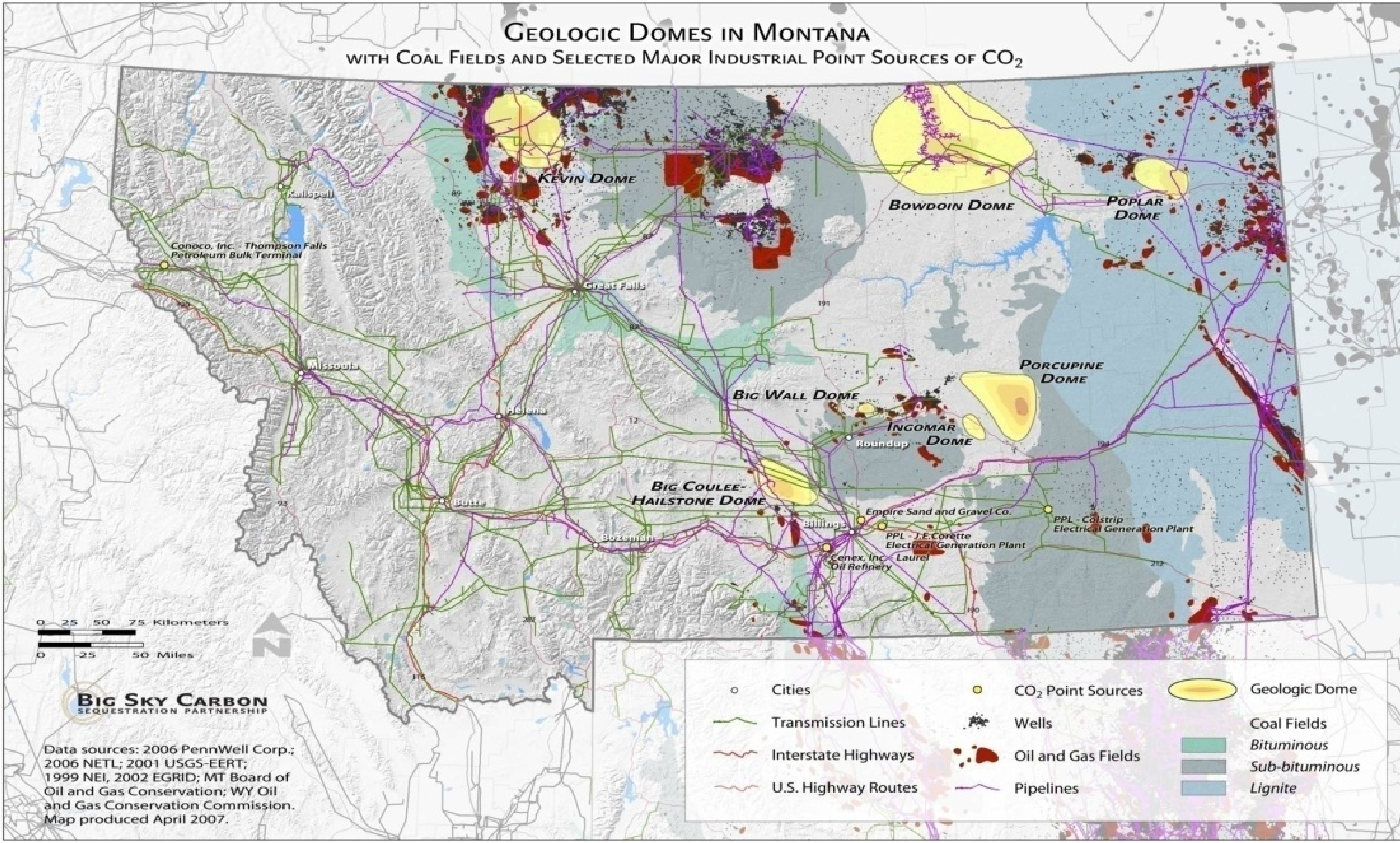
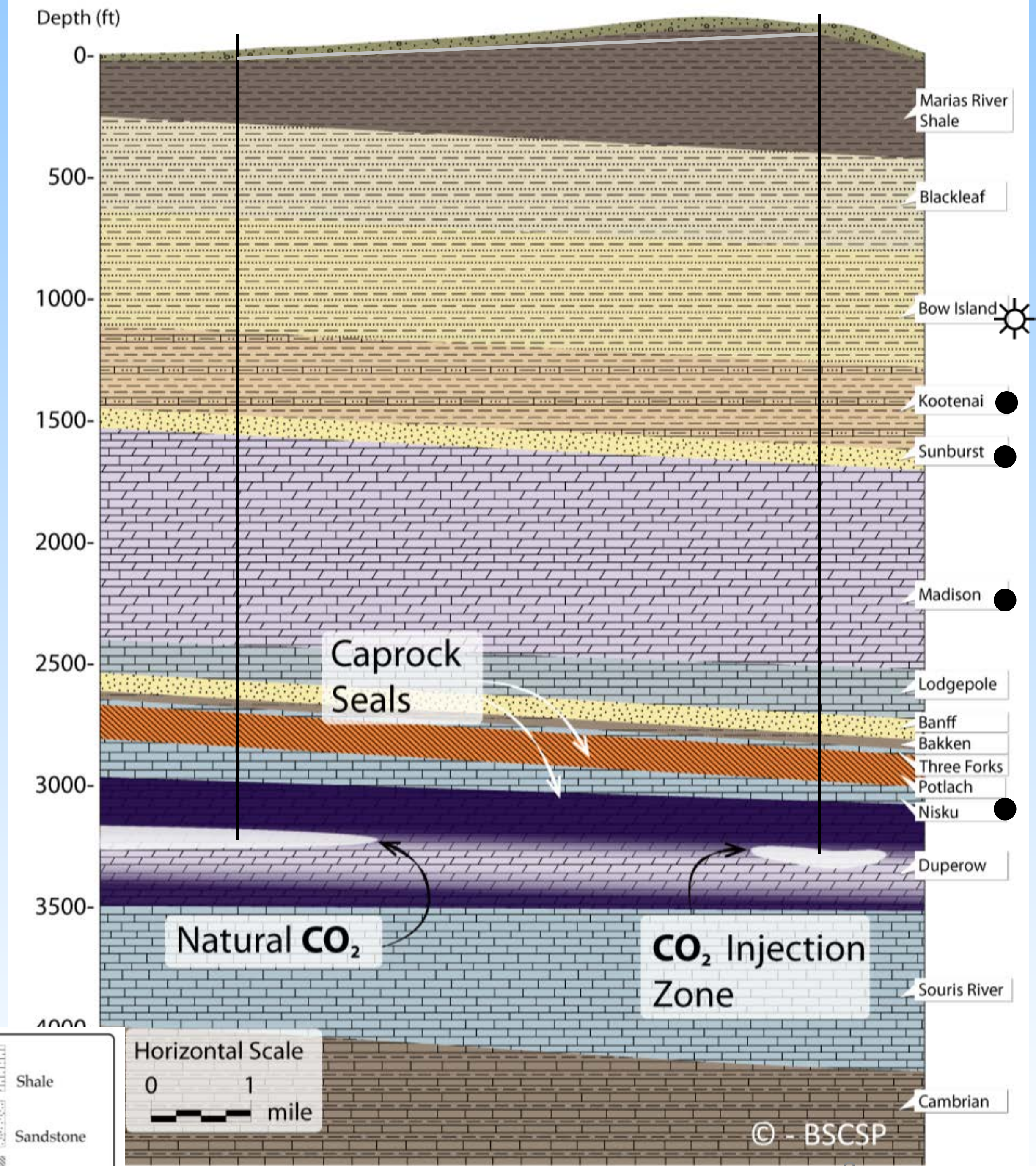
Kevin Dome

