Kevin Dome CO_2 Storage Demonstration Project

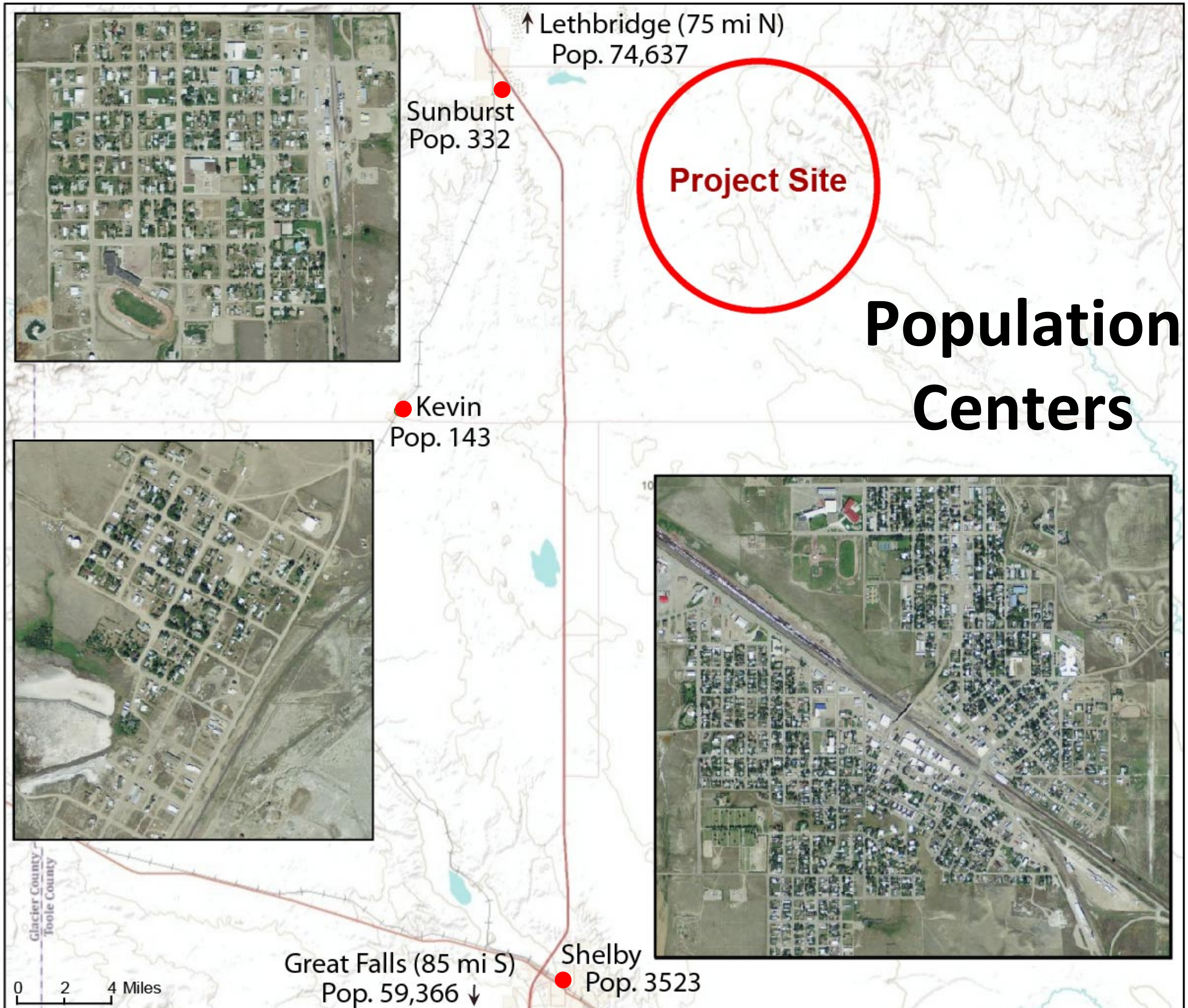
Lee Spangler
Big Sky Carbon Sequestration Partnership

U.S. Department of Energy
National Energy Technology Laboratory
Review
Aug, 2013

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

MONTANA STATE UNIVERSITY

Population Centers



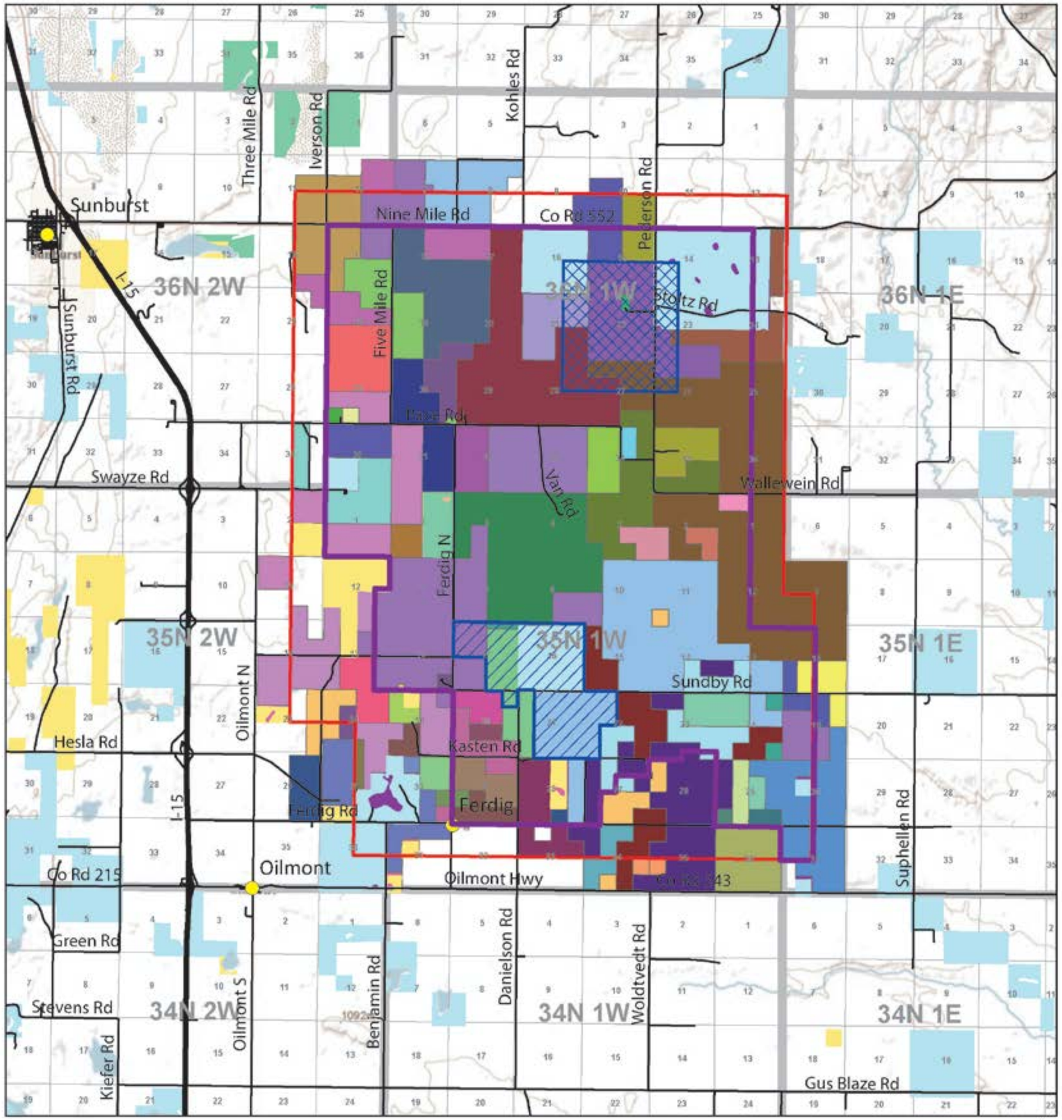
Lessons Learned – Landowner relationships

- 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

BIG SKY CARBON
SEQUESTRATION PARTNERSHIP

Landowners (69 owners)

01/03/2013



Legend

- General Project Area
- Permitted Seismic Boundary Area
- Production Area
- Injection and Monitoring Area
- B.L.M.
- U.S. Fish and Wildlife Service
- State of Montana

0 0.5 1 2 Miles

N

Project Area
Montana

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

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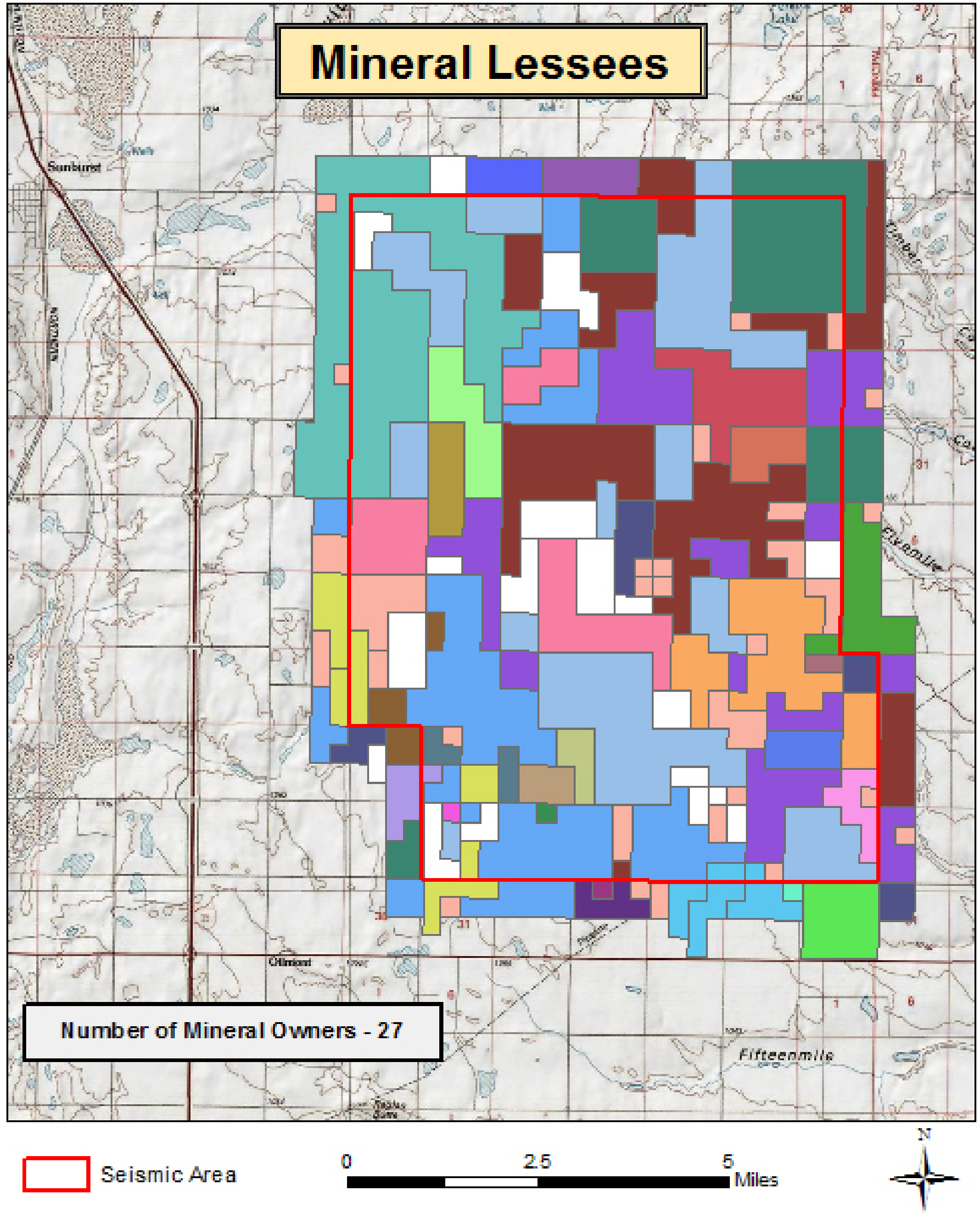

** Confidential ** Confidential **

01-13-12

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

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Lessons Learned – Permitting

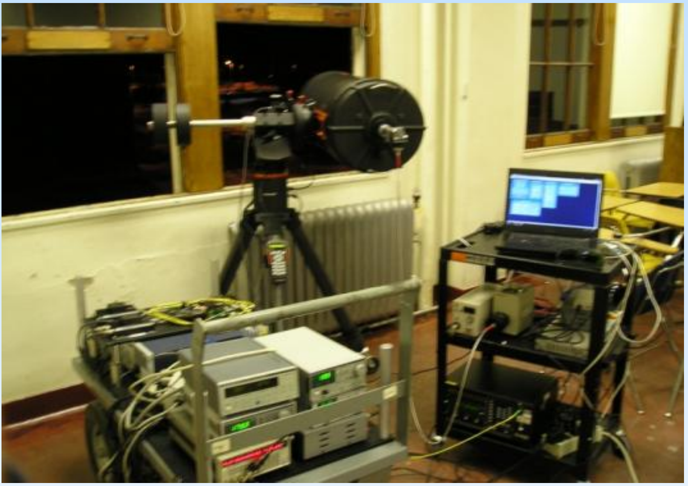
- It will take a major portion of your time

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

ILLINOIS STATE GEOLOGICAL SURVEY
PRAIRIE RESEARCH INSTITUTE

NETL
NATIONAL ENERGY TECHNOLOGY LABORATORY

Schlumberger
Carbon Services

MGSC

Acknowledgements

- The Midwest Geological Sequestration Consortium is funded by the U.S. Department of Energy through the National Energy Technology Laboratory (NETL) via the Regional Carbon Sequestration Partnership Program (contract number DE-FC26-05NT42588) and by a cost share agreement with the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development through the Illinois Clean Coal Institute.
- The Midwest Geological Sequestration Consortium (MGSC) is a collaboration led by the geological surveys of Illinois, Indiana, and Kentucky
- Landmark Graphics software via University Donation Program and Petrel* E&P software platform via Schlumberger Carbon Services are gratefully acknowledged

*Mark of Schlumberger

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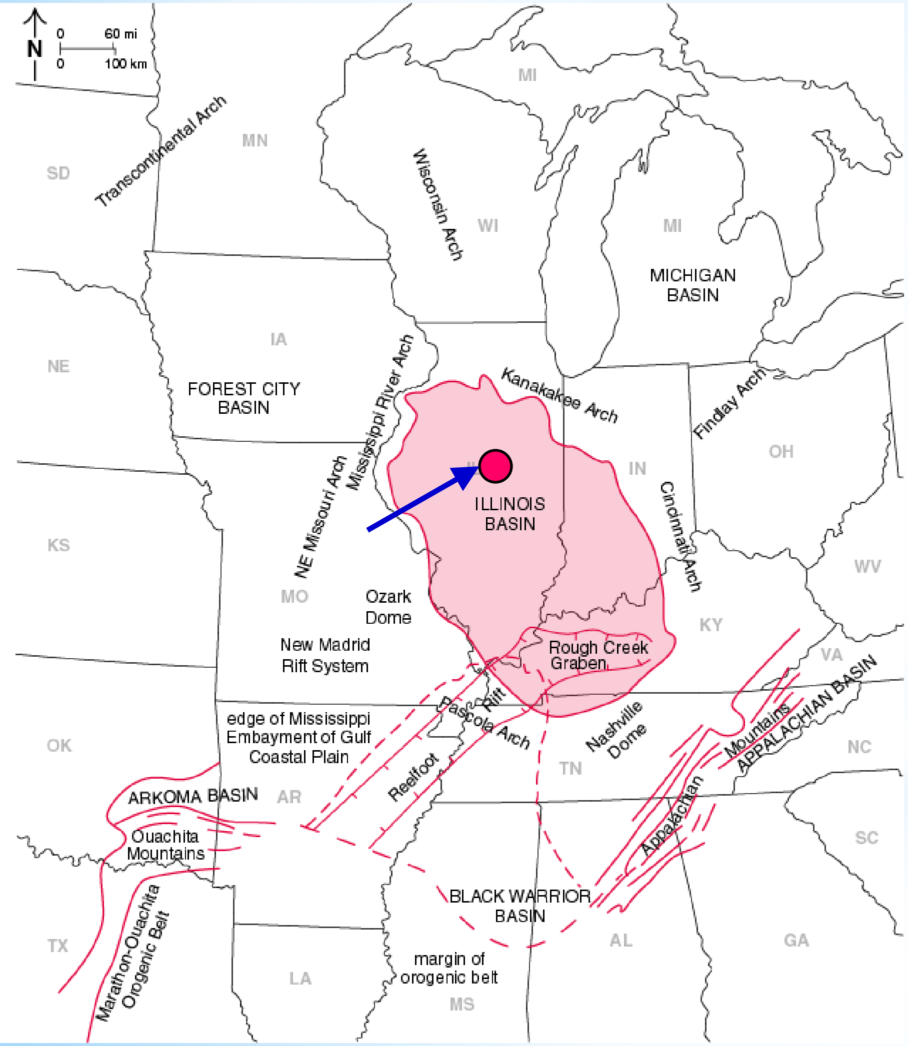
INDIANA UNIVERSITY

KGS

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

Phase III: Illinois Basin – Decatur Project



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

Lessons Learned and Observations Going Forward

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.

Lessons Learned and Observations Going Forward

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.

MGSC

U.S. DEPARTMENT OF ENERGY

ILLINOIS dceo DEPARTMENT OF COMMERCE AND ECONOMIC OPPORTUNITY

ADM

Schlumberger Carbon Services

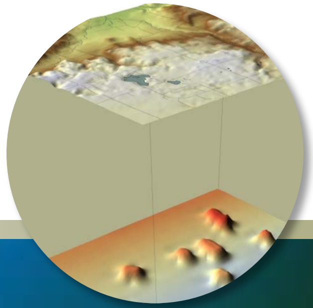
Midwest Geological Sequestration Consortium
www.sequestration.org
finley@illinois.edu

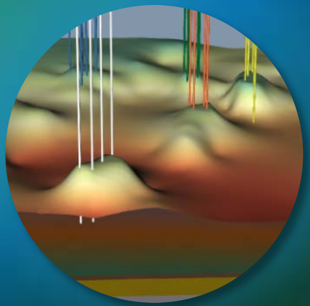
ILLINOIS STATE GEOLOGICAL SURVEY
PRAIRIE RESEARCH INSTITUTE

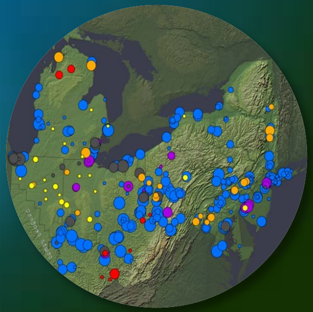
Photo credits: Daniel Byers

Perspectives on 10 Years of Geologic Storage Research by MRCSP

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





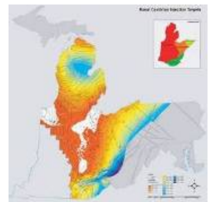
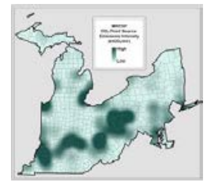


Neeraj Gupta, Ph.D.
Senior Research Leader
Battelle, Columbus, Ohio
gupta@battelle.org 614-424-3820

Overall schedule for MRCSP – 10 Years of achievements and more to come!

