Core Carbon Storage and Monitoring Research (CCSMR)

Field Testing of Emerging Technologies Task 4: CMC Containment and Monitoring Institute (CaMI)

Project Number ESD14-095

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National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

Coauthors/Collaborators

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Acknowledgement:

Mark Piercy - Schlumberger

Mark Woitt – RPS Engineering

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Benefit to the Program

- Program goals being addressed:
  - Develop and validate technologies to ensure 99 percent storage permanence.
  - Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness
- Project benefits:
  - Deployment and testing of new monitoring technologies and methodologies.
  - Broader learnings from leveraged international research opportunities
  - Rapid transfer of knowledge to domestic programs

Monitoring Technology: Supporting the SubTER Program

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Wellbore Integrity and Drilling Technologies

- Improved well construction materials and techniques
- Autonomous completions for well integrity modeling
- New diagnostics for wellbore integrity
- Remediation tools and technologies
- Fit-for-purpose drilling and completion tools (e.g. anticipative drilling, centralizers, monitoring)
- HT/HP well constr. & completion technologies

Subsurface Stress & Induced Seismicity

- State of Stress (measurement and manipulation)
- Induced seismicity (measurement and manipulation)
- Relate Stress and IS to Permeability
- Applied Risk Analysis to Assess Impact of Subsurface Manipulation

Permeability Manipulation & Fluid Control

- Manipulating Physicochemical Fluid-Rock Interactions
- Manipulating Flow Paths to Enhance/Restrict Fluid Flow
- Characterizing Fracture Dynamics and Fluid Flow
- Novel Stimulation Technologies

New Subsurface Signals

- New Sensing Approaches
- Integration of Multi-Scale, Multi-Type Data
- Adaptive Control Processes
- Diagnostic Signatures and Critical Thresholds

Energy Field Observatories

Fit For Purpose Simulation Capabilities

Project Overview: Goals and Objectives

- The Core Carbon Storage and Monitoring Research Program (CCSMR) aims to advance emergent monitoring and field operations technologies that can be used in commercial carbon storage projects. This effort aligns with program goals:
  - Improve estimates of storage capacity and sweep efficiency
  - Develop new monitoring tools and technologies to achieve 99% storage confirmation
- Success criteria is if we are able to advance the technology readiness level (TRL) of targeted technologies from a level of TRL 3 – 5 up to 6 – 7 through leveraged field testing opportunities.

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Advanced Monitoring Technology: Seismic

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- Issue: CO_2 storage requires long term repeated monitoring
  - Active source seismic is an important monitoring tool, and we would like to have data collected repeatedly for monitoring (i.e. semi-permanent), but…
  - Marine seismic is expensive, with high fixed cost (few ‘small’ tests)
  - Land seismic has unique difficulties (surface variability and access)
  - Permanent seismic sensors are expensive for the large numbers (spatial sampling) needed
  - Permanent seismic sources are not standard or generally available

- R&D Approach
  - DAS (distributed acoustic sensing) on fiber optic cables: a promising technology to improve long term repeatable monitoring with permanent sensor installation and large spatial sampling
  - Permanent, remote-controlled source: provide continuous monitoring and ‘trigger’ for full 3D seismic acquisition

