CO2 Capture Project (CCP) – Phase 3 Results

Finding Petroleum– 19th November 2015

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Contents

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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”

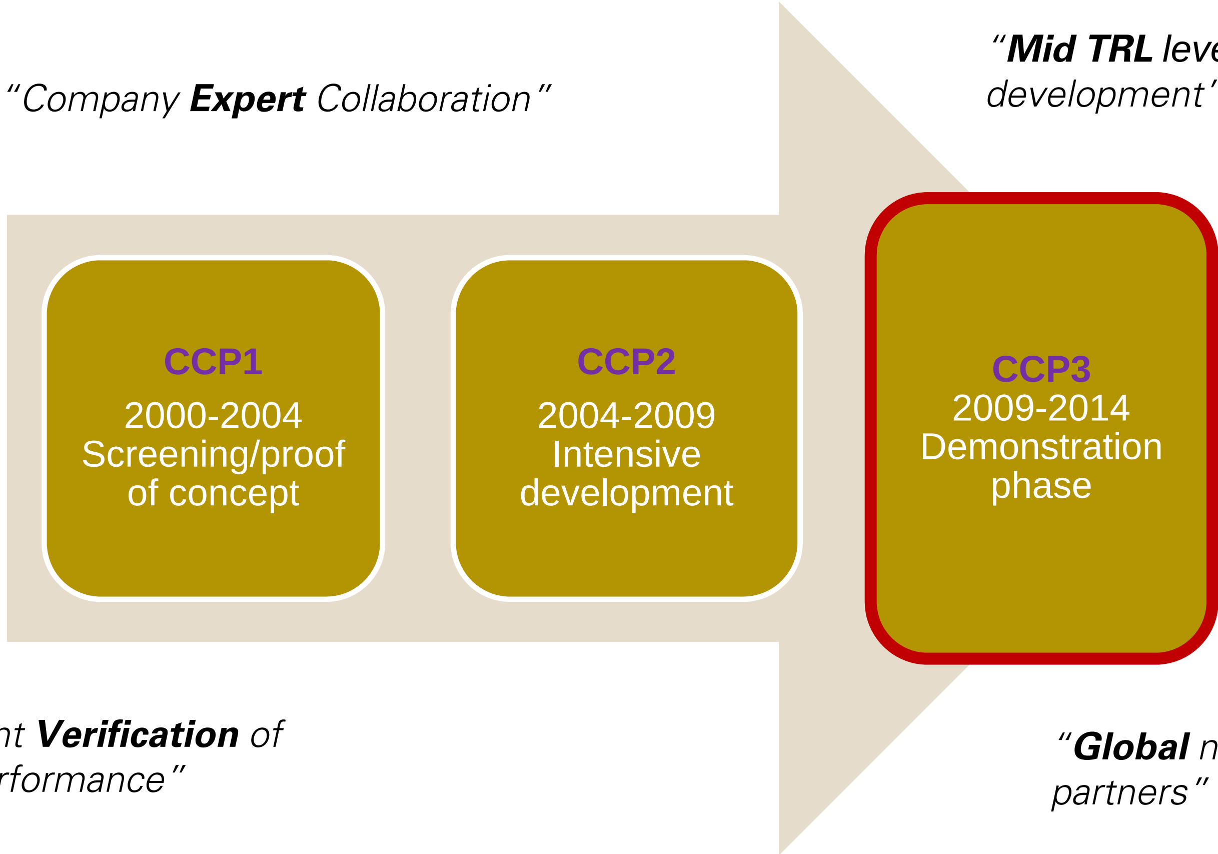
CCP

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

*“Project **Delivery** Focus”*

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

*“Company **Expert** Collaboration”*