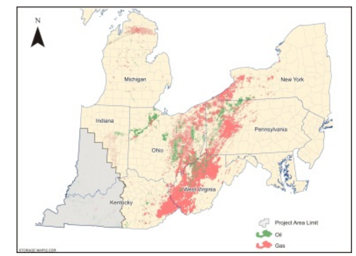
2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018

Phase I
Characterization

Phase II
Small Scale Validation





Phase III
Large Scale Field Validation

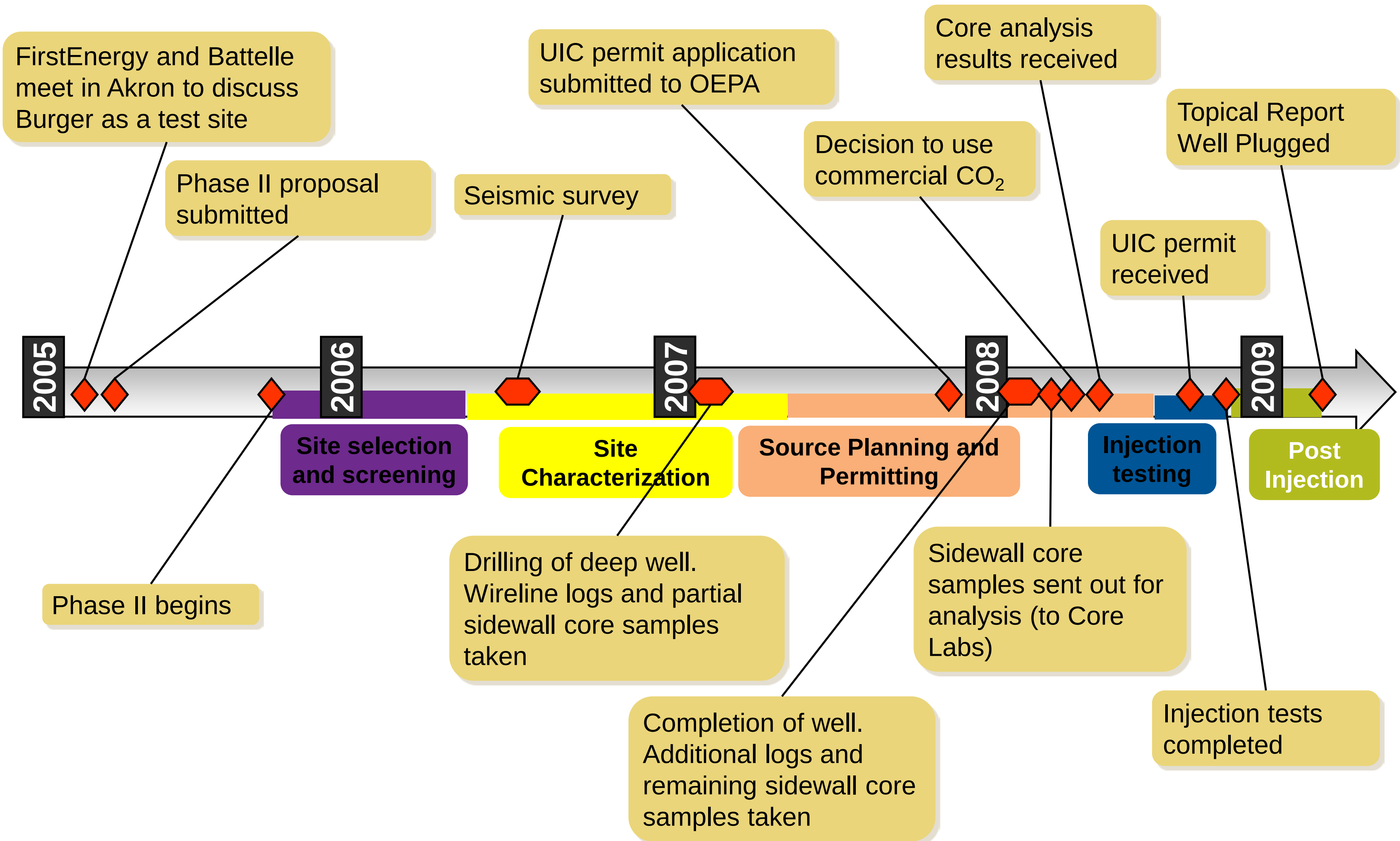
Site Selection, Permitting, Site Characterization, Site Preparation, and Baseline Monitoring

OH Site | **MI Saline** | **MI EOR Fields**

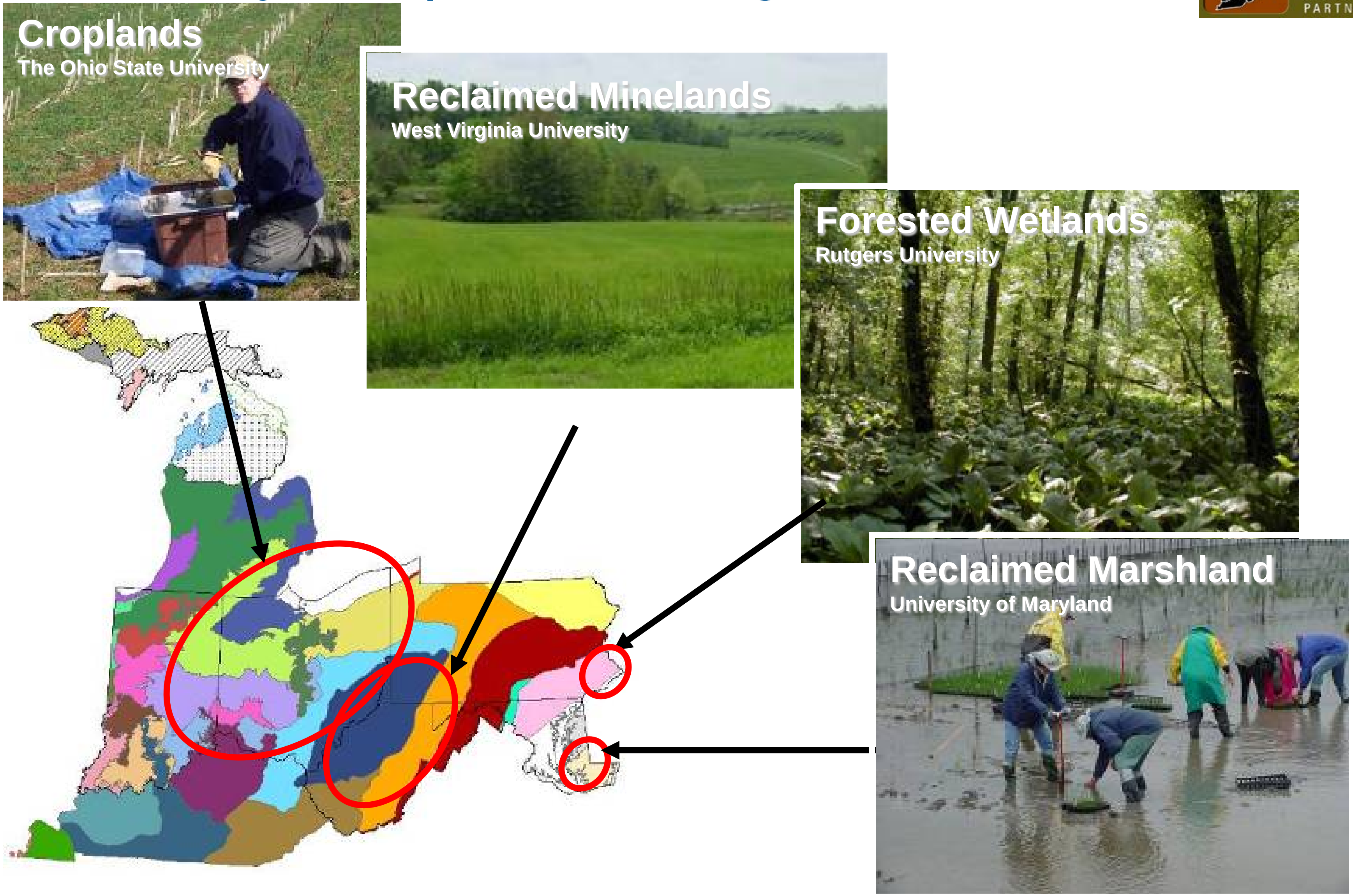
MI Injection Operations (Multiple Reefs)

Post Injection Monitoring

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



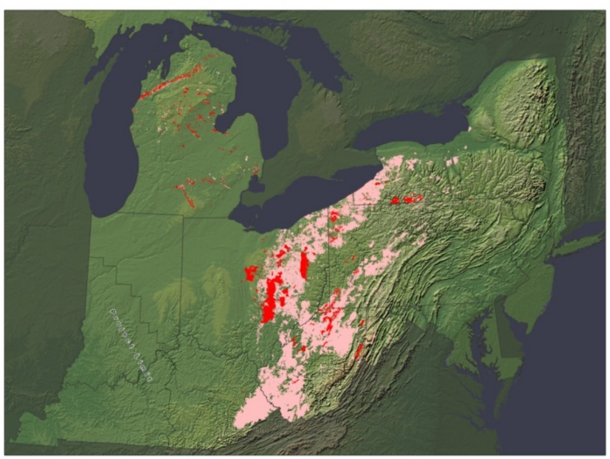
Terrestrial Sequestration – Four field tests successfully completed during Phase II



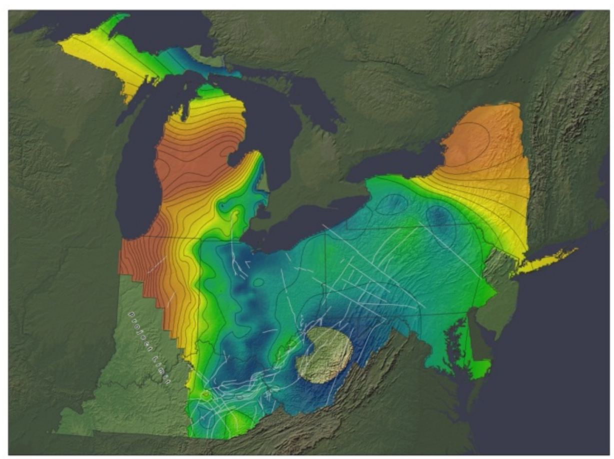
CO_2 Storage Resources – Significant but Heterogeneous Potential

- Many promising units for CO_2 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

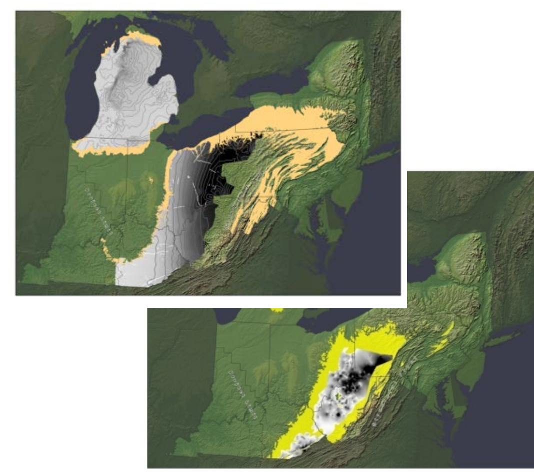
Depleted Oil and Gas Fields: ~8.500 GT



Deep Saline Formations: ~49-194 GT (not including offshore)

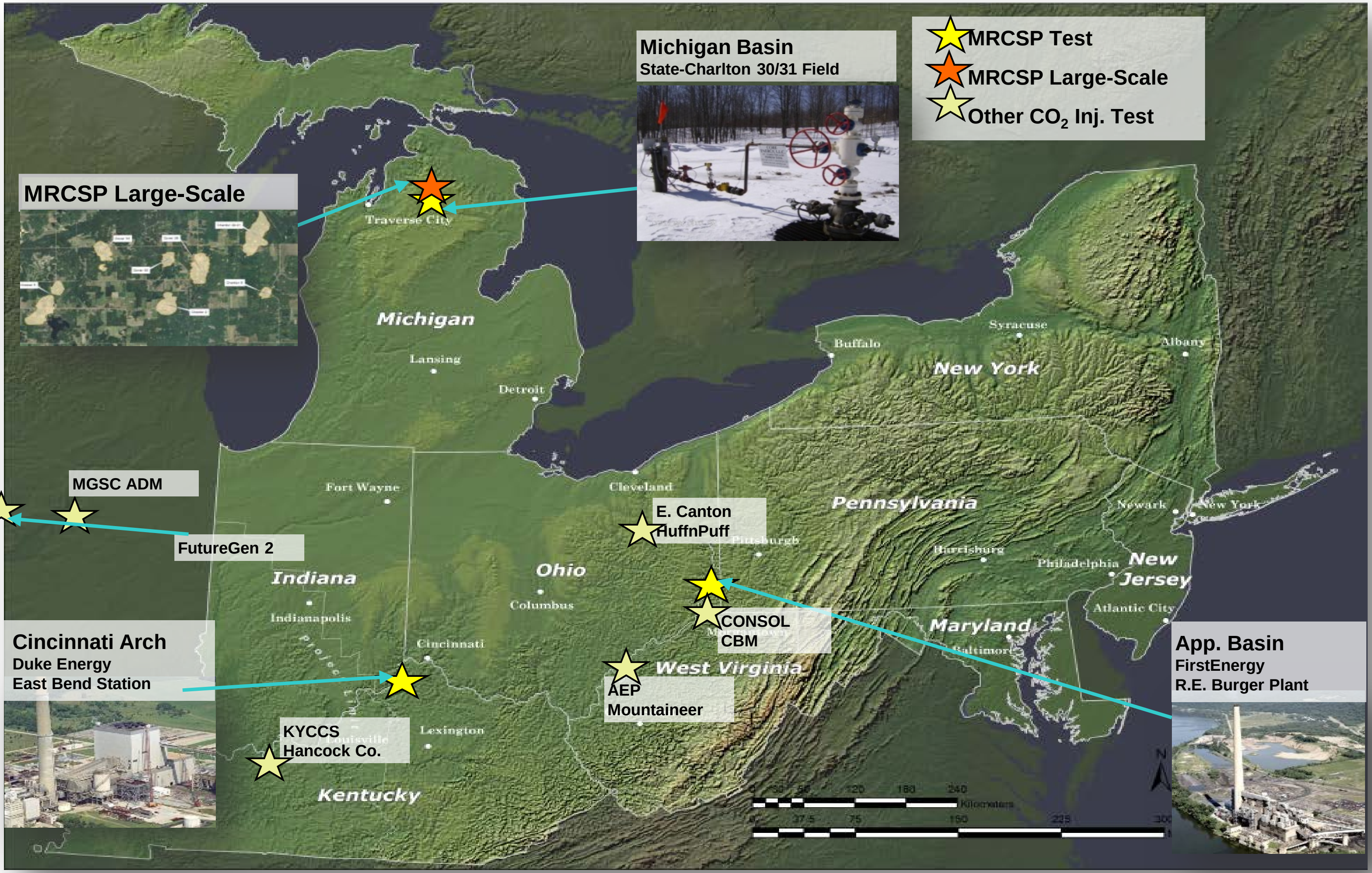


Organic Shales: ~2-30 GT
Unmineable Coal: ~1 GT



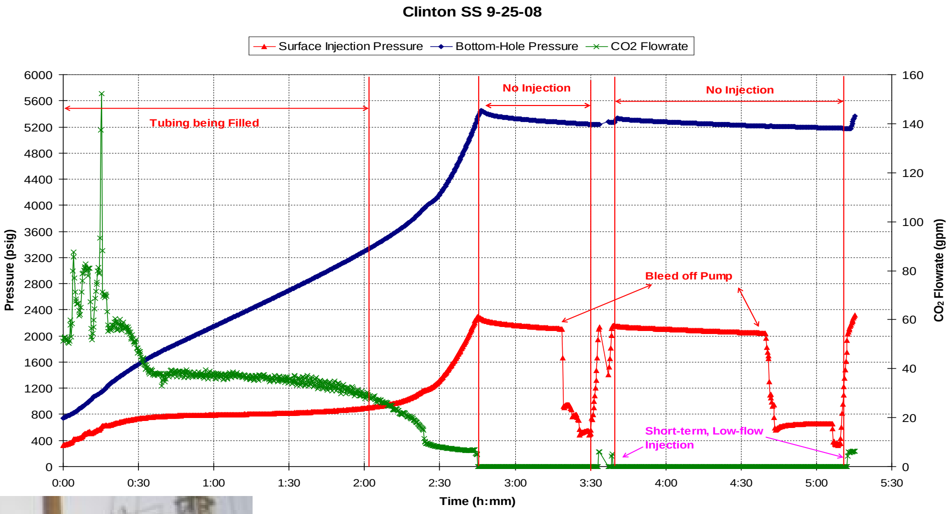
MRCSP region has seen several field tests showing opportunities and challenges

