Frio Brine Pilot: Lessons Learned and Questions Restated

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Frio Brine Pilot: Lessons Learned and Questions Restated

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Abstract

An important product of this study is recommendations to the next generation of developers of geologic CO\textsubscript{2} injection pilot projects. We highlight the value of interactive modeling before and during project development. Numerical simulation of flow strongly guided site selection, well design, and tool selection, and was key in designing a successful project. The two-well design was effective in reaching project goals. We directly detected CO\textsubscript{2} breakthrough at the observation well, sampled formation waters as CO\textsubscript{2} interacted with rock and brine, and recovered tracers to quantify CO\textsubscript{2} saturations and CO\textsubscript{2} dissolution. We used two well hydrologic approaches for evaluating multi-phase flow parameters and cross-well EM and seismic imaging. The observation well provided access during injection for logging CO\textsubscript{2} saturation and “ground truthing” indirect geophysical methods for monitoring. Research team integration is critical but time and labor intensive and required vigorous e-mail communication, phone conferences, in-person meetings, and field coordination. Effective data exchange within the research team was challenging. Engineering designs and the experimental time-lines had to be redone to reduce conflicts between optimal conditions for each instrument, risk of failure, and cost. Redesign eliminated tools with low probability of success or those that could not be effectively implemented under experimental conditions, and substitute tools that would accomplish the required tasks. Even if cost was not an issue, it is impossible to create optimal conditions for each instrument in a single test; compromises must be made, and success is dependent on making thoughtful compromises.

Principle experimental results

(1) Field detection of a small volume of CO\textsubscript{2} using
   - U-Tube sampler and in-line gas analysis
   - Field geochemistry (pH, alkalinity, metals)
   - Stable isotopic signature
   - Introduced tracers
   - Neutron wireline log
   - VSP
   - Cross well seismic
   - Casedhole, cross-well EM
(2) Good match between modeled and observed CO\textsubscript{2} distribution
(3) Post injection retention by “two phase trapping” of CO\textsubscript{2} limits migration

Recommendations and lessons learned

(1) Numerical modeling strongly guided site selection, well design, and tool selection, and was key in designing a successful project.
(2) Two-well design was effective in sampling a representative radius of the plume.
(3) Research team integration is critical but time and labor intensive
(4) Groundwater monitoring using a standard contaminated –site approach is effective in improving public acceptance
(5) Interference between tests was significant and is an area where improvement of tools should be considered.
Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Lessons Learned and Questions Restated
Frio Brine Pilot

Susan D. Hovorka

May 2-5, 2005, Hilton Alexandria Mark Center, Alexandria Virginia
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Modeling for proposal, during design, and to assess results

Year

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Quarter

Activities

- Complete Phase I Feasibility Study
- GEO-SEQ - organize research team
- Optimal site selection study
- Propose field study
- Site characterization - existing data
- Predictive modeling/Refine experiment
- Modify experiment design
- Model refinement
- NEPA permit preparation
- Injection permit preparation
- Modeling to support permits
- Site preparation, workover
- New injection well drilled
- Basin line data collected
- Predictive modeling with improved data
- Injection
- Post-injection measurements
- Calibration of models
- Closure

1-25 TOUGH2 model sets, Christine Doughty, LBNL
Simple Characterization for Proposal

Modeling used to select well spacing, unit thickness, and amount of CO₂ needed.
Will CO2 arrive?
Experimental design interaction with geologic uncertainties

2/2/03
How Modeling and Monitoring Demonstrate Permanence

Residual gas saturation of 5%

• Modeling has identified variables which appear to control CO$_2$ injection and post injection migration.

• Measurements made over a short time frame and small distance confirm the correct value for these variables.

• Better conceptualized and calibrated models will now be used to develop larger scale longer time frame injections.