Advanced Monitoring Technology: CaMI Applications - EM

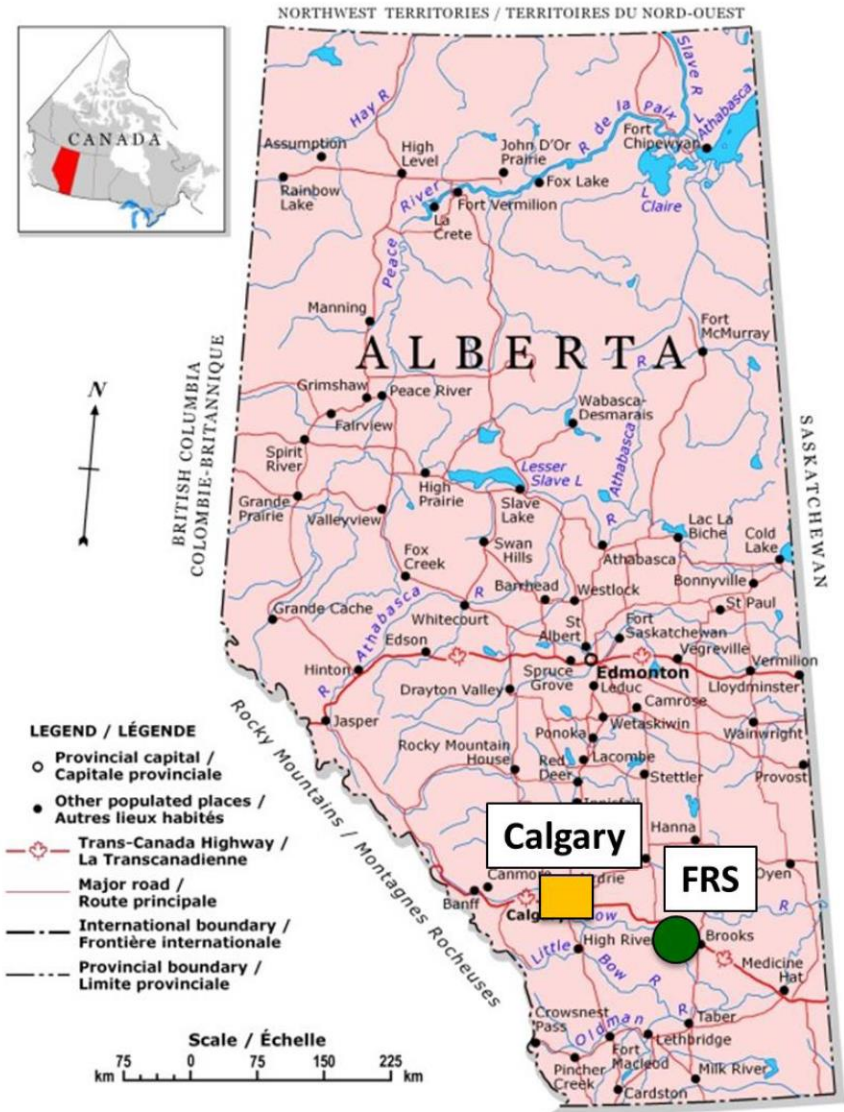
- Previous CO2 injection/storage pilots have focused on verifying storage integrity ("safe storage")
- Monitoring and characterizing potential unwanted migration ('leakage') has different needs than monitoring storage
- Example: Intermediate depth, secondary accumulation of CO_2 in gas phase – detection limit, mass quantification

- Issue:
  - Quantification of CO2 is improved with muti-physics measurements (e.g. Electromagnetic (EM) and Seismic)
- Opportunity:
  - Advance electrical/EM monitoring - access to fiberglass well and installed electrodes (borehole and surface)
- R&D approach:
  - Apply electrical and seismic monitoring methods and use joint-inversion to improve CO_2 saturation estimates
  - Initial Focus: High resolution EM and Seismic Crosswell Tomography

Technical Status

- Initial development of high frequency EM crosswell and surface-borehole instrumentation completed
- Full scale test expected to begin next week at LBNL
- Baseline surveys at CaMI planned for Oct 2016