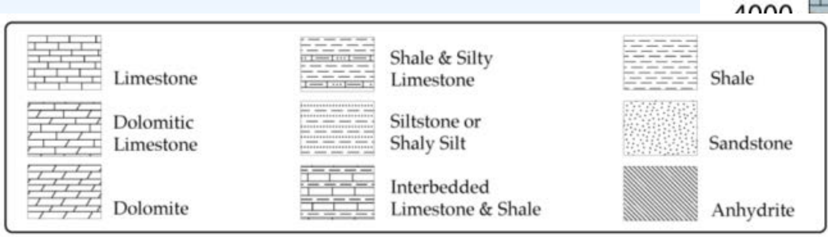


Geologic Domes in Montana
with Coal Fields and Selected Major Industrial Point Sources of CO_2
Kevin Dome
Bowdoin Dome
Poplar Dome
Porcupine Dome
Big Wall Dome
Ingomar Dome
Big Coulee-Hailstone Dome
Kalispell
Conoco, Inc. - Thompson Falls Petroleum Bulk Terminal
Great Falls
Missoula
Helena
Butte
Bozeman
Billings
Roundup
Empire Sand and Gravel Co.
PPL - J.E.Corette Electrical Generation Plant
PPL - Colstrip Electrical Generation Plant
Cenex, Inc. - Laurel Oil Refinery
0 25 50 75 Kilometers
0 25 50 Miles
Big Sky Carbon Sequestration Partnership
Data sources: 2006 PennWell Corp.; 2006 NETL; 2001 USGS-EERT; 1999 NEI, 2002 EGRID; MT Board of Oil and Gas Conservation; WY Oil and Gas Conservation Commission. Map produced April 2007.
Cities
Transmission Lines
Interstate Highways
U.S. Highway Routes
CO_2 Point Sources
Wells
Oil and Gas Fields
Pipelines
Geologic Dome
Coal Fields
Bituminous
Sub-bituminous
Lignite

Kevin Dome

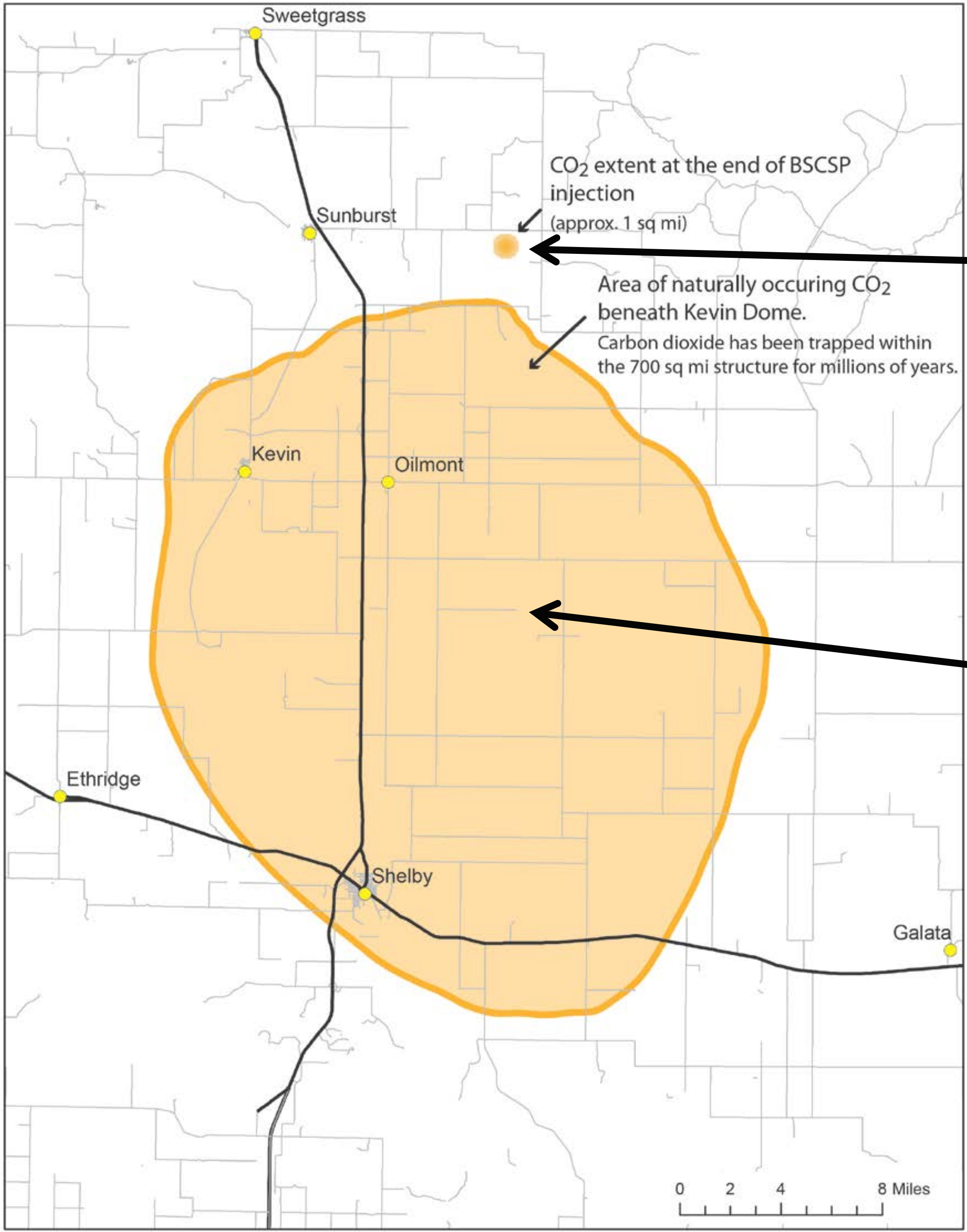
- CO_2 in middle Duperow
- Two "gold standard" seals
  - Upper Duperow ~200' tight carbonates and anhydites
  - Caprock~ 175' Anhydrite Caprock
- Multiple secondary, tertiary Seals





claimer: This graphic is a generalized representation of the subsurface at Kevin Dome. The horizontal and tical scale are independent of one another to fit view on a single page. Surface infrastructure not to scale.

Kevin Dome CO2



Estimated Area of Big Sky Storage Test (Approx. 1 sq. mi.)

Estimated Area of <u>Natural</u> CO_2 Already in Kevin Dome (Approx. 500 sq. mi.)

MONTANA STATE UNIVERSITY

Site Characteristics – Scientific Opportunities

Since nature has stored CO_2 at this site for 50 million years, we viewed this is a very safe place to develop a CO_2 storage field lab that could yield unique and valuable information to science, federal agencies and industry.

- Test monitoring technologies
- Test mitigation methods
- Test stacked storage
- Test detection limits

Site Characteristics – Scientific Opportunities

- Natural accumulation vs. new injection
  - Allows investigation of geophysical detection of CO_2 spatially as well as temporally
  - May help understand seismic response changes – function of fluid fill vs. function of geochemically alteration of rock (9C)
- Great opportunity to study mitigation
  - Use injector (and perhaps monitoring wells) to withdraw injected CO_2 and place back in the gas cap

Big Sky Carbon Sequestration Partnership

Montana State University

Underground Source of Drinking Water (USDW) - Definition

- (40 CFR) Section 144.3 is an aquifer or part of an aquifer which:
  a. supplies any public water system, or contains a sufficient quantity of ground water to supply a public water system and currently supplies drinking water for human consumption or contains fewer than **10,000 milligrams/liter of Total Dissolved Solids (TDS)**; and
  b. is not an exempted aquifer.

