The potential risk of freshwater aquifer contamination with geosequestration

Project Number: FE0002197

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Storage R&D Project Review Meeting

Developing the Technologies and Building the Infrastructure for CO_2 Storage

August 21-23, 2012

Presentation Outline

- Goals & benefits
- Objectives
- Background and overview of projects
- Results from incubations
- Future directions
- Other CCUS projects leveraged by DOE support

Benefit to the Program

- Program goals being addressed:
  - Develop technologies to demonstrate that 99 percent of injected CO_2 remains in the injection zones.
  - Conduct field tests through 2030 to support the development of BPMs for site selection, characterization, site operations, and closure practices.
- Benefits to the program:
  - Estimate the subset of locations where human health risks of CO_2-contaminated waters may be important;
  - Identify geochemical signatures in affected waters that can be used as early-detection criteria;
  - Determine the importance of leak gas composition on water-rock interactions; and
  - Understand the time-dependence of interactions.

Project Overview:
Goals and Objectives

- **<u>MAJOR OBJECTIVE</u>**- Understanding how CCS leaks could affect water-rock interactions in freshwater aquifers

- **<u>OTHER OBJECTIVES INCLUDE</u>**
- Estimating the subset of locations where human health risks associated with CO_2 contaminated waters may be most important;
- Identifying geochemical signatures in affected water which can be used as detection criteria;
- Determining the importance of leak gas composition on water-rock interactions; and
- Understanding the geographic, petrologic and exposure-time dependence of these interactions.

Relevant Projects as Background

Energy and Water Use: (e.g.,)

Chandel, Pratson, & Jackson 2011 The potential impacts of climate-change policy on freshwater use in thermoelectric power generation. Energy Policy 39:6234-6242.

Yang & Jackson 2011 Opportunities and barriers to pumped-hydro energy storage in the United States. Renewable and Sustainable Energy Reviews 15:839–844.

Carbon Capture, Utilization, and Storage: (e.g.,)

Eccles, Pratson, Newell, & Jackson 2009 Physical and economic potential of geological CO_2 storage in saline aquifers. Environmental Science & Technology 43:1962-1969.

Eccles, Pratson, Newell, & Jackson 2012 The impact of geologic variability on capacity and cost estimates for storing CO2 in deep-saline aquifers. Energy Economics 5:1569-1579.

Chandel, Kwok, Jackson, Pratson 2012 The potential of waste-to-energy in reducing greenhouse gas emissions. Carbon Management **3**:133–144.

Introduction

- **Background** - Because freshwater aquifers used for drinking, industry, and agriculture overlie most CCUS sites, leaks could negatively impact ground water and influence public *perceptions* about CCUS. In water, CO_2 forms H_2CO_3, increasing acidity that can speed the dissolution of sediments, potentially releasing harmful elements. However, many factors will alter the effects of a CO_2 leak, including sediment chemistry, the long-term super saturation of CO_2, and the presence of carbonates and other agents that buffer pH.

- **Anticipated benefits** - By running long-term incubations and chemical simulations using sediments from many locations, we will present a risk assessment to prioritize areas of greatest risk, to highlight areas where such risks are low, and to provide early-warning elements for leak detection.

Identifying and Testing Sites of Potential Groundwater Vulnerability

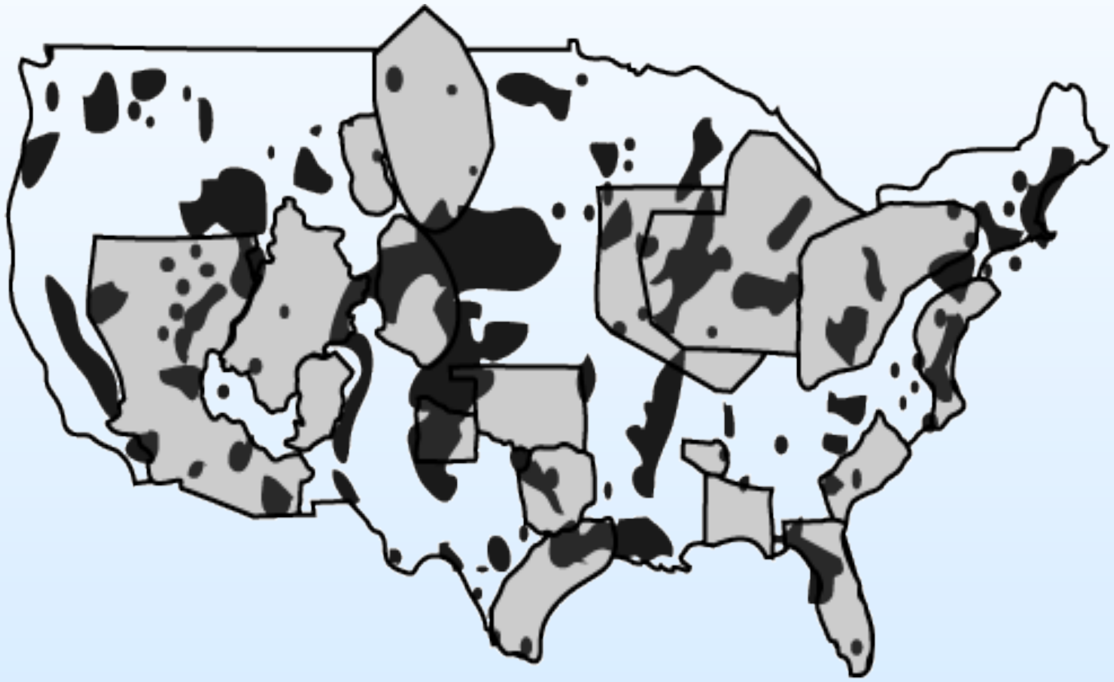
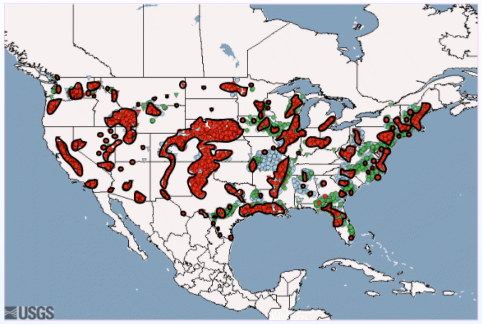
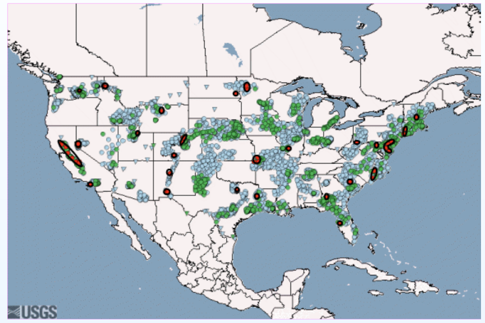


Figure 5. *Groundwater arsenic > 1.0ppb in black; possible deep saline CCS sites in gray*

ARSENIC 1.0 (10% mcl)

