Geologic Sequestration: Deep Saline Aquifers

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OUTLINE

- People
- Research Topics
- Selected Results
- Links and Connections
- A Look Ahead
THE AQUIFER GROUP

Core Faculty:

M. Celia (CEE/EEWR) - Multi-phase Flow, Scale-up
P. Jaffe (CEE/EEWR) - Water Quality, Geochemistry
S. Myneni (GEO/EEWR) - Molecular-scale Chemistry
C. Peters (CEE/EEWR) - Thermodynamics, Risk Assessment
J. Prevost (CEE/MMS) - Geomechanics, Numerical Methods
G. Scherer (CEE/MMS/PMI) - Materials, Cement Properties

Postdocs and Visitors:

A. Altevogt, R. Bruant, D. Giammar, W. Vichit-Vadakan

Graduate Students:

A. Duguid, S. Gasda, L. Li

Major Collaborator: S. Bachu (Alberta Geological Survey)
THE AQUIFER GROUP: FIRST YEAR

◆ Year 1 of Project:
  – Identify Important Practical Questions
  – Formulate Relevant Science Questions
  – Assemble Personnel
  – Develop Specific Objectives and Tasks
  – Form Links: BP, LBL, TxBEG, AGS

◆ Two Broad Issues:
  – Environmental Effects and Safety
    » Is Geologic Sequestration Environmentally Acceptable?
  – Storage Capacity of Aquifers
    » If it works, will it solve the carbon problem?

BP:
  Walt Lamb
  Sheng-Tai Lee
  Shelagh Baines
  Phil Pattillo

AGS:
  Stefan Bachu

TxBEG:
  Sue Havorka

LBL:
  Sally Benson
MAJOR RESEARCH AREAS

- Numerical Simulation
- Leakage Pathways and Environmental Consequences
- Rock-Brine-CO$_2$ Geochemistry
- Data Sources, Field Sites, Practical Applications
- Specialized Areas of Inquiry
  - UIC Program
  - Brine Management
  - Cements
MAJOR RESEARCH AREAS

◆ Development of Advanced, In-House Numerical Simulators
  – Fluid Flow, Miscible Transport, Geomechanics, Geochemistry.
  – Parallel Implementation
  – Flexible Structure
  – Advanced Solvers
  – Finite Element Code
  – Based on Dynaflow

![Mass of CO₂/Volume [kg/m³] vs Depth [m] vs Radial distance [m] graph with T ~ 4 years legend]
NUMERICAL SIMULATOR

- **Status:**
  - Fully coupled geomechanics, two-phase flow, miscible transport, interphase mass transfer, all EOS's.
  - Running on our new parallel computer
  - Still lacks geochemistry modules

- **Links:**
  - AGS, BP

- **Full ppt Presentation at:**
  - web.princeton.edu/sites/cmi-aquifers
  - click on 'For Sponsors' Button
  - Get Login ID from Charles Christopher
MAJOR RESEARCH AREAS

- Identification and Assessment of Leakage Pathways and Associated Environmental Effects
  - Critical Pathways
  - Broad Environmental Effects
    - Groundwater Contaminantion
    - Soil Gases, Vegetation
    - Ecosystems, Monitoring
    - Leakage Patterns to Atmosphere
  - Natural Analogs
  - Cements and Existing Wells
  - Experiments and Modeling

Source: 100% CO$_2$ at 1 atm
Background: 1% CO$_2$
LEAKAGE AND ENVIRONMENTAL EFFECTS

**Pb\(^{2+}\), mol/L**

- **t = 10 yr.**
- **8 yr.**
- **6 yr.**
- **4 yr.**
- **2 yr.**

**Groundwater flow**

**Drinking-water aquifer**

**CO\(_2\) leakage**

**Deep brine aquifer**

**Distance, m**

**Pb\(^{2+}\) concentration, mol/L**

- **t = 2 yr.**
- **10 yr.**
- **8 yr.**
- **6 yr.**
- **4 yr.**
LEAKAGE AND ENVIRONMENTAL EFFECTS

◆ Status:
  – Fully coupled miscible transport model with detailed geochemistry.
  – Paper is currently being prepared (will be posted).
  – Algorithm needs to be improved and incorporated into Dynaflow.

◆ Links:
  – AGS, BP, LBL

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MAJOR RESEARCH AREAS

- Ultimate Fate of Injected CO$_2$: Thermodynamics and Kinetics of CO$_2$-Water-Rock Interactions
  - Experimental Studies
  - Molecular Scale to Core Scale
  - Extension to Field Scale
  - High Pressure and Temperature

- Status:
  - Lab has been constructed
  - Initial Experiments being Performed

- Links:
  - AGS, BP, ...
Laboratory Experiments

High-P Mineral Dissolution Apparatus:

System Characterization:

**Macro-Scale Analysis:**
- Chemical analysis of aqueous samples
- Analysis of solids (surface area, morphology, bulk composition)

**Molecular-Scale Analysis:**
- Infrared Spectroscopy (IR): Capability for in-situ high-P/high-T measurement
- X-ray absorption spectroscopy: Synchrotron radiation (LBL, SSRL, BNL)
**CO₂ Properties:**
- Fugacity \((T, P)\)
- Density \((T, P)\)
- Viscosity \((T, P)\)

**Aqueous Solution Properties:**
- CO₂ Solubility \((T, P, TDS)\)
- Aqueous Density \((T, P, TDS)\)
- Equilibrium Constants \((T, P, TDS)\)

**Application:**
- Reservoir simulations of injected CO₂
- Interpretation of rock-brine-CO₂ chemistry laboratory experiments
MAJOR RESEARCH AREAS

- Identification of Field Site(s), with Applications focused on these sites
  - Data Availability
  - Broad Applicability
  - Strong Collaborations
  - Ongoing Field Activities

We have a collaborative research agreement with Stefan Bachu and the Alberta EUB

QA/QC for Data
CO₂ Sources
Acid-Gas Injections

Alberta Basin

Princeton University
MAJOR RESEARCH AREAS

◆ Additional Studies on a Smaller Scale
  – Hazardous Waste Injection, the UIC Program, and Regulation of CO$_2$ Injection Programs
  – Computational Studies of Brine Management:
    » Possible advantages of brine injection or brine recirculation.
    » Extent of brine migration associated with CO$_2$ injection.
  – Collaborations with Carbon Capture Group, Carbon Science Group.

◆ New Areas of Study
  – Experimental Program on Cement Degradation
CMI: Aquifers Group

The CMI Aquifers Group is one of the four major groups under the Carbon Mitigation Initiative. The Aquifers Group is focused on evaluation of deep saline aquifers for long-term storage of CO₂. This website provides general information about the researchers in the Aquifers Group, and about our research activities.

BP Login info: Ask Charles C.
Future Directions

◆ Computational Studies:
  – Develop simulator specifically for transport in cement
  – Develop initial leakage probability estimates

◆ Experimental Studies:
  – Reactions and rates for various rock-brine-CO$_2$ systems
  – Cement degradation in the presence of CO$_2$, H$_2$S, ...

◆ Environmental Effects:
  – Catalog possible effects in shallow subsurface
  – Couple with global-scale analyses

◆ Field Sites and Links:
  – Initial estimates of storage capacity in Alberta Basin
  – Links within CMI, AGS, BP, (Ford), ...
Carbon Mitigation Initiative at Princeton

Carbon Capture

Carbon Storage

Carbon Science

Carbon Policy