Fundamental Studies in Support of GEO-SEQ

LBNL’s Consolidated Sequestration Research Program (CSRP)
Project Number FWP ESD09-056

Tom Daley
Lawrence Berkeley National Laboratory

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Infrastructure for CCS
August 20-22, 2013
Presentation Outline

• Benefits and Goals of Fundamental Studies
• Technical Status
  – Petrophysical Relationships
  – Geochemical Processes
  – Monitoring Instrumentation
• Accomplishments and Summary
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.

• This research addresses these goals by supporting GEO-SEQ and GCS field studies using investigation of fundamental processes affecting storage and monitoring, including:
  • Petrophysical relationships
  • Geochemical processes
  • Development of monitoring technology and tools.
Benefit to the Program

Core R&D: MVA and Geologic Storage

• DOE and the carbon sequestration community will benefit from:
  – a close working relationship with numerous domestic and foreign industrial and academic teams
  – interactions with and assistance given to other regional projects
  – publications and presentations made available to all parties interested in removing barriers to commercial-scale geologic carbon sequestration.
Project Overview:

Goals

• Improve understanding of processes seen in field studies through use of laboratory scale work
  – petrophysical measurement
  – geochemical assessments.

• Develop field monitoring instrumentation
  • use demonstration scale pilots as R&D testing facilities while contributing to pilot goals
Project Overview:
Objectives

• LBNL’s Consolidated Sequestration Research Project (CSRP) aims to provide knowledge and lessons learned from performing distinct tasks with common overall goals:
  – Developing the knowledge base to enable commercialization of geologic carbon sequestration (GCS)
  – Identifying and removing barriers to sequestration through targeted research.
  – Understanding processes and developing improved tools
    • improve quantitative interpretation of monitoring data to ensure 99 percent storage permanence.
    • ensure containment effectiveness.
Project Overview: Objectives

• Success Criteria (FY13)
  – Demonstration of petrophysical measurements using a resonant bar system on reservoir and/or cap rock materials
  – Perform geochemical assessments for GCS reservoir rock types
  – Contribution of new and/or improved instrumentation for application to GCS
Technical Status

- Fundamental Studies began in FY13 by bringing together existing work to investigate monitoring technologies and fundamental geochemical and petrophysical processes that underpin GCS.
- The work was motivated by GEO-SEQ field projects, and their use as testing facilities to scale up from laboratory to field scale.
- Reorganization within CSRP for FY13

### FY12

**Task 1.0**: Project Management

**Task 2.0**: GEO-SEQ
- Otway
- In Salah
- **Fundamental Studies**
  - Petrophysics
  - Monitoring Instrumentation
  - Partitioning Tracers
- **Geochemical Assessment**
- Certification Framework

**Task 3.0**: Sim-SEQ

**Task 4.0**: Large-Scale Hydrological Impacts of CO₂ Geological Storage

**Task 5.0**: CO2SINK Collaboration

### FY 13

**Task1.0**: Management

**Task 2.0**: GEO-SEQ
- Otway
- In Salah
- CO2SINK
- Aquistore

**Task 3.0**: Fundamental Studies
- Petrophysics
- Geochemical Assessment
- Monitoring Instrumentation Development

**Task 4.0**: Simulation Studies
- Large-Scale Impacts
- Sim-SEQ
- CF CO₂-EOR simulation
- Stochastic Inversion
Petrophysical Relationships
PI: Seiji Nakagawa

• Goal: Improve understanding of relationships between measured data and desired information
• Focus on Seismic Velocity as a function of CO₂ Saturation
  – Changes in seismic velocity have provided excellent ‘maps’ of CO₂ distribution – but what is the true saturation?

Cranfield
Tuscaloossa
Reservoir

Pre Injection  Post Injection  Difference

CO₂ Plume

Ajo-Franklin, et al, 2013 IJGCC.
Utilize Modern Petrophysical Models: ‘Patchy’ Saturation

Analysis of Tuscaloosa D/E (Cranfield Reservoir)

What affects the seismic response calculation?

“Patch Size”, Frequency, pressure, temperature, brine properties, matrix properties (density, moduli of grains), clay percentage and clay properties, porosity, CO₂ property model, CH₄ property model

Variation within reservoir: 10470 ft core data predicts larger change than 10465’ core.