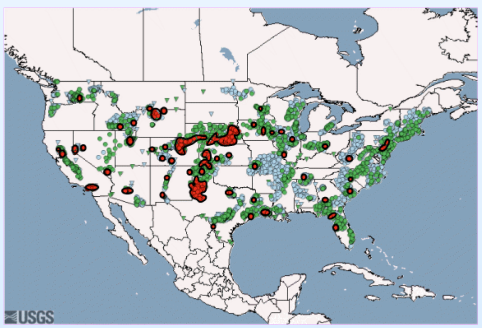


CADMIUM 0.5 (10% mcl)

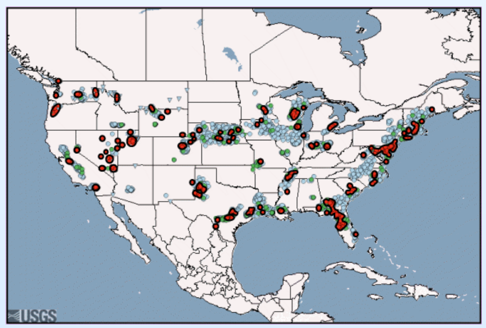


Background Aquifer Data (from USGS national database)

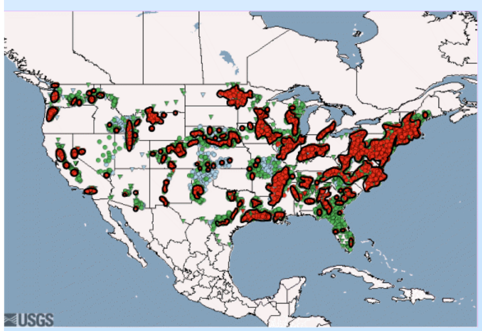
SELENIUM 5.0 (10% mcl)



THALLIUM 0.045 (10% mcl)



MANGANESE 50 (100% mcl



What are the risks?

Identifying and Testing Sites of Potential Groundwater Vulnerability

(MCL= Maximum contaminant level)

The Ogallala as an Example

Areal map and cross section of the arsenic-bearing, freshwater Ogallala and the deep, saline Palo Duro potential CCS site

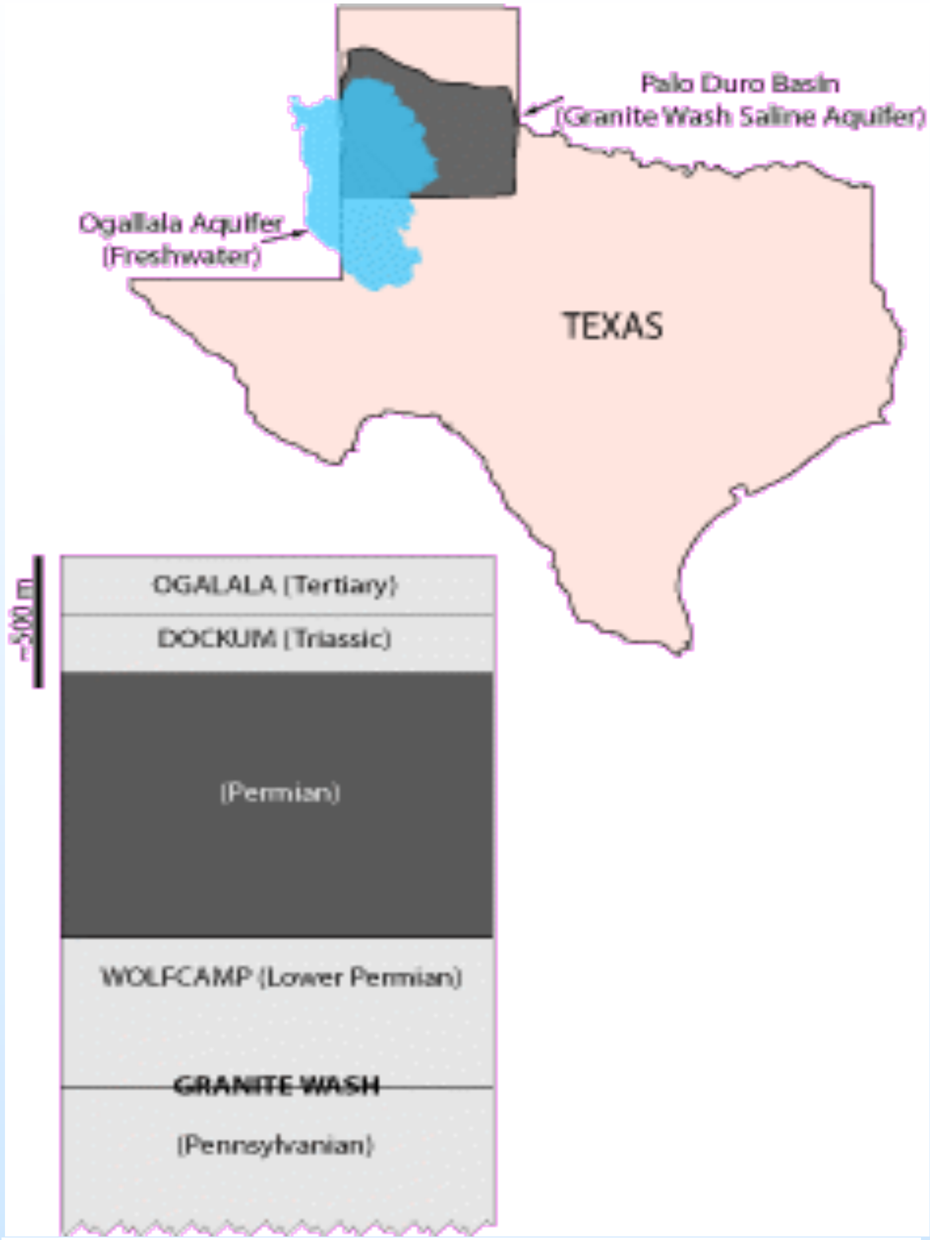
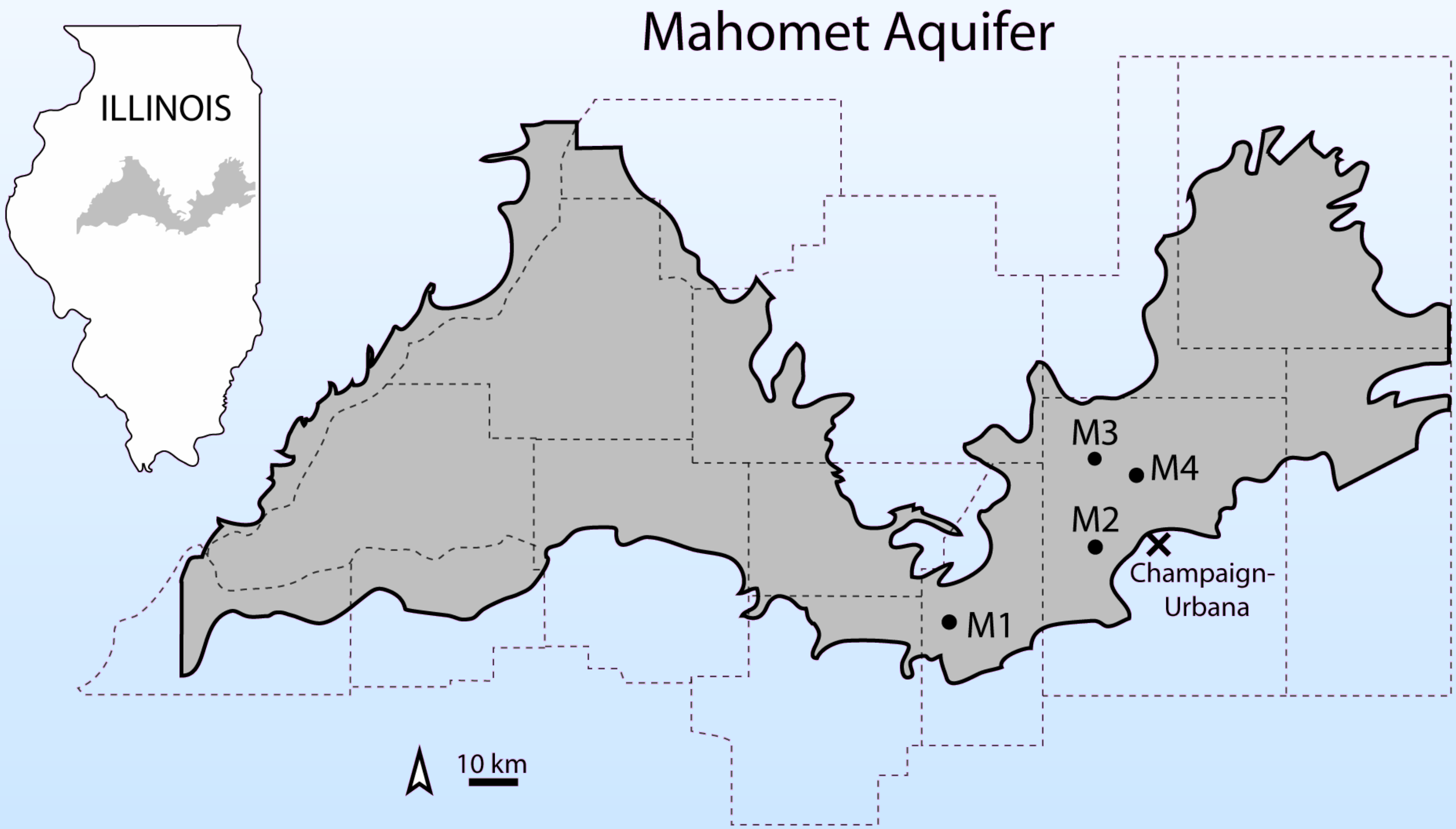