Field Research Station (FRS) : Location



Land leased from Cenovus Energy

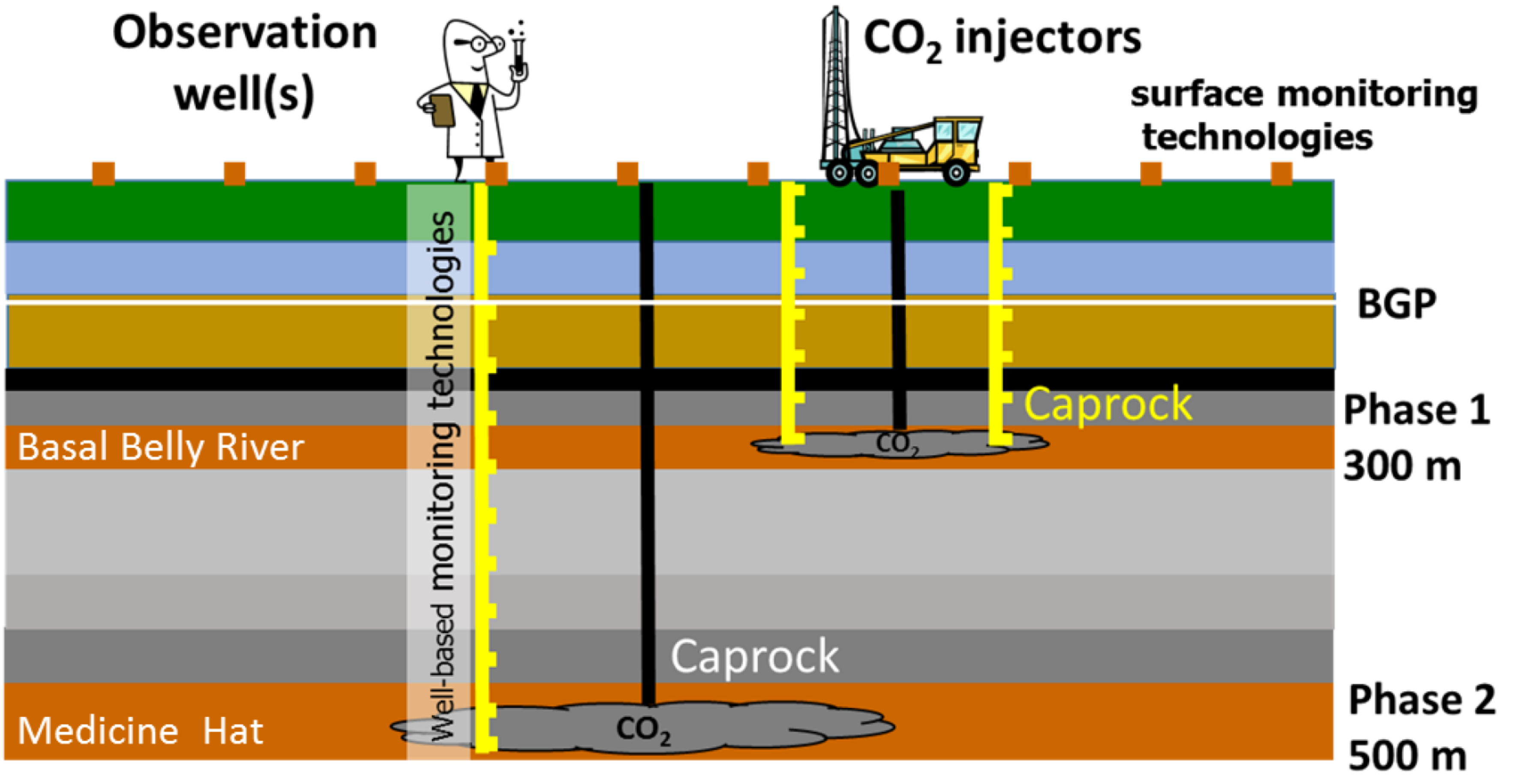
From Lawton, 2016

CaMI/UofC – Field Research Station (FRS)

- A world-leading site for development and demonstration of MMV technologies for fluid containment and conformance
- Undertake controlled CO_2 release at 300 m (Phase 1) & 500 m (Phase 2) depth; up to 1000 t/yr
- Determine CO_2 detection thresholds for different monitoring technologies
- Improve and develop monitoring technologies for tracking the CO_2 plume migration and for cap rock assessment
- Monitor gas migration at shallow to intermediate depths and impacts on intermediate depth groundwater (CO_2 and CH_4)
- Determine fate of CO_2 & CH_4 (trapping/dissolution)
- University & industry field training & research
- Integrating engineering and geoscience
- Public outreach & education