Ajo-Franklin, et al, 2013 IJGCC.
Develop Instruments

Split Hopkins Resonant Bar

- **Laboratory seismic measurements with concurrent x-ray CT imaging**
  - LBNL’s x-ray CT scanner (GE Lightspeed 16).
- **In Situ P/T conditions**

Nakagawa and Kneafsey, LBNL
Petrophysics
Measurement of Fundamental Properties

CT Scan Image of CO\(_2\) in Core

Results:
• Estimate ~ 300 m/s change in velocity
• Measure seismic velocity vs CO\(_2\) saturation
  – Estimate patch size (~1 cm) limited by core size (~2 cm)
• Strong structural anisotropy of the rock

Velocities vs Saturation

Nakagawa, et al, 2013, Geophysical Prospecting
New Results: Intact vs Fractured Reservoir

- Understand how fractures in reservoir influences distribution of CO$_2$, and impacts the seismic velocity and attenuation
- Initial result – difference in attenuation

Nakagawa and Kneafsey, LBNL
Geochemical Assessment

PI: Kevin Knauss, LBNL

• Goals
  – Conduct experiments to understand geochemistry of CO$_2$ sequestration processes spanning injection, neutralization and long-term phases of storage
    • GCS site core samples span expected rock types
    • Evaluate the fate and longevity of released metals into aqueous solutions
  – Develop simplified screening tests that industry can use to evaluate site suitability and predicted performance
Geochemical Assessment

- “real” brine experiments
  - Synthetic brine matched to field composition
    - Frio C- and Blue sands, Cranfield, Weyburn
- Role of O₂ fugacity
  - Metal release
  - Fate upon neutralization
- Screening protocol
  - Develop simplified test
  - Criteria specific to rock type

![Graphs showing pH, Fe, Co, and Ni concentrations over time at 123 °C and 0.7 M NaCl.](image)
New Results
Weyburn Reservoir

- Completed an experiment using the solid material from the Midale Marly Unit of the Weyburn reservoir rock
- Three different stages over 99 days
  - Stage 1: 28 days – Reaction of Marly dolostone with the CO$_2$-saturated fluid
  - Stage 2: the reacting fluid was diluted by injection of a CO$_2$-free NaCl pH = 2.7.
  - Monitored for 49 days
  - Stage 3: 20 days - introduce acidified (pH = 1.7) brine containing elevated levels of metals (Cr, Ni, Zn and Pb)
Monitoring Instrumentation Development

• LBNL’s participation in pilot tests via GEO-SEQ led to development and application of novel monitoring tools for GCS
  – U-tube fluid sampling
  – Continuous Seismic Monitoring (CASSM)
  – Borehole shear-wave source (orbital vibrator)
  – Fiber Optic Monitoring
    • Heat-Pulse Thermal Monitoring
    • Distributed Acoustic Sensing

Custom Packer Design for Monitoring
U-Tube Fluid Sampling
Examples from Otway Project

• Goal: Near continuous measurement of aqueous and gas geochemistry
• Value of U-tube sampling demonstrated at Frio, Otway, Cranfield, and elsewhere


CO$_2$ and CH$_4$ (top); SF$_6$ and wellhead pressure (bottom): Well 31F2
CASSM
Continuous Active-Source Seismic Monitoring

- Goal: Precision In-situ monitoring of seismic properties
  - Current: crosswell geometry
  - Planned: surface – borehole

- Motivation:
  - Monitoring of In-Situ Processes
    - Reservoir dynamics and petrophysics
      - Velocity/Saturation (fluid effects)
      - Coupled flow/seismic data/models
CASSM Applications

Continuous Seismic Monitoring

Day, 2006

![Piezo-Tube Seismic Source](image)

**Velocity-Pore Pressure @ 3.2km**

- Frio-II; Daley, et al, 2008
- Cranfield 2010; Daley, LBNL
Borehole Seismic Source: Orbital Vibrator

- Unique ability to generate P- and S-Waves in 100-1000 Hz band
- Higher power than piezoelectric
Fiber Optic Technology

- Distributed Temperature Sensing

DTS Temperatur-Profile Ktzi 200

Ketzn: Temperature anomaly Ktzi200

Ketzn Data Courtesy Jan Henninges, GFZ
Distributed Acoustic Sensing (DAS)