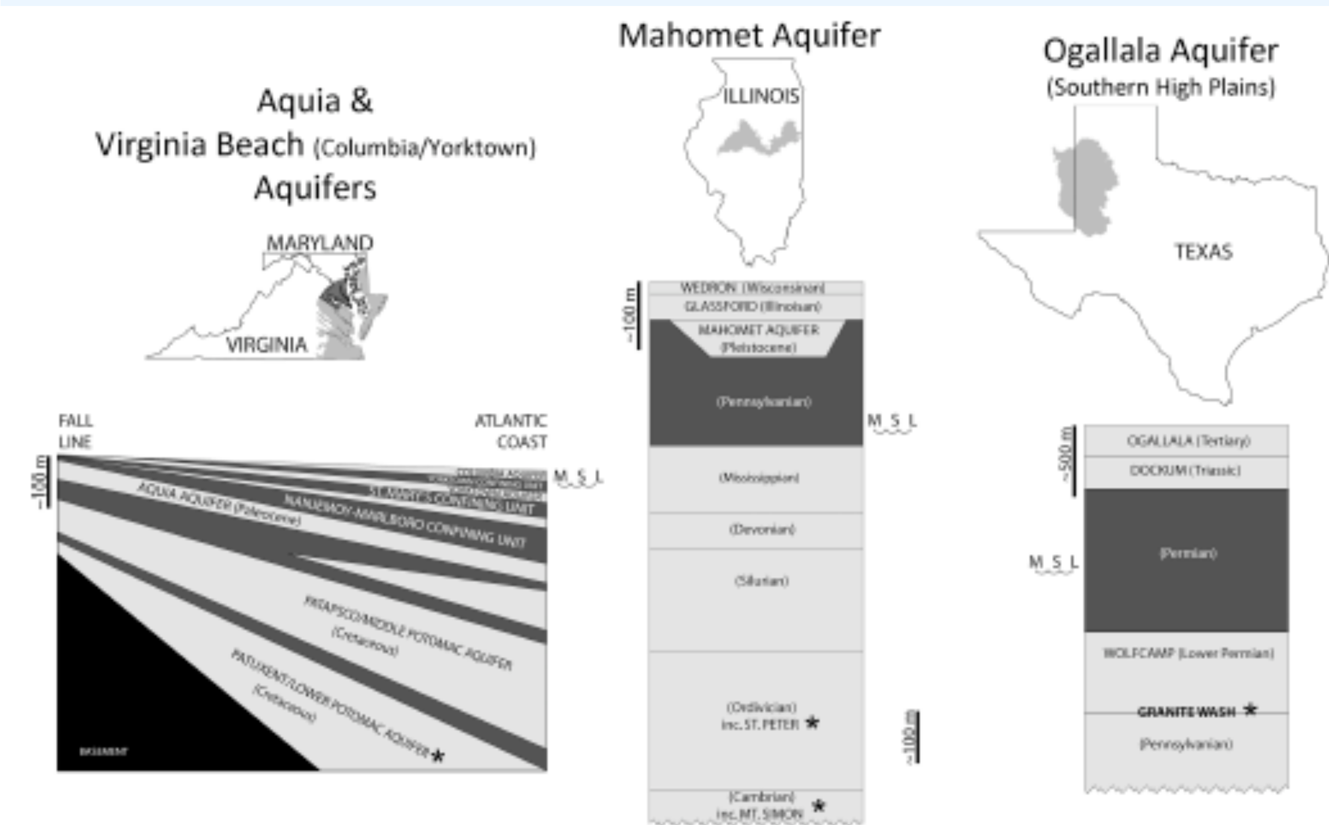
Figure 4. *Areal map and cross section of the arsenic-bearing, freshwater Ogallala and the deep, saline Palo Duro potential CCS site (Henry, 1988; Fogg and Senger, 1985; Gurdak et al., 2007)*

The Mahomet as another site



Highlights of Project to Date

- Accomplishment 1 – Identified and obtained samples from five aquifer systems for incubations.



Central Valley of CA

Highlights of Project to Date

- Accomplishment 2 – Developed method for incubating sediments simulating a CO_2 leak in a range of redox conditions.