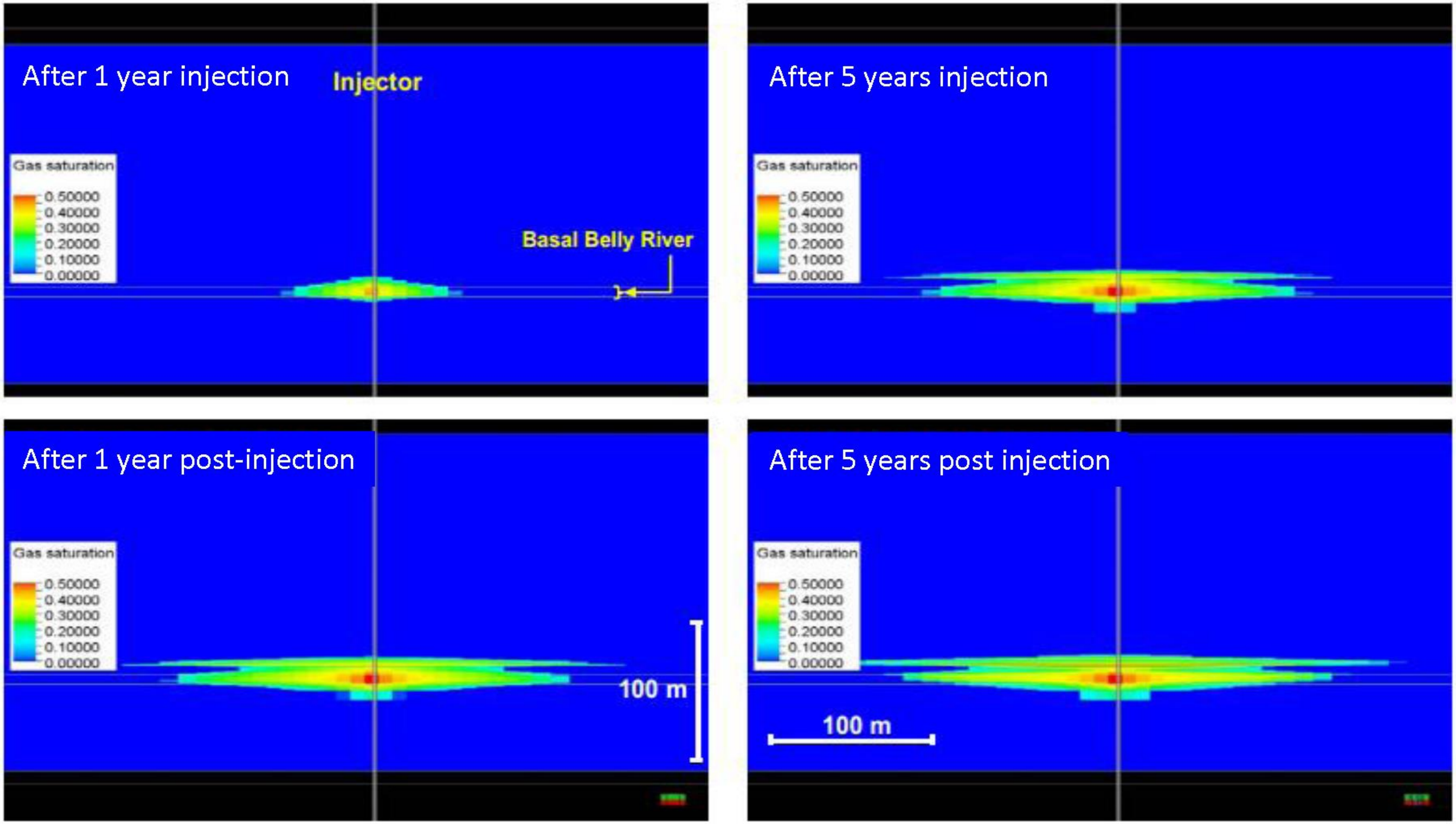
From Lawton, 2016

FRS schematic



From Lawton, 2016

FRS Phase 1 reservoir simulation



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FRS Phase 1 wells

LBNL/DOE at CaMI

- Applying Higher TRL Tools to Novel Experiment
  - Borehole instrument deployment
    - fiber optic cables
    - Integrated DTS – Heat Pulse cable
    - U-tube fluid sampling
    - Pressure-Temperature Gauge
  - Cross-well seismic surveys (LBNL)
- Advancing Lower TRL Tools
  - Cross-well electromagnetic surveys
  - *Surface-borehole electrical/EM surveys**
  - Surface-borehole electrical resistivity surveys
  - Surface helical fiber cable for DAS surface seismic
  - Borehole helical cable for crosswell DAS

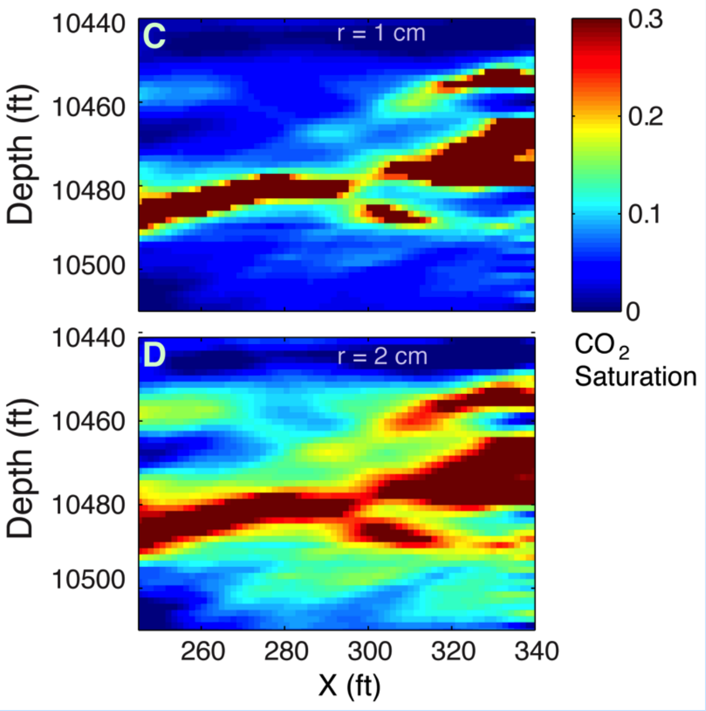
*New technology focused on CaMI, utilizing available fiberglass casing

Crosswell Seismic

Planned Survey Parameters:

- Sensor: Hydrophone array – 20 sensors at 5 m spacing
- Source: piezoelectric
- Source sweep: 300-2500 Hz
- Spatial sampling: 0.5 m