Residual gas saturation of 30%

TOUGH2 simulations
C. Doughty LBNL
Predicted Saturation for History Match – Sensitivity to Residual Saturation

Case 1: $Sl_r=0.30; Sgr=0.05$

Case 2: $Sl_r$ varies, ~0.10, $Sgr$ varies, ~0.25

TOUGH2 model

![Graph showing gas saturation over time for different cases.](Image)
Modeled Long-term Fate
30 years based on observed post-injection saturation

Minimal Phase trapping

Predicted significant phase trapping
Define Clear and Achievable Goals

*Project Goal: Early success in a high-permeability, high-volume sandstone representative of a broad area that is an ultimate target for large-volume sequestration.*

- Demonstrate that CO₂ can be injected into a brine formation without adverse health, safety, or environmental effects
- Determine the subsurface distribution of injected CO₂ using diverse monitoring technologies
- Demonstrate validity of conceptual and numerical models
- Develop experience necessary for success of large-scale CO₂ injection experiments
  - Does not say assure storage of CO₂ for long periods of time, or measure distribution with high precision, or not leak, or do it at low cost.
Usefulness of a two well-design

Spatial, temporal information on concentration, chemistry, cross well techniques
Small is Beautiful

- Closely spaced measurements in time and space
- Emphasis on post-injection period
- High science, low risk
Predicted Saturation Distribution Through Time

Injection Well

Observation Well

Depth (m below top of C sand)

$S_g$

2 days
5 days
9 days
30 days
30 days Case 2

2 days
5 days
9 days
30 days
30 days Case 2
Observed Saturation Distribution Through Time-Injection Well

Borehole correction

- Borehole salinity: run high, run 5&6 fresh water
- 6 run: pressure gradient in borehole: water gradient
- Run 5&6: constant temperature

Sigma

- Elapsed days
- 0 4 10 66
Tool Selection Appropriate for Goals and Subsurface Environment

• No one tool is “Best”
  – Case specific
    • what is needed?
    • What is possible?

• Interference among tools
  – Geophysics vs. sampling
  – Surface monitoring vs. subsurface sampling
Determine the subsurface distribution of injected CO2 using diverse monitoring technologies.
Interference among tests

- Sampling and pressure measurements require wells (open to formation, those in plume produce CO$_2$, and acid fluid). Geophysics require boreholes, control of wellbore fluids and pressures.
- Surface monitoring should be sensitive to detect very small seepage (using tracers for example). Other operations such as surface activities and production of downhole fluids produce large perturbations.
Interference among tests
Invasion by kill fluids

RST 1 Oct 04
RST 2 Dec 04
RST 3 Feb 05
Not BH corr.

RST3 not borehole corrected
Groundwater Monitoring

- A standard test = high public assurance
- A low-cost test
- An effective test – reduced complexity, integrator of multiple leakage paths
More work needed: experiments not done at Frio

<table>
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<tr>
<th>Experiment</th>
<th>why not done?</th>
<th>Experiment</th>
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<tbody>
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<td>Large volume of CO₂</td>
<td>Risk, $</td>
<td>During experiment pressure monitoring in overlying brine aquifers, fresh aquifers</td>
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<td>Interaction with faults premature</td>
<td>Risk, complex, $</td>
<td>Ecosystem CO2 flux towers</td>
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<td>4-D survey</td>
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<td>Surface CO2 monitoring lasers</td>
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<td>Airborne/ satellite monitoring</td>
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<td>Microseismic array</td>
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<td>Exhaustive logging</td>
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<tr>
<td>WAG</td>
<td>Interference</td>
<td>Other edgy down hole monitoring</td>
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<tr>
<td>EOR</td>
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<td>Long-term monitoring</td>
<td>problematic, $</td>
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<td>Inject low, recover high</td>
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<td>Long-term geochemistry</td>
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Problematic = estimated to be unlikely to collect useful measurements at Frio scale, duration, site specific conditions
Interference = interferes with success of another experiment
$ = cost prohibitive in total project context. Might be used in a larger budget project