Original Experimental Design

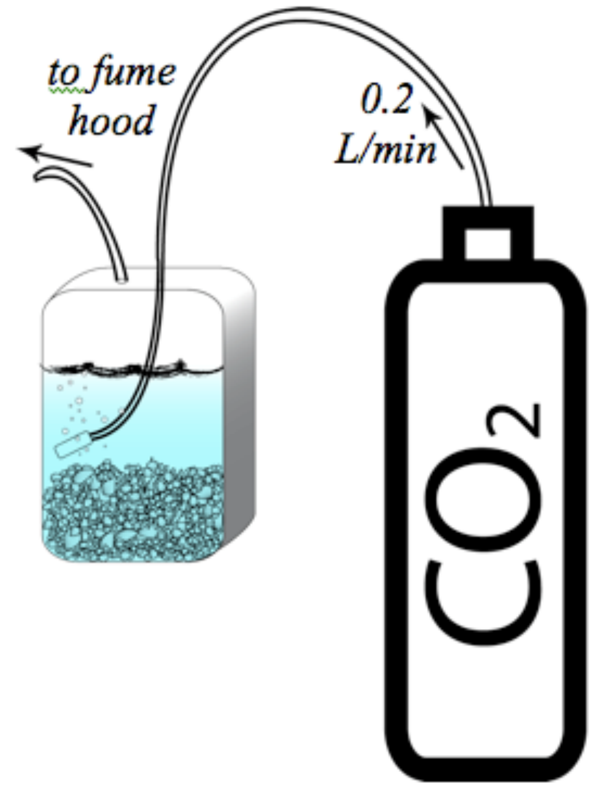
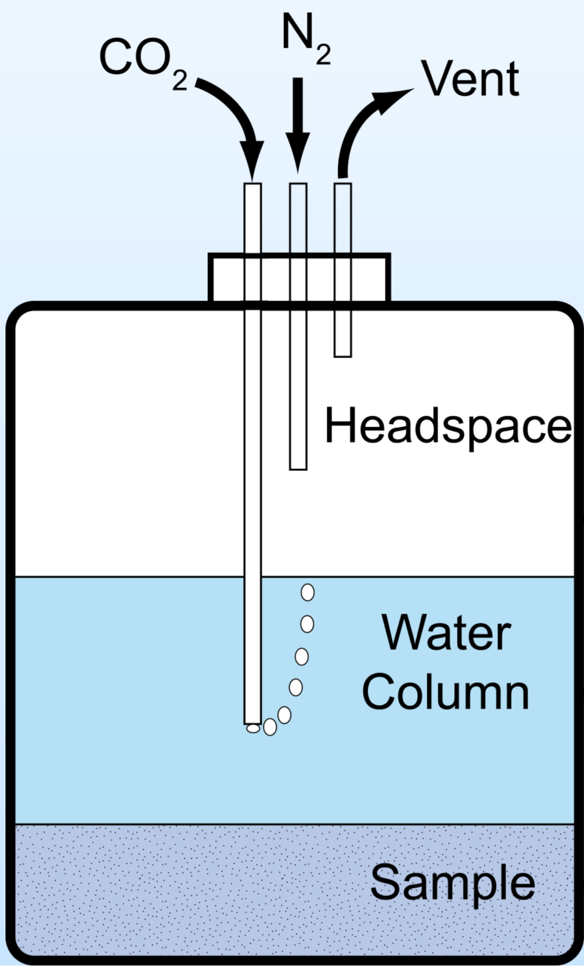


Figure 2. *Experimental design for simulating CO_2-contaminated groundwater*

Highlights of Project to Date

- Accomplishment 2 (continued) – Developed method for incubating sediments simulating a CO_2 leak in a range of redox conditions.



Different Experimental Design

Polyethylene Terephthalate (PET):
- Has been shown to be an effective barrier to CO_2 and O_2 transmission (soft drink industry)

Headspace Nitrogen:
- Provides an additional barrier against the introduction of air

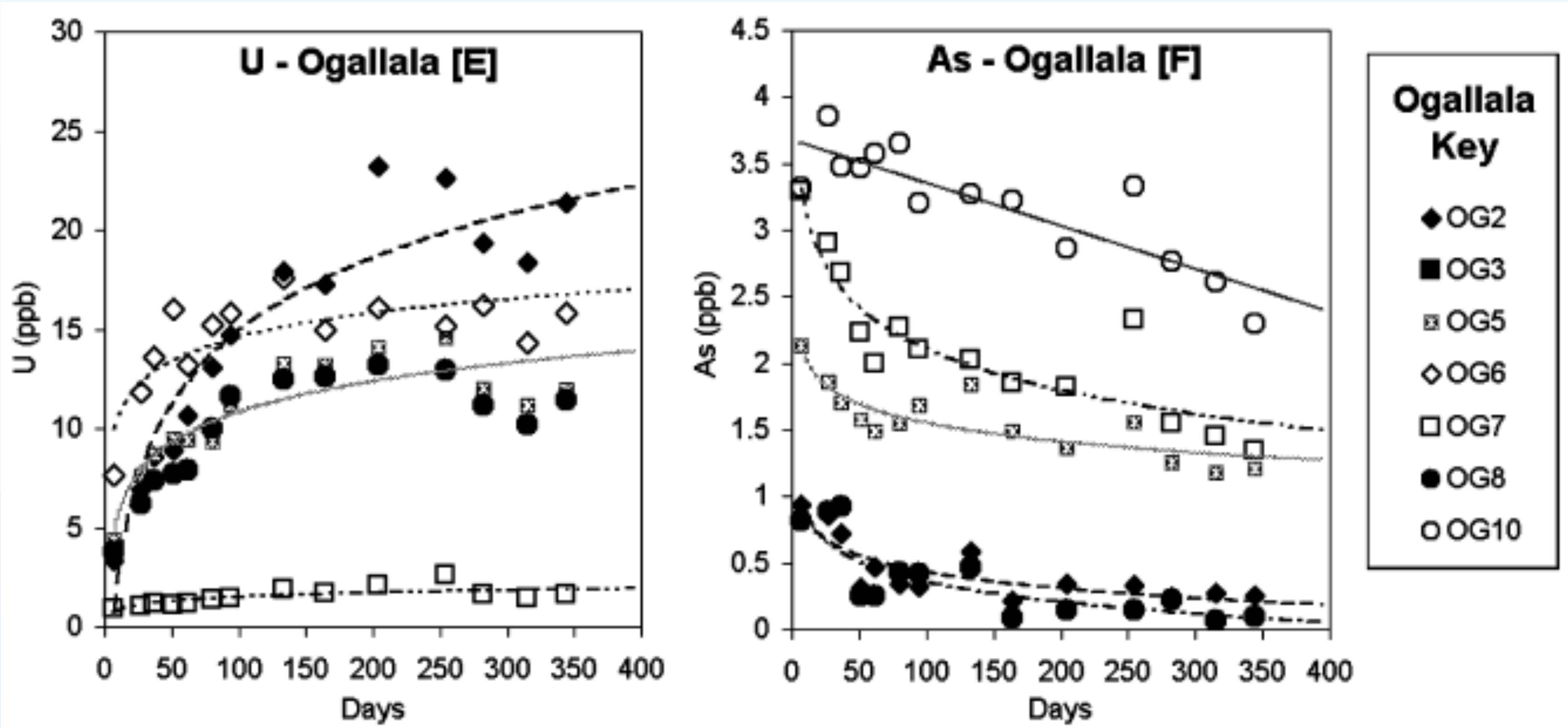
Degassed Water

Measure Redox Conditions
- ORP or trace elemental speciation

Highlights of Project to Date

- Accomplishment 3 (cont.) – Published our first papers of changes to sediment/water systems for a one-year incubation.