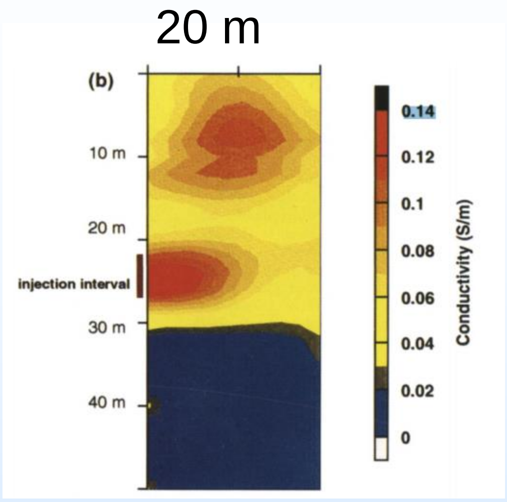
- Issue: seismic alone has uncertainty in CO2 saturation
- Should reduce uncertainty with conductivity (EM crosslwell)



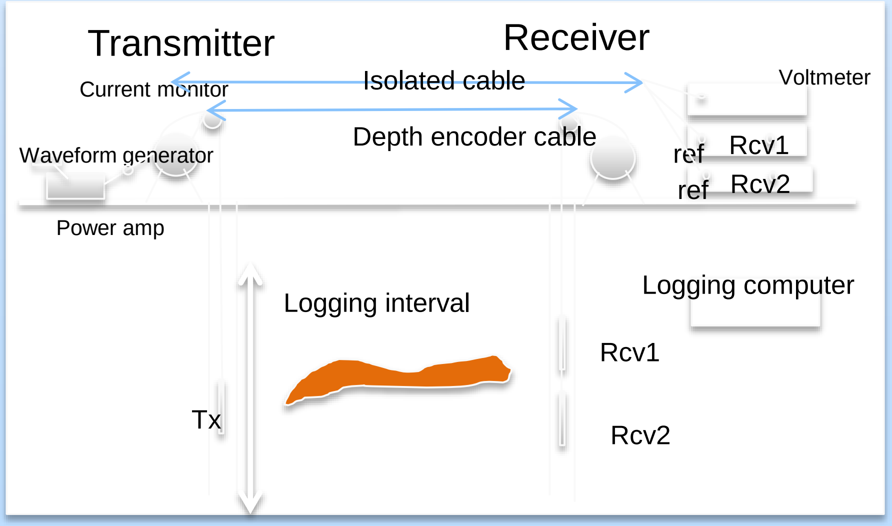
Example from Cranfield, Ajo-Franklin, et al, 2012

High Frequency Crosswell EM

- Moving prototype system to field operation ready
- Frequencies from 10 Hz to 20 kHz
- well spacing's from 20m to over 500m, and depths to 2km.
- Only one Fiberglass well available for CaMI Phase 1, so frequency is reduced (~200 Hz)
- Multi-level Sensor tool
- Obtain 2D resistivity map at depth



Example High Frequency EM Tomography (Wilt, et al, 1995)



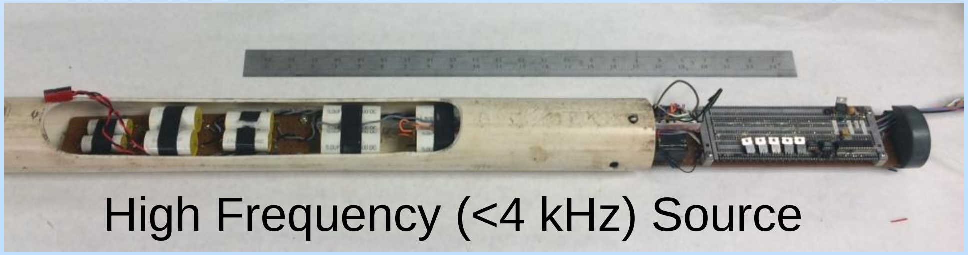
Crosswell EM Tools

Transmitter Source

- Size
  - Diameter 3.5” (8 cm)
  - Length ~12 ft (4 m)
  - Weight ~ 120 lbs (50 kg)
- Coil Make up
  - 2.5” Ferrite core 8 ft long
  - 1000 turns of wire on core
  - Tuning capacitors on internal circuit
- Frequency
  - 1- 4000 Hz
    - 1-500 Hz untuned,
    - Tuning 1, 1.5 2 and 4 khz. Selectable by software
- Dipole Moment
  - Maximum moment 1500 A-m^2

Sensors (1 -5 levels)