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

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

*“Technology **Impartial”***

*“**Effectively** managed and run”*

CCP4
participating organizations

bp Chevron PETROBRAS SUNCOR

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

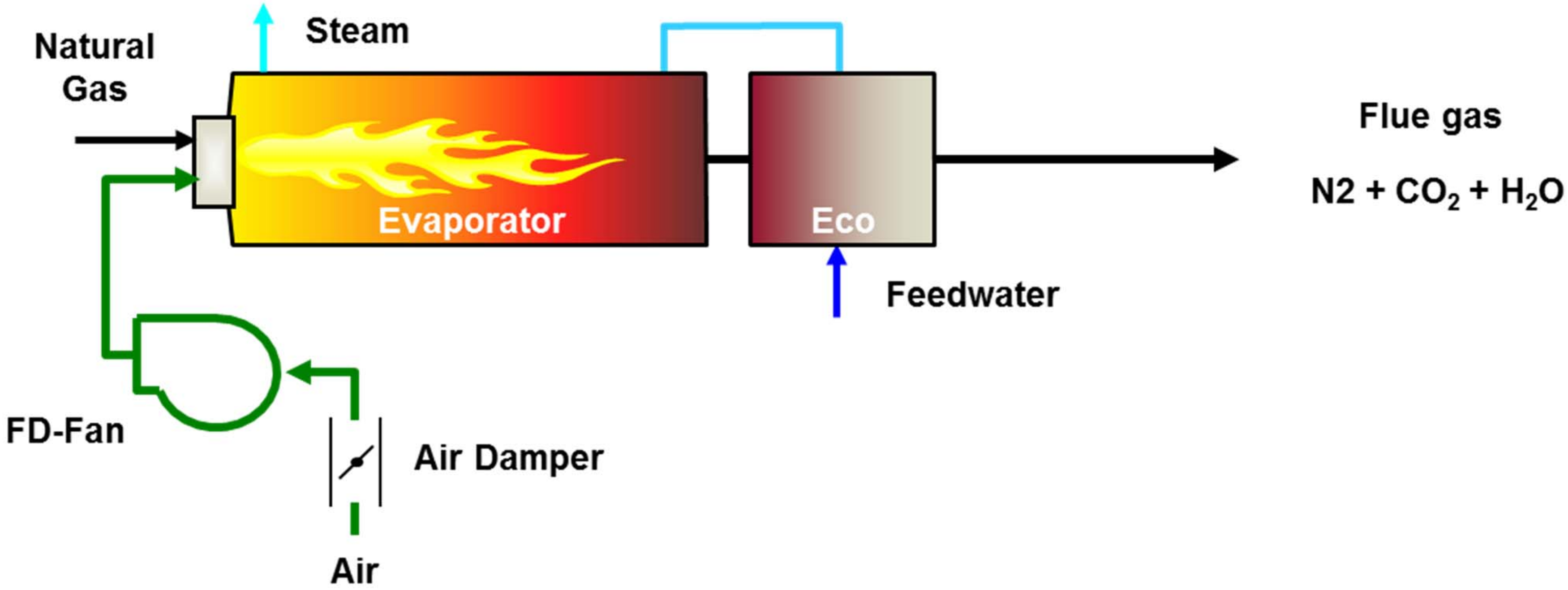
- Field demonstration of Fluid Catalytic Cracking (FCC) oxy-firing capture technology at Petrobras, Brazil
- FCC is one of the main sources of oil refinery CO_2 emissions (20-30%)
