At the Forefront of Energy Innovation, Discovery & Collaboration
Optimizing accuracy of determinations of CO$_2$ storage capacity and permanence, and designing more efficient CO$_2$ storage operations: An example from the Rock Springs Uplift, Wyoming

DOE Project DE-FE0009202

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University of Wyoming Carbon Management Institute
Presentation Outline

- Benefits of this program to DOE’s CCUS goals
- Objectives and goals of the study
- Technical overview: integrated approach to characterizing and assessing uncertainty relative to geologic heterogeneity
- Conclusions
Benefit to the Program

Creation and refinement of tools and methodologies to reduce storage site uncertainties

- Development of a new seismic workflow analysis
- Large-scale tectonic processes characterization and their impacts on the confining potential of sealing strata; seal bypass systems
- Identification of the impact of well completion techniques and in-situ testing on formation brine chemistries: introduced anthropogenic uncertainty
- Reservoir brine analysis methodologies for fluid containment, evolution, and reactions

Identification of essential steps for reducing uncertainty and maximizing storage and containment

- Identify primary lithologic character of best seals; diagenetic enhancement of seals
- Perform in-situ well testing for reservoir conditions, fracture gradient, etc.
- Utilization of stacked reservoir analysis for reducing sealing uncertainties, and defining best injection targets
- Application of sensitivity analysis for highest uncertainties, periods of high risk
- Development of well design scenarios that minimize scaling risks
- Identified critical research gaps
Benefit to the Program (continued)

Testing and validation of tools and steps on RSU site

- Identified primary and secondary seals
- Implementation of new calculations for CO$_2$-water-rock systems, high-pressure mercury injection, interfacial tension, and wettability data that are realistic for the study site
- Development of new, conservative CO$_2$ column height (plume) estimates for structural traps/dipping strata-lowest risk volume
- Refined storage estimates of Wyoming’s Paleozoic reservoirs based on new conclusions
- Extrapolate geologic heterogeneity to other potential storage sites
The objectives for the project are as follows:

1) Reduce uncertainty in estimates of CO$_2$ storage capacity at the Rock Springs Uplift;

2) Evaluate and ensure CO$_2$ storage permanence at the study site by defining sealing potential and character, specifically with regards to geological heterogeneity; and

3) Improve the efficiency of potential storage operations by designing an optimal CO$_2$ injection/brine production strategy.

**Working towards overall goal of reducing uncertainty to the lowest possible levels.**
Uncertainty Reduction Progression for Determining Optimal CO₂ Storage Capacity/Dynamics/Permanence

1. CO₂ Storage Permanence Evaluations
2. CO₂ Storage Permanence Evaluation
3. Confining Layer Characterization (capillary properties, strength & continuity)
4. Insitu/Laboratory Injectivity
5. Reservoir Heterogeneity
6. Data Acquisition (3-D seismic survey & stratigraphic test well)
7. Simulations with Regional Data (structural/stratigraphic frameworks; with homogeneous reservoir domain)
8. Pressure Management
9. CO₂ Storage Capacity of Reservoirs (Performance Assessments)
Technical Overview
Stratigraphic Section of the Well
Idealized lithologic seal chart, sealing lithology from this study are highlighted in red.

Figure modified from IEAGHG, March 2009.
Seal Bypass Systems

Method: Reflection continuity analysis of seismic data correlated with regional geologic history: Curvature, Coherency, Amplitude, Gradients, Spectrogram Analysis
Seal Bypass Systems

Curvature Analysis: Interpreting Fold, Joint, and Fracture Systems in Horizon Slices

Preliminary Analysis

1. Triassic seal

Interpreted Slices

2. Madison reservoir
Dominant joint/fracture systems formed during the Laramide – related to flexure of sediments on the flank of the RSU
Coherency Analysis: Interpreting Anomalous (non-lateral) Features in Horizon Slices

Seal Bypass Systems

Triassic Seal

Permian Seal

Mississippian Reservoir
Coherency Analysis: Interpreting Anomalous (non-lateral) Features in Vertical Sections
Seal Bypass System: Heterogeneity Analysis

