DEVELOPING AND VALIDATING PRESSURE MANAGEMENT AND PLUME CONTROL STRATEGIES IN THE WILLISTON BASIN THROUGH A BRINE EXTRACTION AND STORAGE TEST (BEST) (FE0026160)

Carbon Management Project Review Meeting
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This material is based on work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Award No. DE-FE0026160.
Objectives:

- Validate efficacy of brine extraction as a means of active reservoir management (ARM)
  - Applications that can enable the implementation and improve the operability of industrial carbon capture and storage (CCS) projects.
  - Manage injection performance and formation pressure.
  - Model, predict, monitor, and validate movement of fluids and pressure.
  - Provide data set to enable evaluation and design of ARM applications at compatible CCS sites.
  - Improve use and efficiency of geologic CO₂ storage resources.

- Implement and operate a brine treatment technology development and test bed facility
  - Enable development of brine treatment technologies capable of treating high-total dissolved solids (TDS) brines associated with geologic CO₂ storage target.

Project Details:

- Phase II project: $22,573,604
  - DOE share: $18,103,044
  - Cost share: $4,470,560
    - Schlumberger: $3,760,280
    - CMG: $710,280

- Period of Performance:
  July 2016 – May 2023
SUCCESS CRITERIA

Validate efficacy of ARM applications to industrial CO$_2$ storage projects (through a field test).

Demonstrate the steps necessary to design and implement ARM for industrial CCS projects.

Enable development of water treatment technologies with application to treating high-TDS brines associated with geologic CO$_2$ storage targets.
GEOLOGIC CO$_2$ STORAGE
CONSIDERATIONS FOR INDUSTRIAL PROJECTS

• Buoyant fluid
• Large volumes = large footprint
• Access to pore space
  – Leasing, unitization/amalgamation, trespass
• Compliance with regulatory and incentive programs
• Assuring permanence for incentives or credits
  – Conformance and storage efficiency

Because of a host of technical, social, regulatory, environmental, and economic factors, brine disposal tends to be more accessible and generally quicker, easier, and less costly to implement compared to dedicated CO$_2$ storage.
TWO COMPLEMENTARY COMPONENTS

ARM Test
- Mitigate pressure interference between neighboring CCS projects.
- Improved storage efficiency / increase capacity of a permitted CO₂ storage site.
- Reduce stress on sealing formation.
- Geosteer injected fluids (injection and extraction of brine).
- Divert pressure from potential leakage pathways
- Reduce area of review (AOR)
- Improve injectivity, capacity, and storage efficiency.
- Accelerated pressure dissipation after injection.

Brine Treatment Test Bed
- Alternate source of water
- Reduced disposal volumes
- Salable products for beneficial use

Illustration modified from Lawrence Livermore National Laboratory https://str.llnl.gov/Dec10/aines.html
THE SITE
ACCOMPLISHMENTS TO DATE

Designed and Implemented ARM Field Test (COMPLETE)
• Brine extraction well proximal to two saltwater injection wells.
• Deep water injection well to reinject extracted water (proxy for ARM at a CCS site).
• Acquired reservoir and well performance data over multimonth brine injection/extraction tests.
• Confirmed that a measurable pressure and injection response was achieved using brine extraction.

Geophysical Simulation and Modeling (in progress)
• Calibrate and validate performance of ARM proxy models by integrating monitoring data.
• Evaluated efficacy of ARM strategies for varying operating and deployment scenarios relevant to geologic CO₂ storage.
• Evaluating revised injection/extraction scenarios with increased scaling to better represent potential commercial CO₂ injection scenarios.

Machine Learning (ML) Analysis (COMPLETE)
• Developed a model based on ML to simulate reservoir pressure based on injection and extraction rates.
• Applied the ML model to predict reservoir pressure at various scenarios of operation.
• Validated results against field data.
RAW DATA PROCESSING FOR SIMULATION INPUT

Recorded SCADA Data

Processed Daily Pressure/Rate
Red line illustrates the history match results.

- Real-world sites introduce significant complexities to the data set. We observed regular well shut-ins and opening of the wells as well as changing fluid properties throughout the experimental duration.

- We were able to achieve a usable history match to explore predictive cases.
**CO₂ INJECTION SIMULATION**

- Use history-matched model to test initial CO₂ injection scenarios to evaluate how production wells can increase total storage capacity of CO₂ through ARM.
  - Used preliminary modeling to ascertain the scale of impact that brine extraction can have on CCS performance with relation to positioning of extraction wells relative to injection wells and injection/extraction rates.
  - Results inform a matrix of simulation cases to explore the impact of well position, injection/extraction rate, and various operational and development strategies relative to ARM applications to CCS.