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

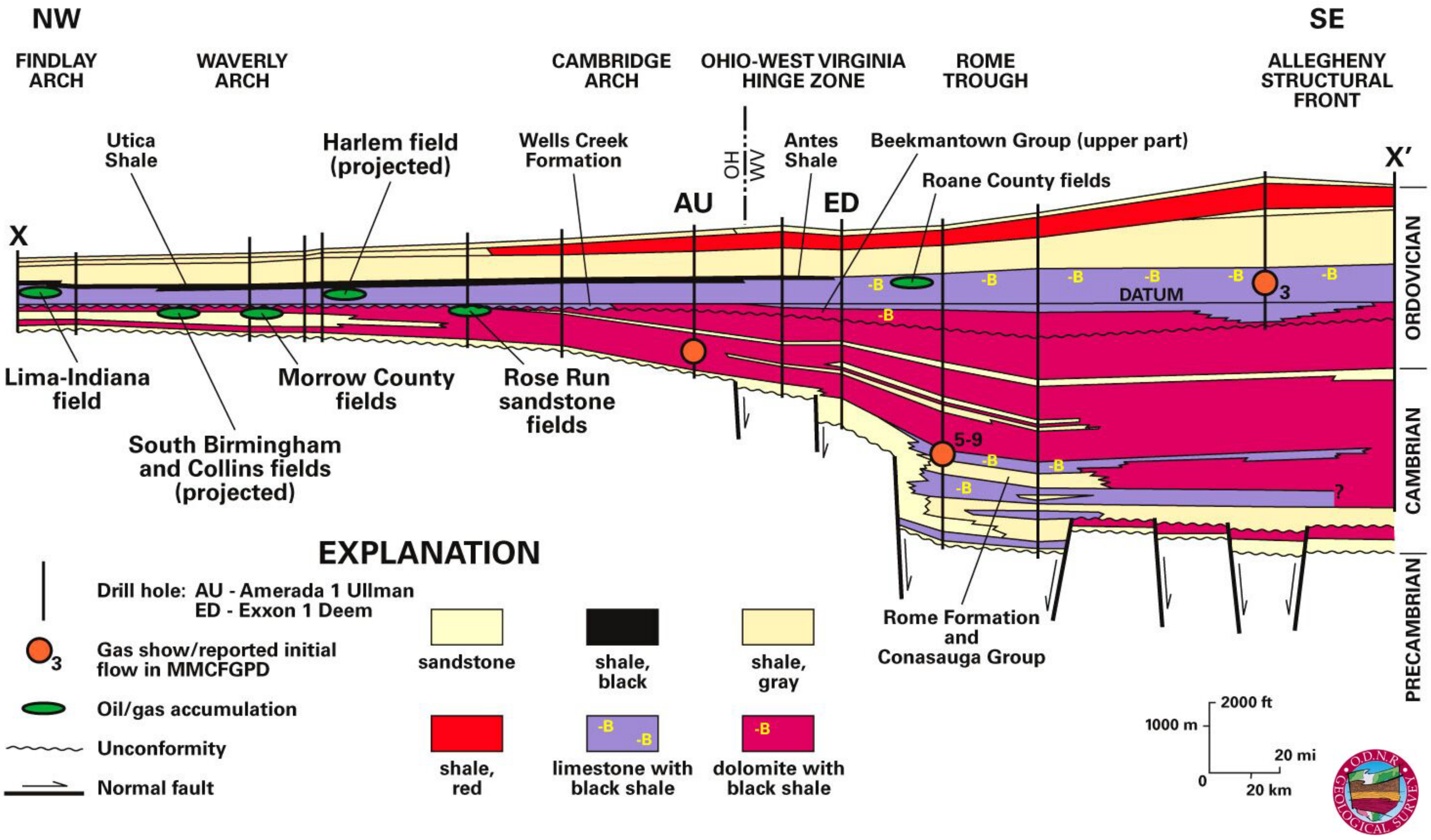
Eastern Ohio Test Site



Clinton Sandstone Test Pressure buildup

Injection Testing, October 2008

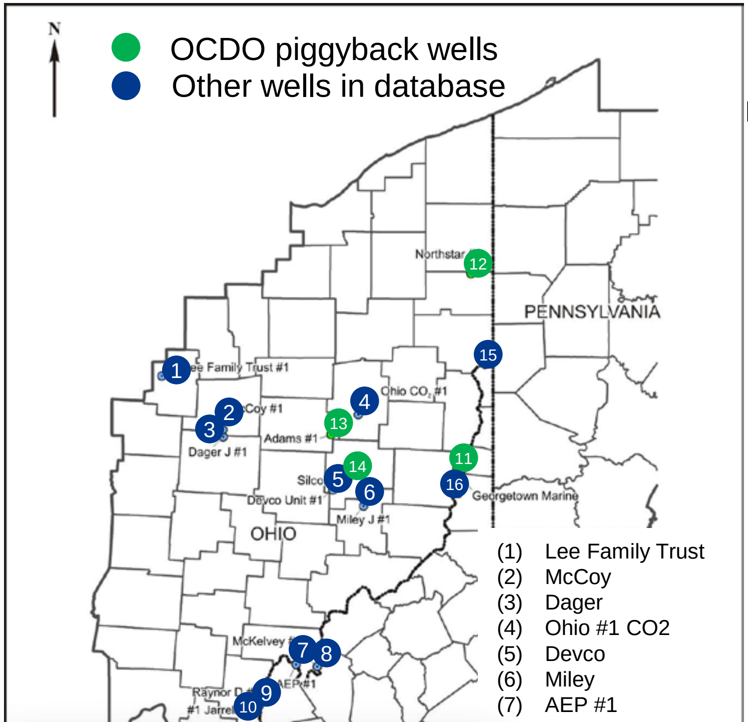
Regional geology mapping with wellbore and seismic data is needed to find storage zones

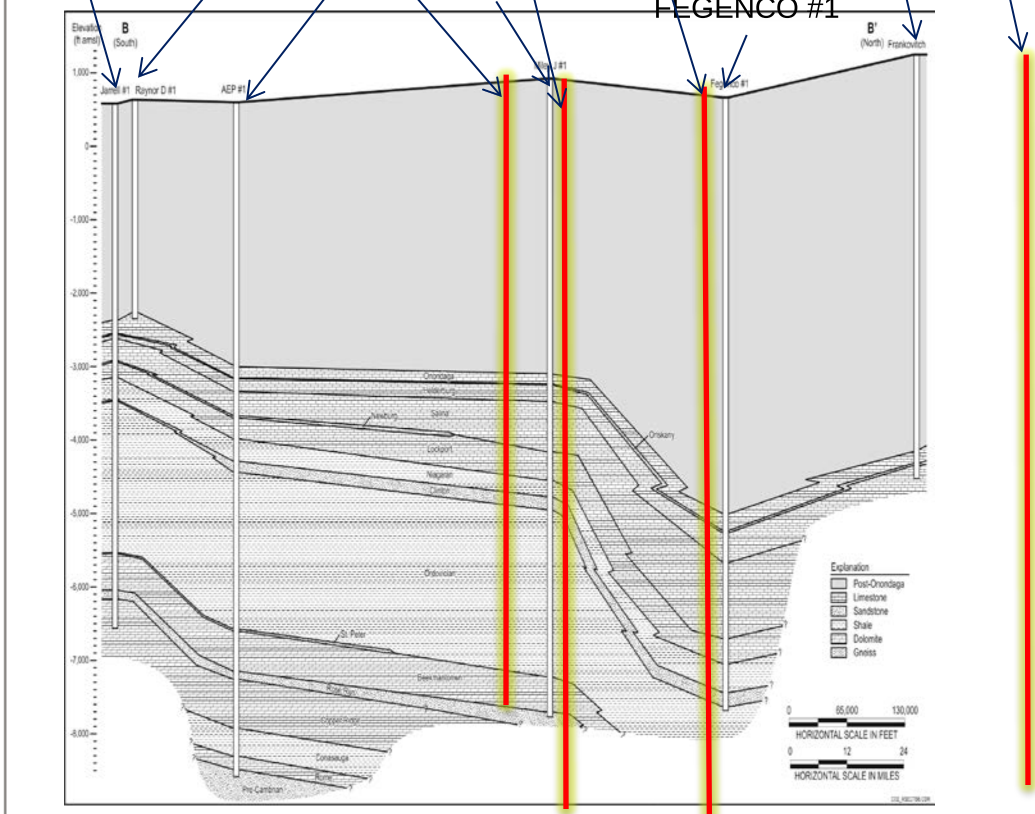


- Extremely low data availability in deeper Appalachian, Michigan, and Illinois Basin

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

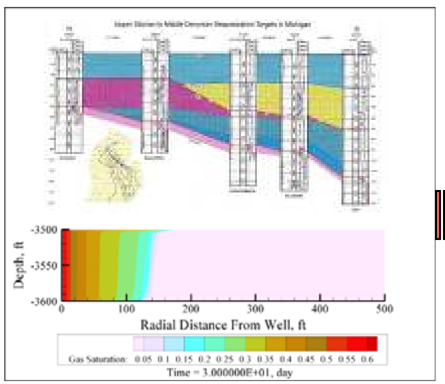




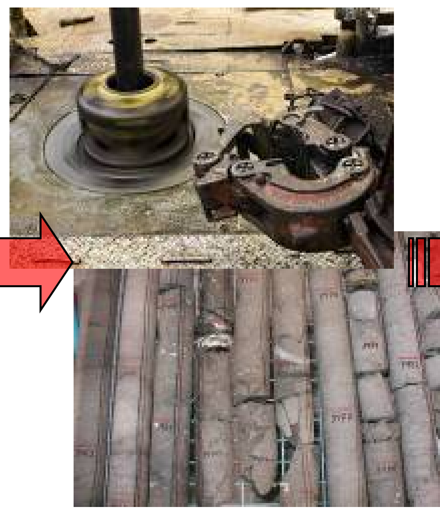
Michigan Phase II site example – Building layers of knowledge

Simulations were calibrated to test data to improve model capabilities and demonstrate confidence in reservoir models.

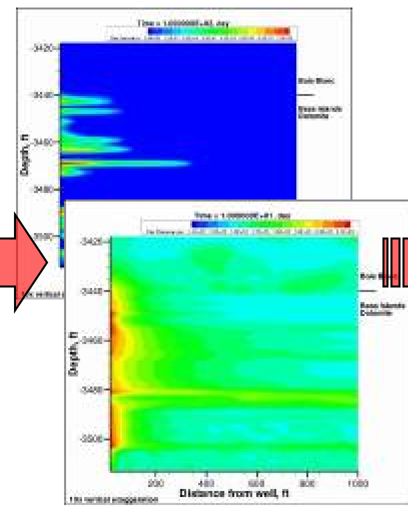
Preliminary Modeling Based on Regional Data



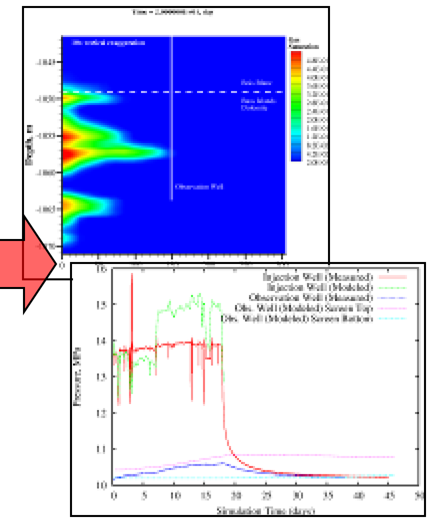
Site Drilling & Testing



Site Specific Modeling



Calibration to Monitoring Data



Measured vs predicted results from falloff test

- 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 CO_2–EOR site in the Midwest

Location:
Otsego County, Michigan

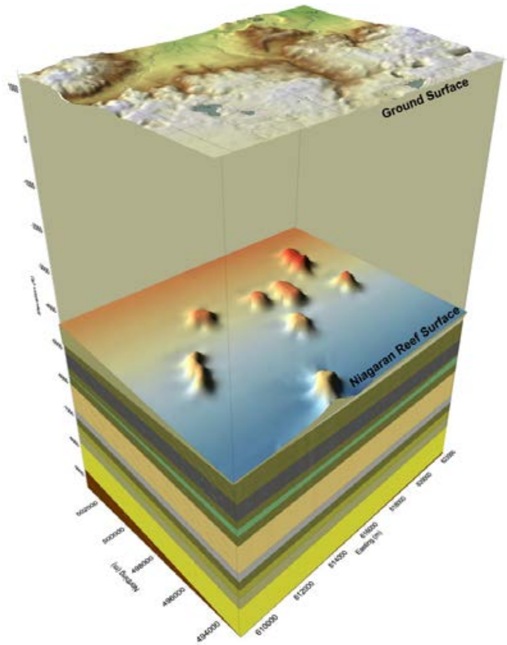
Host Company:
Core Energy LLC

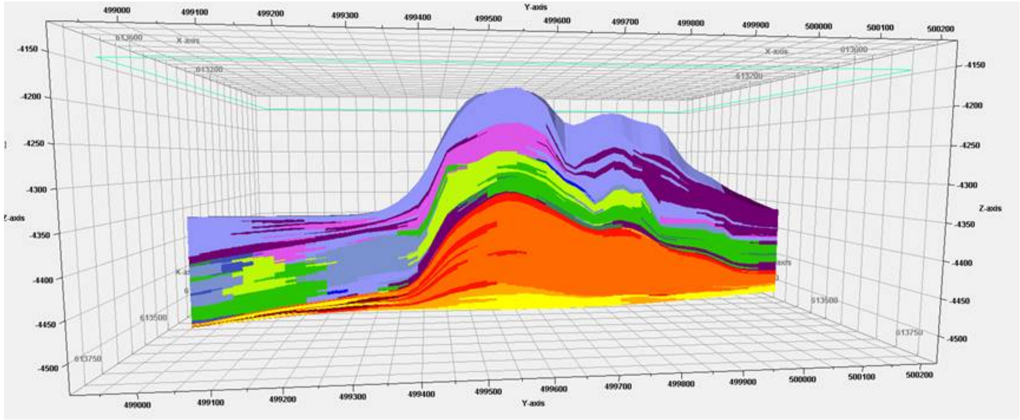
Reservoir Type:
Closely-spaced, highly compartmentalized oil & gas fields located in the Northern Michigan Niagaran Reef Trend

Source of CO_2:
Natural Gas Processing Plant

Injection Goal:
At least 1 million metric tons of CO_2 over ~four years

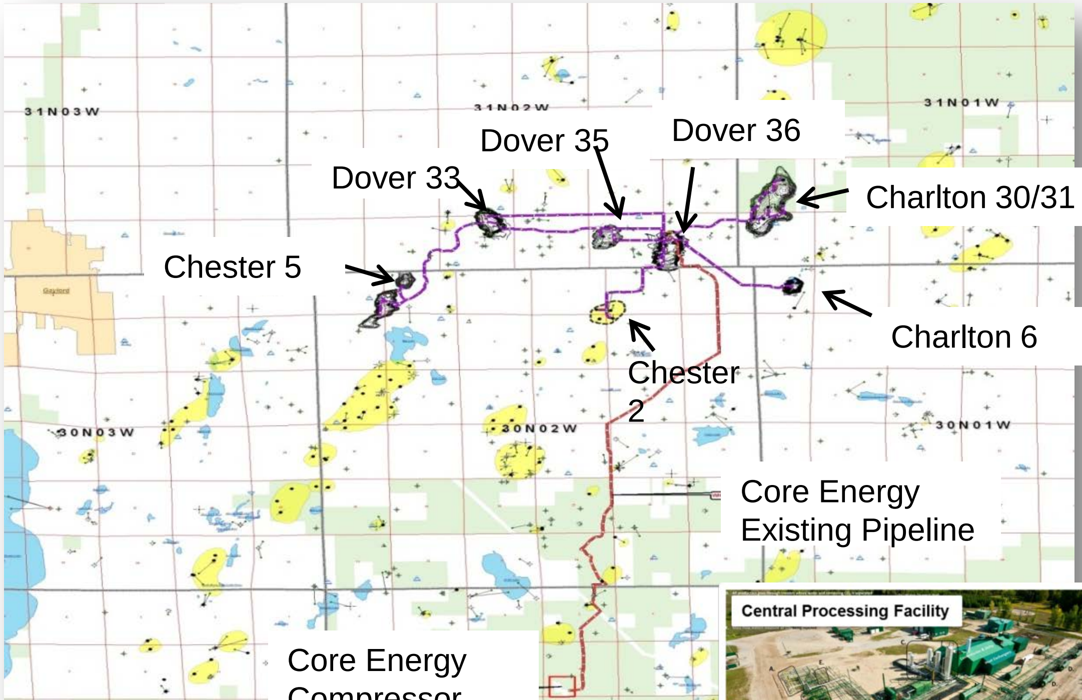
Local Participants:
Western Michigan University





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_2-EOR fields in varying life stages
- MRCSP goal – inject and monitor >1 MMT
- Extensive monitoring and operational assessment underway



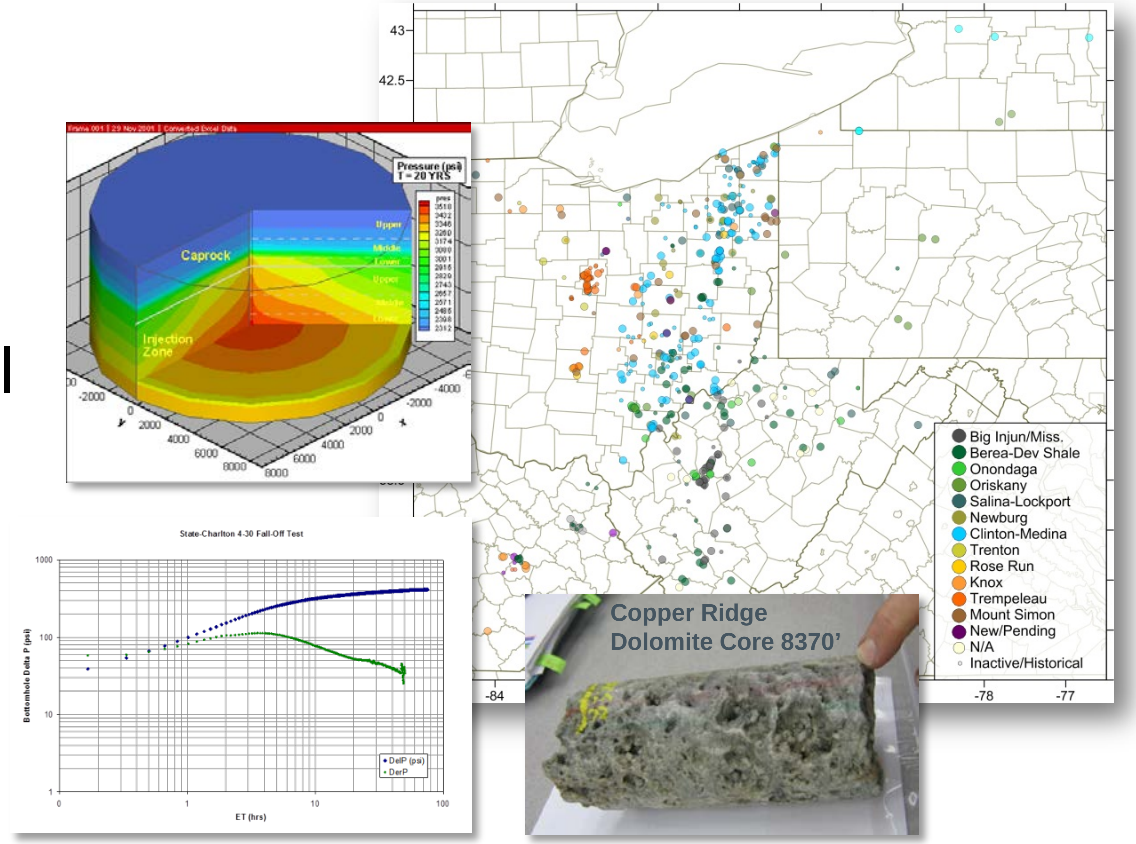
Complexity and cost for siting larger projects can increase substantially

- 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

Battelle
KGS
RPSEA
Research Partnership to Secure Energy for America



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

Lessons Learned Through ... P Activities – ...ns CO_2 Reduction ... Partnership

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

Energy & Environmental Research Center (EERC)…
The International Center for Applied Energy Technology®

EERC Energy & Environmental Research Center® Putting Research into Practice

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."