- Size 2-level (5 m spacing)
  - Diameter 2.5” (7 cm)
  - Length ~6 ft (2 m)
  - Weight ~ 30 lbs (12 kg)
- Coil Make up
  - 1” mu-metal core 1m long 8
  - 20,000 turns of wire on core
  - Tuning capacitors on internal circuit
- Frequency
  - 1- 10000 Hz; Flat 10-1000Hz
- Sensitivity
  - 0.1 V/nTesla
  - Noise estimated at 10^{-6} nT



High Frequency (<4 kHz) Source

Multi-level Sensor Coils

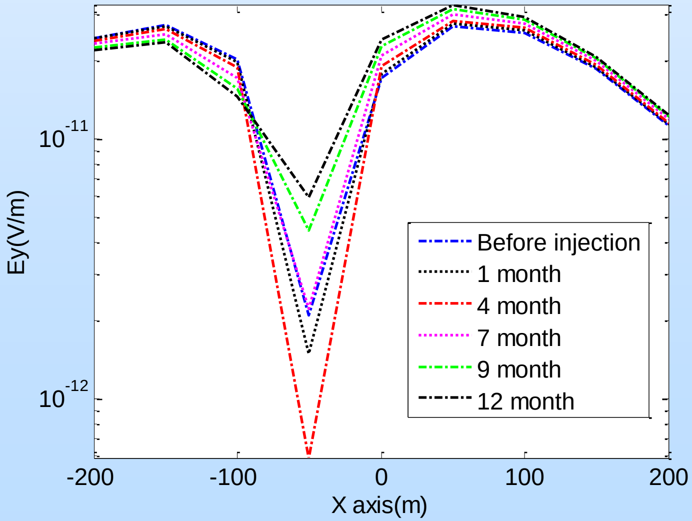
EM Surface to Borehole

- Crosswell EM limited when second monitoring well changed from fiberglass to steel casing: decided to add surface-borehole EM
- Preliminary numerical modeling (borehole-to-surface) indicated:
  - surface to borehole EM will provide good sensitivity to a CO_2 target of modest size at CAMI assuming CO_2 saturation of 20-30%.
  - optimal frequency of operation should be in the range of 500-2000Hz
- Preliminary measurement plans calls for a distribution of tangential transmitters of 500 Hz with borehole receivers covering a depth interval of 150-350m, with data recovery up to 2.5 kHz.

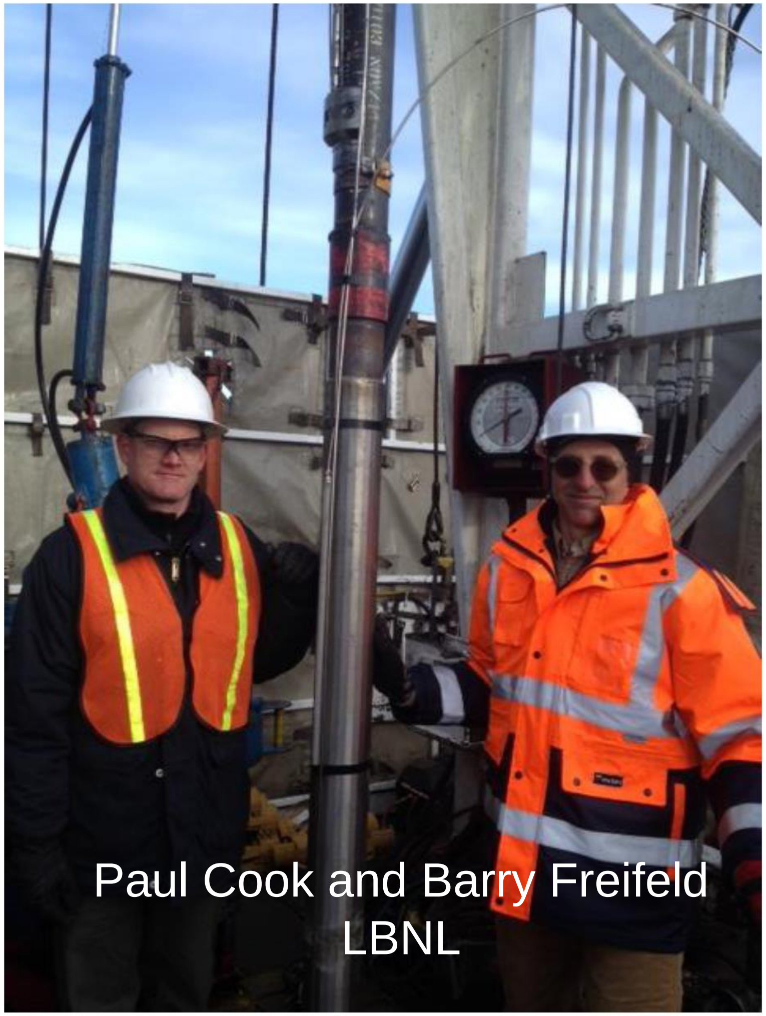
Borehole to Surface EM
Model (Evan Um, Mike Wilt)
Electric field amplitude (V/m)