Spectrogram Analysis: 1-D to 2-D Transformation for Lithological Heterogeneity
Theory of Spectrogram Analysis

- A SPECTROGRAM of a well log is a visual representation of the spectrum of spatial wavenumbers (wavelengths) as they vary with depth. The algorithmic instrument used for spectrogram calculation is direct Fourier transform. Computationally, the Fourier transforms are done continuously at every depth sample with a set of log data in parametrically defined windows. The transformed results obtained for different size of spatial windows are stacked together and normalized. This technique allows to bypass the Heisenberg's uncertainty principle, and to provide the balanced resolution (both in depth and wavenumber). Depending on the geological task, the balancing factor can be set to improve either depth or wavelength resolution.
Regional petrophysical evaluation of targeted seals
Petrographic correlations

Regional core

Study site
Depositional and diagenetic history has increased sealing potential
Mineral saturation indices for reactive minerals: calcite, dolomite and anhydrite

- Calcite dissolves in both reservoirs
- Continued injection leads to dolomite dissolution
- Anhydrite precipitates in both reservoirs as a response to excess calcium from calcite dissolution

Overall, predicted porosity increase, though scaling response in produced fluids
Evaluation of fluid confinement

Reservoir fluids are isotopically distinguishable

- Weber Sandstone has radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ values (0.7505 to 0.7424) indicative of interaction with older detrital grains
- The $\delta^{13}\text{C}_{\text{CH}_4}$ of the Weber Sandstone are relatively light (-22.0 and -21.0 ‰) relative to Madison samples (-46.0 and -41.0 ‰)
- Both isotopic compositions are indicative of thermogenic methane.
Evaluation of seal failure

Two main mechanical failures are recognized to occur during CO₂ injection, tensile fracturing and shear slip of pre-existing fracturing (Rohmer and Seyedi, 2010). Geochemical conceptual models have been developed to represent these failures scenarios.

In the result of seal failure it is estimated that:
• pH increases from 4.5 to >7
• Calcite, and some dolomite will precipitate
• Calcite precipitation may increase the original calcite volume in the fracture by 200%, suggesting that fractures would fill relatively quickly

These estimations are consistent with observations made on the RSU core; calcite filled fractures in the core suggest high pCO₂ fluids have moved through the system and calcite has dropped out.
Optimized water production engineering
Potential for scaling at all depths
Well sizing, scale modeling and corrosion analysis

Well Inputs
- Wellhead data
- Bottom-hole data
- Mass production rate
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Sensitivity analysis

Diagram showing various factors and their relationships with variables such as density, CO2 concentration, column height, CO2 column probability, contact angle, sealing capacity, and interfacial tension.
IFT of seals in a multi-phase fluid regime introduces the most uncertainty relative to containment.
Irregular shape of the CO₂ plume because of the reservoir heterogeneity/local structure. Quaternary fault interferes with the plume.
Column height calculations; reassessing the CO₂-H₂O-Brine system
Verification of the integrity of the confining layers - injected CO$_2$ is trapped below the upper most portion of the Madison Limestone and the Amsden Formation.

FEHM Simulation Results for the Madison Limestone, RSU
Homogeneous Porosity/Permeability Rock/Fluid Volume
Porosity 10%, Permeability 10 md, 50 Mt/50 years

Property color key

CO$_2$ Saturation

0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0.0

CO$_2$ Injection Well

Weber Sandstone
Amsden Formation
Madison Limestone

450 ft
400'

Primary: Mm1mt0md10phi50y_co2.co2.faces

XY units: US feet
Z units: feet
Z exag: 1.95313

1000'
1.6 mile plume radius at the study site before plume risks approaching column height max (450’). Identified as red circle.

An estimated total of 25MT of CO$_2$ could be conservatively stored at the study site.