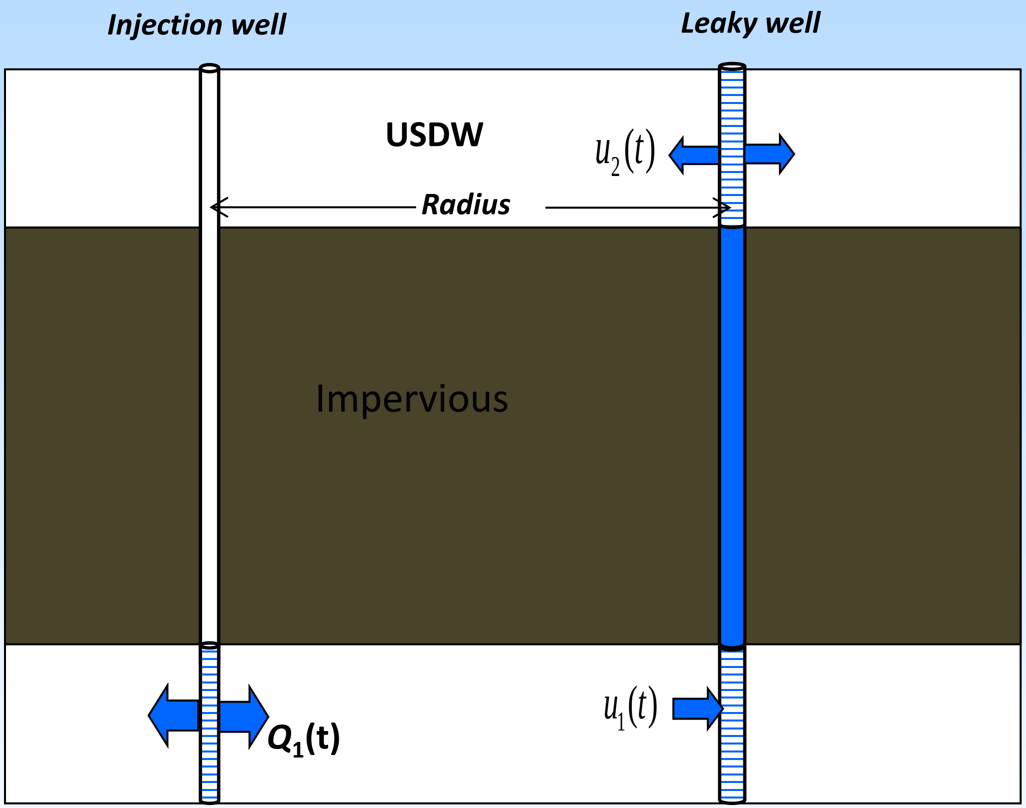
- An "exempted aquifer" is part or ... which meets the definition of a USDW but which has been exempte... ...ia found in 40 CFR Section 146.4:
  1. It is mineral, hydrocarb... ...ermal ener... ...ing, or can be demonstrated by a permit applicant as p... ...application f... ...II or III operation to contain minerals or hydroca... ...ring their qu... ...nd location are expected to be commercially produ...
  2. It is situated at a de... ...ocation ... ...kes reco... ...water for drinking water purposes economic... ...echnologi... ...actica...
  3. It is so contaminated ... would be eco... ...ologically impractical to render that water fit for hum... ...mption;
  4. It is located over a Clas... ...ining area s... ...ubsidence or catastrophic collapse; or
  5. The total dissolved solids con... ...ater is more than 3,000 and less than 10,000 milligrams/liter and it is not ...sonably expected to supply a public water system.

Original Area of Review Definition

Area where pressure can lift brine from storage reservoir to lowermost USDW through an open conduit

Madison is under-pressurized in our region – leads to infinite area of review

	Storage Reser	USDW
Thickness	50 m	50 m
Average Initial Head	1036.4 (m)	817.35 (m)
Density*	1090.55 (kg/m^3)	1002.77(kg/m^3)
Viscosity*	9.30×10^{-4} (Pa.s)	9.26×10^{-4} (Pa.s)
Salt mass fraction	0.13	0.0035
Temperature	34.7 (Celsius)	23.3 (Celsius)
Brine compressibility*	3.45×10^{-10} (Pa^{-1})	4.46×10^{-10} (Pa^{-1})
Pore compressibility	1.63×10^{-9} (Pa^{-1})	1.63×10^{-9} (Pa^{-1})
Permeability	30, 50, 80 mD	30, 50, 80 mD
Porosity	0.1	0.1
Specific Storativity	2.11×10^{-6} (1/m)	2.04×10^{-6} (1/m)
Injection well radius	0.15 m	0.15 m
Injection rate	835.32 m^3/d	0
Leaky well radius	0.15 m	0.15 m
Leaky well permeability	10^{-7} m^2	10^{-7} m^2



- CO_2 injection rate is 7.921 kg/s for 4 years.
- Assuming the density of CO_2 is 819.3 kg/m^3, the equivalent single –phase injection rate is equal to 835.32 m^3/d.
- The thickness of the formations between the storage reservoir and the USDW is 172.8 m.

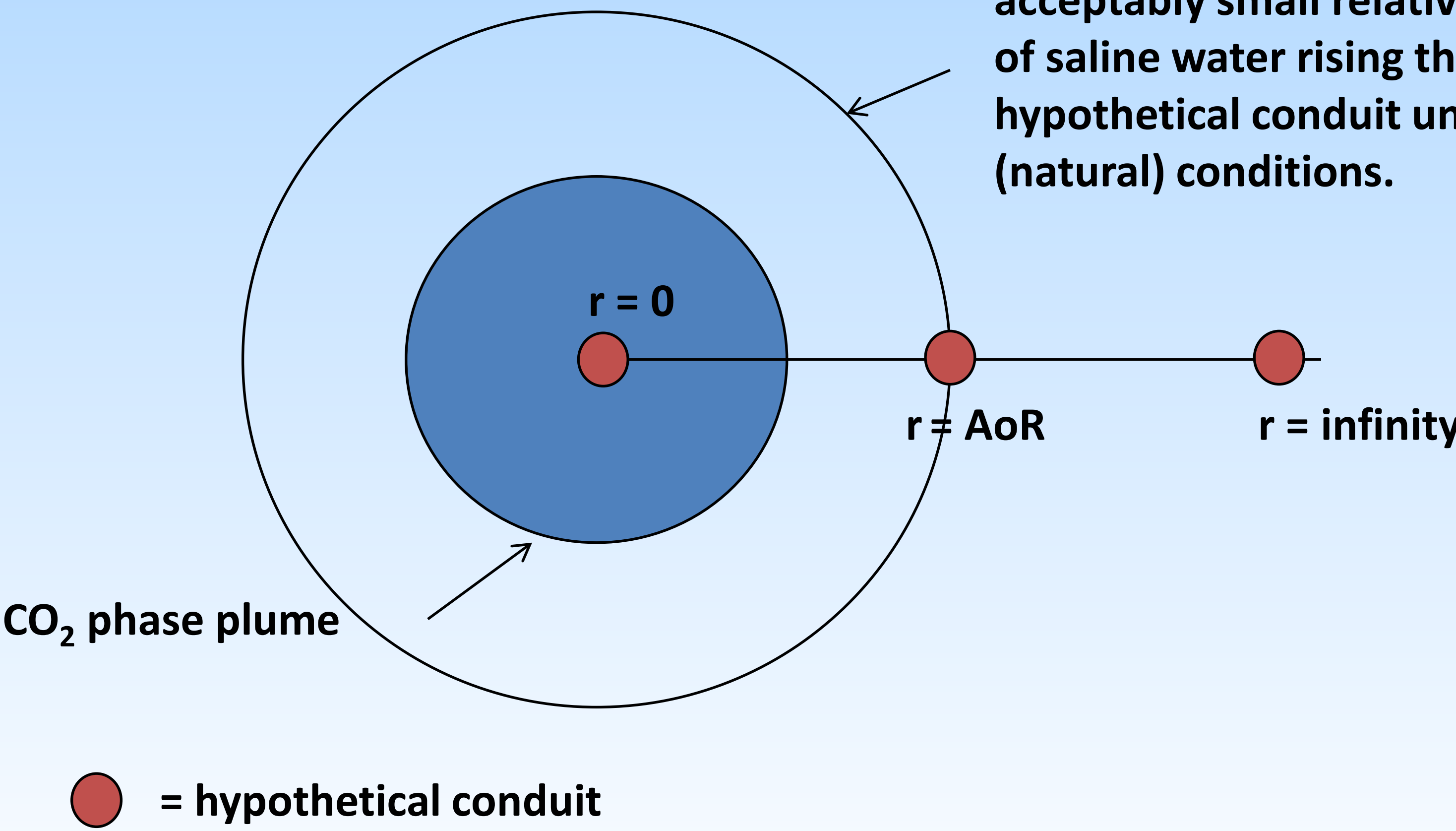
Big Sky Carbon Sequestration Partnership