- Aim: to evaluate operability, test start-up, shut down procedures and obtain data for scale-up

Heavy Oil Production – Steam Generation

Image courtesy of Cenovus Energy Inc.

Oxy-fired – Once Through Steam Generation

- 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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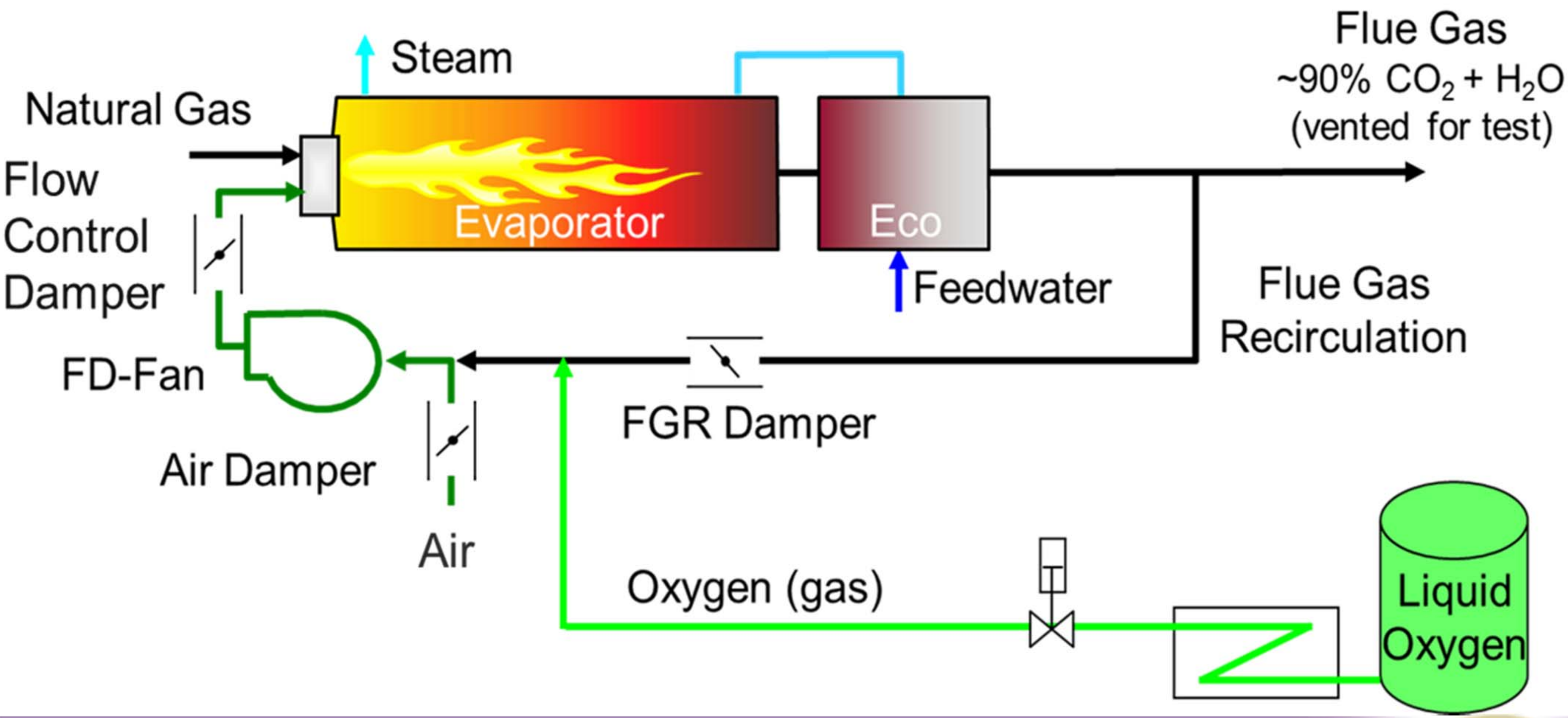
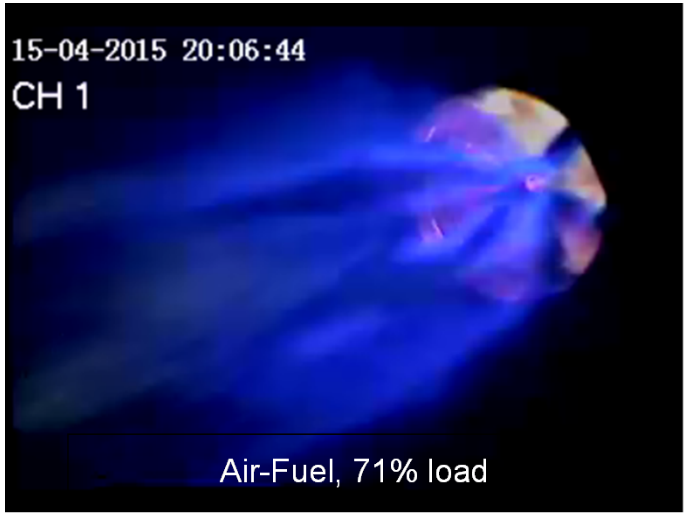
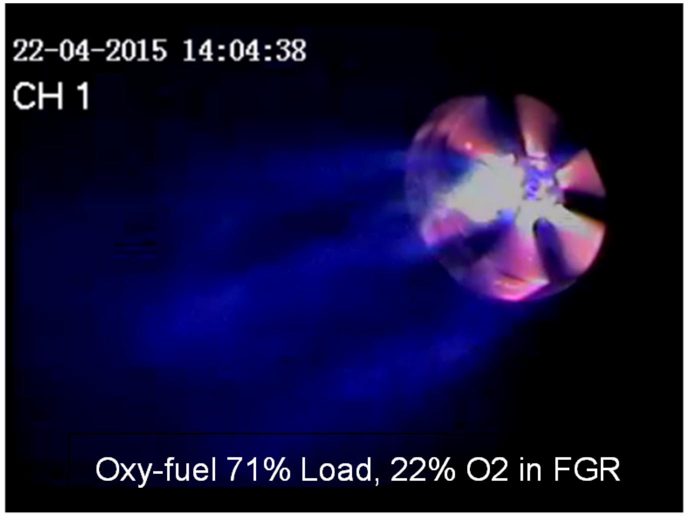


