New Developments: Solved and Unsolved Questions Regarding Geologic Sequestration of CO$_2$ as a Greenhouse Gas Reduction Method

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New Developments – Solved and Unsolved Questions Regarding Geologic Sequestration of CO$_2$ as a Greenhouse Gas Reduction Method

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To reduce CO$_2$ emissions to air from point sources...

Carbon extracted from a coal or other fossil fuel is currently burned and emitted to air. CO$_2$ is shipped as supercritical fluid via pipeline to a selected, permitted injection site. CO$_2$ is injected at pressure into pore space at depths below and isolated (sequestered) from potable water. CO$_2$ is stored in pore space over geologically significant time frames.

Geologic Sequestration of Carbon – Put it back

Return it to the Earth where it came from.
Gulf Coast Carbon Center (GCCC)

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bp
Chevron
EASTMAN
ConocoPhillips
Shell
KINDER MORGAN
Luminant
LCRA
AUSTIN ENERGY
Entergy
PRAXAIR
MARATHON
NRG
ENVIRONMENTAL DEFENSE
Schlumberger
GCCC Field Tests for Monitoring and Verification Technologies DOE NETL support

SECARB Phase II&II Cranfield

Frio Test Site

SACROC Southwest Partnership NM Tech

Pipelines for naturally occurring CO₂

CO₂-EOR candidate reservoirs

Existing CO₂ pipelines

Additional oil-production area with CO₂-EOR production and potential

Major oil plays
Geotechnical Progress - Permanence

- Field documentation of immiscible non-wetting phase residual saturation (Phase trapping). Increased confidence in long term trapping [Frio pilot]
- Continued uncertainty about the significance of dissolution of CO$_2$ into brine – volumetrics of dissolution trapping
- Reduced expectation for mineral trapping in average sedimentary rocks
Geotechnical Progress - Risk

- Risks of brine displacement resulting from large scale CO$_2$ injection recognized (Area of Review – AOR issue) [Nicot/Hovorka model results]
- Concerns about old well and long term well performance have not been resolved (Celia Princeton, LANL, CCP II)
- Risks to fresh water as a result of leakage of CO$_2$ – role of reactive grain coats rather than bulk mineralogy identified (BEG/Kharaka USGS)

Increasing interest in feasibility of groundwater monitoring for leakage (SACROC, Canfield) no results yet.

Realistic (reduced) expectations for seismic monitoring.

New method—deep above-zone monitoring—Favorable initial result (Frio), larger-scale testing planned (Cranfield).
Monitoring Schemes: Monitoring in Mature Commercial Context

- Benson study showing that cost of a monitoring scheme, basic or enhanced, is a small fraction of the cost of the whole project.
- Should a large injection then have a large monitoring program?
## Current Monitoring Selection is Not Mature

<table>
<thead>
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<th>Engineered Systems</th>
<th>MIT, positive annular pressure</th>
<th>Slepner</th>
<th>Weyburn</th>
<th>West Pearl -Queen</th>
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Parsimonious Monitoring Hypothesis: the Box

- **Atmosphere**
  - Ultimate receptor but dynamic
- **Biosphere**
  - Assurance of no damage but dynamic
- **Soil and Vadose Zone**
  - Integrator but dynamic
- **Aquifer and USDW**
  - Integrator, slightly isolated from ecological effects
- **Above injection monitoring zone**
  - First indicator, monitor small signals, stable.
- **In injection zone - plume**
  - Oil-field type technologies. Will not identify small leaks
- **In injection zone - outside plume**
  - Assure lateral migration of CO₂ and brine is acceptable

New proposal - monitoring box
Two areas need monitoring: buoyant CO$_2$ and elevated pressure in brine

In EOR CO$_2$ injection is approximately balanced by oil, CO$_2$, and brine production no pressure plume beyond the CO$_2$ injection area

CO$_2$ injection (no production) pressure plume extends beyond the CO$_2$ injection area
Two Areas of Concern in Area of Review

Footprint of area of elevated pressure

Footprint of area over CO2

Injection well

Plume of injected CO2

Most workers in CCS are most concerned about area (1).

Most UIC is concerned about area 1 +2
Risk is different in different parts of the AOR, and changes with time.

Footprint of area of elevated pressure

Leakage risk is for brine into USDW or to surface water

Footprint of area over CO₂

Leakage risk is for CO₂ into the atmosphere, also possibility for damage to biosphere, to USDW or surface water.
The relative size of both parts of the area of review is sensitive to geologic characterization.

