Kevin Dome CO$_2$ Storage Demonstration Project

The Big Sky Carbon Partnership Region

Lee Spangler
Big Sky Carbon Sequestration Partnership

U.S. Department of Energy
National Energy Technology Laboratory
Review
Aug, 2013
Lessons Learned – Landowner relationships

• Community values have to be respected
  – Rural and low population
  – Concerned about outside influence

• Landowner stipulations can vary
  – Access via only one corridor
  – Change access periodically to prevent deep rutting

• Landowners don’t receive royalties like in oil & gas operations
Lessons Learned – Permitting

• It will take a major portion of your time
Lessons Learned – Lack of Infrastructure

• While there are extensive oil and gas wells, many are old and practices aren’t up to CS standards
• Not working with a single landowner on a brownfield site
• Materials, rigs, equipment limited
Lessons Learned – Monitoring Purpose

- Public wants assurance
- Oil & Gas operations don’t want research activities to set unreasonably high standards or expectations
Key Observations with Regard to Phase II EORs and the Phase III Illinois Basin – Decatur Project

Robert J. Finley, Scott M. Frailey, and the MGSC Project Team

Midwest Geological Sequestration Consortium
University of Illinois, USA

Pittsburgh, PA
21 August 2013
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*Mark of Schlumberger

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MGSC

Acknowledgements
Phase II: Key Observations from Three EOR Pilots

- Projects “of opportunity” have well spacing and piping/oil collection systems that may not be optimal for data collection to characterize oil, water, and CO$_2$ production response.
- Variations in timing of truck delivery of CO$_2$ led to variations in bottomhole pressure and lower average reservoir pressure.
- Well clean up and workovers should be completed in advance of CO$_2$ injection to establish fluid production baselines to better assess responses attributable to the EOR effort.
- Opportunities to better characterize oil and water volumes produced by wells and more frequent well testing would improve reservoir model calibration and assessment of pilot performance.
A collaboration of the Midwest Geological Sequestration Consortium, the Archer Daniels Midland Company (ADM), Schlumberger Carbon Services, and other subcontractors to inject 1 million metric tons of anthropogenic carbon dioxide at a depth of 7,000 +/- ft (2,000 +/- m) to test geological carbon sequestration in a saline reservoir at a site in Decatur, IL.
Operational Injection: 17 November 2011

- IBDP fully operational 24/7
- IBDP is the first 1 million tonne carbon capture and storage project from a biofuel facility in the US
- Injection through November 2014
- Intensive post-injection monitoring under MGSC through fall 2017

Cumulative Injection (12 August 2013): 559,301 tonnes
Diligent effort needs to be made to ensure that operations proceed smoothly, that the interface among project partners is open, and that partners can respond to project changes/regulatory requirements.

Do not underestimate the commitment necessary to put a project in place and to develop effective ongoing attention to details that crop up. Significant coordination is required.
Lessons Learned and Observations Going Forward

Some research components will fail from time to time and some degree of redundancy is beneficial for data collection and subsequent interpretation.

Post-demonstration assessments should be planned to assess data value vs. cost, operational complexity, and overall benefit to supporting confidence in geological storage among future site operators, regulators, legislators, and the general public.
Lessons Learned and Observations Going Forward

IBDP has been operating under a State of Illinois Class I Nonhazardous permit as we prepare for the transition to a US EPA-administered Class VI.

IBDP Class VI permit provisions are not yet known. Application of Class VI regulations has been a hurdle for other projects where flexibility, given the scale of demonstration testing, may better serve development of a knowledge base shared between researchers and regulators.
The implementation of the Illinois Basin – Decatur Project has been demanding to the point where peer-reviewed publication of results has been lagging behind formal reporting requirements and conference presentations, both of which are less structured and comprehensive.

Focus now is on catching up, but diligence will be required to make it happen.
Lessons Learned and Observations Going Forward

Consideration of a priori barriers to geological storage can easily become a discussion focus.

Yet, many problems can be worked through with pursuit of geoscience and engineering best practices adapted to geological storage development. This is important to point out in public venues.
Perspectives on 10 Years of Geologic Storage Research by MRCSP

Carbon Storage R&D Project Review
Pittsburgh
August 20-22, 2013

Neeraj Gupta, Ph.D.
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Overall schedule for MRCSP – 10 Years of achievements and more to come!