Additional storage on the RSU could be implemented, with careful consideration of overlap to decrease the risk of seal failure.
Accomplishments to Date

- Identification of analysis crucial to determining seal assessments relative to CO₂ injection capacities; identified the seal variables with the highest uncertainties and primary and secondary seals
- Development of new, conservative CO₂ column height estimates for dipping Paleozoic strata in southwest Wyoming; relevant to all structural traps
- Development of methodologies for utilizing limited subsurface data and stacked reservoirs for reducing regional sealing uncertainties
- Development of well design scenarios that minimizes scaling risks at the site
- Refined storage estimates of Wyoming’s Paleozoic reservoirs relative to new findings
Research gaps

- Realistic column height calculations: lack of IFT data on sealing lithologies
- Lack of comprehensive, pressurized-deep brine geochemical/isotopic lab
- Unified pressure mitigation techniques for pressure control
Conclusions

• The study site in southwest Wyoming can retain injection volumes with 99% certainty relative to sealing strata data
  – Multiple primary and sealing strata with minimal permeability and characterized lithologies (i.e. diagenetic effects, mechanical properties, etc.)
  – Non-communicable reservoir fluid systems (isotopes, geochemistry, fluid migration histories, in-situ pressure tests)
  – Geologically old seal bypass systems up-dip, less risk

• Refined injection and storage model estimates for the study site relative to the lowest possible uncertainties and risk suggest a holding capacity of 25MT

• Development of integrated production/injection strategies has optimized storage capabilities at the study site

• Highest risk introduced during injection phase: robust reservoir pressure management plan significantly reduces the risk of seal failure
Summary
Ensuring storage permanence; transferrable conclusions for reducing the uncertainties of sealing systems

• Stacked reservoir systems ideal for sites with limited data
• Characterization of geologic heterogeneity, geochemistry, and paragenetic history is necessary for lateral seal evaluations
• Seismic derivation of seal bypass systems coupled with geologic interpretation will identify primary structural risks
• Reservoir fluid analysis will identify interconnectivity of stacked reservoirs
• Accurate IFT analysis is critical for true holding capacity estimates
• Storage in dipping strata will impact column height estimates
• Geologic heterogeneity assessments are critical for accurate storage estimates and injected fluid responses
• Highest/uncertainty risk introduced during injection phase
  – A robust reservoir pressure management plan will greatly reduce the risk of leakage
Acknowledgements

This project is funded in part by the U.S. Department of Energy’s National Energy Technology Laboratory (Project DE-FE0009202), and the authors would like to thank Project Manager Karen Kluger for her guidance and support.
Appendix

- Organization chart
- Gantt chart
- Bibliography
Organization Chart

DOE

UW/CMI
PI - J. McLaughlin

Task 1: Project Management and Planning
S. Dahl

Task 2: Geophysical assessment of the Rock Springs Uplift based on seismic analyses
Y. Ganshin

Task 3: Geological and mechanical characterization of confining lithologies using laboratory measurements
J. McLaughlin

Task 4: Characterize formation fluids to determine hydraulic isolation of the target formation
S. Quillenan

Task 5: Simulations to evaluate seal integrity, injection rate, and pressure management
Z. Jiao

Task 6: Simulations of formation brine production to assess wellbore scaling/well integrity and surface treatment
R. Bentley

Schlumberger: Cooperator
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<td>1.3 Reporting</td>
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* Denotes milestone
Red bar denotes completed tasks/subtasks
Yellow bar denotes continuing progress through December 31, 2013
Green bar denotes tasks/subtasks began earlier than scheduled and continuing progress of those tasks.
Bibliography

21st Annual Geological Society of America – Denver, CO – October 2013
Abstracts presented:
• An Integrative Strategy to Increase the Economic Feasibility of CO2 sequestration: Mining Brines from Saline Storage Reservoirs
• Geochemical evolution of deep saline brines from Paleozoic reservoirs in southwest Wyoming; implications for potential CO2 sequestration

Thirteenth Annual Carbon Capture, Utilization and Storage Conference – Pittsburgh, PA – April 2014
Abstracts presented:
• Geologic Controls on Sealing Capacity; Defining Heterogeneity Relative to Long-Term CO₂ Storage Potential in Wyoming
• The Geochemical Characterization of Reservoir Fluids: Defining the Fluid and Rock System and Identifying Changes to Baseline Conditions Due to Well Completion
• Geologic and Stratigraphic Characteristics of Multiple Stacked Sealing Formations at the Rock Springs Uplift, Wyoming