Case A has a pressure seal essentially no fluid flow under possible pressure contrasts. The area of pressure elevation is large relative to area of CO$_2$ footprint.

Case B has a capillary entry seal vertical hydraulic conductivity contrast allows brine movement however CO$_2$ cannot cross the seal. The area of pressure elevation is smaller relative to area of CO$_2$ footprint.
Stacked Storage

• By developing multiple injection zones, the footprint of the CO$_2$ and pressure plume can be minimized.
Test adequacy of Mississippi well completions for CO₂ sequestration

Monitoring Zone

13-Chrome Isolation packer w/ feed through
13-Chrome Selective seat nipple
Pressure transducer Side Pocket Mandrel w/dummy gas valve
1/4" tubing installed between packers to
Provide a conduit between isolation packers

CO₂ Injection Zone

13-Chrome Production packer w/ feed thrus
Pressure transducer Side Pocket Mandrel w/dummy gas valve

Confining system

Tuscaloosa perforation
Box Case example 1 - Dipping saline formation
Large volume injection plan

- Upper Seal – Salado-Tansill
- Lower Seal – Seven Rivers
- Monitoring zone – Yates
- Delaware Mountain Group
  Thick section of fine sandstone and organic-rich siltstones

Array of injection wells with horizontal completions
Large volume monitoring plan – the box

- Dip
- Major fracture orientation
- Monitoring wells of the ‘box’ sides
- Above zone array
- Area of elevated pressure
- Horizontal injectors and CO₂ plumes
Monitoring Plan

Excellent baseline surveys – air, soil, water, 3-D seismic

Pressure at injector

Far-field pressure

Saturation at injectors

Saturation logging program at injectors

Injection
Monitoring Plan – finds unacceptable response

- Reservoir not arealy extensive?
- Far-field pressure much higher than expected
- Asymmetrical pressure plume
- Low saturation = poor sweep efficiency
- Pressure much lower than expected = a leak?
- Far-field pressure much higher than expected
- Extensive saturation logging program at injectors

Excellent baseline surveys – air, soil, water, 3-D seismic
Injection into a structure

"Box" wells

CO₂ plume
Faults as seals and as conduits

Faulted environments fairly common in prospective CCS areas

Limited lateral and vertical distribution.

You don’t have to work in faulted areas, but other considerations may make those areas attractive.

Meckel, 2007
Common environments for economic hydrocarbon accumulations

Example: Offshore Gulf of Mexico

N = 2145

- Majority of HC environments involve faults: provide structure
- Faults demonstrably sealing with respect to hydrocarbons
Prediction – Integrate knowledge

- Future performance knowable

**TRANSMISSIVE PROPERTIES:**
Predicting fluid flow

Shale Gouge Ratio (e.g. Yielding et al., 1997; AAPG Bull.)

The Shale Gouge Ratio is used to estimate the amount of clay in the fault zone.

SGR is converted to $K_{\text{fault}}$ using empirical relations.

Fault zone width is estimated from fault throw.

\[
\text{SGR} = \frac{\Sigma (V_{\text{clay}} \cdot \Delta z)}{\text{Throw}} \cdot 100\%
\]

**DYNAMICS:**
Predicting slip tendency with increases in fluid pressure

Hypothesis: Parsimonious Monitoring Program in a Mature Industry

- Standardized, dependable, durable instrumentation, reportable measurements
- Frequent pressure measurements above-zone and in-zone – documents conformance
- Episodic saturation logging (at injectors?) syn- and post-injection documents sweep.
- Trigger points:
  - an unexpected measurement initiates a pre-planned research type monitoring program to assess origin of response.

Parameter A
- not within acceptable limits: test
  - within acceptable limits: continue

Parameter B
- not within acceptable limits: stop & mitigate
  - within acceptable limits: test
Technical input to policy issues

• Well leakage concern- needs resolution with respect to GHG reduction role for EOR - several tests are underway

• Area of Review – large footprint of high pressure area in brine around a large volume plume. Not applicable to EOR context.

• Mature monitoring plan is needed - hierarchical with trigger points.
Technical input to policy

- Recent policy concerned with feasibility of large scale (M tone/year), long term injection is not technically justified. Methods for increasing injectivity in low permeability rocks (long horizontals) are mature and have been deployed for CCS (Weyburn, In Salah).
- Focus should be shifted to documentation of (1) proof of adequacy of characterization (lateral connectivity of reservoir, quality of seal, sealing faults) and (2) correct prediction of maximum pressure and maximum plume extent.