Lessons Learned – PCOR Partnership (continued)

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.

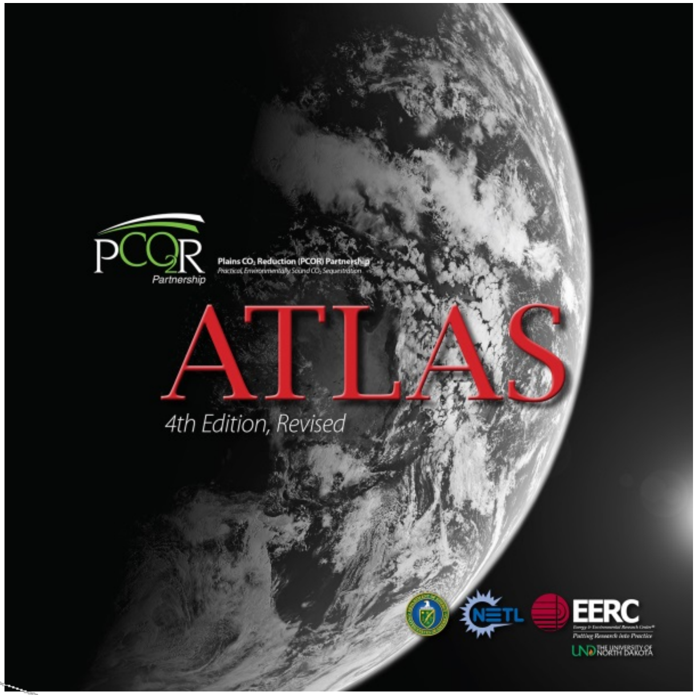
- The geologic, socioeconomic, and legal and regulatory differences across North America are important to carbon capture and storage (CCS).
- The key word is **partnership!** This approach has resulted in 43 states, four Canadian provinces, and 400 entities partnering in the RCSPs and 40 field validation tests and demo projects!

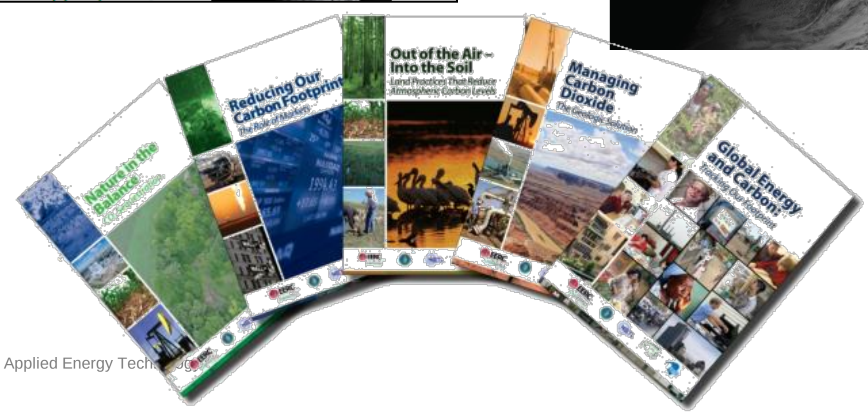
Lessons Learned – PCOR Partnership (continued)

"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."

Lessons Learned – PCOR Partnership (continued)

Lesson 2 – Outreach is very important.



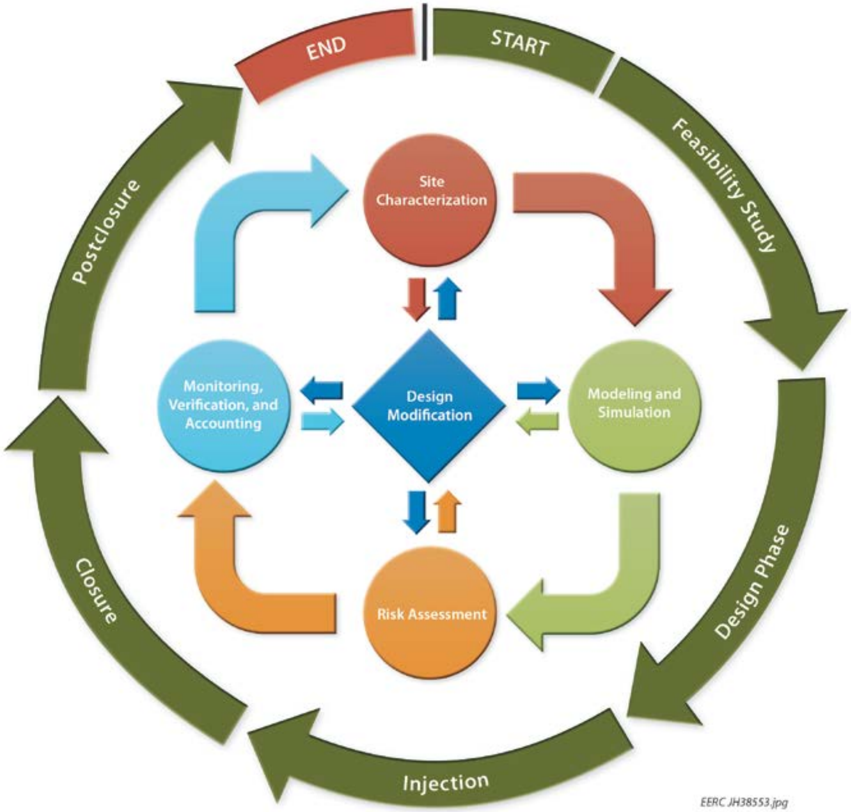


Lessons Learned – PCOR Partnership (continued)

"Timing has a lot to do with the outcome of a rain dance."

Lessons Learned – PCOR Partnership (continued)

Lesson 3 – The most effective approach to MVA (or whatever they call it now) starts with *judicious site selection* and is *iterative*.



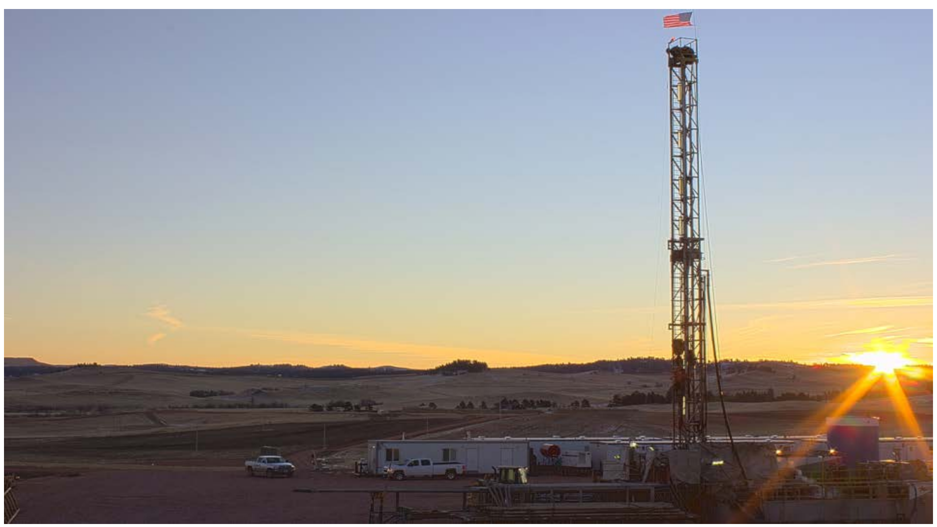
Lessons Learned – PCOR Partnership (continued)

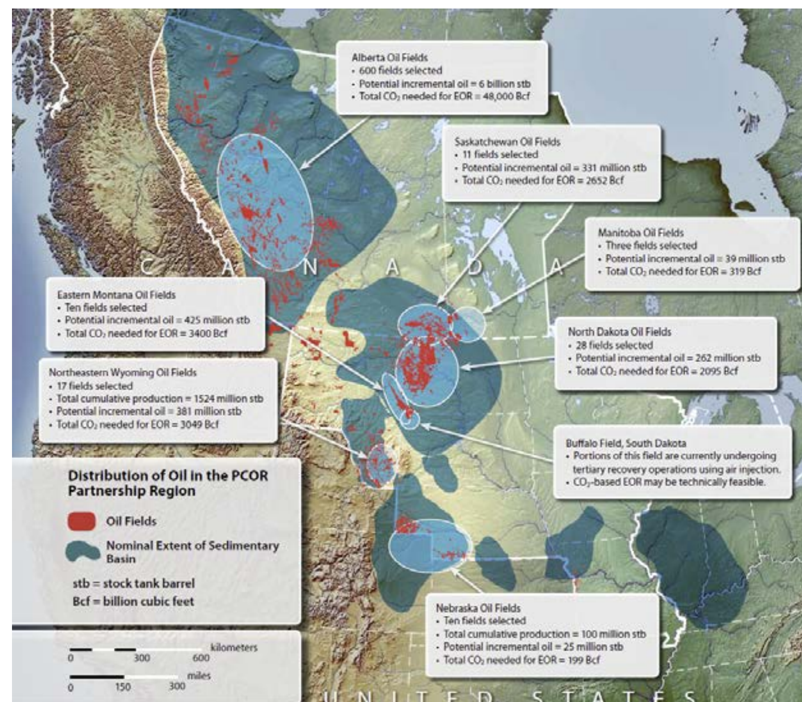
"Behind every successful rancher is a spouse who works in town."

Lessons Learned – PCOR Partnership (continued)

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!

Contact Information

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Ed Steadman, Deputy Associate Director for Research
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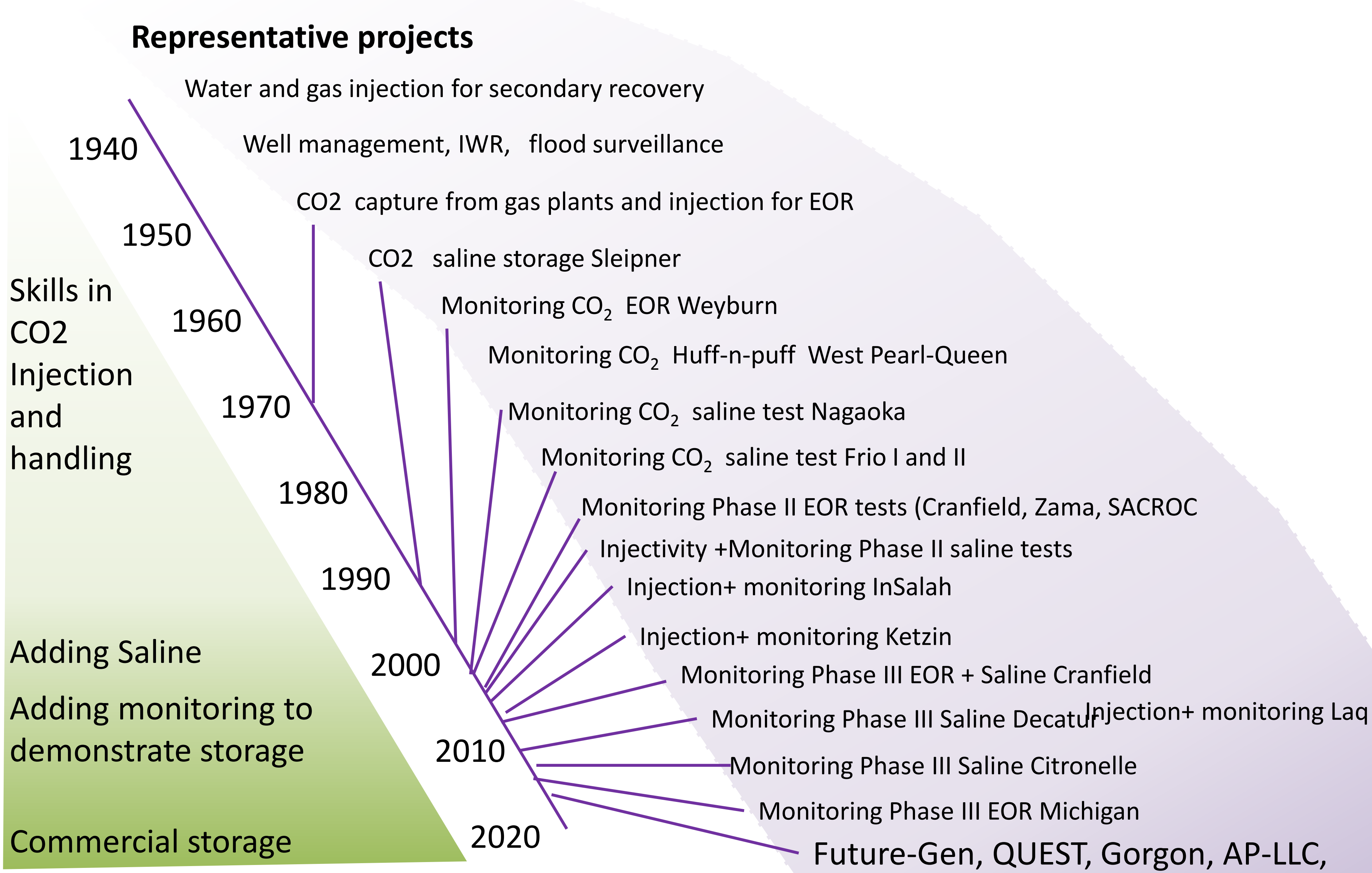
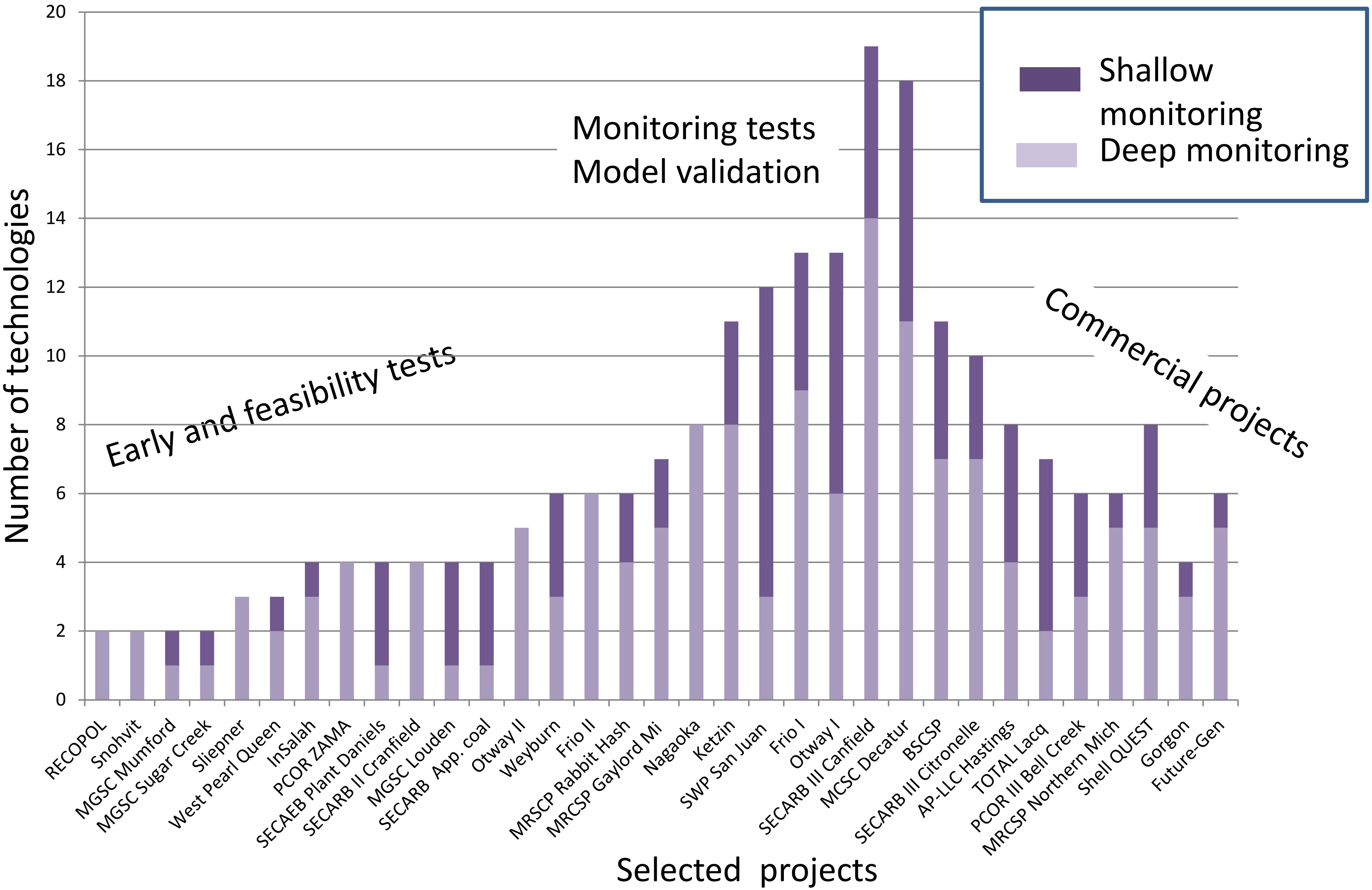
10 Years Progress in the Regional Carbon Sequestration Partnerships – SECARB perspective: R&D to Commercial

Susan Hovorka
Gulf Coast Carbon Center
Bureau of Economic Geology
The University of Texas at Austin

Safe and Effective Injection > 50 years



Amount of Monitoring



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_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?

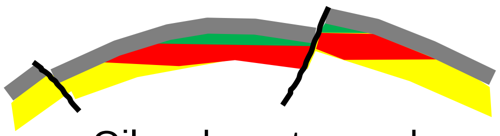
Measure saturation during multiphase plume evolution

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 CO_2 is retained

High confidence in storage permanence through characterization



Oil and gas trapped over geologic time

Material Risk of failing to retain

Uncertainty and risk assessment → Semi-quantitative assessment via Certification Framework

Research Questions

P&A well performance in retention?

Limited analogy between injected and natural fluid retention

Off structure migration?

Response to pressure elevation?

Selected assessment approach

shallow

Well-pad vadose gas

Ground water chem.

AZMI pressure

4-D Seismic

4-D VSP

IZ pressure

Microseismic

deep

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.