Concentration vs. Time (Ogallala Aquifer)

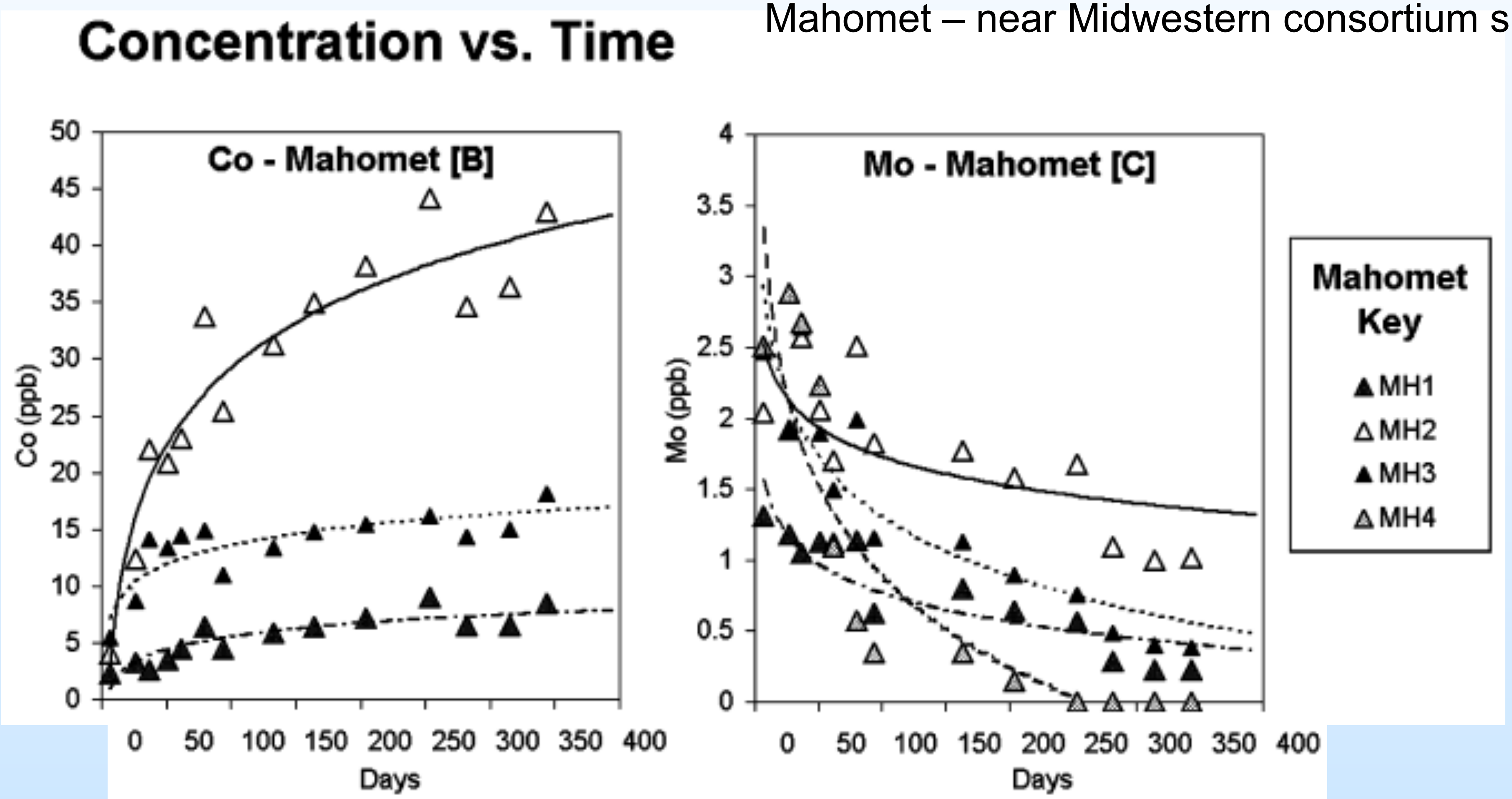


Little & Jackson 2010, 2011 Environmental Science & Technology

Highlights of Project to Date

- Accomplishment 3 (cont.) – Published our first papers of changes to sediment/water systems for a one-year incubation.

Mahomet – near Midwestern consortium site



Little & Jackson 2010, 2011 Environmental Science & Technology

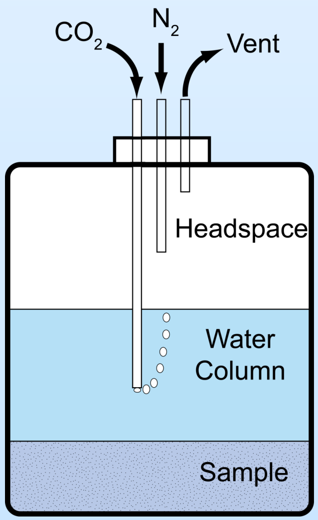
Highlights of Project to Date

- Accomplishment 4 – Based on the initial year-long incubation, identified manganese, iron, and calcium (along with pH) as potential geochemical markers of a CO_2 leak. The concentrations of these elements increased within two weeks of exposure to CO_2.

Little and Jackson 2010, 2011 Environmental Science & Technology

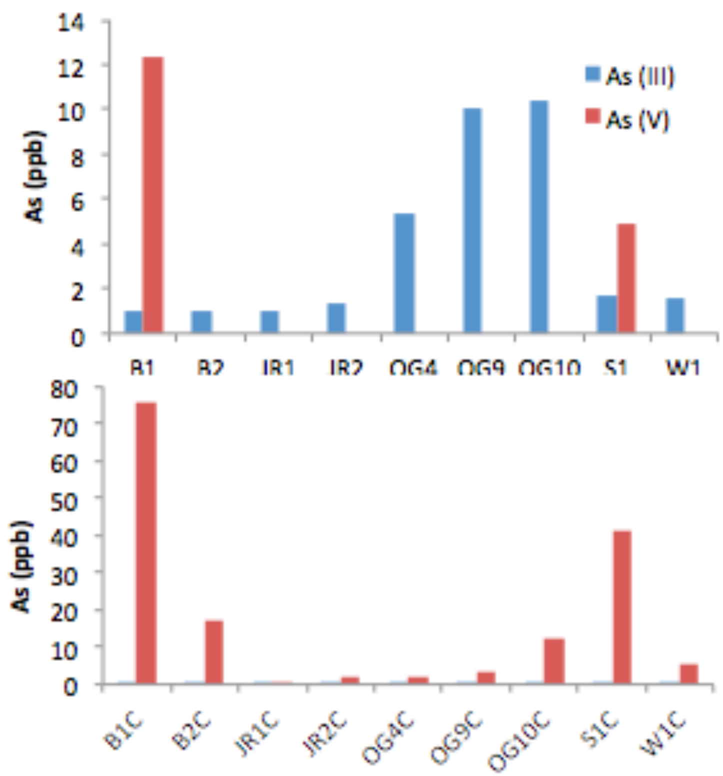
Additional Incubations Currently Underway

- Our published analyses simulated relatively reducing conditions. Such conditions are appropriate for many aquifers, but not for all, such as parts of the Ogallala. Thus, we are doing incubations in a range of reducing conditions.
- Along with our initial samples, we obtained additional cores, including a series from USGS cores from the central valley of CA.