- Influential parameters to bottomhole pressure responses:
  - Permeability near extraction and injection wells.
  - Offset injection wells outside the study area have an impact.
  - Appropriate permeability and volume modifiers and boundary conditions for subsequent case studies.
• Injection rate equivalent of 1 MMt/yr.
  – Injected at reservoir conditions.
• Extraction ratios (volume extracted to volume injected) of 1:1, 3:4, 1:2, and 1:4.
• Simulated two injection wells with one extraction well.
  – Offset distance of extraction well for half-mile increments (0.5 miles to 2.5 miles).
  – Extraction well shuts-in when breakthrough is observed.
• 20 cases were evaluated.
CO₂ INJECTION RESULTS
A HYPOTHETICAL CCS SCENARIO

- The drop of the liquid production rate (blue line) represents the point where injected gas broke through to the extraction well.
  - Extraction well was shut in.
- At the breakthrough point (~10 years), the difference in injected gas is ~2.7 MMt.
  - ~15% volume increase compared to the nonextraction base case.
- At end of simulation (25 yr), difference grows to ~7.8 MMt.
  - ~20% volume increase compared to the nonextraction base case.

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CO₂ INJECTION RESULTS
A HYPOTHETICAL CCS SCENARIO – RESERVOIR PRESSURE DECREASE

![Graph showing average reservoir pressure over time with different extraction ratios and cases.](image-url)
CO₂ INJECTION RESULTS

GEOSTEERING – OFFSET WELLS
CO$_2$ INJECTION RESULTS

GEOSTEERING – TWO WELLS, PROGRESSIVE
CO₂ INJECTION RESULTS
IMPROVED DISSOLUTION – WATER INJECTION ABOVE CO₂

Volume of mobile CO₂ reduced.
CO₂ INJECTION RESULTS
IMPROVED DISSOLUTION – WATER INJECTION ABOVE CO₂
FUTURE MODELING
DO TRENDS SCALE?

• Increase size of modeled region
  – 36 mi² to 900 mi²

• Increase injection volumes
  – 1–10 MMt/yr

• More complex injection and extraction arrangements
  – Multiple patterns to be investigated

• Maintain geologic heterogeneity from original site
MOTIVATION FOR USING ML

• Complex system of injection and extraction.
  – Dynamic and variable rates, pressures, and fluid densities observed throughout the course of the field tests.
  – Inherent noisiness of field data is challenging to evaluate using traditional techniques.
• Power of ML methods in data mining and prediction.
  – Helps with automation and provides savings in data processing.
• Predicted reservoir pressure could be used to monitor reservoir response to brine/CO$_2$ injection.
XGBOOST MODEL PERFORMED WELL IN PREDICTING RESERVOIR PRESSURE

Modeling Evaluation

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• XGBoost model performed very well with both the training and test data sets.

Variable Importance Plot

• Reservoir pressure was more greatly influenced by injection than extraction.
The contour plot was created to model reservoir pressure response to different scenarios of injection and extraction operations.

- Higher injections always correspond to higher pressure.
  - E.g., pressure can increase ~200 psi when injection rate increased from 2000 to 5000 bbl/day.
- Under some conditions, extraction could decrease reservoir pressure (<100 psi).
BOREHOLE-TO-SURFACE ELECTROMAGNETIC SURVEY (BSEM) EXPERIMENT IN MONITORING

- Geophysical method of subsurface investigation using a borehole-deployed electrical source.
  - Receivers deployed at surface to create a 3D map of resistivity within a target reservoir(s).

- Baseline survey conducted in September 2018.
  - Repeat survey could not be conducted.

- Analysis of the baseline survey was able to resolve salinity variations resulting from brine injection into the Inyan Kara Formation.
  - Subsequent evaluation suggests this method could be effective for CO₂ injection monitoring.
  - Results to be published at GHGT-16.
NORTH DAKOTA BRINE TREATMENT FACILITY – WATFORD CITY, NORTH DAKOTA
BRINE TREATMENT TECHNOLOGY SELECTION AND TESTING

• Over 30 different technologies and providers of brine treatment/management technologies were solicited and reviewed for applicability to high-TDS brines.

• Technologies were reviewed and ranked according to selection criteria, including 1) project benefits (reduction of injection costs, etc.), 2) technology strengths (scientific soundness, readiness level), and 3) organizational strengths (IP, capability for further development, etc.).

• Four technologies were identified and recommended for pilot-scale demonstration.

• An inaugural demonstration of a mechanical vapor recompression (MVR) technology provided benchmark testing for comparison.
ACCOMPLISHMENTS TO DATE
BRINE TREATMENT DEVELOPMENT FACILITY

• Four additional demonstrations to occur in late 2021 and 2022.
  – Demonstrations include a second extended steady-state evaluation of the MVR technology and three other innovative technologies.
    ♦ MVR technology to acquire data under extended steady-state operation (August 2021) – equipment failure
    ♦ Internally heated supercritical water desalination technology (September 2021)
    ♦ Thermally assisted membrane distillation technology (October 2021)
    ♦ Zeolite-derived membrane technology (pending)
Hypothesis – Coinjection of dissolved CO\(_2\) into saltwater disposal (SWD) wells could accommodate meaningful quantities of geologic CO\(_2\) storage with a significantly reduced risk profile that is easier to permit that could enable a distributed CO\(_2\) storage model.