Oxy-fired – Once Through Steam Generation



Air-fired with small flue gas recycle flow



Oxyfired with 2.5% J-burner

Image courtesy of Cenovus Energy Inc.

- 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.

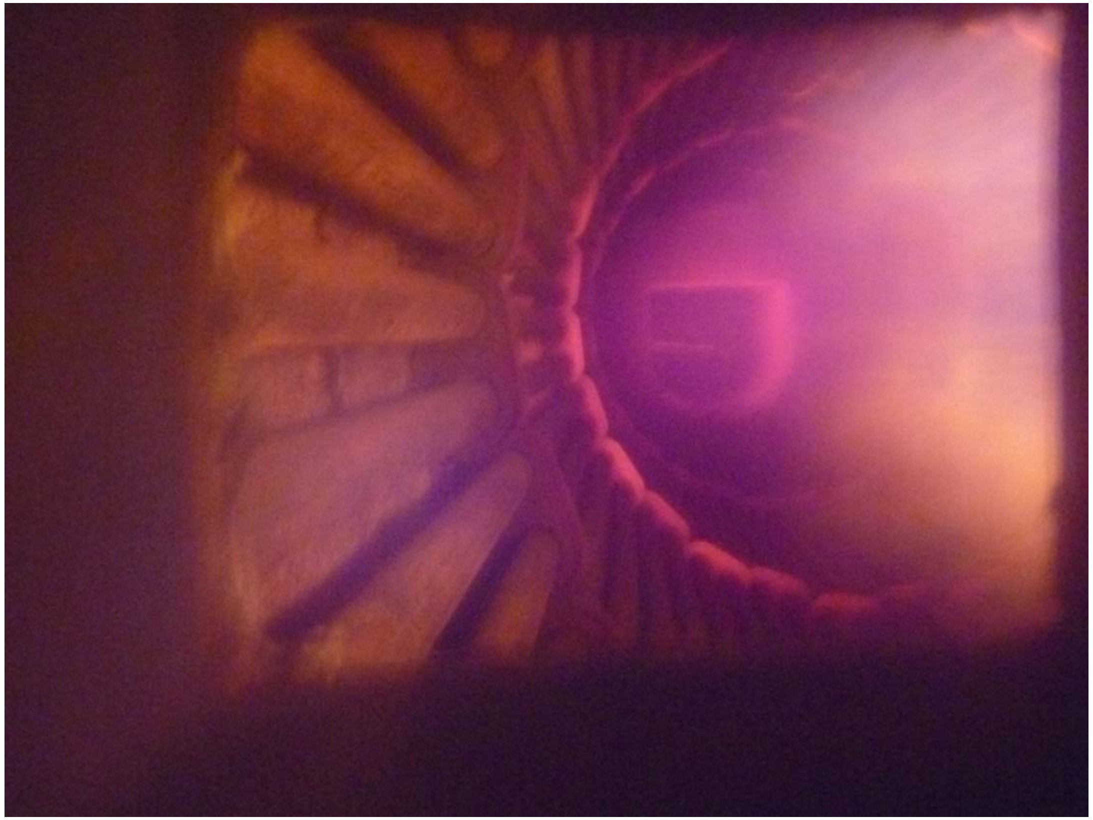


Image courtesy of Cenovus Energy Inc.

Capture Team – Other Key Projects

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 captured	CO_2 avoided	CO_2 captured 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	122.9
FCC Oxyfuel Retrofit (99.5% O_2)	Carbon	64.8	100	83.5	108.3	129.7
Fired Heater Post-Combustion	Fuel gas	26.6	85	65	118.6	156.5
Fired Heaters Pre-Combustion	Fuel gas	284	90	76	111.1	160.1
Refinery SMR with Post-Combustion	Nat. gas	36.1	85.5	65.5	95.9	123.3
Oil Sands Steam Generation – Fort McMurray						
OTSGs Post-Combustion	Nat. gas	67.4	90	76	170.7	237.9
OTSGs CLC	Nat. gas	63.3	100	86	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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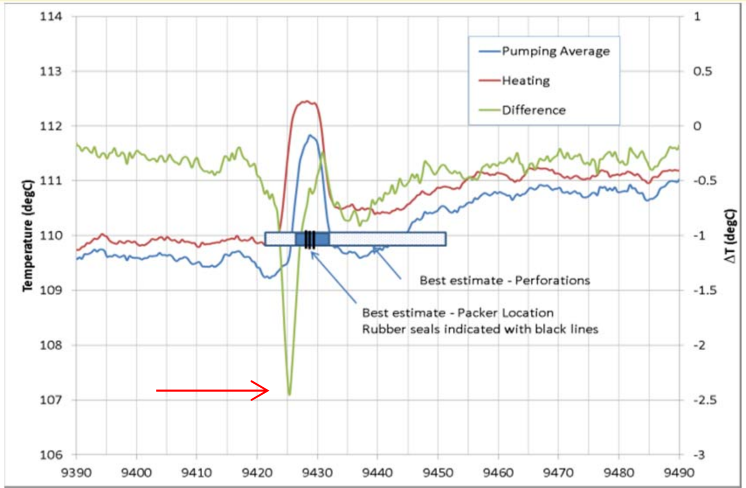
SMV Program – Themes

- **Well Integrity** – Stability of well barrier function with geomechanical and geochemical alteration
- **Subsurface Processes** – Physico-chemical 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

- Modular Borehole Monitoring system
  - Design (Design) [T. Daley et al., LBNL]
  - Deployment (Citronelle) [SECARB, LBNL, EPRI, ARI]
- 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]
- Downhole to surface EM evaluation at Aquistore [LBNL, Groundmetrics,]
- Soil Gas Monitoring Method [K. Romanak, UT-BEG]



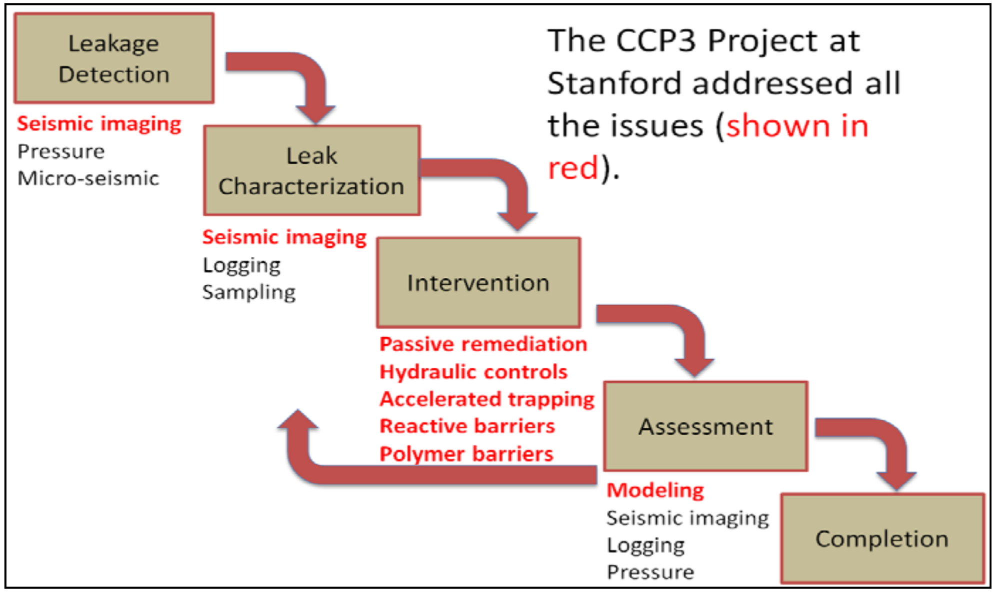
Successful diagnosis of pressure bleed off issue – i.e., DTS showed fluid influx above packer due to off depth perforations, not the MBM assembly (B Freifeld, LBNL & R Trautz, EPRI)