Montana State University

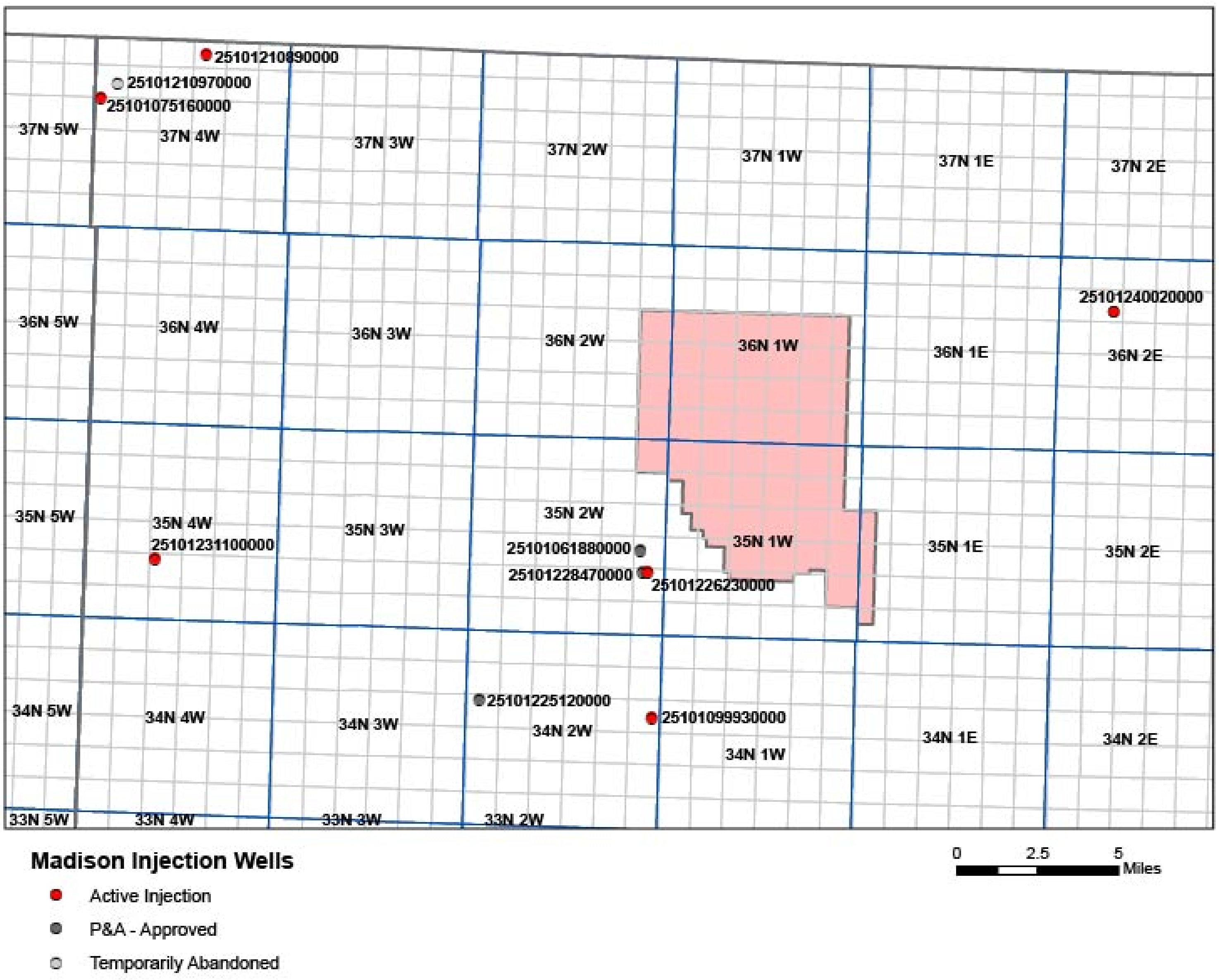
Berkeley Lab

Guidance Document Area of Review

Radius of the location of a hypothetical conduit through which the incrementally larger flow rate of saline water would be acceptably small relative to the flow rate of saline water rising through the same hypothetical conduit under existing (natural) conditions.