- Screening-level techno-economic feasibility assessment shows potential for implementation.
- A significantly reduced risk profile of carbonated brine storage can be achieved versus supercritical CO\(_2\) injection.
- Uncertain regulatory environment is a significant barrier to implementation.
- Reporting in progress.
CHALLENGES

SITE OPERATIONS

Stock Tank Repairs

Stock tank cracked
Stock tank repaired

Free Water Knockout (FWKO) Issues

Water dump and pop-off valves damaged

Hot Weather

Electric motor upgrade

Water Treatment Facility Corrosion

High-salinity waters accelerate corrosive processes
Adaptability.

Committed partners, leverage stakeholder experience.

Maintain an up-to-date risk register, mitigate risks where prudent, incorporate flexibility where possible, robust designs and contingency plans, be adaptive as conditions change.

Large field tests have elevated risks and dynamic conditions.

Risk, cost, and objectives must be managed together.

Field data should be expected to be complex; traditional strategies for data management and interpretation may not be sufficient.
PROJECT SUMMARY

• Key Findings:
  – The field trials showed injection is a greater contributor to reservoir pressure than extraction, but extraction can reduce reservoir pressure in certain scenarios.
  – Modeling suggests a 20% increase in storage potential could be achieved with comparable volumetric injection and extraction rates.
    ♦ Multiple variables of impact – optimization is key.
    ♦ Additional simulation to pursue scalability is being evaluated.
  – Experimental brine treatment technologies exist that are capable of treating the saline waters that are likely to be associated with CO$_2$ storage sites applying ARM. Additional technology development is needed to enable and produce commercialized solutions.

• Next Steps:
  – Evaluation of varying ARM implementation and optimization steps for CO$_2$ injection guided by preliminary results using the history-matched model.
  – Complete field trials and analysis of brine treatment technologies.
  – Project reporting and knowledge sharing.
APPENDIX
**BENEFITS TO THE PROGRAM**

This project is expected to result in the development of engineering strategies/approaches to quantitatively effect changes in differential formation pressure and to monitor, predict, and manage differential pressure plume movement in the subsurface for future CO$_2$ saline storage projects. Additionally, the brine treatment technology evaluation is expected to provide valuable information on the ability to produce water for beneficial use. The results derived from implementation of the project will provide a significant contribution to the U.S. Department of Energy’s (DOE’s) Carbon Storage Program goals. Specifically, this project will support **Goals 1 and 2** by validating technologies that will improve reservoir storage efficiency, ensure containment effectiveness, and/or ensure storage permanence by controlling injected fluid plumes in a representative CO$_2$ storage target. Geologic characterization of the target horizons will provide fundamental data to improve storage coefficients related to the respective depositional environments investigated, directly contributing to **Goal 3**. In addition, this project will support **Goal 4** by producing information that will be useful for inclusion in DOE best practices manuals.
ORGANIZATION CHART

Senior Oversight
Ed Steadman
John Harju
Charles Gorecki

Project Advisors
Jim Sorensen
Wes Peck
Larry Pekot

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Energy & Environmental Research Center (EERC)
Principal Investigator (PI)
John Hamling
Assistant PI
Ryan Klapperich

Host Site Operator
Nuverra Environmental Solutions

Project Partners
U.S. Department of Energy
Nuverra Environmental Solutions
Schlumberger Carbon Services
Computer Modelling Group Ltd.

Cost-Share Providers
Schlumberger Carbon Services
Computer Modelling Group Ltd.

Task 1
Project Management, Planning, and Reporting
Lead
John Hamling

Task 2
ARM Site Preparation
Lead
Lonny Jacobson

Task 3
Test Bed Site Preparation
Lead
Lonny Jacobson

Task 4
ARM Operations
Lead
Ryan Klapperich

Task 5
Test Bed Treatment Operations
Lead
Marc Kurz

Task 6
ARM Data Processing/Project Closeout
Lead
Lonny Jacobson

Task 7
Test Bed Data Processing/Project Closeout
Lead
Marc Kurz

Critical Challenges. Practical Solutions.
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Note: The contract modification for Phase II was fully executed on September 9, 2016.

Deliverables

- Project Kickoff Meeting
- Water Treatment Test Bed Fully Operational
- Water Treatment Test Bed Decommissioning/Disposition

Milestones (M)

- Project Kickoff Meeting
- Water Stage 1 of Experimental Scenario
- Water Collection of Operational Data
- Water Stage 2 of Experimental Scenario
- BSEM Time-Lapse Sensitivity Study Complete
- Completion of Water Treatment Technology Demonstration
- Water Treatment Test Bed Decommissioning/Disposition Complete
BIBLIOGRAPHY


• Hamling, J.A., Klapperich, R.J., Jiang, T., Ge, J., and Bosshart, N.W., 2018, Field implementation plan (FIP) finalized—developing and validating pressure management and plume control strategies in the Williston Basin through a brine extraction and storage test (BEST): Phase II Task 2 Deliverable D2 for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FE0026160, Grand Forks, North Dakota, Energy & Environmental Research Center, December.