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

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

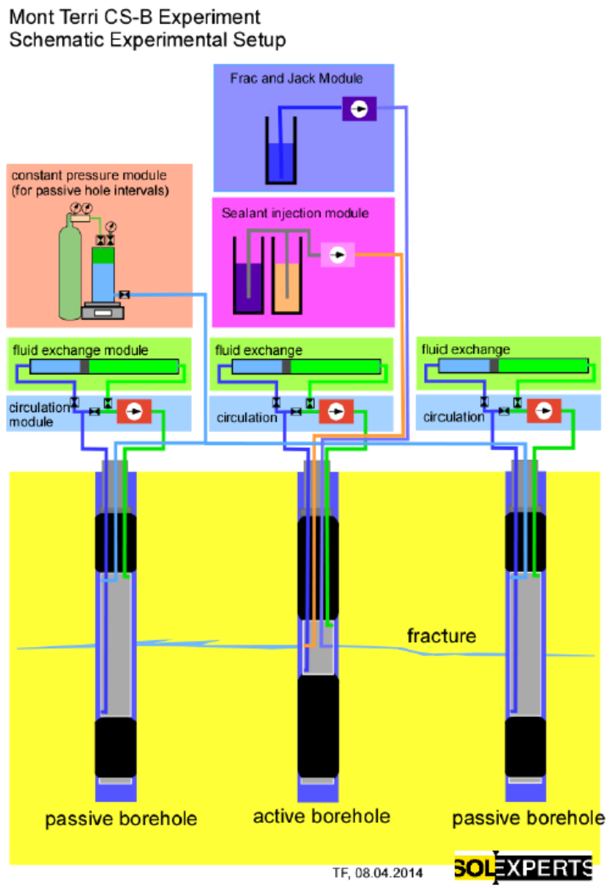


Figure 11: Schematic experimental setup

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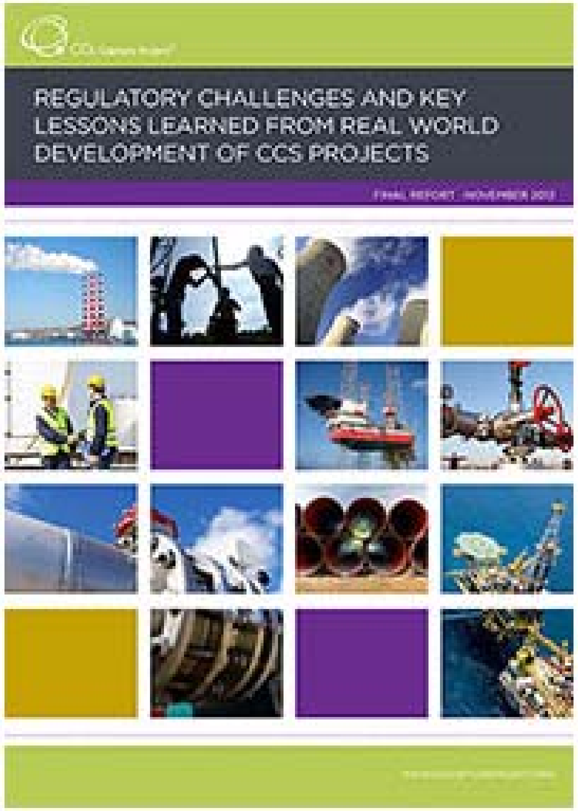
CCP3 Policy & Incentives Program

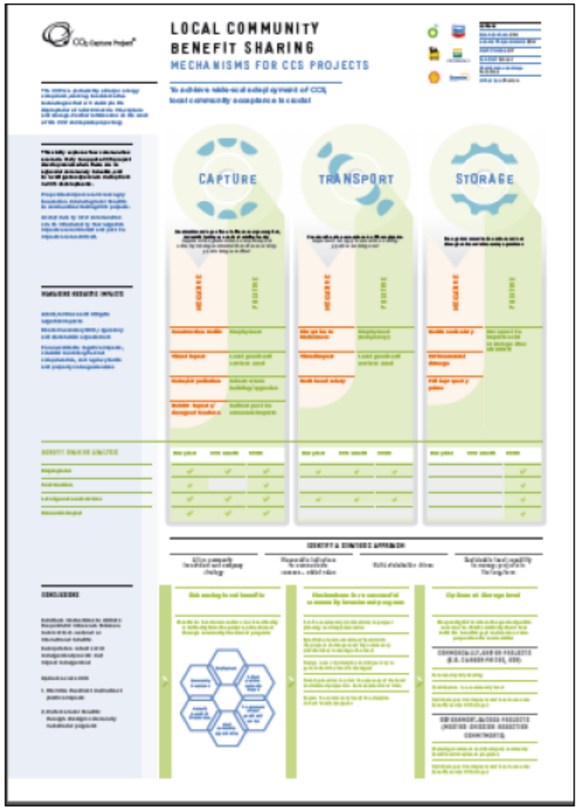
Program Objective: Inform the development of legal and policy frameworks through