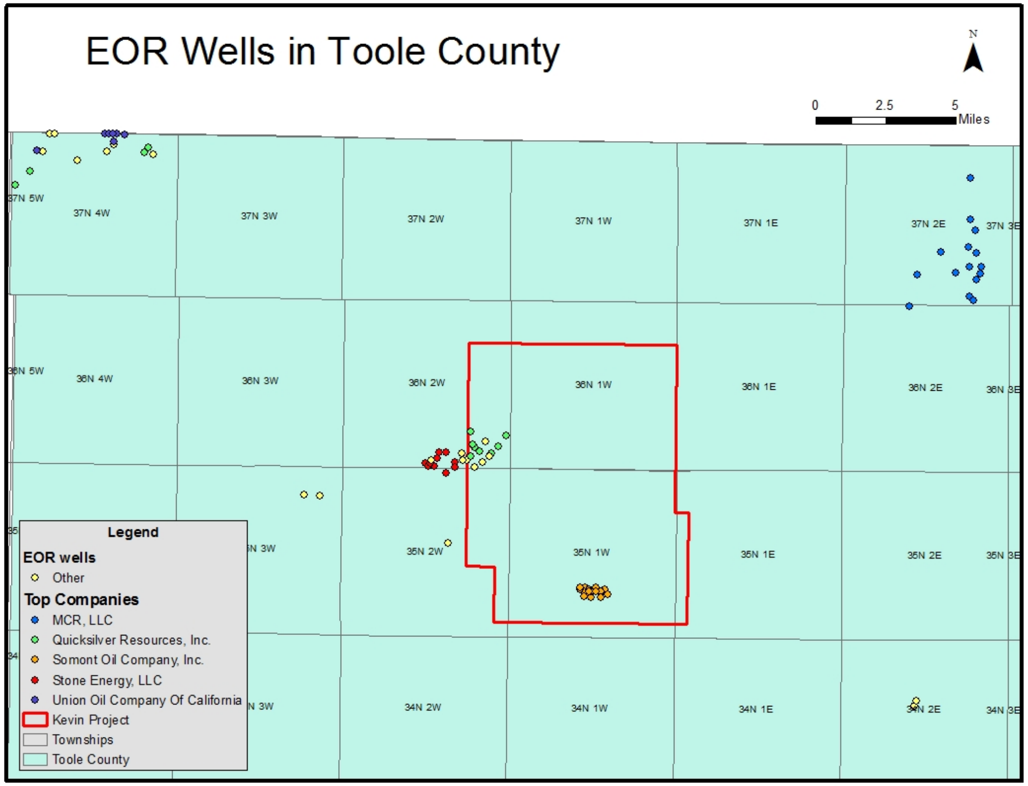


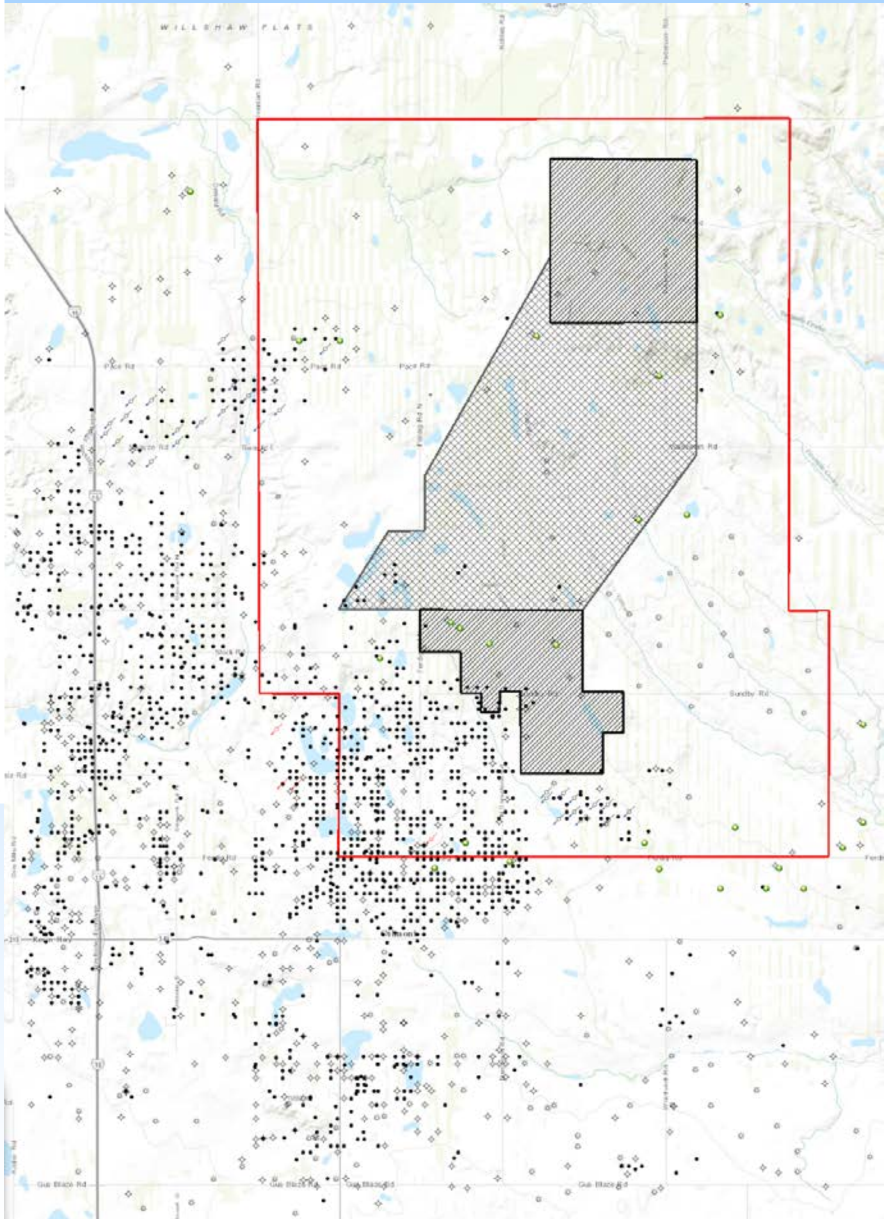
Wastewater Disposal in USDW?



BIG SKY SEQUESTRATION

EOR in USDW?





BIG SKY CARBON
SEQUESTRATION PARTNERSHIP

Compliance or Science?

- Project was not designed with Class VI compliance in mind
- Class VI compliance is significantly more expensive
- Those costs cannot come out of infrastructure or operations because then there would be no project
- Those costs directly impact the amount of science performed reducing information useful to agencies, industry, etc.
  - Injector requires larger diameter through Madison (2100’). Lost circulation risk.
  - Madison Monitoring Well
  - PISC – Larger surveys later will cost as much as several smaller surveys earlier
  - Mitigation test – PISC implied liability means we can’t do this

Why is Class VI so much more expensive?

Why is Class VI so much more expensive?

- Injector requires larger diameter through Madison (2100'). Lost circulation risk.
- Madison Monitoring Well

Expense of 1-2 deep observation wells

- PISC – Larger surveys later will cost as much as several smaller surveys earlier
- Mitigation test – PISC implied liability means we can't do this
- These are examples, not underlying reason

Why is Class VI so much more expensive?

- EPA documentation indicates concern about risk related to total quantity of injectate (Preamble to Rule, Factsheet, Multiple presentations).
- This makes sense. A 500 MW power –plant could inject ~4MT / yr for 50 years – 200 MT total. And there could be many. This is a different scale than current UIC activities.
- But current experimental demos are ~250 kT over 4 yrs, 6.25% of the injection rate and 2% total quantity of a commercial project.
- Can we do something to confirm EPAs intuition that risk scales with injectate quantity? Can EPA issue guidance reducing stringency so demos can yield more useful information?

Everything we can do to SAFELY reduce the 4-dimensional extent of compliance monitoring / actions will recoup some of the science

Challenges

- PISC
  - Default period has private sector partner & university uneasy
  - May have to incur significant cost to have period reduced via directors discretion
  - Uncertainty in this process is an issue
- Financial Assurance
  - Affordable assurance may not be long enough term