Conclusion:

- Time-lapse changes due to CO2 injection observable
- Maximum change at intermediate time



LBNL Geochemical Fluid Sampling: U-Tube Behind Casing



Paul Cook and Barry Freifeld
LBNL

U-Tube Fluid Sampler
On Casing

From Lawton, 2016

Borehole Sensor Deployment

OBS Well #2
Cables for
Geophones and
Electrodes

Fiber from HWC
(Helical Wound
Cable)

Photos: Paul Cook

Trenched Surface Sensors (Seismic DAS and Electrodes)

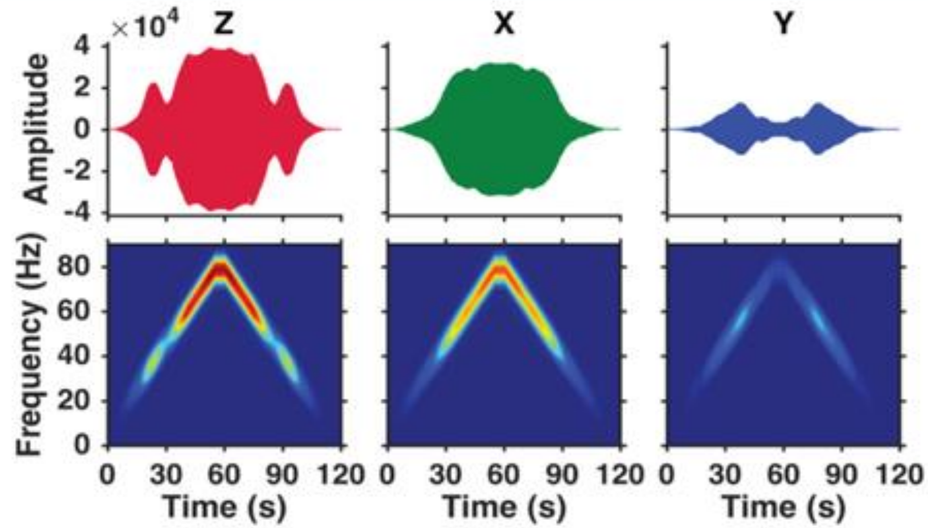
August 2016

Photos: Paul Cook

Trenched Surface Cable with HWC:
Helical Wound Cable:
angular sensitivity

HWC cable: 30-deg winding

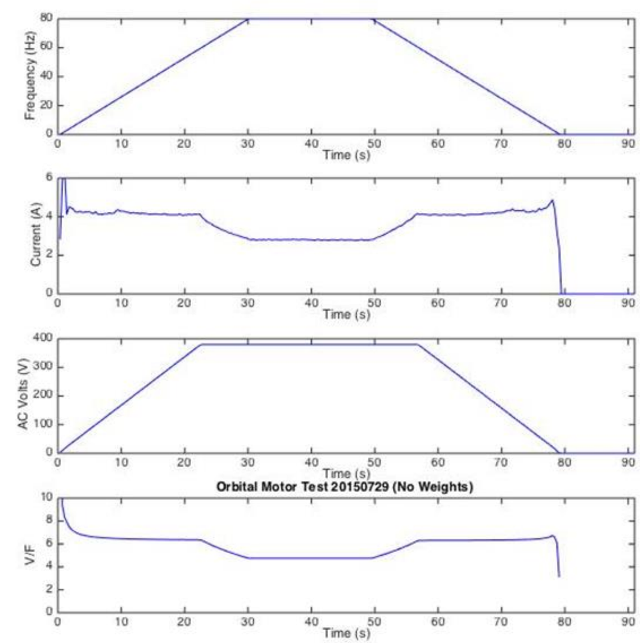
Surface Orbital Vibrator
Controlled AC Motor w/Eccentric Mass



Max Frequency 80 Hz, Force (@80Hz) 10 T-f
Phase stability is not maintained. Operate 2.5 hr/d

Force is adjustable

$F = m\omega^2 r$



Accomplishments to Date

- Collaboration with CaMI on monitoring program
- Preliminary EM Modeling
- Development of crosswell EM instrumentation (raise TRL level)
- Deployment of helical (and straight fiber) cable in observation wells – first time for helical in well!
- Deployment of U-Tube geochemical sampling system in observation wells
- Planning/design of crosswell EM and Seismic surveys