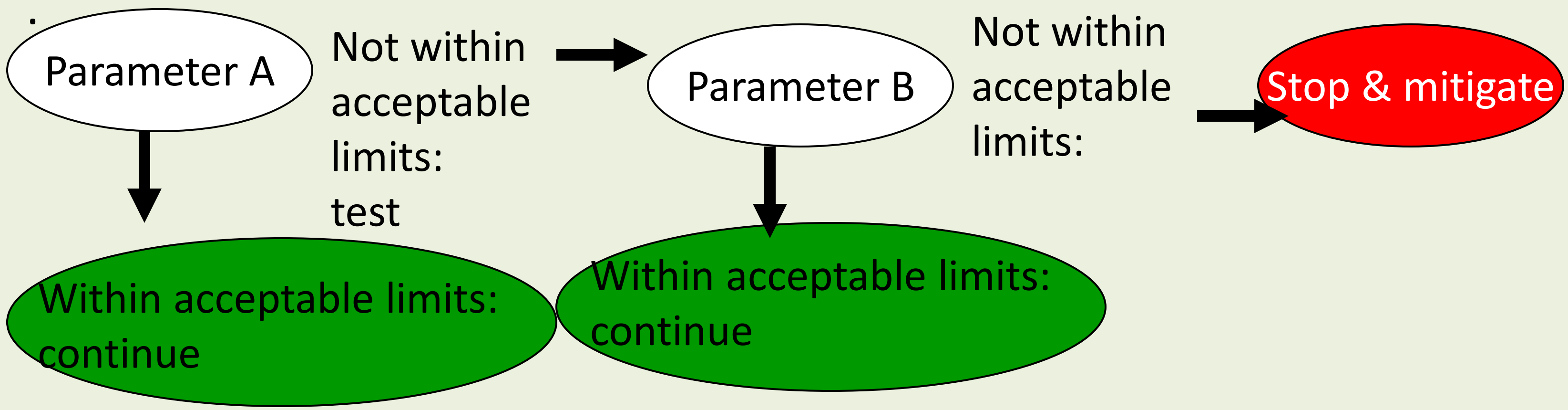
Commercial Monitoring

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



Outline

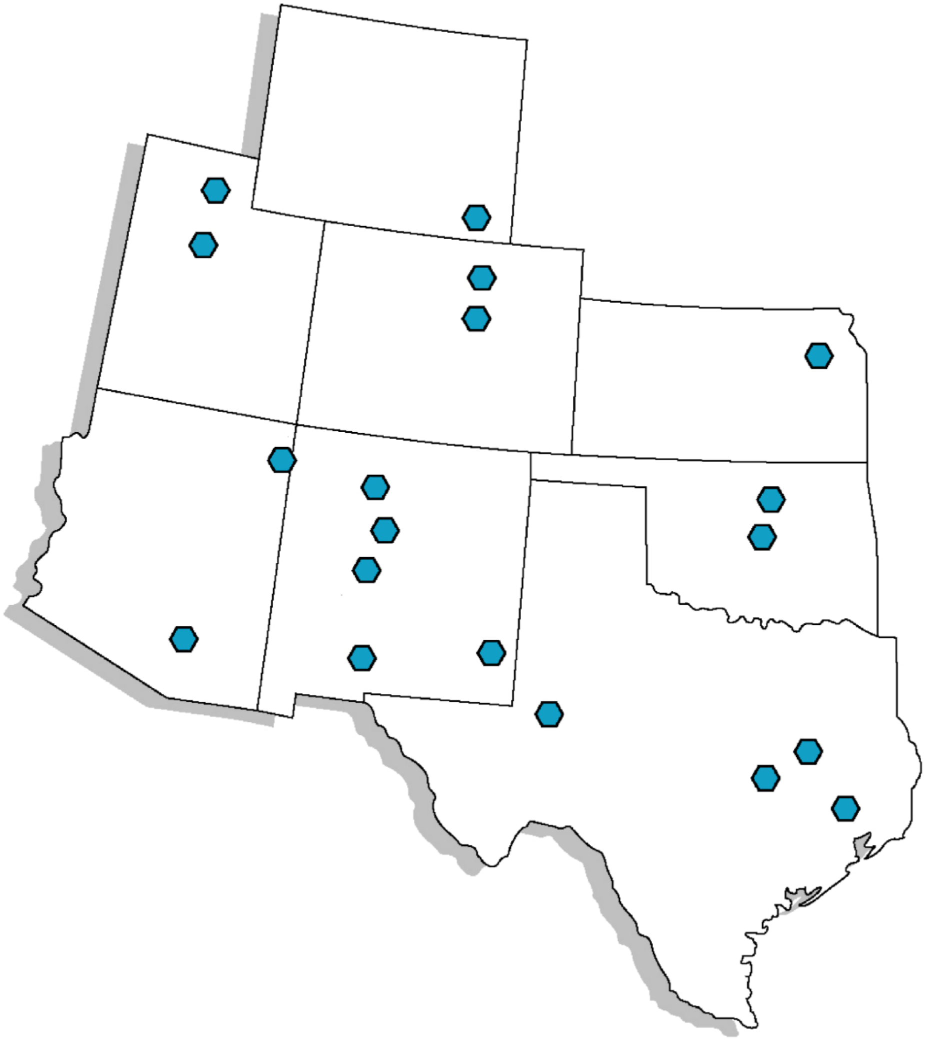
Southwest Partnership Field Tests

Selected Lessons Learned:

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

(2) Difficulty of predicting geomechanical processes

The Southwest Carbon Sequestration Partnership



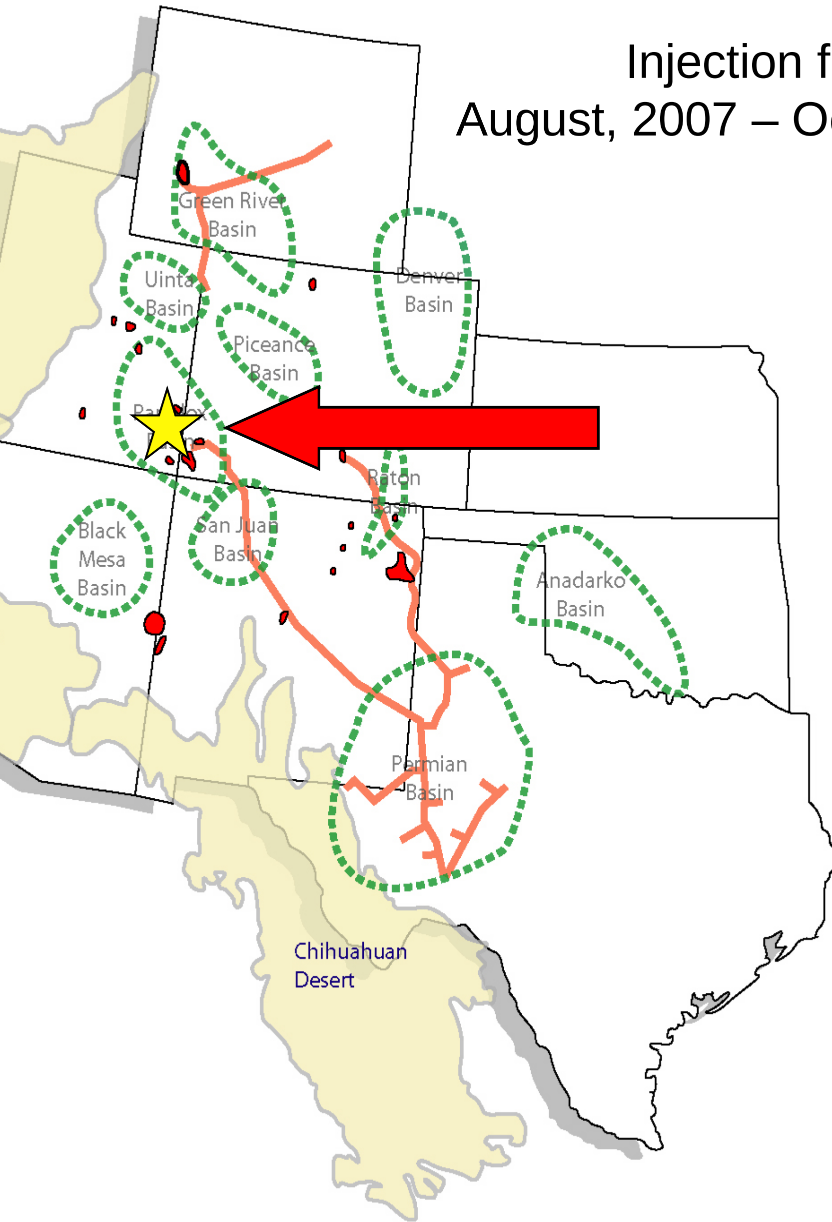
In all partner states:

- major universities
- geologic survey
- other state agencies

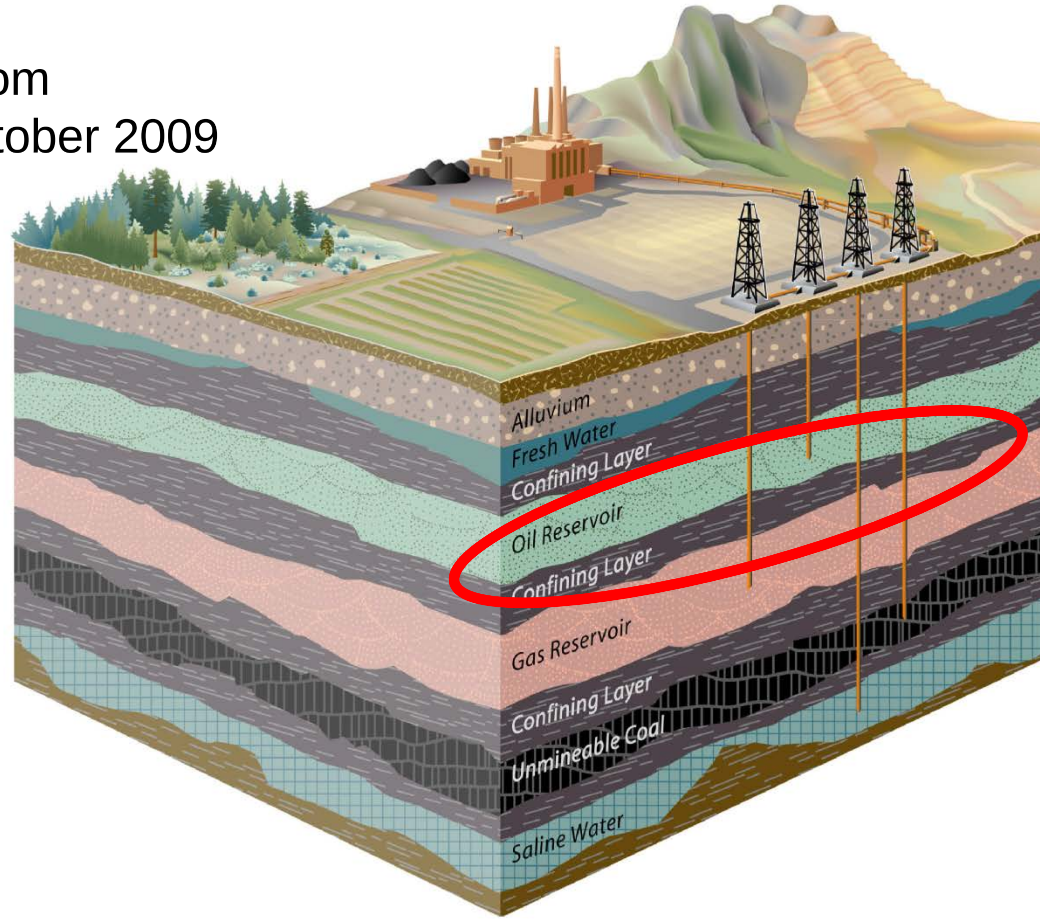
as well as

- Western Governors Association
- five major utilities
- seven energy companies
- three federal agencies
- the Navajo Nation
- many other critical partners

SWP Field Test Portfolio



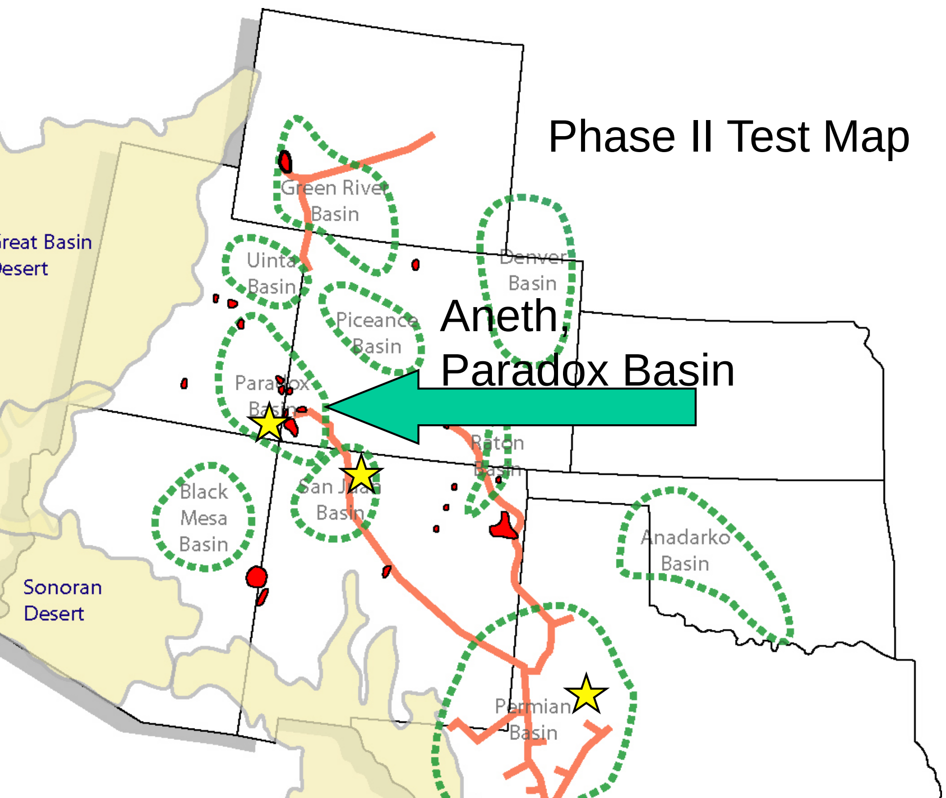
Injection from
August, 2007 – October 2009



Paradox Basin, Utah: 150,000 tons/year

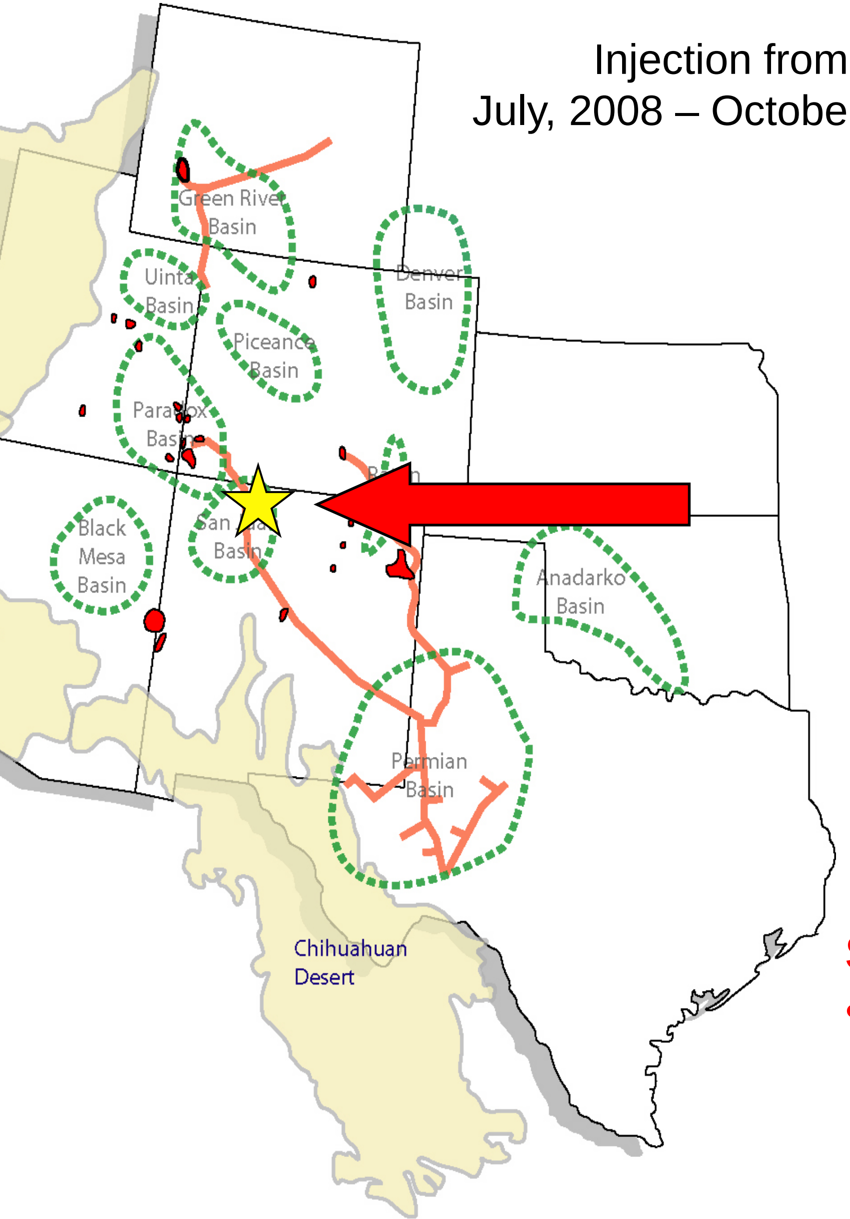
- **Combined enhanced oil recovery with sequestration**

