Deep and Near-Surface Monitoring for Enhanced CO₂ Storage Security*

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Abstract

Geologic storage is in a research and demonstration phase in preparation for commercialization. It is important that policy developers recognize that a monitoring program for a research project is intrinsically different from the monitoring program for a commercial site. A research project challenges hypotheses about the nature of the subsurface perturbation created by injection by comparison of response predicted by conceptual or numerical models to the response observed via monitoring. A demonstration also tests the performance and sensitivity of monitoring tools to determine the extent to which they are able to detect the perturbation, the conditions under which they are useful and the reliability under field conditions.

Monitoring at a commercial site where CO₂ is being injected can serve three functions. Monitoring is used to confirm that the predictions of containment made based on site characterization at the time of permitting are valid. This is conceptualized as making observations of change over time that are reasonably close to model predictions. From this monitoring result, confidence is gained to continue the injection. Secondly, monitoring could be used to confirm that no unacceptable consequences result from injection. Lastly, monitoring during injection could be designed to prove-up confinement so that monitoring frequency could be diminished through the life of the project and eventually stop, allowing the project to be closed.

Monitoring to be conducted during a commercial project needs to be sufficiently standardized so that both operator and regulator know what is required. Dependability and durability is needed for repeat measurements to be made over decades. Measurements should be designed to be reportable to the stakeholders so that oversight is obtained. Commercial sites should plan and budget for the possibility of detections that are not compliant with expected results.
Such an occurrence would likely require a follow-up testing program similar in some ways to a research program in that it would test hypothesis explaining non-compliance. Outcomes from this investigation could range from an improved model to documenting inadequacy of containment, requiring remediation of the project. To optimize commercial monitoring we should separate early research elements from activities that will be used over the life of a project so that research expectations do not cross into regulations for commercial projects.

**Websites**


Deep and Near Surface Monitoring for Enhanced CO$_2$ Storage Security

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Why Monitor CO$_2$ injection?

In case where injection is to enhance oil recovery - EOR

- Optimize economic performance
  - Balance flood
- Comply with regulation
  - Mechanical integrity testing
  - Comply with permits e.g. maximum pressure, volumes

Oil producer
Investor
Regulator
Monitor for CO$_2$ emissions reduction?

- More players
  - Policy driver – who will that be?
  - CO$_2$ source
    - electric utility
    - Public Utilities Commission
  - EPA/ state primacy
- Doesn’t yet exist
  - May be under EPA class VI
  - conditions where CO$_2$ credits are verified
What’s new about monitoring a CO2 injection? Comparing Class V - VI to Class I-II

<table>
<thead>
<tr>
<th>Higher environmental expectations 2009 than 1974?</th>
<th>Role of high level nuclear waste storage research?</th>
<th>Role of superfund experience?</th>
<th>Role of field experiments.</th>
<th>Many factors remain same</th>
</tr>
</thead>
<tbody>
<tr>
<td>Role of superfund experience?</td>
<td>Role of field experiments.</td>
<td>Possible to image the free-phase CO₂ in reservoir</td>
<td></td>
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</tr>
</tbody>
</table>

- Well head pressure, injected volumes, injectate composition to assure compliance with maximum injection pressure
- Mechanical integrity testing of engineered system
Proposed Monitoring Strategy

An overview of some selected tools used in pilots or mentioned in EPA Class VI draft rules

Goals of Monitoring a Commercial Project

• Confirm predictions of containment based on site characterization are valid.
  - Observations (reasonably) close to model predictions.
  - Confidence gained to continue the injection.

• Prove-up confinement
  - Monitoring diminished through the life of the project
  - Eventually stop, allowing the project to be closed.

• Confirm that no unacceptable consequences result from injection.
Research Monitoring Underway Now

- Research monitoring programs
  - Under EPA class V (experimental) or class II
  - Monitoring is mostly voluntary or negotiated
  - Improve current understanding and confidence in CCS
Research Monitoring: Improve current understanding and confidence in CCS

- Challenge hypotheses
- Comparison numerical models to the response observed via monitoring.
- Test performance and sensitivity of monitoring tools
  - Conditions under which they are useful
  - Reliability under field conditions
  - Redundant measurements
SECARB Early Experimental Monitoring
At Detail Area Study

