CO$_2$ Storage, Monitoring, Verification and Accounting

Vanessa Nuñez-Lopez

CO$_2$ for EOR as CCUS: Texas-Norway Symposium
Houston, Texas
November 19 to 21, 2013
Monitoring goals for carbon storage

Show that:

• Storage capacity and injectivity are sufficient
• CO₂ will be contained in the target formation
• Know aerial extent of the plume elevated pressure effects compatible with other uses
• Advance warning to allow mitigation if needed
• Public acceptance provide confidence in safe operation
Who requires an MMV plan?

In the US:

- The Federal GHG accounting regulations (under the Safe Drinking Water Act and the Clean Air Act)
- The U.S. Environmental Protection Agency (EPA) and the Underground Injection Control (UIC) program.

In the European Directive (2009/31/EC):

- Article 13: “Member States shall ensure that the operator carries out monitoring of the injection facilities, the storage complex (including where possible the CO2 plume), and where appropriate the surrounding environment…”

In Australia: *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cth)
Where do we monitor?

- Too complex
- Dynamic
- Stable first indicator
- Standard oil field technologies
Geophysical monitoring methods

- Seismic Surveys: 2D, 3D, time-lapse 3D (4D)
- Vertical Seismic Profiles (VSP)
- Cross Well Seismic
- Well Logging
- Electrical Resistance Tomography (ERT)
- Others
Pressure Monitoring

- In-zone
- Shallow AZMI
- Deep AZMI
- Soil Gas
- Injection Well
- CD2
- Abandoned Well
- Upward Flow
- CO2 Plume
- Updip Flow
Groundwater and vadose zone monitoring

Characterization of groundwater before CO2 injection begins, followed by annual sampling.
Surface deformation: space geodesy (GPS/InSAR)

- **Principle**: increased reservoir pressure from CO$_2$ injection may lead to measurable uplift; short term leakage may lead to subsidence.

- GPS (point positions, high temporal resolution) and InSAR (high spatial resolution, low temporal resolution) could provide a good combination for long term monitoring of sequestration sites.

- InSAR demonstrated for CCS at InSalah, Algeria (dry).

- InSAR not yet demonstrated for CCS in humid, vegetated areas.
Microseismic: passive seismic monitoring

From RITE: Nagaoka Site
SECARB Phase III at Cranfield, Mississippi

Special Section dedicated to Cranfield in the October issue of the International Journal of Greenhouse Gas Control

SECARB Test Site Location

Cranfield Phase III early

Jackson Dome Natural CO₂ source

Frio Brine Storage tests
Cranfield: goals and objectives

RCSP program goals:
• Predict storage capacities within +/- 30%
• Evaluate protocols to demonstrate that it is probable that 99% of CO\(_2\) is retained

SECARB Cranfield “Early Test” goals:
• Obtain early results for the RCSP program
• Provide early information to policy makers

SECARB Cranfield “Early Test” technical objectives:
• Effective environmental assurance
• Predicting and monitoring the extent of CO\(_2\) plume migration in the injection interval
• Predicting and monitoring the magnitude and extent of pressure increase
Cranfield: geological location

Based on log annotation and recent side-walls

Tuscaloosa D-E reservoir

Tuscaloosa confining system

Oil-water contact
Based on log annotation and recent side-walls
Cranfield: detailed area of study (DAS)

Closely spaced well array to examine flow in complex reservoir
Cranfield: DAS observation well construction

- 2 7/8” tubing
- U-tube sampler 1/4 “SS
- Seismic sources/receivers
- BHP+ T
- Casing-conveyed pressure sensor
- ERT – 20 electrodes
- Fiberglass non-conductive casing
- Distributed temperature and heater loop
- Cross well array in two wells
- High injection volumes
- Far-field monitoring microseismic, P&T, chemistry, surface seismic
- 200’
- 100’
- Tuscaloosa DE

Bureau of Economic Geology
The University of Texas at Austin
Jackson School of Geosciences
Gulf Coast Carbon Center
Cranfield: baseline cross-well tomogram

West

East

112 m
Cranfield: cross-well z-seis profile

Baseline Sep. 2009

Nov. 2010
Cranfield: electrical resistivity tomography

Anomaly – real or not?
Conductive plume = workover fluids?
Reservoir
Resistive plume = CO2 in reservoir

10,380.67 feet MD
10,394.30 feet MD
10,570.44 feet MD
10,569.36 feet MD

1/4/2010
Charles Carrigan, LLNL

Operation
50.0
25.0
0.000
-25.0
-50.0
High frequency fluid sampling via U-tube yields data on flow processes

Small diameter sampler with N₂ drive brings fluids quickly to surface with tracers intact

CO₂ dissolution into brine liberates dissolved CH₄

BEG, LBNL, USGS, ORNL, UTDoG,

data compiled by Changbing Yang BEG
Wireline Logging
Reservoir Saturation Tool (RST)
Cranfield: conclusions

- More than 4.5 Million tons of injected CO\textsubscript{2} have been monitored
- CO\textsubscript{2} has been effectively retained in the injection zone, even in area of 1943-1944 wells
- Flow and pressure elevation was predicted within the range of uncertainty
- CO\textsubscript{2} moved in preferential paths along fluvial channels. A number of successfully deployed imaging tools support this channel-dominated flow theory.
- CO\textsubscript{2} moved downdip, indicating buoyancy forces were not flow dominating at the interwell scale of the experiment.
- BEG’s risk-targeted monitoring program was designed to build confidence in carbon geologic storage.
- It is hoped that learnings based on success and weakness of this project will be relevant at future sites
### Transitioning from research monitoring to commercial EOR monitoring

#### Research Monitoring

**Tests**-
- Hypotheses about the nature of the perturbation created
  - compare response modeled to the response observed via monitoring.
- Performance and sensitivity of monitoring tools
  - sensitivity to the perturbation
  - conditions under which tool is useful,
  - reliability under field conditions.

#### Commercial Monitoring

**Confirms** -
- Predictions of containment based on site characterization at the time of permitting are correct
- Confidence to continue injection
  - monitoring observations that are *reasonably close* to model predictions
  - any non-compliance explained.
  - no unacceptable consequences result from injection
- Diminishing of monitoring frequency through the life of the project
  - eventually stopped, allowing the project to be closed.
General conclusions

• Diverse tools are available to determine if a site is performing correctly. Most of these tools have been extensively tested in similar settings and have been or are now being tested at CO2 sequestration sites.
• The optimal tool combination for mature projects need to be site-specific.
• In-zone reservoir fluid pressure is a well-known measure of reservoir response and provides data that test the correctness of reservoir models.
• There is value in high-frequency pressure data that document short term transients in the rate of pressure change, which are not visible in low-frequency measurements.
• Time lapse measurements of CO2 saturation show complexities that are not included in traditional model matching.
• Groundwater monitoring for a geologic storage site should draw upon classic contaminated-site protocols.
Questions?