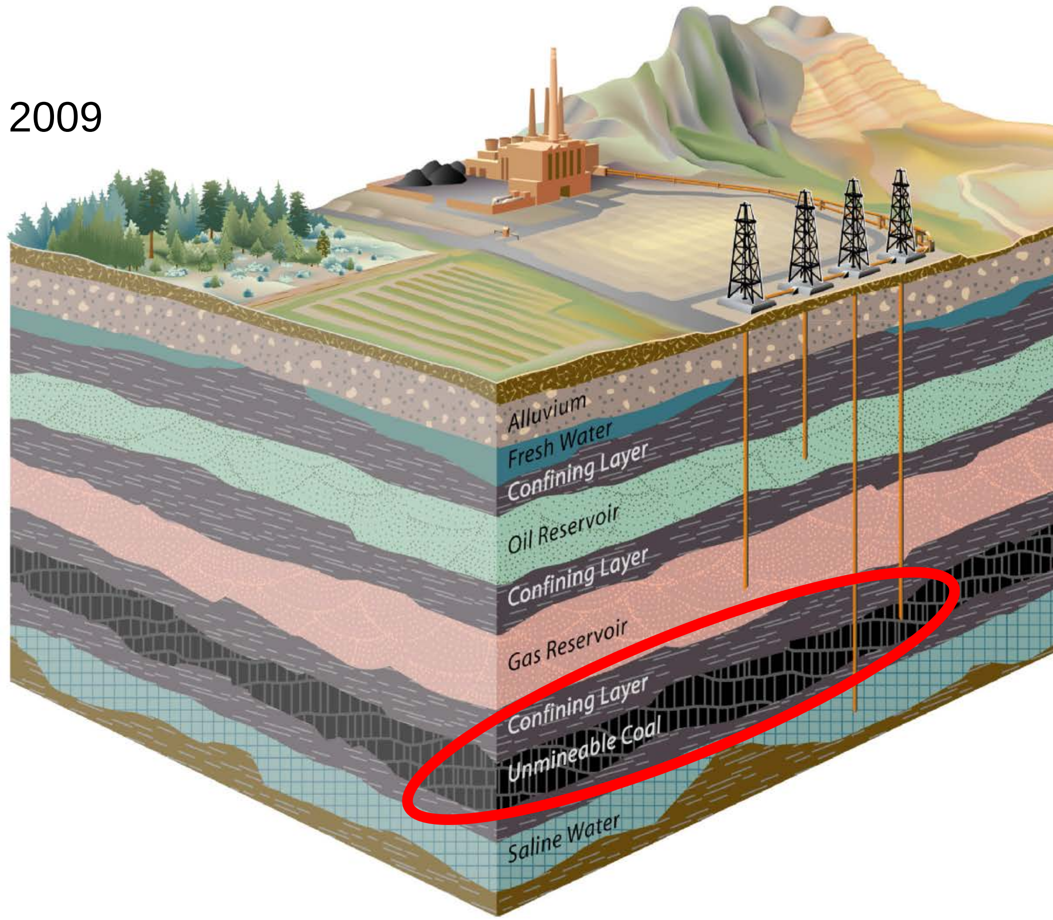
SWP
Field Test Portfolio



SWP Field Test Portfolio

Injection from
July, 2008 – October 2009



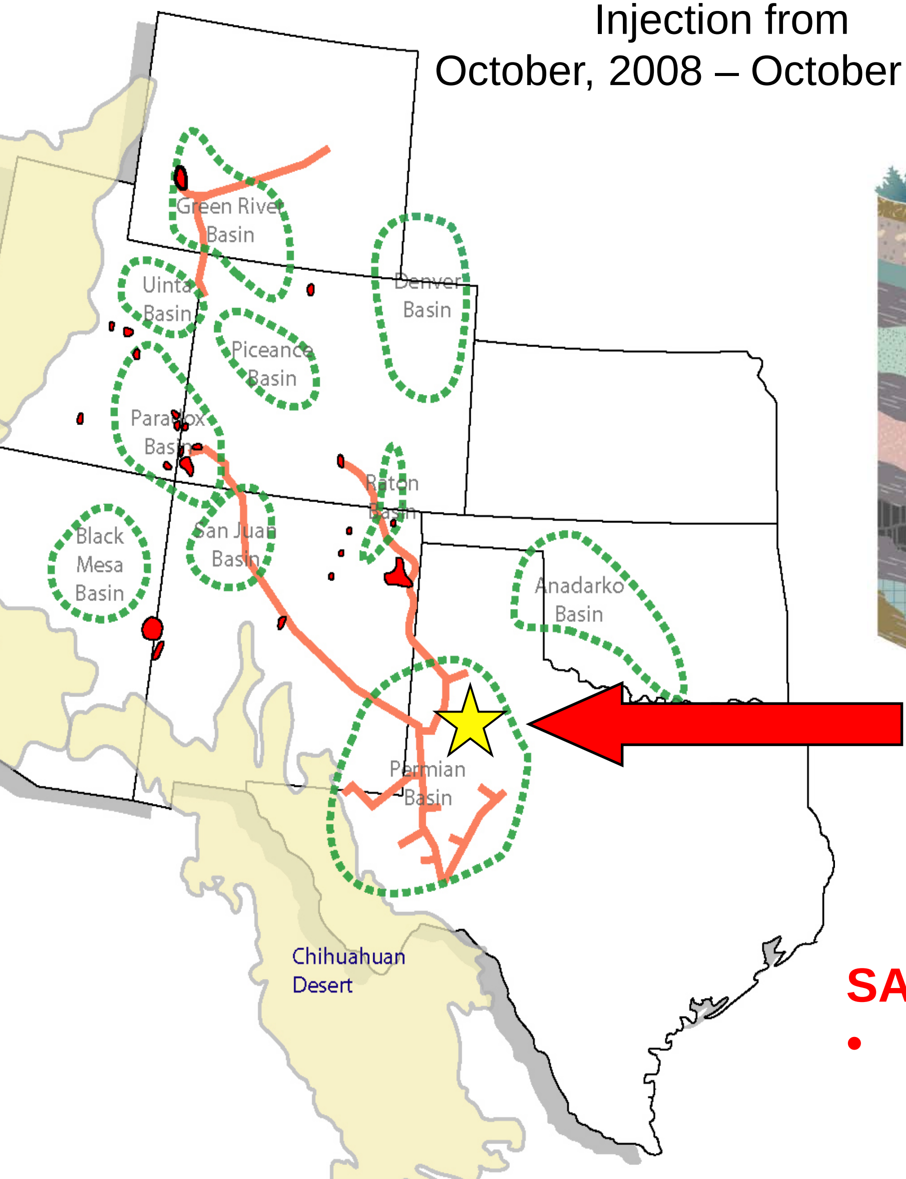


San Juan Basin, NM: 75,000 tons/year

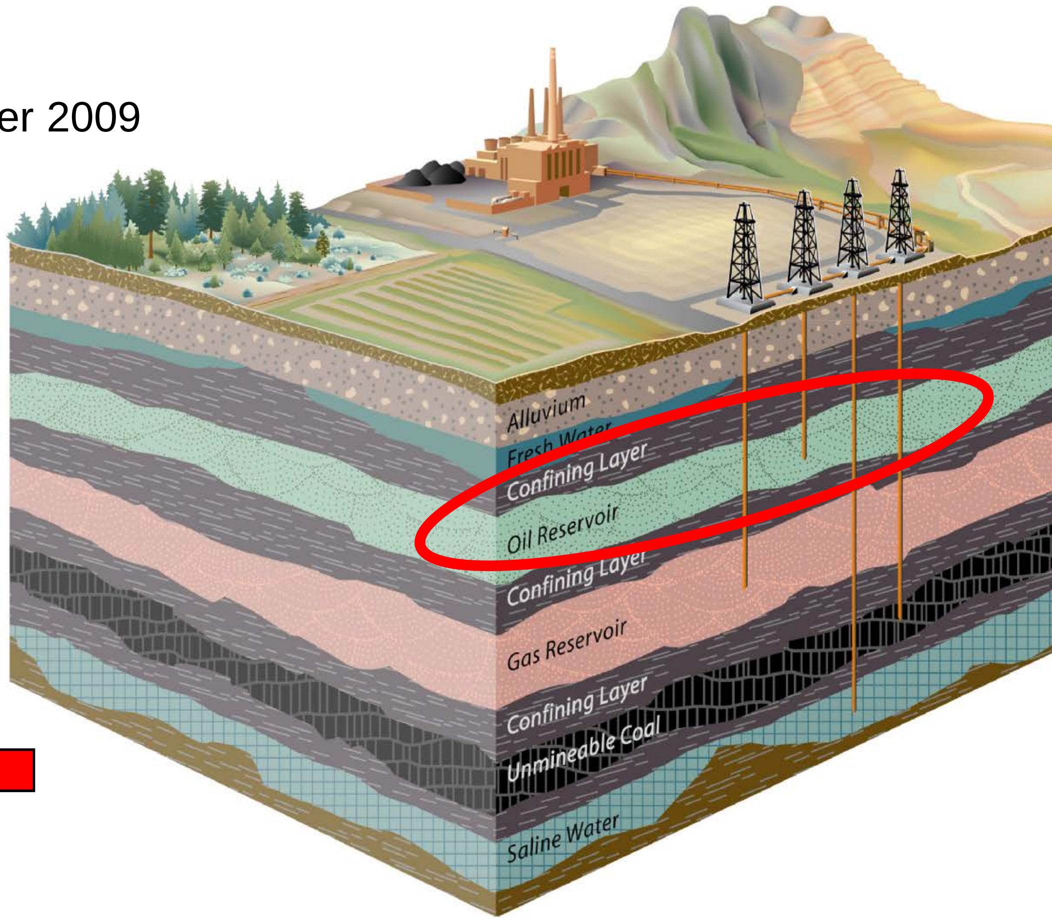
- **Combined enhanced coalbed methane recovery with sequestration**


Injection from
July, 2008 – October 2009
Field Site

SWP Field Test Portfolio



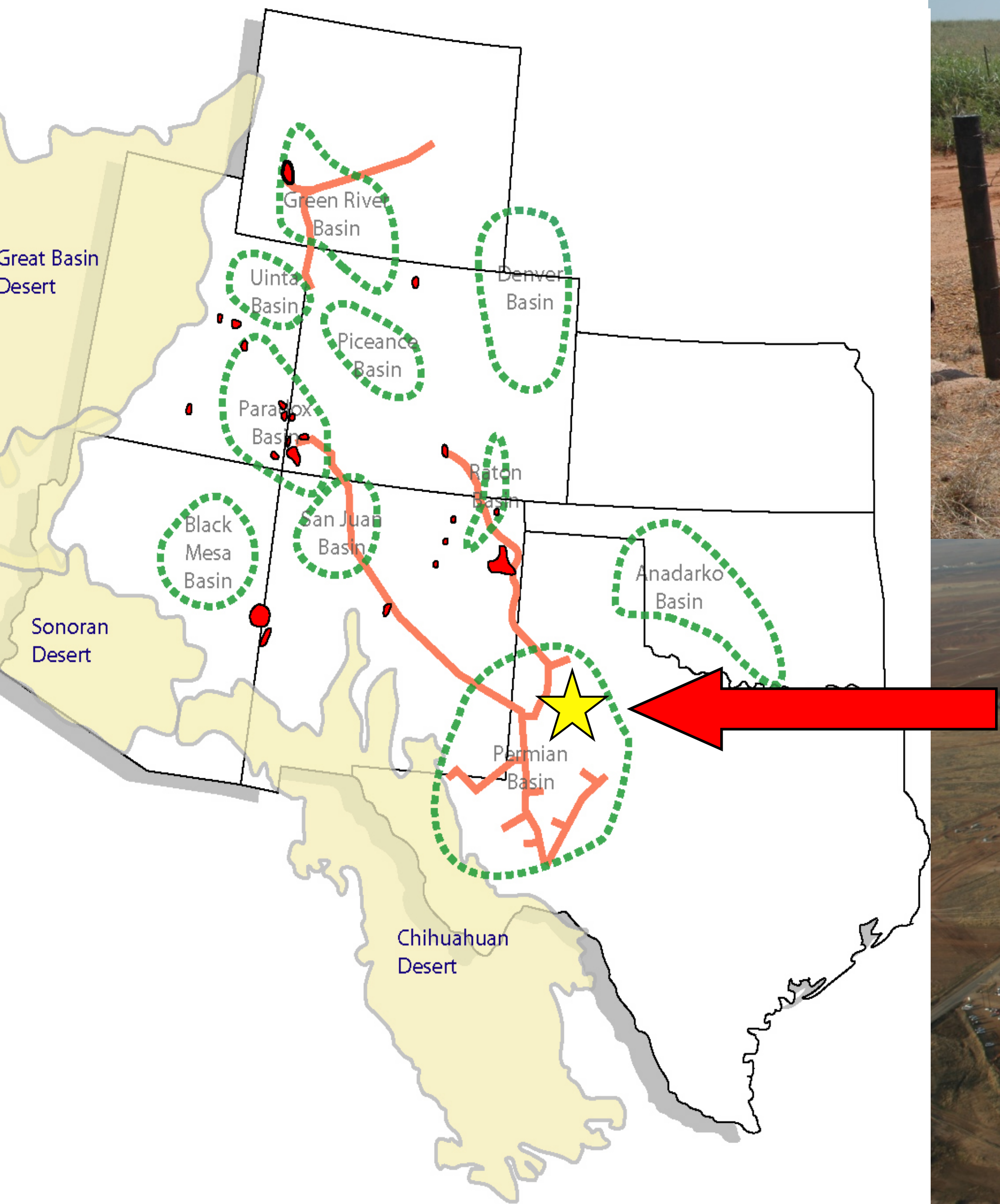
Injection from
October, 2008 – October 2009



SACROC Unit, Texas: >350,000 tons/year

- **Combined enhanced oil recovery with sequestration**

SACROC Injection Test



Outline

Southwest Partnership Field Tests

Selected Lessons Learned:

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

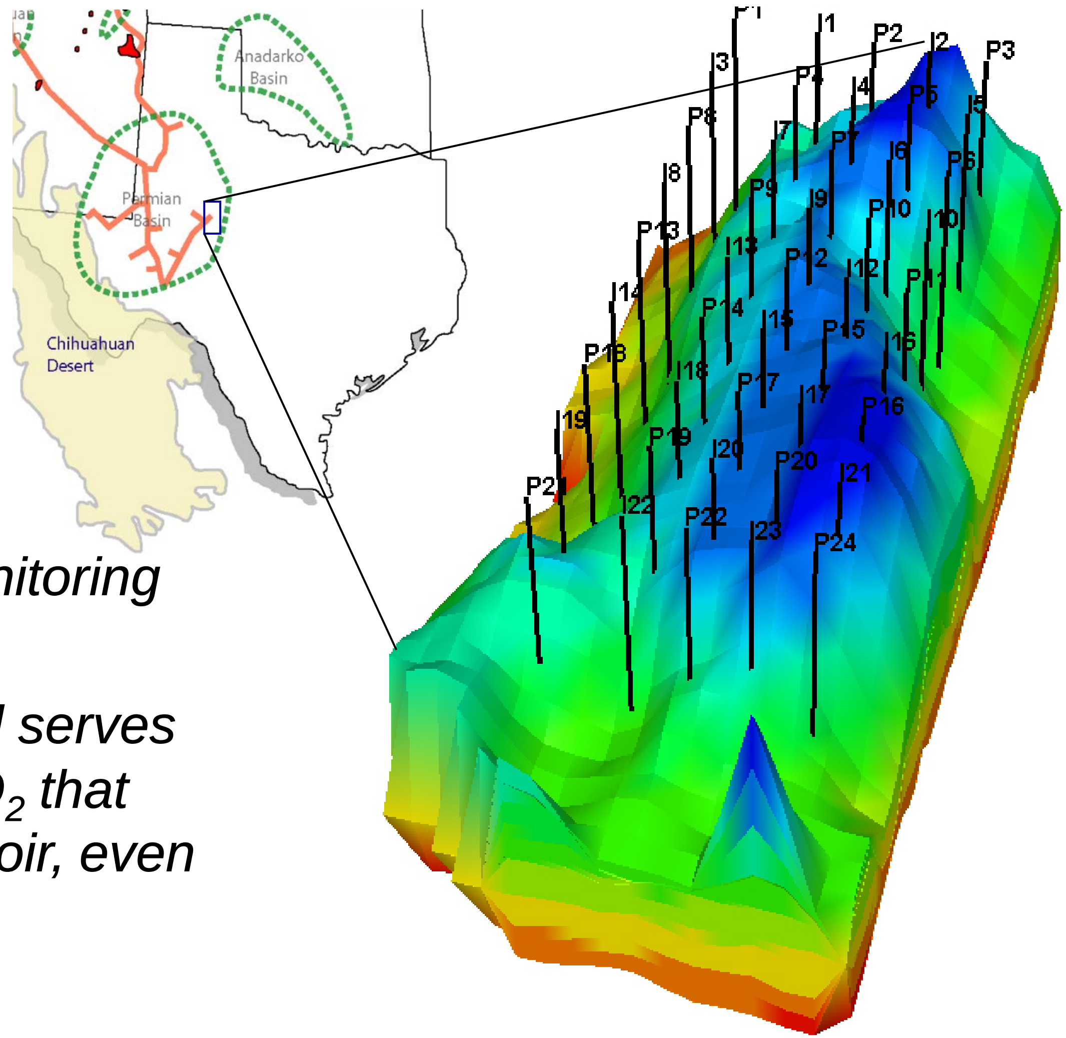
(2) Difficulty of predicting geomechanical processes

Benefit of Deep Saline Storage Under Oil Fields

Injection and storage in deep saline units UNDERNEATH oil/gas fields is promising because:

- *existing infrastructure for delivering CO_2*
- *existing infrastructure for monitoring*
- *in oil fields specifically, the oil serves as a "catchers mitt" of any CO_2 that makes its way to the oil reservoir, even at low oil saturations*

SACROC (north platform)



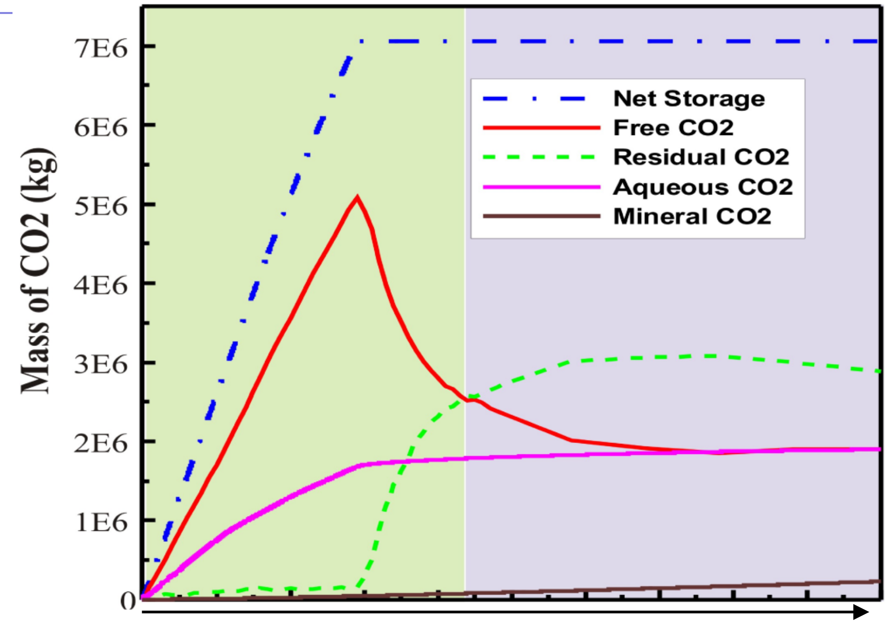
15,470 elements

Benefit of Deep Saline Storage Under Oil Fields

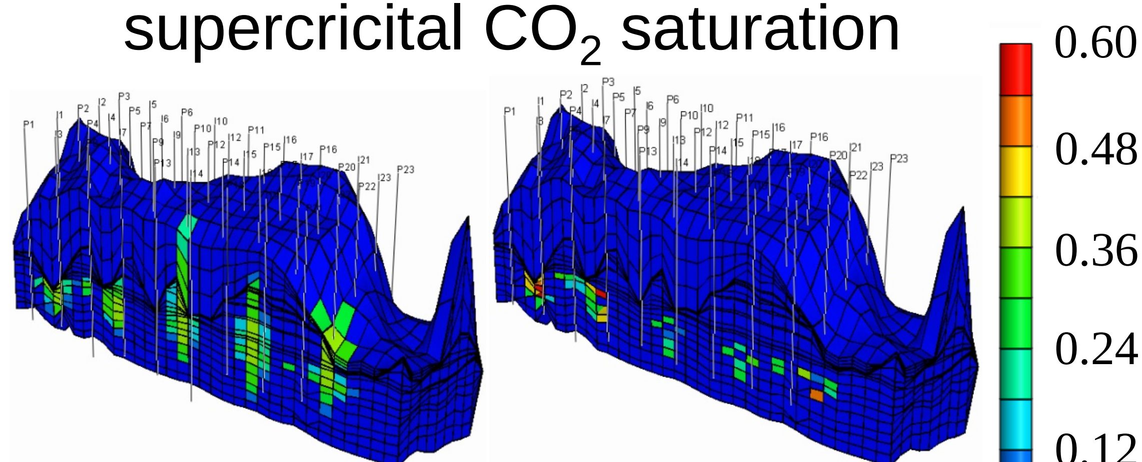
Injection and storage in deep saline units UNDERNEATH oil/gas fields is promising because:

- *existing infrastructure*

- *in oil fields specifically, the oil dissolves CO_2 that makes its way to the oil reservoir, even at low oil saturations*



supercricital CO_2 saturation



without oil | with oil

Outline

Southwest Partnership Field Tests

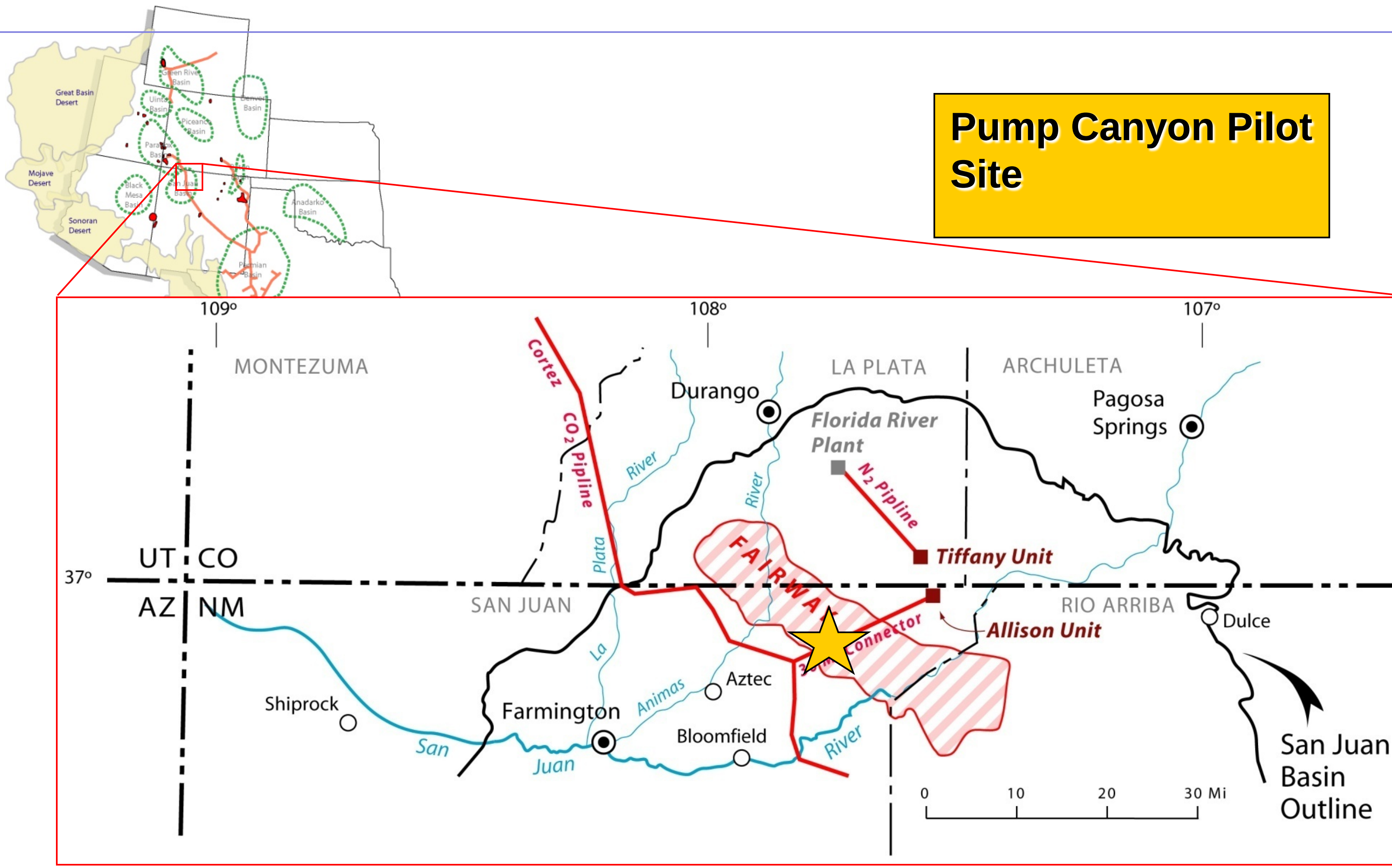
Selected Lessons Learned:

(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)

Hydrogeomechanical Impacts: Coal Swelling

Geertsma (1973) proposed an analytical equation for surface displacement associated with subsurface coal swelling:

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

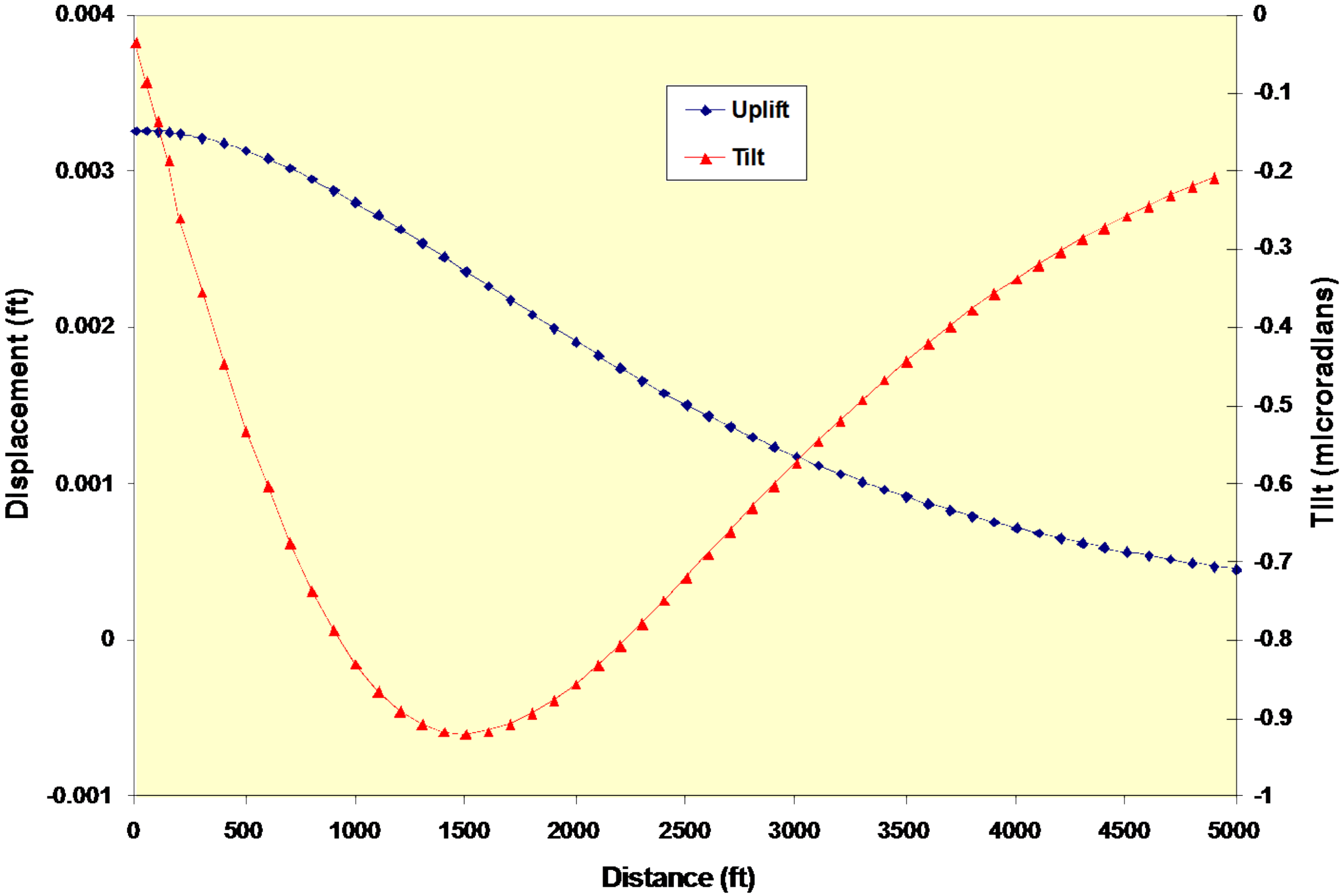
And Eason (1955) provides a solution for an equation of this form:

$$u_z = -2c_m(1-\nu)\Delta pH\begin{cases} \dfrac{-k\eta}{4\sqrt{\rho}}F_o(k)-\dfrac{1}{2}\Lambda_o(k,p)+1 & \rho<1 \\ \dfrac{-k\eta}{4}F_o(k)+\dfrac{1}{2} & \rho=1 \\ \dfrac{-k\eta}{4\sqrt{\rho}}F_o(k)+\dfrac{1}{2}\Lambda_o(k,p) & \rho>1 \end{cases}$$

J_x = Bessels functions
F_o and Λ_o = elliptic integrals

Hydrogeomechanical Impacts: Coal Swelling

A plot of this analytical solution:



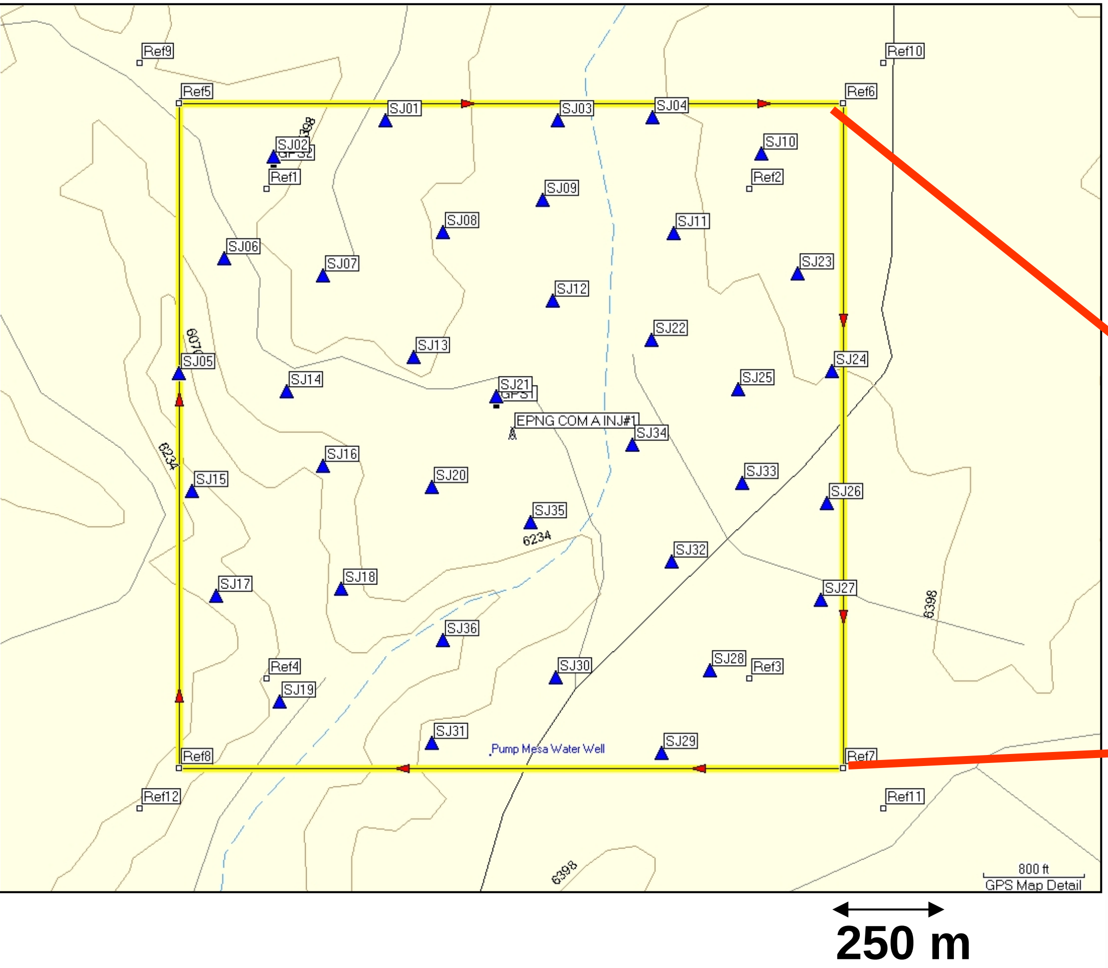
Suggesting that this tilt should be detectable at the surface:

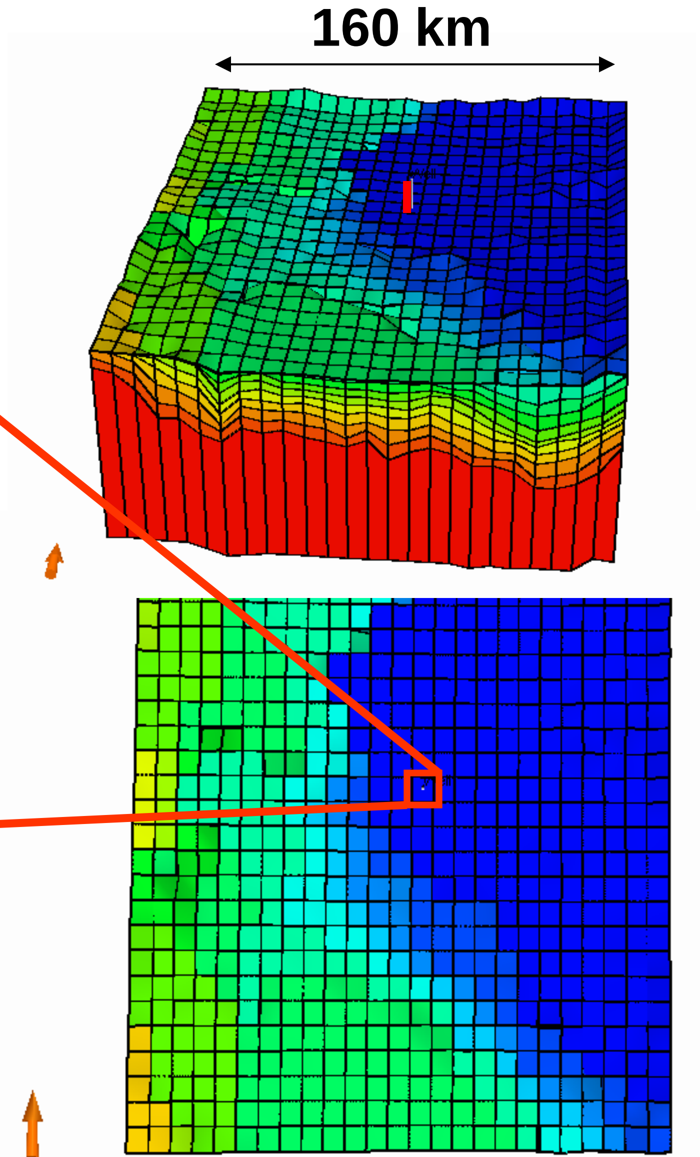
tiltmeters

Analysis and Plot by Norm Warpinski, Pinnacle Technologies

Hydrogeomechanical Impacts:
Coal Swelling

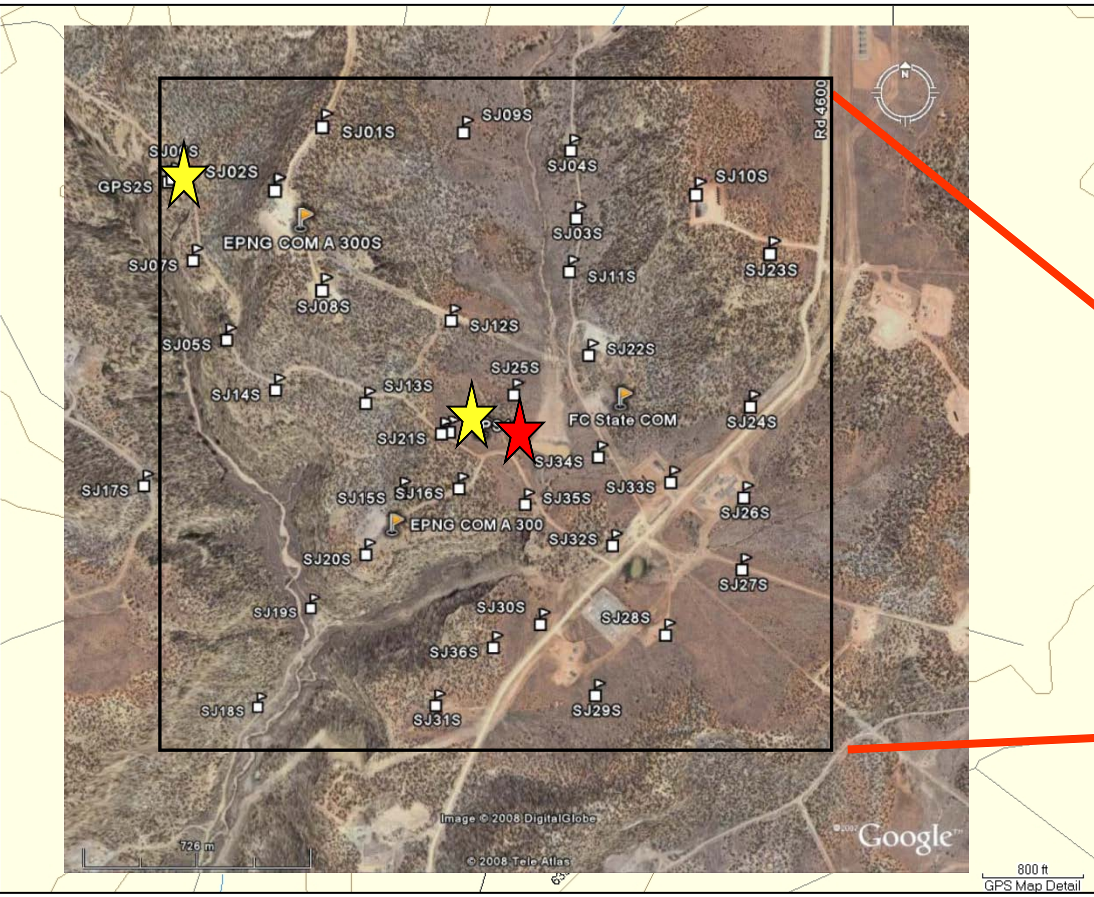
Tiltmeter array deployed :