Injector CFU 31F1

Obs CFU 31 F2

Obs CFU 31 F3

Closely spaced well array to examine flow in complex reservoir

Denbury Onshore LLC

DRI

Sandia Technologies, LLC

NETL

SECARB

Southern States Energy Board

Injection Zone

Above Zone Monitoring

10,500 feet BSL

68m

112 m
<table>
<thead>
<tr>
<th>Theory and lab</th>
<th>Field experiments</th>
<th>Hypothesis tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity of tools; saturated-vadose modeling of flux and tracers</td>
<td>Surface monitoring: instrument verification Groundwater program CO₂ variation over time Above-zone acoustic monitoring (CASSM) &amp; pressure monitoring</td>
<td>CO₂ retained in-zone-document no leakage to air-no damage to water</td>
</tr>
<tr>
<td>Lab-based core response to EM and acoustic under various saturations, tracer behavior</td>
<td>CO₂ saturation measured through time – acoustic impedance + resistivity Tomography and change through time 3- D time lapse surface/ VSP seismic Dissolution and saturation measured via tracer breakthrough and chromatography</td>
<td>CO₂ saturation correctly predicted by flow modeling</td>
</tr>
<tr>
<td>Advanced simulation of reservoir pressure field</td>
<td>Microseismic test, pressure mapping Acoustic response to pressure change over time</td>
<td>Pressure (flow plus deformation) correctly predicted by model</td>
</tr>
</tbody>
</table>

**Commercial Deployment by Southern Co.**

**SECARB Cranfield Research: Theoretical Approaches Through Commercialization**
Commercial Monitoring System

Tools selected to achieve specific goals
- Confirm expected performance “model validation”
- Confirm absence of unexpected performance “no leaks”

Tools tuned to site, especially to risks
- Tool location optimized vertically, aerially, with depth

- Tools are staged
  - Time lapse – measure change over time
  - In response to previous events
  - Less monitoring needed as confidence builds
  - More monitoring needed if unexpected measurements are made
Need for Parsimonious Monitoring Program in a Mature Industry

- Standardized, dependable, durable instrumentation, reportable measurements
- Possibility of above-background detection:
  - Need for a follow-up testing program to assure both public acceptance and safe operation
- Hierarchical approach:

  Parameter A
  - Within acceptable limits: continue
  - Not within acceptable limits: test

  Parameter B
  - Within acceptable limits: continue
  - Not within acceptable limits: Stop & mitigate
Stages of a Project

**Pre-Operation Phase**: Project design is carried out, baseline conditions are established, geology is characterized, and risks are identified.

**Operation Phase**: Period of time during which CO2 is injected into the storage reservoir.

**Closure Phase**: Period after injection has stopped, during which wells are abandoned and plugged, equipment and facilities are removed, and agreed upon site restoration is accomplished. Only necessary monitoring equipment is retained.

**Post-Closure Phase**: Period during which ongoing monitoring is used to demonstrate that the storage project is performing as expected until it is safe to discontinue further monitoring. Once it is satisfactorily demonstrated that the site is stable, monitoring will no longer be required except in the very unlikely event of leakage, regulatory requirements, or other matters that may require new information about the status of the storage project.

**Site selection, characterization**: Multi staged process, deep investment in selecting a site with geologic characteristics that provide high assurance of permanent storage.

**Permitting via state/ federal/ other process**: Hydrologic characterization of reservoir, demonstration of well integrity

**Operational monitoring and reporting**: Extensive baseline data (part overlap with characterization).

- Parsimonious monitoring program.
- Reporting to regulator.
- Additional testing to reduce uncertainly in permanence of trapping.
- Follow up on any near surface anomalies.
- Good operational monitoring
- Proof of effective trapping = site closure permit

Testing wells – possible flaws

- Heat as a tracer for upward leakage
- Deeper fluids are warm, show warm thermal anomaly as they move upward
- \(\text{CO}_2\) flash to gas – cool thermal anomaly.
Notes by Presenter: Just such an example is the EGL 7. Luckily, geology is such that we can use it as a test for the ability of cement, even ~60 year old cement to seal and restrict leakage of CO₂ being injected into the Tuscaloosa injection zone.
Separate Research (Now) from Commercial Practices (Later)

**Research**
- What is needed to develop technical and public confidence
  - Case specific
  - Innovative
  - Comprehensive

**Commercial**
- Only what is required to allow injection to continue and site to be eventually closed
  - Standardized
  - Parsimonious
Research Sponsors

Gulf Coast Carbon Center Sponsors

- bp
- Chevron
- Marathon

Other SECARB projects

- SWP
- BES - UT Center for Energy Frontiers
- EPA projects
- CCP
- State of Texas Offshore Repository - FOA 33

Industry sponsored projects

- FOA 15

Parallel projects GCCC involvement