Redox conditions

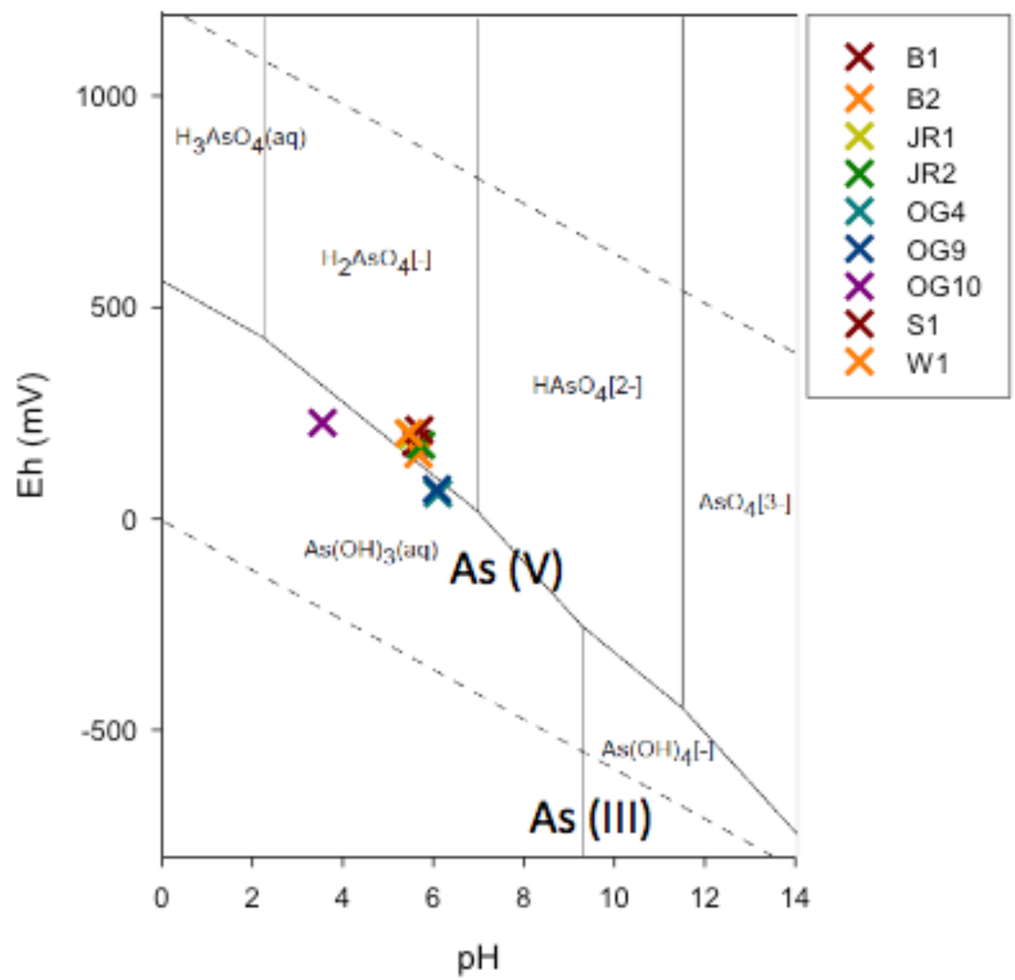
Arsenic Speciation



- Where concentrations are higher than 2 ppb: As is in reduced phase, As (III), within Ogallala groundwaters
- California samples show oxidized As (V) to be more dominant.

ORP/pH Observations

- Eh and pH measurements also show Ogallala groundwaters to contain reduced As.



Dissolved O_2 measurements indicate DO < 1 mg L^{-1}

- ORP, pH and As speciation results show experiment waters are more reduced than the control waters.
- Arsenic speciation data corroborates pH and ORP data, providing confidence in our determination of redox conditions.
- Dissolved oxygen measurements show incubations waters to be hypoxic.
- Further steps are being taken to eliminate infiltration of O_2 into experiment waters
- New observations and initial modeling results will be presented at the 2012 Geological Society Annual Meeting in Charlotte, NC.

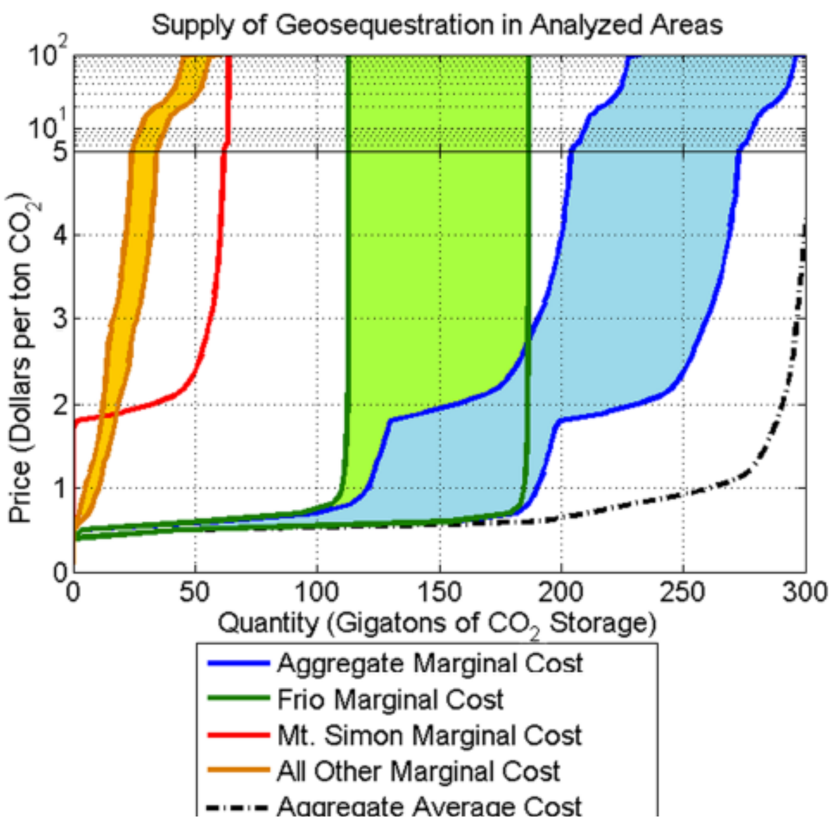
Geochemical and groundwater flow modeling