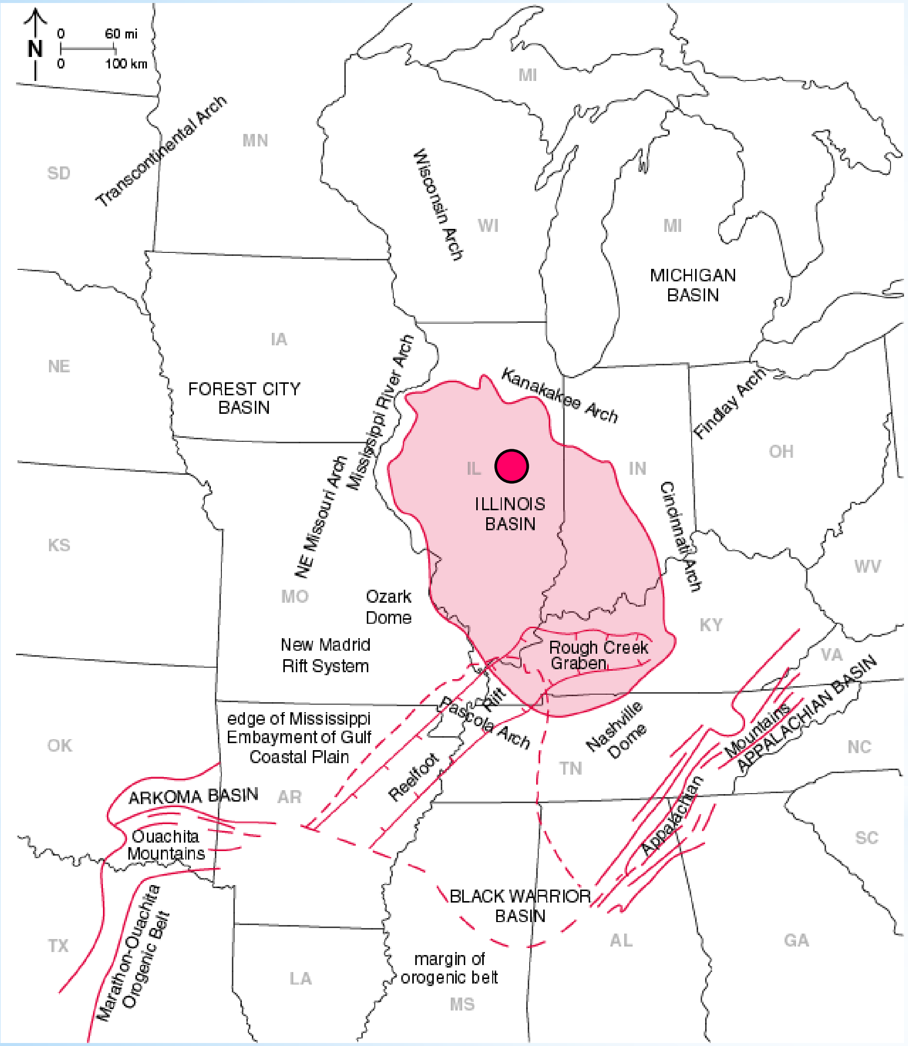
Illinois Basin – Decatur Project

CCS Regulatory Lessons Learned

Presented by
Dr. Sallie E. Greenberg
Assistant Director, Advanced Energy Technology Initiative - Illinois State Geological Survey

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

Illinois Basin – Decatur Project



- Collaboration:
  - Midwest Geological Sequestration Consortium,
  - Archer Daniels Midland Company (ADM),
  - Schlumberger Carbon Services,
  - Additional subcontractors
- Objective:
  - Inject 1 million metric tons of anthropogenic carbon dioxide at a depth of ~2,130 m
  - Demonstrate geological carbon sequestration in a saline reservoir at a site in Decatur, IL

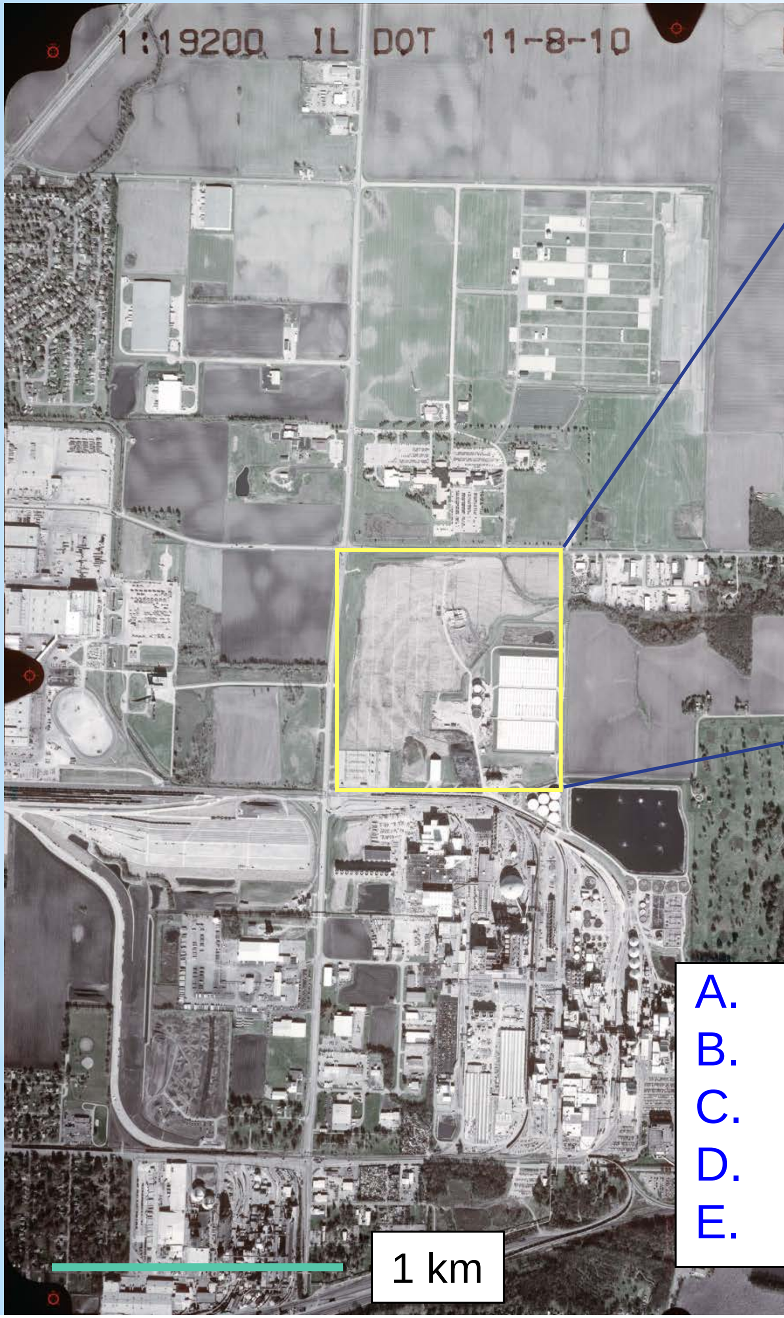
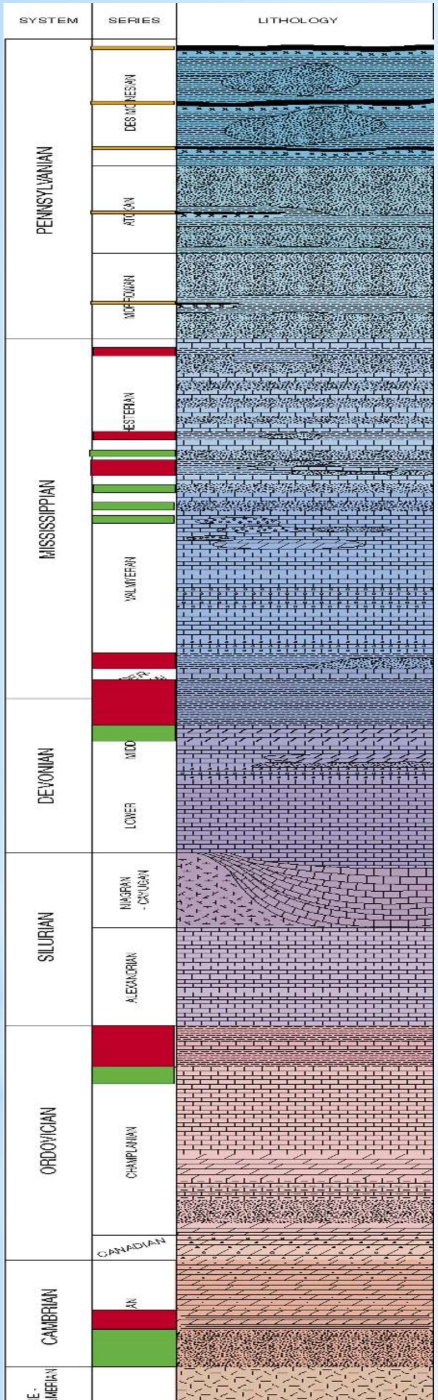


photo by Illinois Dept. of Transportation, 8 November 2010

Illinois Basin Stratigraphic Column



Pennsylvanian coal seams

New Albany Shale

Back-up seals

Maquoketa Shale

St. Peter Sandstone

Eau Claire Shale – Primary Seal

Mt. Simon Sandstone - Reservoir

fluvial sandstones

Permitting Context

- Underground Injection Control (UIC) program under Safe Drinking Water Act – subsurface injection
- IBDP permitted as Class I – non hazardous by Illinois
- Submitted Jan 2008, permission to inject October 2011
  - Application, hearing, minor modification, major modification, completion reports, permission to inject
- Class VI – federal primacy
  - December 2010
  - Reapply
  - Awaiting response
  - Monitoring implications