- 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**





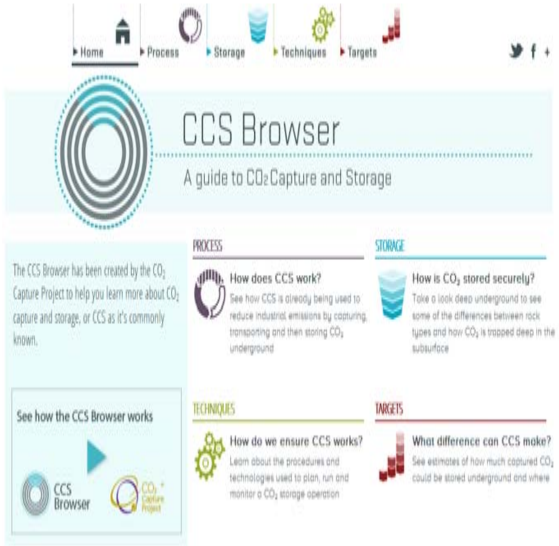
CCP3 Communications

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



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participating organizations

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CCP Conclusions

- Post combustion capture technologies have seen some recent improvements, but post-combustion amines remain the technology with the best economics currently
- 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

Acknowledging...

Our teams:

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Pulse Brands

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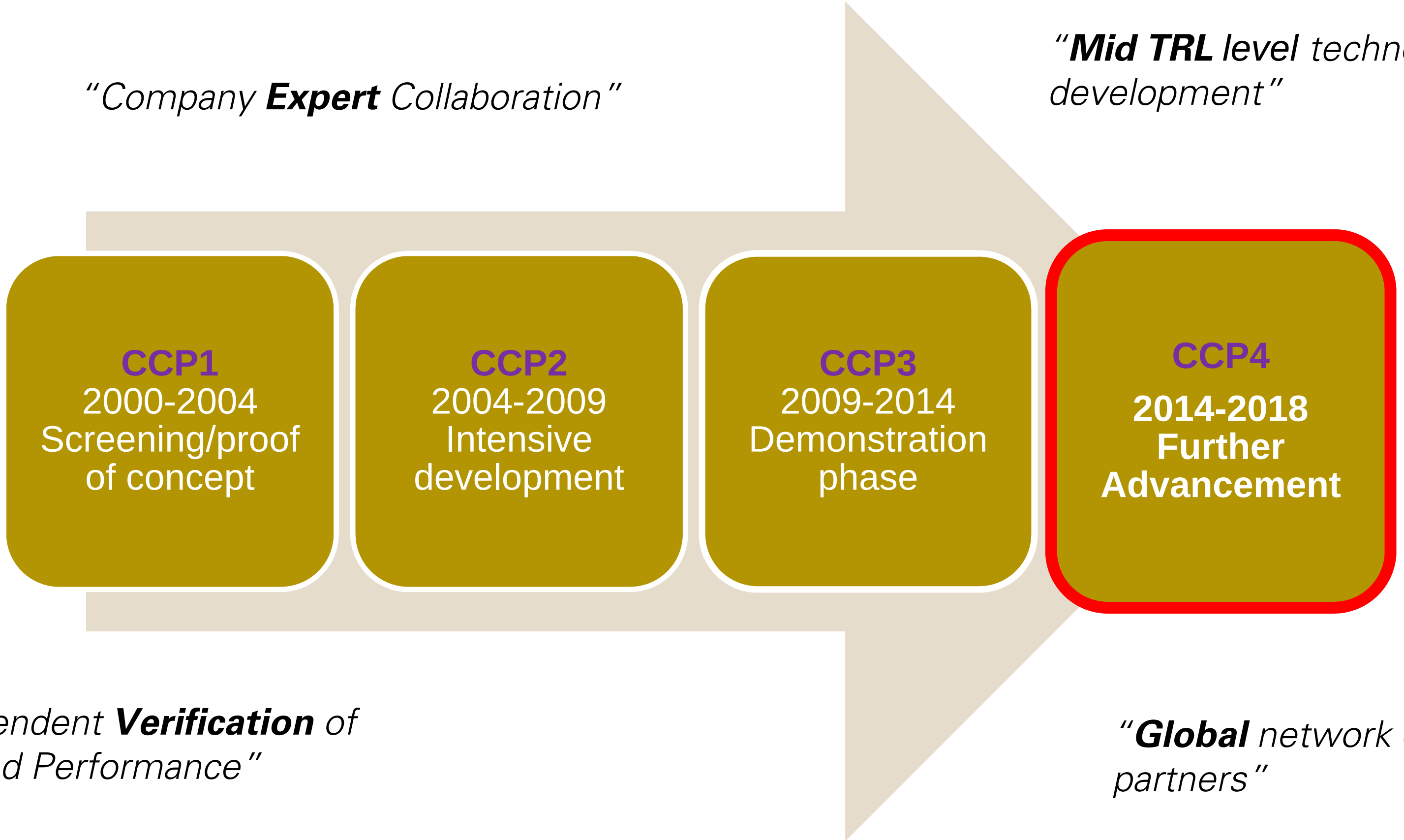
CCP4 "*Advancing CCS technology deployment and knowledge for the oil and gas industry*"