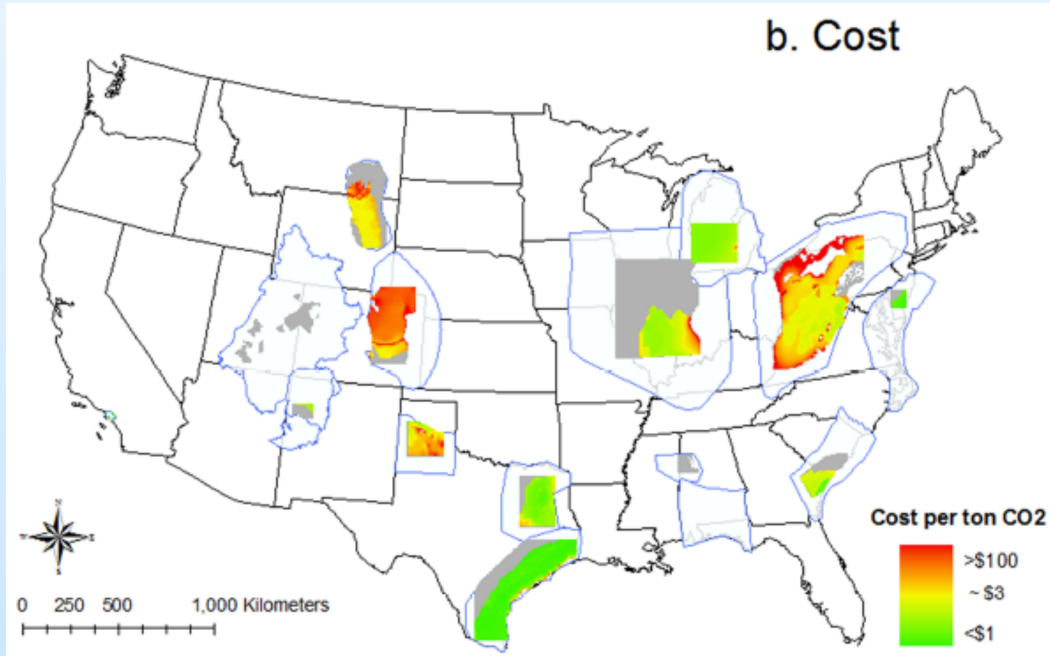
- PHREEQC
  - The USGS low-temperature aqueous geochemistry modeling program. We are currently using PHREEQC to model mineral stability in incubation waters. We plan to utilize modules to simulate mineral equilibration with groundwater and groundwater mixing.
- MODFLOW
  - USGS 3d groundwater flow model. MODFLOW will be used to characterize the spatiotemporal patterns of geosequestered CO_2 invasion into surface aquifers.

Other CCUS Work Leveraged by DOE Funding

Eccles, Pratson, Newell, & Jackson 2012 The impact of geologic variability on capacity and cost estimates for storing CO_2 in deep-saline aquife
rs. Energy Economics 5:1569-1579.

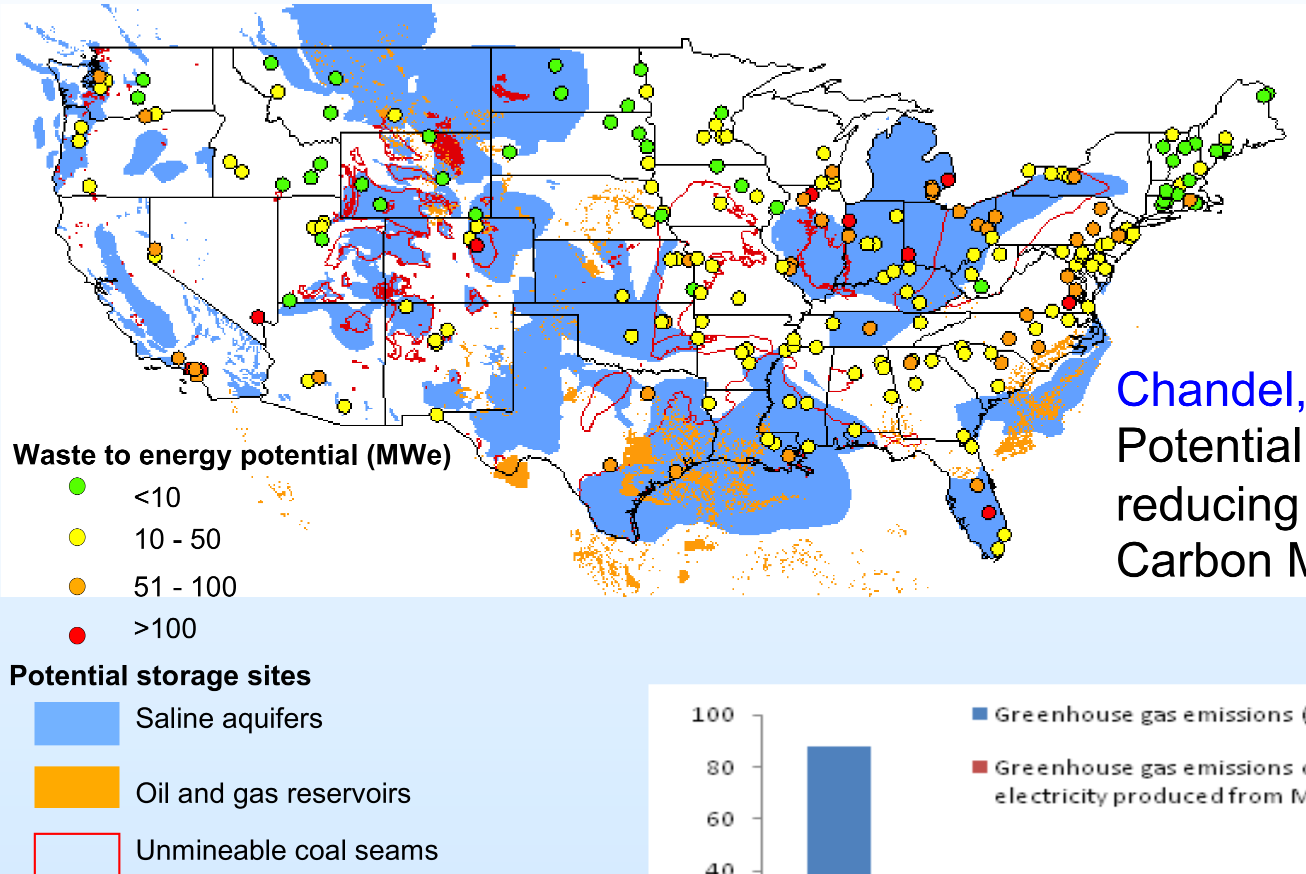
Produces geo-referenced rasters of estimated storage capacity and cost for 15 deep-saline sandstone aquifers. A majority of the total estimated storage capacity in the rasters is concentrated in the Frio Formation and the Mt. Simon Formation, which comprise only ~20% of the areas analyzed.