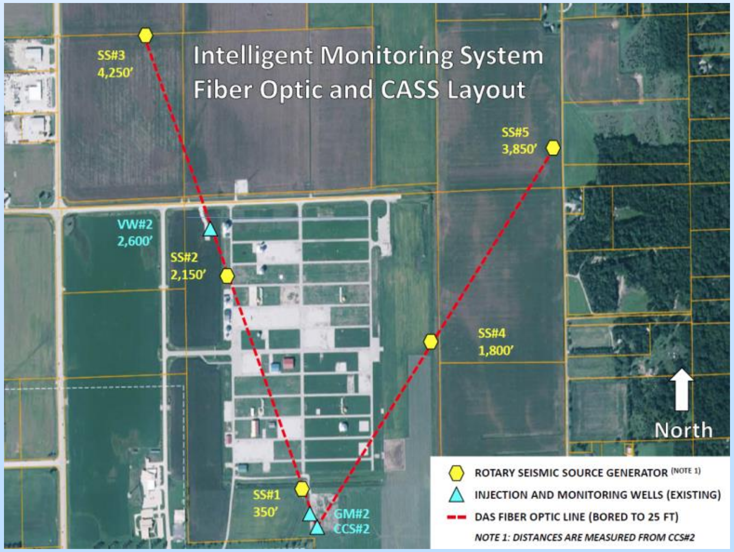
Synergy Opportunities

- – Deployment of fiber optic cables in the subsurface allows multiple measurements (Temperature, Acoustics, Chemistry)
- – Permanent sensor deployments with semi-permanent sources allows ‘continuous’ monitoring

Deep Controlled Source Electro-Magnetic Sensing: A Cost Effective, Long-Term Tool for Sequestration Monitoring - Multi Phase Technologies LLC - Douglas LaBrecque

Distributed Fiber Optic Arrays: Integrated Temperature and Seismic Sensing for Detection of CO_2 Flow, Leakage and Subsurface Distribution - Electric Power Research Institute Inc. - Robert Trautz

ADM Intelligent Monitoring System
Thursday, 4:35 PM : B. Freifeld



Summary

- Key Findings
  - CaMI fills an important need in storage R&D: intermediate depth, gas phase detection/monitoirng
  - LBNL/DOE is adding to a comprehensive monitoring program by applying high TRL tools and advancing lower TRL tools
  - Crosswell EM and seismic; U-Tube sampling; heat pulse monitoring; surface and borehole helical DAS;
- Lessons Learned
  - Plans need to be flexible while project is developing (e.g. change from 2 fiberglass casing to 1 +1 steel
- Future Plans
  - Acquire baseline data ~ Oct 2016
  - Begin injection
  - Monitor co2 plume

Acknowledgements

- Funding for LBNL was provided through the Carbon Storage Program, U.S. DOE, Assistant Secretary for Fossil Energy, Office of Clean Coal and Carbon Management, through the NETL, for the project “Core Carbon Storage and Monitoring Research” (CCSMR).
- Carbon Management Canada (CMC) Containment and Monitoring Institute (CaMI) Field Research Station (FRS)

Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart

- CMC CaMI Project Management: Don Lawton
- CMC CaMI monitoring lead: Don Lawton
- LBNL
  - co-PIs: Tom Daley and Barry Freifeld
  - Field Support, Installation and Instrumentation: Paul Cook
  - EM R&D: Mike Wilt

- Carbon Management Canada (CMC) organized the Containment and Monitoring Institute (CaMI) which is led by Don Lawton. Mark Piercy of Schlumberger provides in-field logistical support and management at the CaMI Field Research Station (FRS).

Gantt Chart

MILESTONE GANTT CHART

Milestone Reporting accompanies Quarterly report	Q1 FY16			Q2 FY16			Q3 FY16			Q4 FY16		
Subtask Description	**OCT**	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**
Task 1 Project Management and Planning												
Task 2 Otway Project			A*									B
Task 3 Aquistore Collaboration			C						D			
Task 4 Carbon Management Canada, FRS						E			F			

TASK 4. Carbon Management Canada FRS Collaboration

Milestone 4-1 (E)
Title: Integrated behind casing monitoring well design and installation plan
Planned Completion (Reporting) date: Q2 3/31/16 (4/30/2016)
Verification Method: Quarterly Progress report

Milestones 4-2 (F)
Title: Description of design and laboratory testing of borehole electro-magnetic (EM) source and multi-level borehole EM senor array for CO_2 monitoring. Planned Completion (Reporting) date: Q3 6/30/16 (7/31/2016) Note: delayed due to funding gap
Verification Method: Quarterly Progress report and supplement

Bibliography

- No Journal Publications, specific to CaMI, as of now