*"Project **Delivery** Focus"*

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

*"Company **Expert** Collaboration"*

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



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

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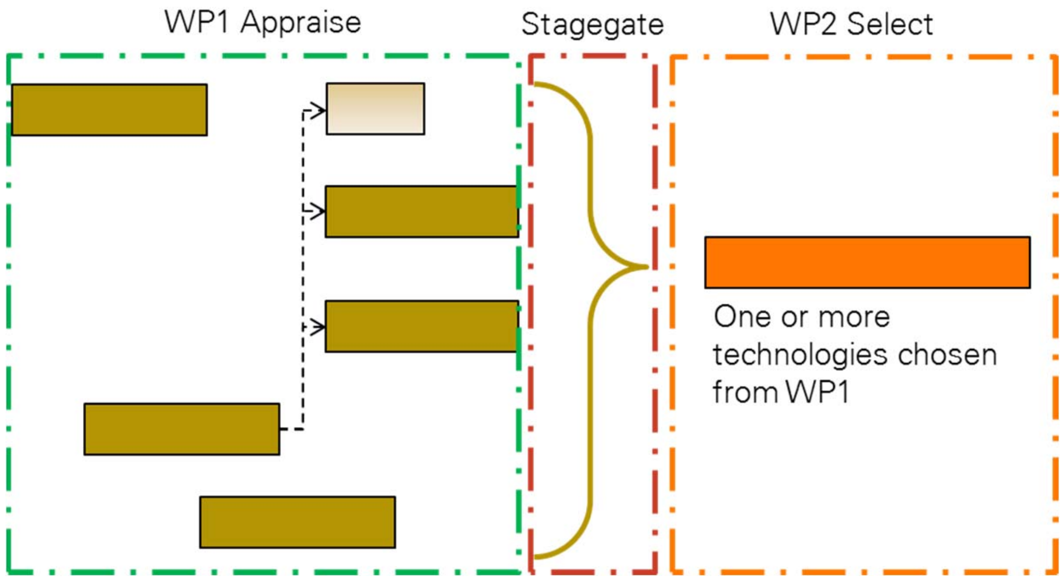
Step-out Novel Capture Technologies Assessment

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

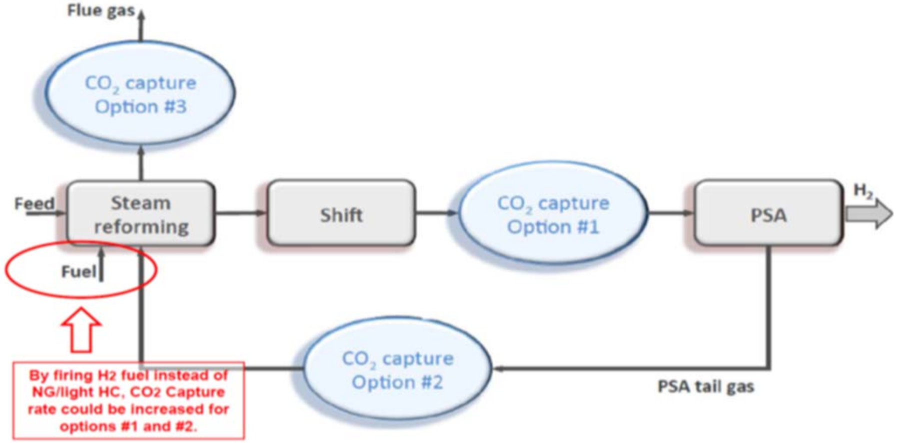


Image courtesy of Amec Foster Wheeler

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

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Well-Sealing Experiment at Mont Terri

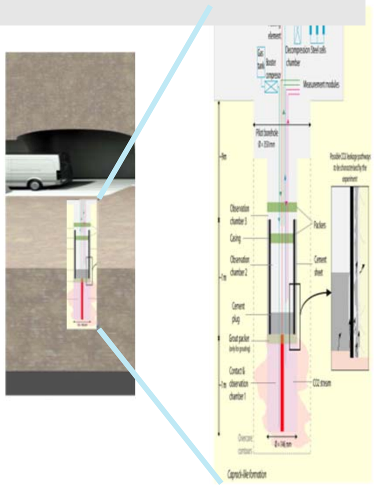
Study Purpose:

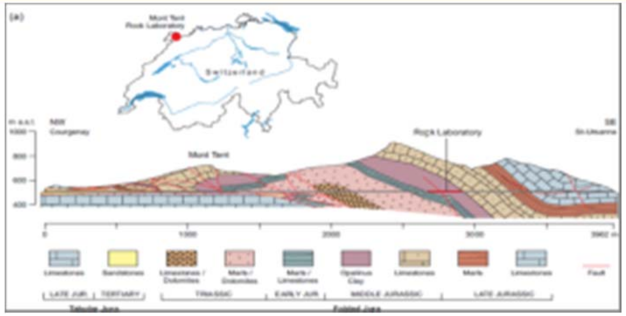
- Determine ability to intervene in difficult to mitigate, small aperture CO_2 leaks in annular space or cement sheath using novel materials