Phase I Characterization

Phase II Small Scale Validation

Phase III Large Scale Field Validation

Site Selection, Permitting, Site Characterization, Site Preparation, and Baseline Monitoring

OH Site MI Saline MI EOR Fields

MI Injection Operations (Multiple Reefs)

Post Injection Monitoring
Phase II Appalachian Basin Test – Even small tests can take years

FirstEnergy and Battelle meet in Akron to discuss Burger as a test site

Phase II proposal submitted

Seismic survey

UIC permit application submitted to OEPA

Core analysis results received

Decision to use commercial CO₂

Topical Report Well Plugged

UIC permit received

Site selection and screening

Site Characterization

Source Planning and Permitting

Injection testing

Post Injection

2005

2006

2007

2008

2009

Drilling of deep well. Wireline logs and partial sidewall core samples taken

Completion of well. Additional logs and remaining sidewall core samples taken

Sidewall core samples sent out for analysis (to Core Labs)

Injection tests completed

Phase II begins
Terrestrial Sequestration – Four field tests successfully completed during Phase II

Croplands
The Ohio State University

Reclaimed Minelands
West Virginia University

Forested Wetlands
Rutgers University

Reclaimed Marshland
University of Maryland
CO₂ Storage Resources – Significant but Heterogeneous Potential

- Many promising units for CO₂ storage including saline formations, depleted oil/gas fields, and potentially organic shales, and coal beds
- Mapping and understanding the storage zones is an ongoing effort
- Primary targets include Mt. Simon Sandstone along the arches and carbonate layers in deeper basins

**Depleted Oil and Gas Fields:** ~8.500 GT  
**Deep Saline Formations:** ~49-194 GT (not including offshore)  
**Organic Shales:** ~2-30 GT  
**Unmineable Coal:** ~1 GT
MRCSP region has seen several field tests showing opportunities and challenges

Region is home to several field tests – but many more are needed
Appalachian Basin Testing – Limited Injectivity Showed Need for Exploration and Regional Mapping in Deeper Zones

Eastern Ohio Test Site

Clinton Sandstone Test Pressure buildup

Injection Testing, October 2008
Regional geology mapping with wellbore and seismic data is needed to find storage zones.

- Extremely low data availability in deeper Appalachian, Michigan, and Illinois Basin.
Regional Exploration in Appalachian Basin – Filling Key Data Gaps

- Projects co-funded by Ohio Coal Development Office and DOE Over 10 years; Jointly with Ohio Geological Survey

- OCDO piggyback wells
- Other wells in database
Simulations were calibrated to test data to improve model capabilities and demonstrate confidence in reservoir models.

- Monitoring includes: Crosswell seismic, Microseismic, PFT tracers, Fluid sampling, Pressure and Temperature
- Permeability higher than predicted
- Monitoring led to updating geologic models
MRCSP large-scale test site — only CO₂–EOR site in the Midwest

Location:
Otsego County, Michigan

Host Company:
Core Energy LLC

Reservoir Type:
Closely-spaced, highly compartmentalized oil & gas fields located in the Northern Michigan Niagaran Reef Trend

Source of CO₂:
Natural Gas Processing Plant

Injection Goal:
At least 1 million metric tons of CO₂ over ~four years

Local Participants:
Western Michigan University
Existing EOR infrastructure enables cost effective research for MRCSP tests

- Injection started in April 2013 at more than 1,000 t/day (~10% of 500 MW power plant)
- 7 CO\textsubscript{2}-EOR fields in varying life stages
- MRCSP goal – inject and monitor >1 MMT
- Extensive monitoring and operational assessment underway
Complexity and cost for siting larger projects can increase substantially

- Stakeholder concerns (NIMBY)
- Site access agreements, storage rights, land purchase - Should we pay storage fee to landowners?
- More rigorous permitting
- Larger-3D seismic, more wells, more coring, logging, pre-injection testing, geomechanical assessment
- Larger, more complex site models
- Well design and materials for longer-term tests
- Risk management, liability, insurance, long-term stewardship planning
RCSP research also proving useful for oil and gas issues such as brine disposal

- Applying MRCSP knowledge to shale gas environmental issues
- 2-year project funded by DOE through RPSEA
- Evaluate brine disposal capacity, protocols
- Assess safe injection pressure
- Economic issues
- Knowledge sharing
MRCSP Lessons Learned

**Technical Issues**
- Small-scale tests extremely useful in proving safety and effectiveness – more needed
- Injectivity different at each site
- Monitoring data redefined geologic model in all cases
- Regional heterogeneity necessitates mapping and multiple field tests
- Continued testing and evaluation of monitoring technologies needed to build confidence

**Social Issues**
- Proactive outreach and collaboration with host site teams crucial for public acceptance

**Permitting**
- Class V experimental permits enabled testing
- EOR sites can enable CCUS deployment and research – but only one site in MRCSP region