- Goal: Robust, less expensive, continuous monitoring
- DAS acquisition allows seismic monitoring with fiber optic
  - Sensitivity less than standard geophone, but
  - Spatial sampling and ease of deployment much greater
DAS Data from Ketzin CO2 Pilot
Fiber deployed behind casing (but not cemented at all depths)

Analysis courtesy GFZ
Aquistore Project: DAS
Vertical Seismic Profile

- Behind Casing, cemented, 3 km, explosive shot

Raw data, May 2013
Accomplishments to Date

– Petrophysics
  • Development of Resonant Bar with CT Scanning
  • Seismic theory tested with measurements at field scale (wavelength) on GCS reservoir core
  • Improved estimates of in-situ CO$_2$ saturation

– Geochemical Processes
  • Analysis of core samples spanning expected rock types
  • Emphasize metal mobilization and impact of O$_2$ fugacity
  • Develop simplified screening tests that industry can use to evaluate site suitability and predicted performance

– Instrumentation Development
  • Improved fluid sampling (U-tube)
  • Improved seismic monitoring (CASSM, Orbital Vibrator)
  • Development/Testing of Fiber Optic Technology
Summary

– Key Findings
  • Seismic estimates of saturation need petrophysical measurements and constraints
  • Need simplified screening tests for geochemical effects
  • Fiber optic monitoring has notable potential

– Lessons Learned
  • Fundamental studies are needed and best motivated by field applications

– Future Plans
  • Further analysis and development of
    – petrophysical relationship between seismic velocity and CO₂ saturation
    – Geochemical effects on GCS on reservoir rocks
    – Monitoring technology and tools
Appendix

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

- Fundamental Studies is a subtask of LBNL’s Consolidated Sequestration Research Program lead by Barry Freifeld
- Closely linked to GEO-SEQ also lead by Barry Freifeld
- Fundamental Studies has three tasks with principal investigators (PI) and scientific task leads
  - PI: Tom Daley
    - Petrophysical Relationships PI: Tom Daley
      - Task Leads: Seiji Nakagawa, Tim Kneafsey, Jonathan Ajo-Franklin
    - Geochemical Assessment PI: Kevin Knauss
    - Monitoring Instrumentation PI: Tom Daley
      - Task Leads: Barry Freifeld, Jonathan Ajo-Franklin

<table>
<thead>
<tr>
<th>Fundamental Studies</th>
<th>Title</th>
<th>Role in Task/Subtask</th>
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<tbody>
<tr>
<td>T. Daley</td>
<td>PI and Research Scientist</td>
<td>Lead scientist for fundamental studies</td>
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<tr>
<td>S. Nakagawa</td>
<td>Research Scientist</td>
<td>Scientist working on rock mechanics using resonant bar apparatus</td>
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<tr>
<td>J. Ajo-Franklin</td>
<td>Research Scientist</td>
<td>Geophysicist supporting laboratory studies and field seismic data processing</td>
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<tr>
<td>M. Robertson</td>
<td>Project Scientist</td>
<td>Coordinator of field projects and oversees geophysical measurement facility support</td>
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<tr>
<td>P. Cook</td>
<td>Scientific Engineering Associate</td>
<td>Mechanical engineering and project support</td>
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<tr>
<td>K.G. Knauss</td>
<td>PI and Research Scientist</td>
<td>Geochemist supervising laboratory studies</td>
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<tr>
<td>J.P. Icenhower</td>
<td>Research Scientist</td>
<td>Geochemist working on CO2 laboratory studies</td>
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<tr>
<td>G.D. Saldi</td>
<td>Postdoc</td>
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<tr>
<td>N.J. Pester</td>
<td>Postdoc</td>
<td>Geochemist working on CO2 laboratory studies</td>
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The Fundamental Studies Task began in FY13 with reorganization of LBNL’s CSRP. FY13 milestones shown.

Current planning for FY14 is in progress.

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<th>Subtask Description</th>
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<th>Q2 FY13</th>
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<td>Subtask 3.1 Petrophysics</td>
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Bibliography (FY13)


Geochemical Assessment

• **Accomplishments**
  – Completed all phases for Cranfield Reservoir
  – clean sand, dirty sand and altered sand
  – Participated in international calibration exercise
    • Develop CO₂ sequestration research experimental protocols

• **Plans**
  – Complete carbonate case experiments
  – Complete “real” brines experiments
  – Design simplified tests specific to rock type