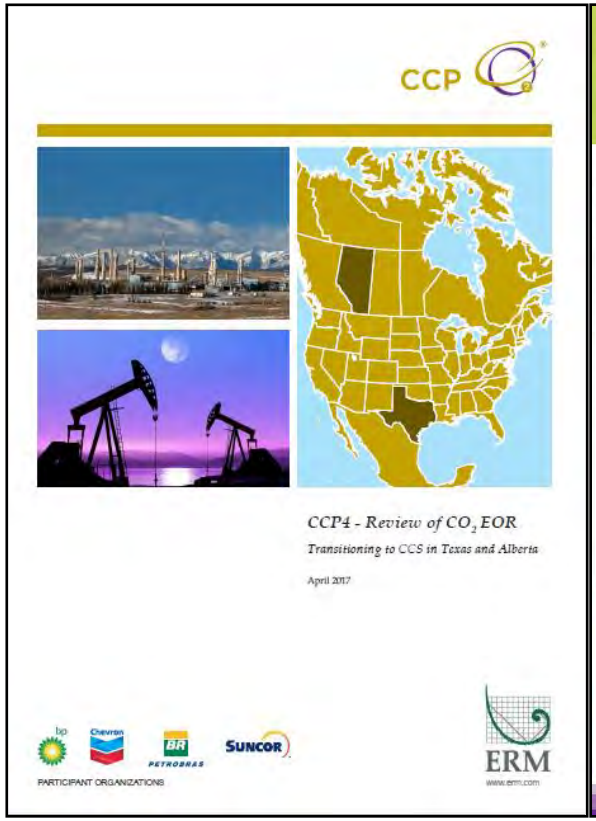
Policy & Incentives Program

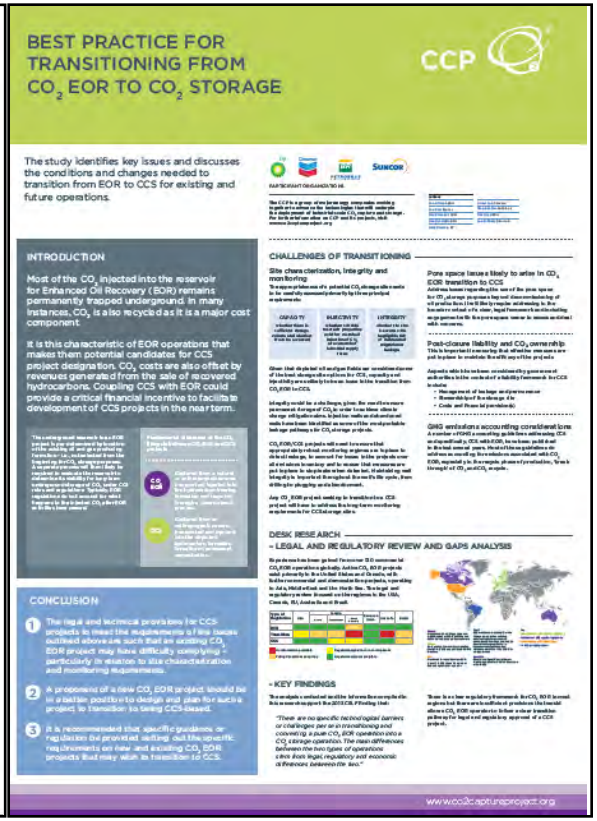
Purpose: Inform the development of legal and policy frameworks through

- Technical and economic insights
- Project experience of regulatory processes

Results at a Glance:

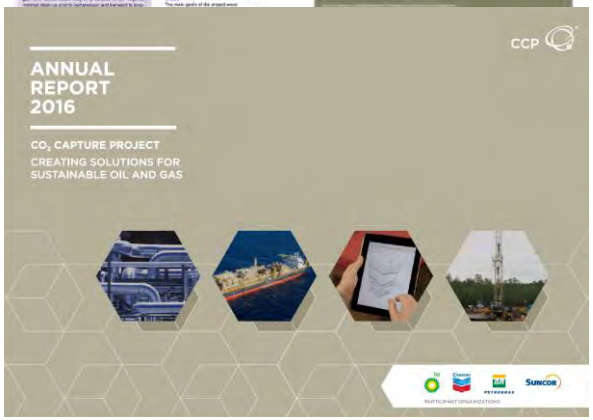
- Local Community Benefit Sharing Study, 2011 - local community benefit sharing can help to address the potential imbalance between local costs vs. national or international benefits associated with some major developments
- Regulatory Study, 2012 – Update of regulatory issues facing CCS projects, documented lessons learned & found that pathways for approval do exist
- Best Practice for Transitioning from CO_2 EOR to CO_2 Storage, 2016
- Review of CO_2 EOR: Transitioning to CCS in Texas and Alberta 2017





Communications Program

Communications Program

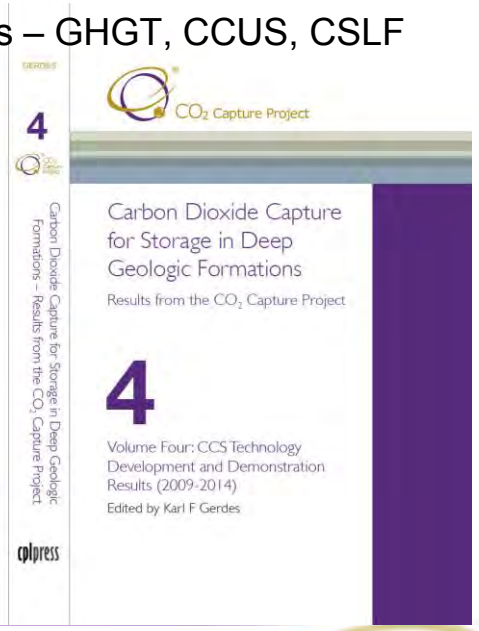


Purpose

- Sharing CCP's work and expertise

Results at a glance:

- Range of digital, print and face-to-face tools for industry, NGO and public audiences
- Member-only tools – management briefings, risk toolkit
- Increasing use of web and digital to extend reach cost-effectively – CCS Browser, In Depth tool
- Presence at CCS conferences – GHGT, CCUS, CSLF



CCP4
participating organizations

bp Chevron PETROBRAS

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Acknowledging our teams

Acknowledging....

Our teams:

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Mark Crombie (BP), Arthur Lee (Chevron), Vinicius Lima (Petrobras)

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CCP4 SMV Research partners & collaborators:
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CCP4 Policy & Incentives partner :
Environmental Resources Management (ERM)

CCP4 Communications partner:
Pulse Brands

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