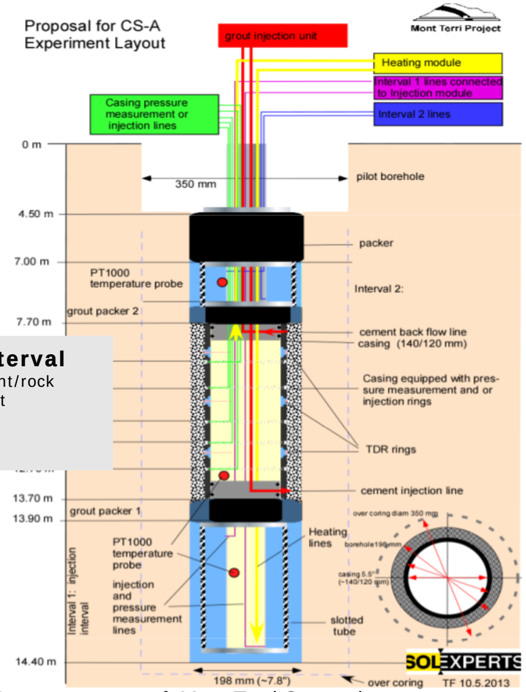
Study Approach:

- 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.

Image courtesy of Mont Terri Consortium

CCP4 participating organizations

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.

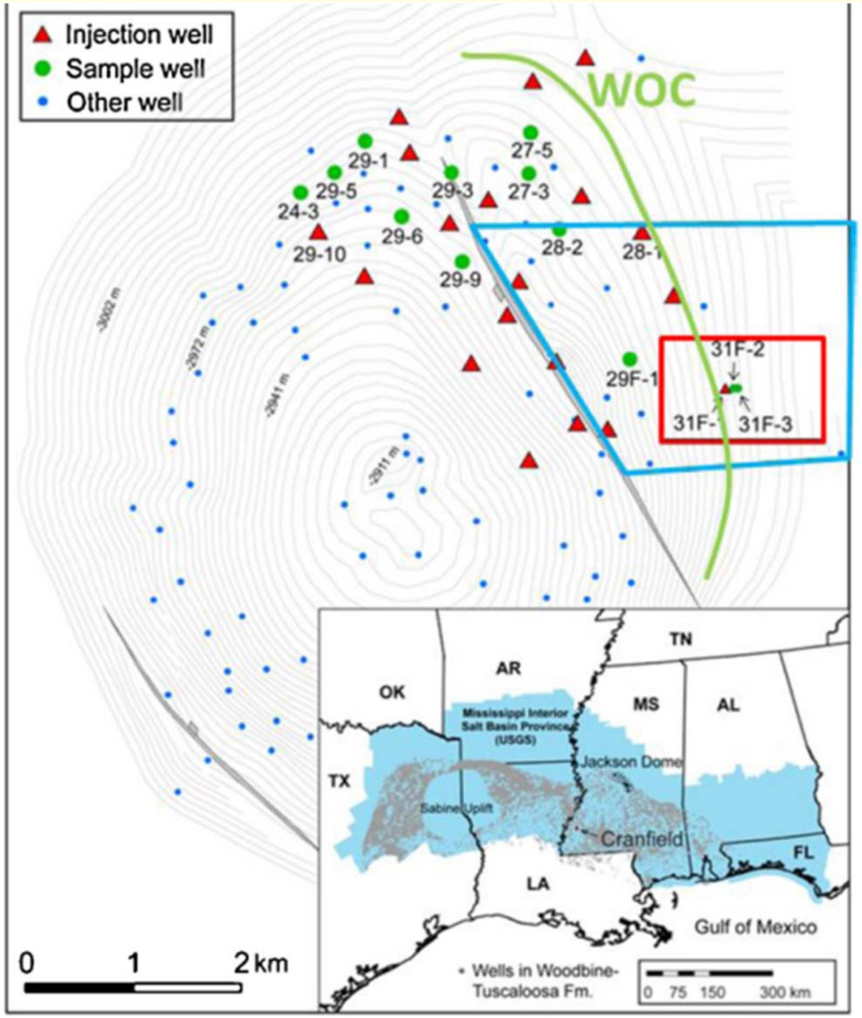


Image courtesy of UT-BEG

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

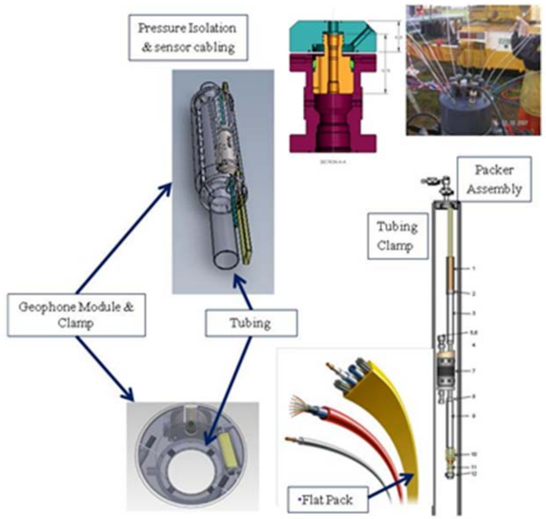


Image courtesy of LBNL

Questions?