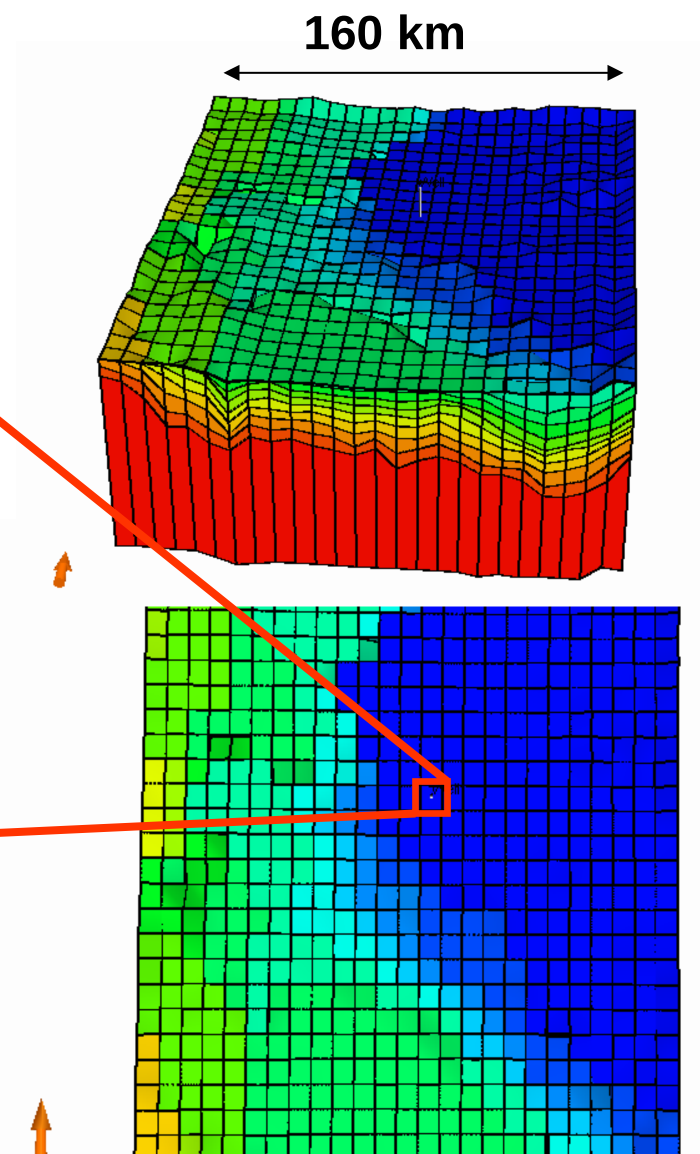


Hydrogeomechanical Impacts: Coal Swelling

Tiltmeter array deployed :



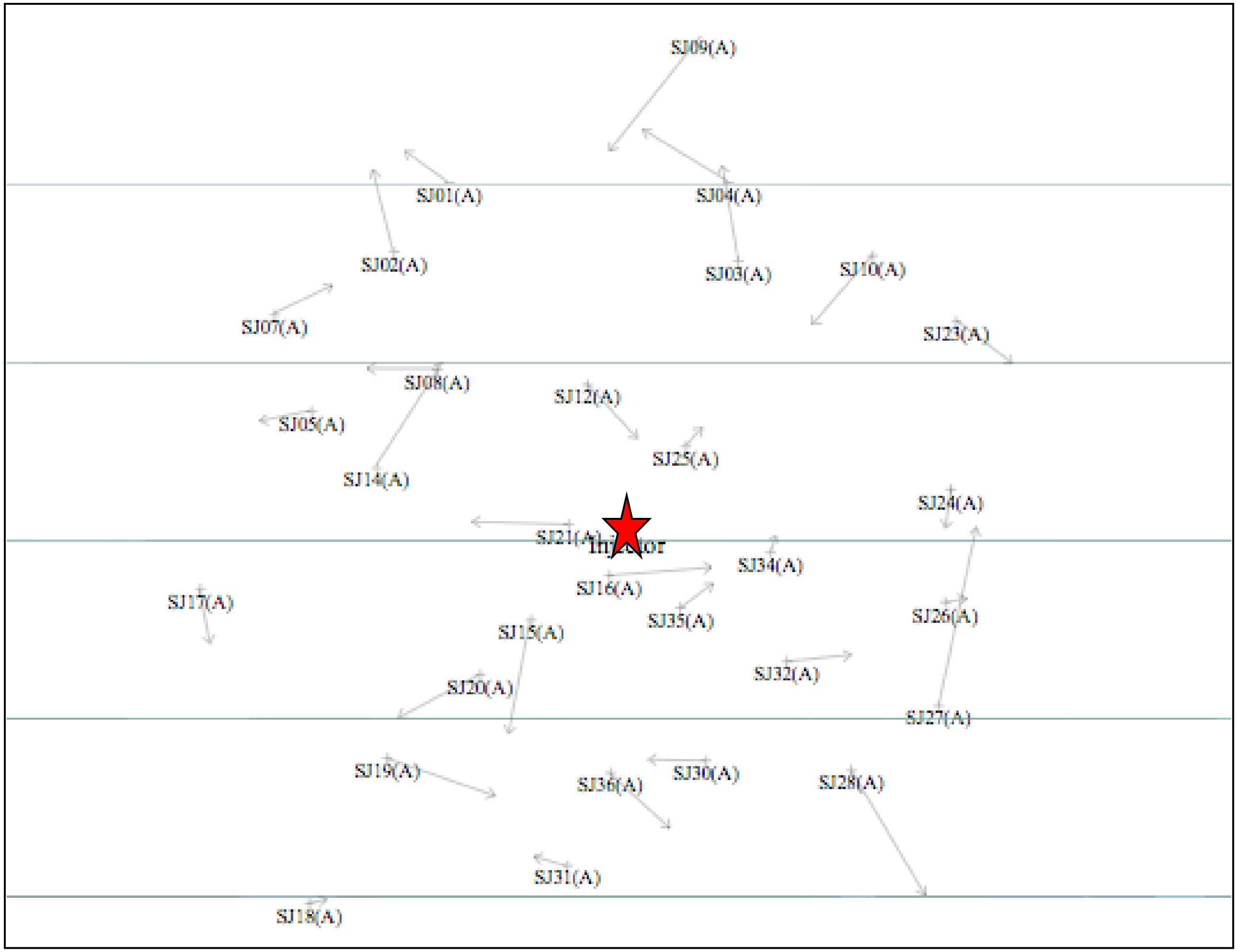
250 m



GPS Reference Sites

Injection Well

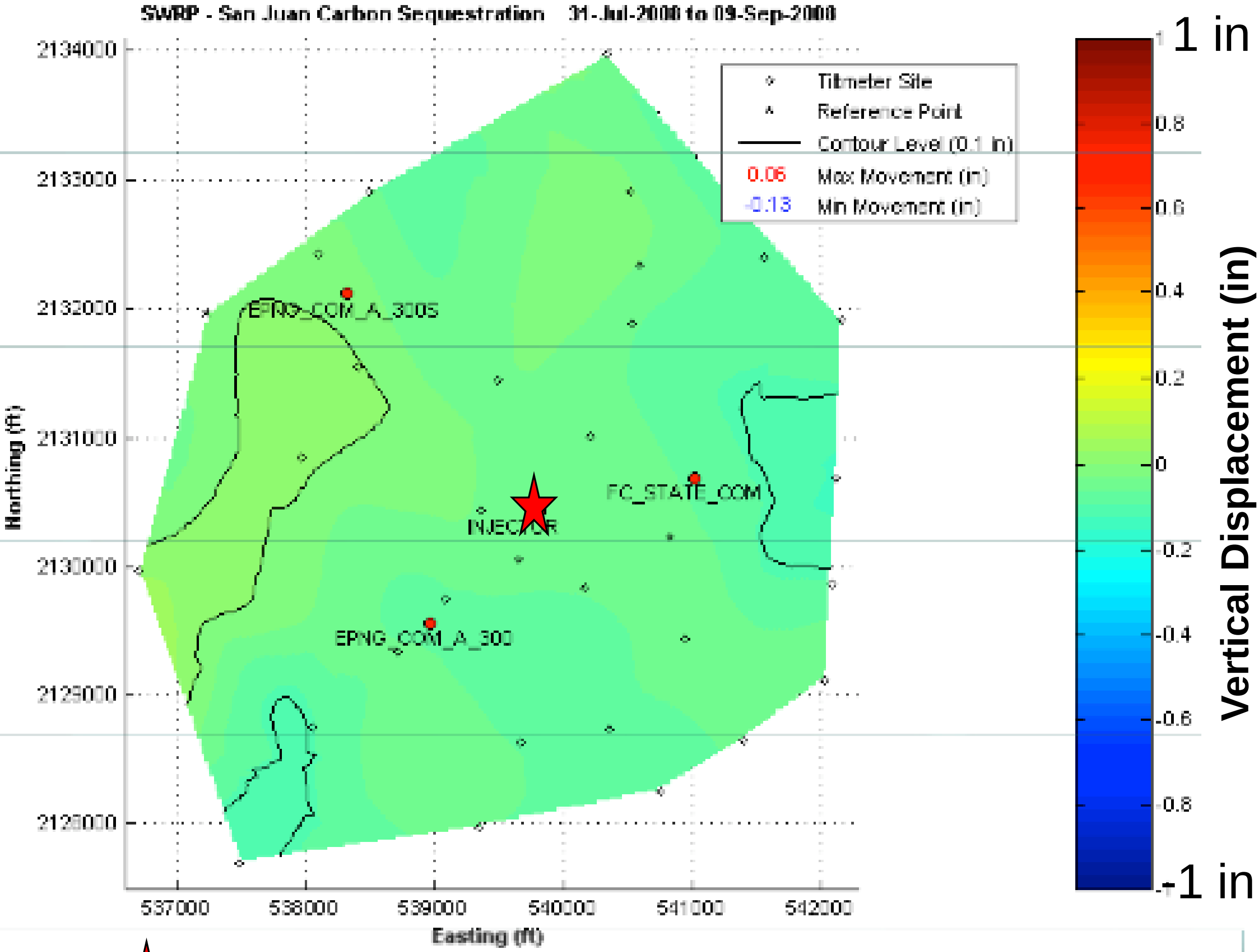
Tiltmeter and GPS Results



No coherent signal pattern observed within the tiltmeter array

★ Injection Well

Tiltmeter and GPS Results



Injection Well

Minimal surface Deformation observed, although a slight amount of uplift may be inferred close to the injector

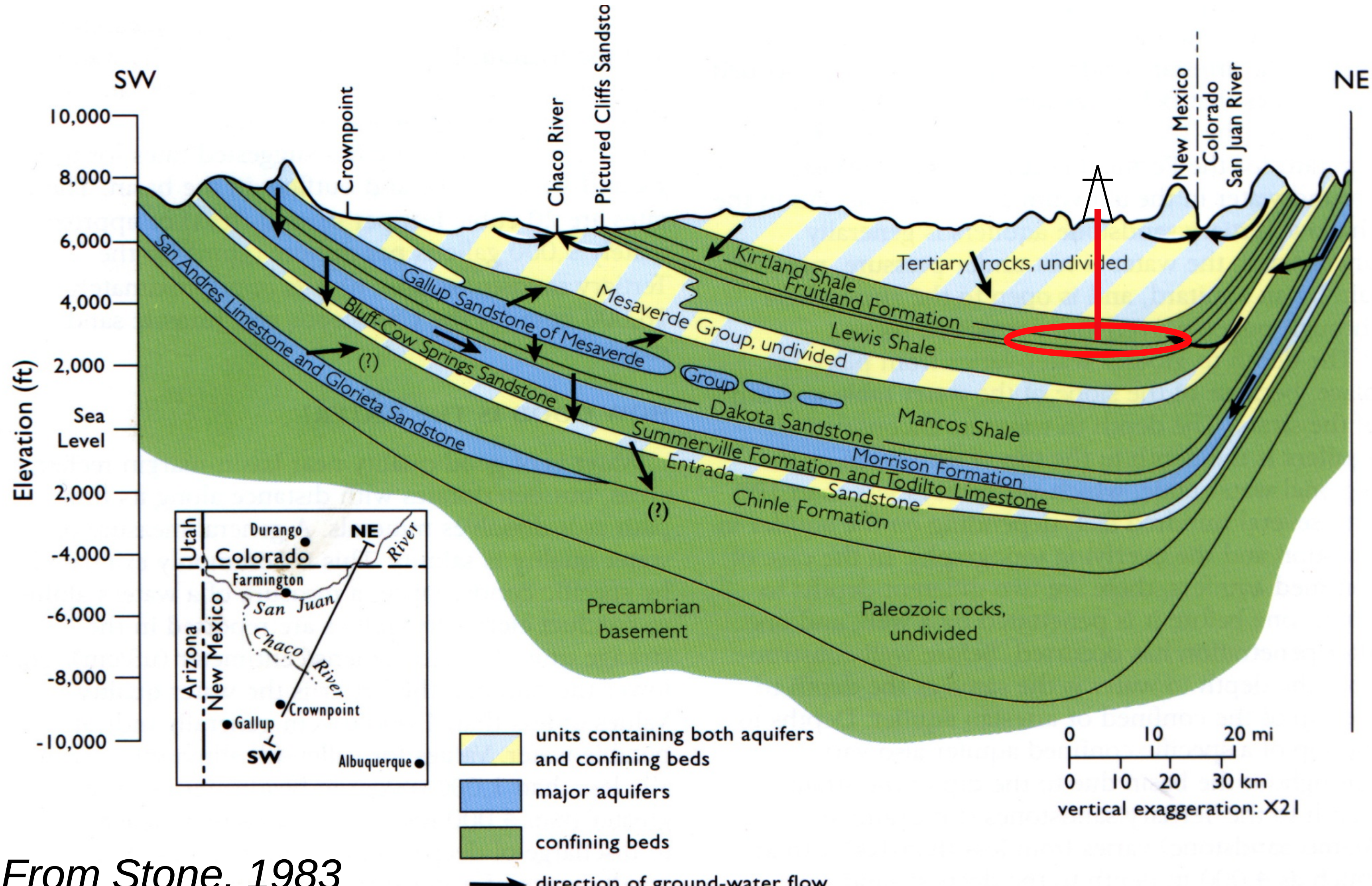
Tiltmeter and GPS Results

- 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

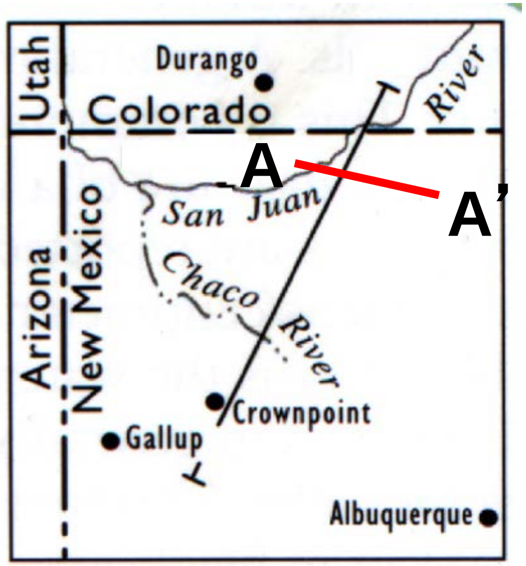
- No significant deformation after initiation of CO_2 injection
  - Analysis of several coarse time slices
  - Negligible volumetric deformation observed to-date
  - Results corroborated by GPS

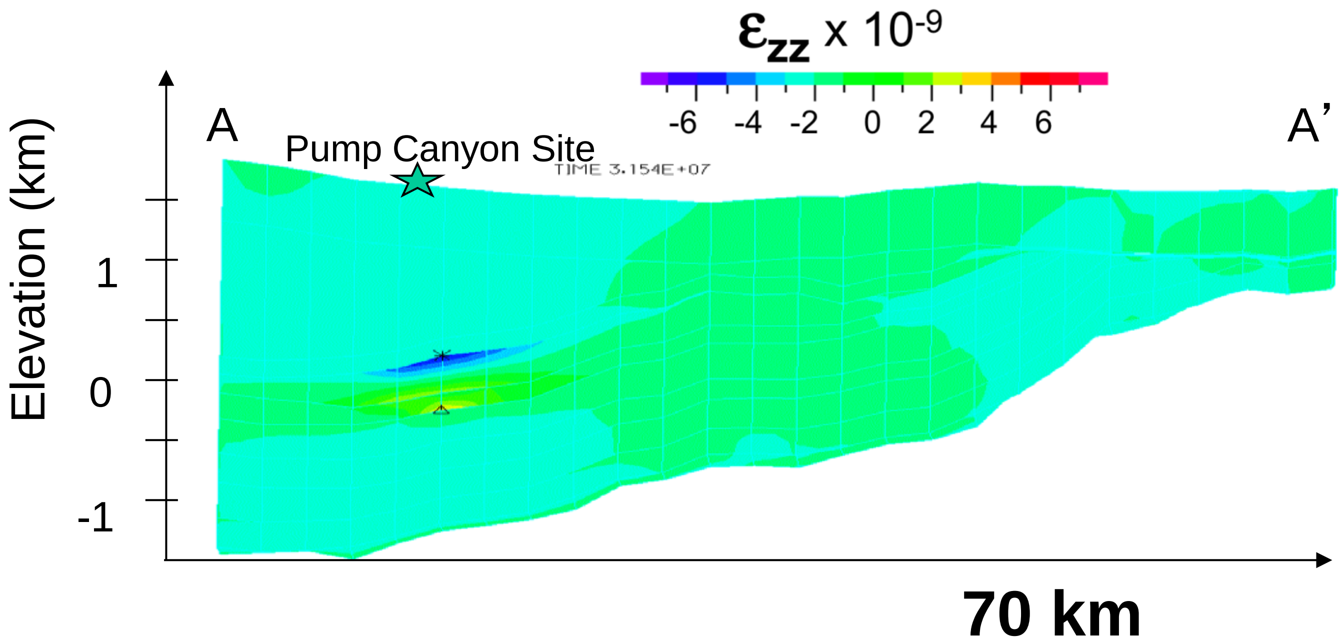
Poroelastic Simulation of San Juan Injection Site



From Stone, 1983

Poroelastic Simulation of San Juan Injection Site





- 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)