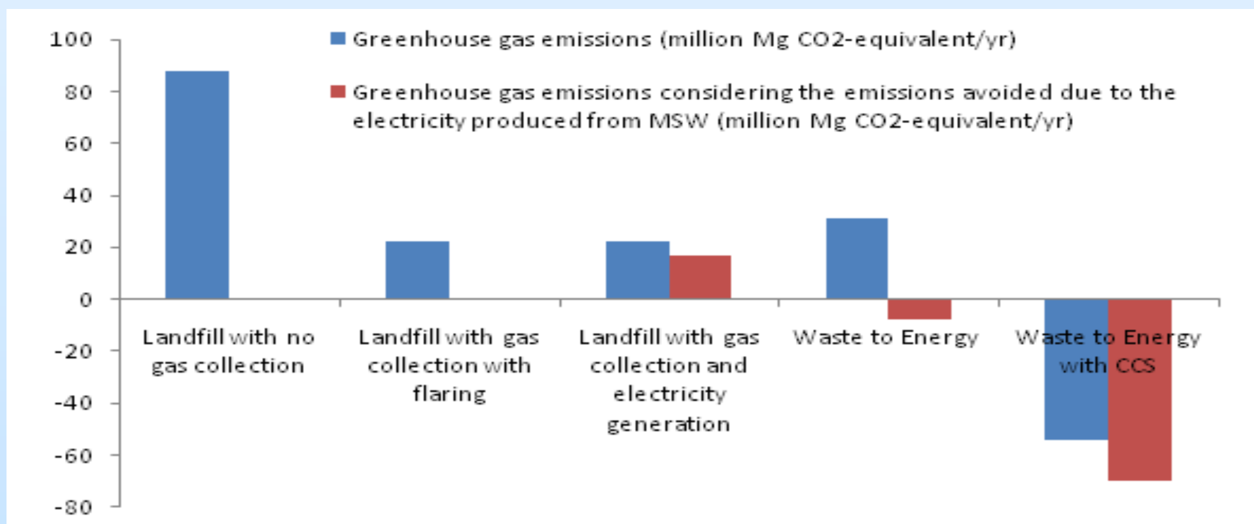


Additional CCUS Work Leveraged with DOE Funding

Landfills, Negative Carbon Emissions, and CCS



Chandel, Pratson, & Jackson 2012
Potential of waste-to-energy in reducing greenhouse gas emissions. Carbon Management 3:133-144.



Accomplishments to Date

- Identified and obtained samples from five aquifer systems for incubations.
- Developed method for incubating sediments simulating a CO_2 leak in a range of redox conditions.
- Identified Mn, Fe, and Ca (along with pH) as potential geochemical markers of a CO_2 leak; their concentrations increased within two weeks of exposure to CO_2.
- Published our first papers documenting changes to sediment/water systems for the one-year incubations.
- Published additional papers on combined waste-to-energy and CCUS for the U.S. as well as estimates of capacity and cost for CCUS in deep-saline aquifers.

Summary

– Key Findings

As described above, identified key elements that change if CO_2 leaks into shallow aquifers, as well as early-warning criteria

– Future Plans:

We hope to obtain core/sediment samples from each regional consortium and test them using our framework.

Chemical modeling to broaden the range of simulated conditions for our simulations.

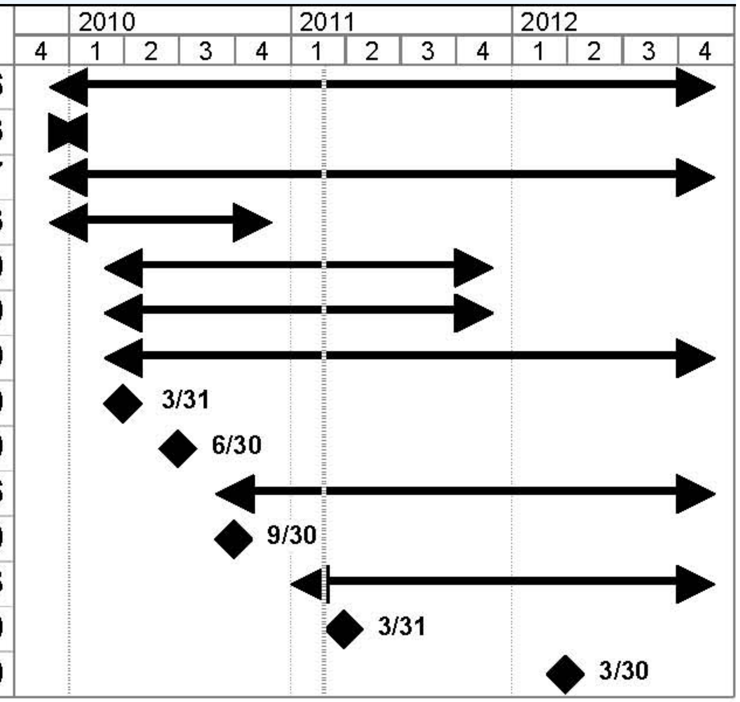
Organization Chart

- Project team, organization, and participants.

- Robert B. Jackson, Professor and PI (jackson@duke.edu)
- Avner Vengosh, Professor and co-PI
- Stephen Osborn, Mark Little, and Josiah Strauss, Postdoctoral associates
- David Vinson, Graduate student – performed chemical analyses, particularly redox tests
- Jennifer Huang and Elizabeth Vergnano, Undergraduate students – assisted with lab analyses

Gantt Chart

Task Name	Cost
Total Project Costs	$296,917.96
Task 1.1: Initial Project Management Plan	$1,912.63
Task 1.2: Planning and Reporting	$6,887.27
Task 2.0: Identification of Groundwater Resources	$17,277.83
Task 3.1: Aquifer Sediment Sample Collection	$36,320.10
Task 3.2: Aquifer Evaluation and Water Sample Collection	$36,320.10
Task 4.1: Incubation and Bubbling Simulations	$83,097.89
HQ Milestone: Project Kick-off Meeting	$0.00
HQ Milestone: Educational Program Instituted	$0.00
Task 4.2: Analysis	$50,630.76
HQ Milestone: Semi-Annual Progress Report	$0.00
Task 4.3: Analytical Modeling	$64,471.38
HQ Milestone: Yearly Review Meeting	$0.00
HQ Milestone: Yearly Review Meeting	$0.00



Bibliography

Peer reviewed publications generated from project

- Little MG, RB Jackson 2010 Potential impacts of leakage from deep CO_2 geosequestration on overlying freshwater aquifers. Environmental Science and Technology 44:9225–9232; DOI: 10.1021/es102235w.
- Little MG, RB Jackson 2011 Response to Comment on “Potential Impacts of Leakage from Deep CO_2 Geosequestration on Overlying Freshwater Aquifers.” Environmental Science and Technology 35:3175-3176.
- Eccles JK, L Pratson, RG Newell, RB Jackson 2012 The impact of geologic variability on capacity and cost estimates for storing CO_2 in deep-saline aquifers. Energy Economics 5:1569-1579.
- Chandel MK, G Kwok, RB Jackson, LF Pratson 2012 The potential of waste-to-energy in reducing greenhouse gas emissions. Carbon Management **3**:133–144, doi:10.4155/cmt.12.11.