IBDP Regulatory Lessons

- Regulations will drive monitoring activities
  - Ongoing and evolving
  - Research has not yet defined monitoring requirements
  - Researchers should consider obligation to evaluate commercial needs
- Environmental baseline essential regardless of regulatory requirements
  - Risk mitigation
  - Support CCS primary deployment goals
- Public engagement guidelines should be exceeded
  - Proactive approach increases transparency
  - Move beyond formal engagement requirements
- Provide balance of information – detail important, but can distract

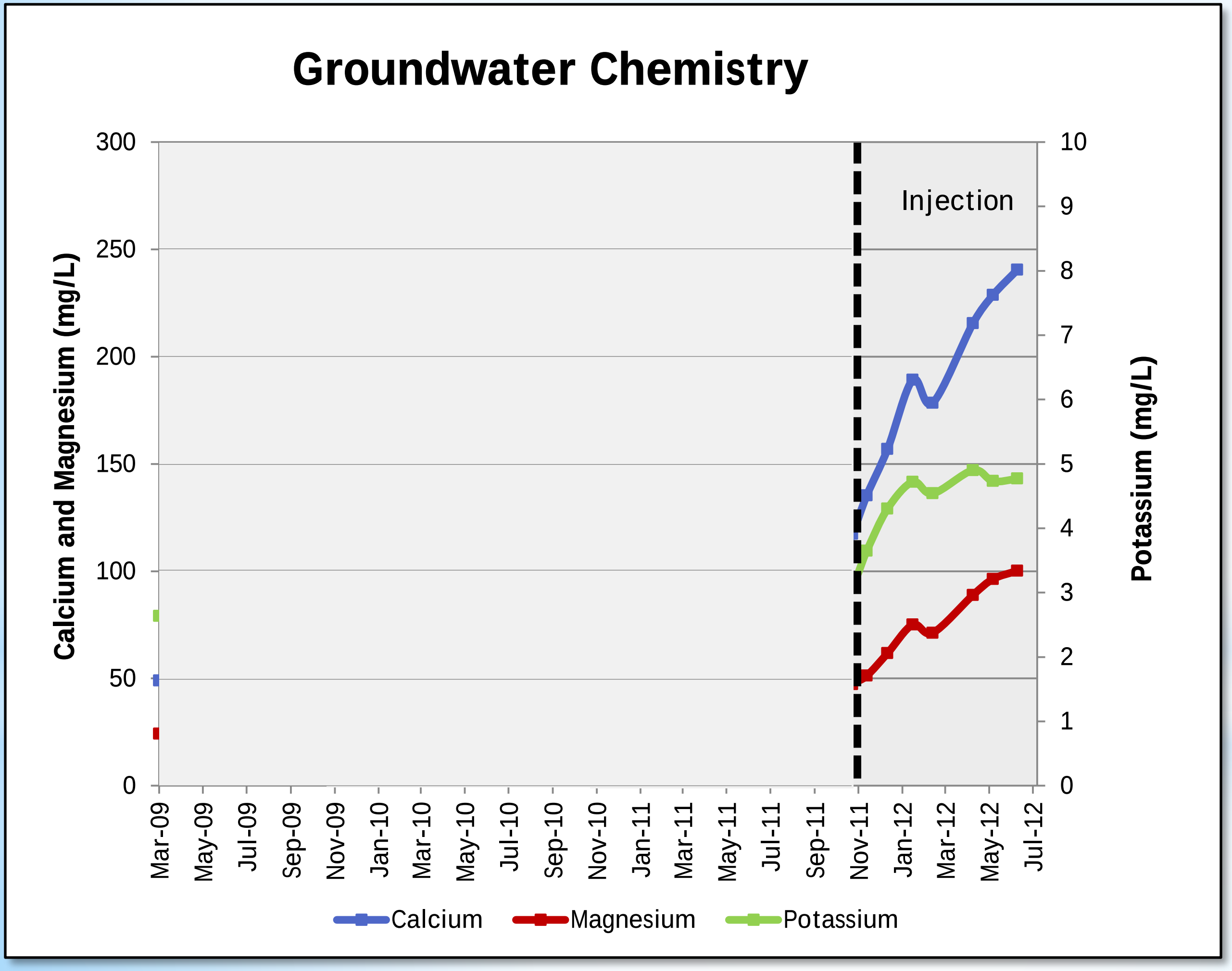
IBDP Regulatory Lessons

- Modeling
  - Generation
  - Verification
- Proactively educate regulators
  - Engage early
  - Familiarize yourself with regulatory time clock
- Start early
- Seek out examples (publicly available)
- Remain flexible

IBDP Environmental Monitoring Framework

Near Surface			Deep Subsurface	
Atmos.	Soil and vadose zone	Shallow ground water	Above seal	Injection zone
Eddy covariance Meteorological conditions Ambient CO_2 Tunable diode laser for CO_2	CIR aerial imagery InSAR and GPS Soil gases Soil CO_2 flux Tunable diode laser for CO_2	Geophysical surveys Geochemical sampling P/T monitoring	Geophysical surveys Geochemical sampling P/T monitoring	Geophysical surveys Geochemical sampling P/T monitoring

Baseline Is Important



- Increases in Nov 2009 and Nov 2011, but not Nov 2010
- One year of preinjection data not enough to show seasonal cycle

Acknowledgments

- The Midwest Geological Sequestration Consortium is funded by:
  - **U.S. Department of Energy** (DOE) through the National Energy Technology Laboratory (NETL) via the Regional Carbon Sequestration Partnership Program (contract number DE-FC26-05NT42588)
  - And by the **State of Illinois** via a cost share agreement with the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development through the Illinois Clean Coal Institute.

Southeast Regional Carbon Sequestration Partnership
Citronelle Project: Experiences with Permitting and Regulations on CCS

Carbon Storage R&D
Project Review Meeting
August 21, 2013

Kimberly Sams
Assistant Director, Geoscience Programs
Southern States Energy Board

Permitting Outline & Project Location

- National Environmental Protection Act (NEPA)
- Alabama Historical Commission
- U.S. Fish and Wildlife
- U.S. Army Corps of Engineers
- Alabama Department of Environmental Management (ADEM)