**Other**
- RCSP research can also benefit other energy development
Carbon Storage R&D Project Review Meeting
Overall Key Lessons Learned During the Last 10 years and Looking Forward to the Future of CCS
Pittsburgh, Pennsylvania
August 21, 2013

Ed Steadman
Major lessons learned will be illustrated through cowboy quotes.
Lessons Learned – PCOR Partnership

“Good judgment comes from experience, and a lot of that comes from bad judgment.”
Lesson 1 – There is a lot of wisdom in the regional approach that the U.S. Department of Energy (DOE) took when it established the Regional Carbon Sequestration Partnership (RCSP) Program.

- The geologic, socioeconomic, and legal and regulatory differences across North America are important to carbon capture and storage (CCS).
- The key word is partnership! This approach has resulted in 43 states, four Canadian provinces, and 400 entities partnering in the RCSPs and 40 field validation tests and demo projects!
“If you are riding ahead of a herd, take a look back every now and then to make sure it’s still there with you.”
Lesson 2 – Outreach is very important.
“Timing has a lot to do with the outcome of a rain dance.”
Lesson 3 – The most effective approach to MVA (or whatever they call it now) starts with *judicious site selection* and is *iterative*. 
“Behind every successful rancher is a spouse who works in town.”
Lesson 4 – At least for the PCOR Partnership region, most of the activity in CCS is likely to be associated with enhanced oil recovery.

- Economics are the key.
- Tremendous potential for environmental and economic win-win.
Looking Ahead – PCOR Partnership

“Never miss a good chance to shut up.”

Thanks for your kind attention!
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10 Years Progress in the Regional Carbon Sequestration Partnerships – SECARB perspective: R&D to Commercial

Susan Hovorka
Gulf Coast Carbon Center
Bureau of Economic Geology
The University of Texas at Austin
Safe and Effective Injection > 50 years

Representative projects

Water and gas injection for secondary recovery
Well management, IWR, flood surveillance

CO₂ capture from gas plants and injection for EOR
CO₂ saline storage Sleipner

Monitoring CO₂ EOR Weyburn
Monitoring CO₂ Huff-n-puff West Pearl-Queen
Monitoring CO₂ saline test Nagaoka
Monitoring CO₂ saline test Frio I and II
Monitoring Phase II EOR tests (Cranfield, Zama, SACROC)
Injectivity + Monitoring Phase II saline tests
Injection + monitoring InSalah
Monitoring Phase III EOR + Saline Cranfield
Monitoring Phase III Saline Decatur
Injection + monitoring Ketzin
Monitoring Phase III Saline Citronelle
Monitoring Phase III EOR Michigan
Monitoring Phase III Saline Decatur

Skills in CO₂ injection and handling

Adding Saline
Adding monitoring to demonstrate storage
Commercial storage

Future-Gen, QUEST, Gorgon, AP-LLC,
Motivation for Monitoring Programs

- **Historic Motivation**
  - Groundwater and surface water protection
  - Historic damages = salinization

- **Current motivations**
  - Benefit to the atmosphere

- Follow the $ - Who pays gap between cost of capture and purchase price of CO\textsubscript{2}? - now taxpayer -- ultimately electricity rate payer
  - Liability

- Public concerns/values/standards
Regional Carbon Sequestration Program
goal: Improve prediction of storage capacities

Existing data on reservoir volumetrics

Production history
37,590,000 Stock tank barrels oil
672,472,000 MSCU gas
(Chevron, 1966)

7,754 acres x 90 ft net pay x 25.5% porosity
(Chevron, 1966)

X E  [pore volume occupancy (storage efficiency)] = Storage capacity
injection rate – limited by pressure response?

Measure saturation during multiphase plume evolution

Increase predictive capabilities by validating numerical models

Observation: pore volume occupancy was rate and dependent: not a single number
Regional Carbon Sequestration Partnership program goal: **Evaluate protocols** to document that CO₂ is retained

- High confidence in storage permanence through characterization
- Uncertainty and risk assessment
- P&A well performance in retention?
- Limited analogy between injected and natural fluid retention
- Off structure migration?
- Response to pressure elevation?