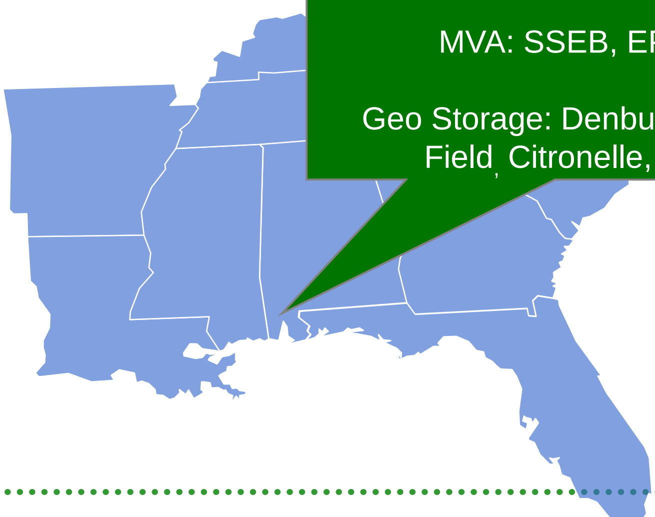
Anthropogenic Test

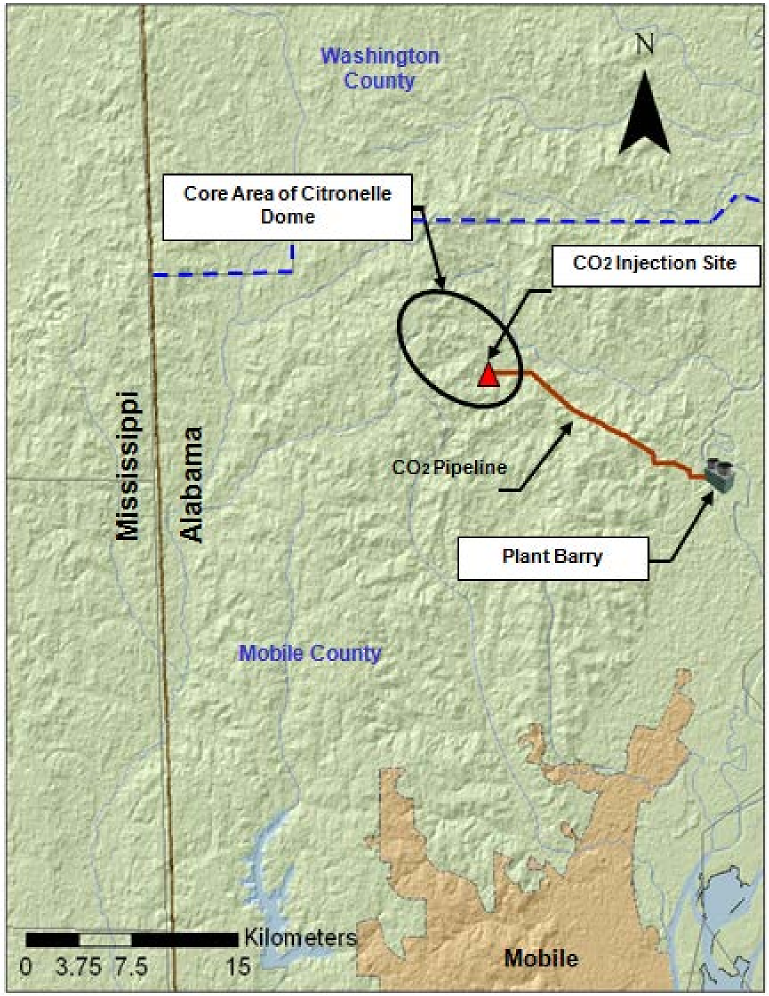
Capture: Alabama Power 's Plant Barry, Bucks, Alabama

Transportation: Denbury

MVA: SSEB, EPRI, ARI

Geo Storage: Denbury's Citronelle Field, Citronelle, Alabama



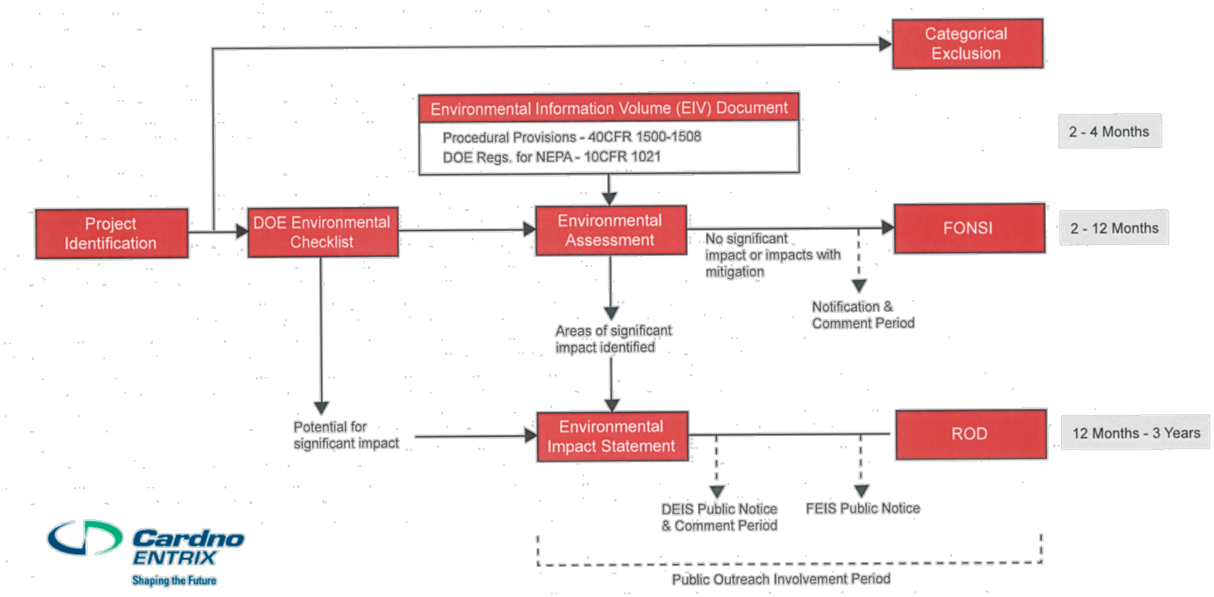


SECARB Southeast Regional Carbon Sequestration Partnership · NETL · Southern States Energy Board · Bureau of Economic Geology · Gulf Coast Carbon Center · EPRI · Advanced Resources International, Inc. · Southern Company · Denbury

National Environmental Protection Act

Environmental Impacts

- Categorical Exclusion: All locations performing office work, planning, coordination, etc.
- Environmental Assessment (EA)
  - Environmental Information Volume and Supplements for Pipeline and Electric Transmission Line
  - Finding of No Significant Impact (FONSI) issued by NETL on March 18, 2011



Alabama Historical Commission

State Cultural or Archaeological Assets

- 2 cultural resources assessments
- 4 archaeological sites discovered in the Transmission Line survey, though not eligible under the National Register of Historic Places – no further investigations warranted
- No cultural resources were discovered – no further investigations warranted
- Following review of EA, "…agree with the EA as it pertains to no effect to National Register eligible cultural resources" by State Historic Preservation Officer, April 2011

U.S. Fish and Wildlife

Threatened and Endangered Species

- Endangered Gopher Tortoise habitat
- 110 burrows in/adjacent to construction area
- Directional drilling of pipeline
- Marked burrows at well pad site

SECARB Southeast Regional Carbon Sequestration Partnership · NETL · Southern States Energy Board · Bureau of Economic Geology · Gulf Coast Carbon Center · EPRI · Advanced Resources International, Inc. · Southern Company · Denbury

U.S. Army Corps of Engineers

Wetlands

- Pipeline route
  - 12 miles
  - Directional drilled 18 sections of the pipeline, 30-60 ft deep, under wetlands, roads, utilities, railroad tracks, and tortoise colonies
  - Surface re-vegetation and erosion control
- Well pad construction
  - Wetlands impacts mitigated after drilling completed

AL Dept. of Environmental Management

Underground Sources of Drinking Water

- Class V Experimental UIC Permit issued by the Alabama Department of Environmental Management (ADEM) on November 22, 2011
  - U.S. Environmental Protection Agency Headquarters Involvement
    - Provided comments to ADEM regarding permit requirements
    - Many Class VI standards applied to the Class V Permit (see below)
- Permission to Inject issued by ADEM on August 8, 2012
- Injection began in August 20, 2012

Injection Area of Review (AOR) determined by annual modeling
Periodic AOR updates based on monitoring and modeling results
Extensive deep, shallow and surface CO_2 monitoring
Monthly reporting of injection pressures, annular pressures and injection stream composition
Injection stream monitoring
Periodically updated Corrective Action Plan
Site closure based on USDW non-endangerment demonstration (5-yr renewal)
Pressurized annulus throughout injection (+/- 200 psig)
Emergency and remedial response plan
Post-injection site care plan