**Research Questions**

- Material Risk of failing to retain
- Protocol Sensitivity & reliability

**Selected assessment approach**

- Shallow: Well-pad vadose gas, Ground water chem., AZMI pressure
- Deep: 4-D Seismic, 4-D VSP, IZ pressure, Microseismic

**Protocol Sensitivity & reliability**
Transition From... To

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 is gained
  - monitoring observations that are reasonably close to model predictions
  - any non-compliance explained.
  - no unacceptable consequences result from injection
- Monitoring frequency could be diminished through the life of the project
  - eventually stopped, allowing the project to be closed.
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
  - 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
Outline

Southwest Partnership Field Tests

*Selected* Lessons Learned:

1. Role of oil/gas fields for deep saline sequestration
2. Difficulty of predicting geomechanical processes
The Southwest Carbon Sequestration Partnership

In all partner states:
• major universities
• geologic survey
• other state agencies

as well as
• Western Governors Association
• five major utilities
• seven energy companies
• three federal agencies
• the Navajo Nation
• many other critical partners
Paradox Basin, Utah: 150,000 tons/year
• Combined enhanced oil recovery with sequestration
SWP
Field Test Portfolio

Phase II Test Map

Aneth, Paradox Basin

Great Basin Desert
Sonoran Desert
San Juan Basin, NM: 75,000 tons/year

- Combined enhanced coalbed methane recovery with sequestration

Injection from
July, 2008 – October 2009

SWP Field Test Portfolio
Injection from
July, 2008 – October 2009

Field Site
SACROC Unit, Texas: >350,000 tons/year
- Combined enhanced oil recovery with sequestration

Injection from October, 2008 – October 2009

SWP Field Test Portfolio
SACROC Injection Test
Outline

Southwest Partnership Field Tests

Selected Lessons Learned:

(1) Role of oil/gas fields for deep saline sequestration

(2) Difficulty of predicting geomechanical processes
Injection and storage in deep saline units UNDERNEATH oil/gas fields is promising because:

- existing infrastructure for delivering CO₂
- existing infrastructure for monitoring
- in oil fields specifically, the oil serves as a “catchers mitt” of any CO₂ that makes its way to the oil reservoir, even at low oil saturations
Injection and storage in deep saline units UNDERNEATH oil/gas fields is promising because:

- existing infrastructure

- in oil fields specifically, the oil dissolves CO$_2$ that makes its way to the oil reservoir, even at low oil saturations
Outline

Southwest Partnership Field Tests

Selected Lessons Learned:

(1) Role of oil/gas fields for deep saline sequestration

(2) Difficulty of predicting geomechanical processes
Difficulty of Predicting Geomechanical Processes

Pump Canyon Pilot Site

CO$_2$ injection thought to induce coal expansion (swelling)
Geertsma (1973) proposed an analytical equation for surface displacement associated with subsurface coal swelling:

$$u_z = -2c_m (1 - v) \Delta p HR \int_0^\infty J_1(Rt) J_0(rt) e^{-Dt} dt$$

And Eason (1955) provides a solution for an equation of this form:

$$u_z = -2c_m (1 - v) \Delta p H \left\{ \begin{array}{ll}
\frac{-k\eta}{4\sqrt{\rho}} F_o(k) - \frac{1}{2} \Lambda_o(k, \rho) + 1 & \rho < 1 \\
\frac{-k\eta}{4} F_o(k) + \frac{1}{2} & \rho = 1 \\
\frac{-k\eta}{4\sqrt{\rho}} F_o(k) + \frac{1}{2} \Lambda_o(k, \rho) & \rho > 1
\end{array} \right.$$
A plot of this analytical solution:

Suggesting that this tilt should be detectable at the surface: tiltmeters

Analysis and Plot by Norm Warpinski, Pinnacle Technologies
Hydrogeomechanical Impacts: Coal Swelling

Tiltmeter array deployed:

160 km

250 m
Hydrogeomechanical Impacts: Coal Swelling

Tiltmeter array deployed:

- GPS Reference Sites
- Injection Well

Dimensions:
- Width: 250 m
- Length: 160 km
No coherent signal pattern observed within the tiltmeter array.
Minimal surface deformation observed, although a slight amount of uplift may be inferred close to the injector.

Tiltmeter and GPS Results
Tiltmeter and GPS Results

• No significant out-of-zone CO$_2$ migration observed from InSAR, GPS or Tiltmeter responses.

• No significant deformation observed prior to CO$_2$ injections
  – Corroborated by Tilt (after setting period), GPS and InSAR

• No significant deformation after initiation of CO$_2$ injection
  – Analysis of several coarse time slices
  – Negligible volumetric deformation observed to-date
  – Results corroborated by GPS
Poroelastic Simulation of San Juan Injection Site

From Stone, 1983
Poroelastic modeling suggests that injection will induce significant strain within the coals and induce compaction of units above it.

Model results do not suggest significant or uplift at surface (10 year simulation)