the ENERGY lab

PROJECT FACTS

Carbon Storage - GSRA

CO_2 Geological Storage: Coupled Hydro-Chemo-Thermo-Mechanical Phenomena—From Pore-Scale Processes to Macroscale Implications

Background

The focus of the Department of Energy's (DOE) Carbon Storage Program is to develop and advance technologies that will significantly improve the effectiveness of geologic carbon storage, reduce the cost of implementation, and prepare for widespread commercial deployment between 2025 and 2035. Research conducted to develop these technologies will ensure safe and permanent storage of carbon dioxide (CO_2) to reduce greenhouse gas (GHG) emissions without adversely affecting energy use or hindering economic growth.

Geologic carbon storage involves the injection of CO_2 into underground formations that have the ability to securely contain the CO_2 permanently. Technologies being developed for geologic carbon storage are focused on five storage types: (1) oil and natural gas reservoirs; (2) saline formation; (3) unmineable coal seams; (4) basalts; and (5) organic-rich shales. These technologies will work towards meeting carbon storage programmatic goals of (1) estimating CO_2 storage capacity +/- 30 percent in geologic formations; (2) ensuring 99 percent storage permanence; (3) improving efficiency of storage operations; and (4) developing Best Practices Manuals. Deploying these technologies in commercial-scale applications will require a drastically expanded workforce trained in carbon capture and storage (CCS)-related disciplines, including geologists, engineers, scientists, and technicians. Training to enhance the existing CCS workforce and to develop new professionals can be accomplished through focused educational initiatives in the CCS technology area.

The National Energy Technology Laboratory (NETL), through funding provided by the American Recovery and Reinvestment Act (ARRA) of 2009, managed 43 projects that received more than $12.7 million in funding that focus on conducting geologic storage training and support fundamental research projects for graduate and undergraduate students throughout the United States. The training and projects can be categorized under one or more of the DOE Carbon Storage Program's five Technology Areas: (1) Geologic Storage and Simulation and Risk Assessment (GSRA), (2) Monitoring, Verification, Accounting (MVA) and Assessment, (3) CO_2 Use and Re-Use, (4) Regional Carbon Sequestration Partnerships (RCSP), and (5) Focus Area for Sequestration Science. This project investigated multiple fundamental geochemical processes that enhanced the permanent storage of CO_2.

Project Description

NETL partnered with the Georgia Institute of Technology (GT) to explore the consequences of coupled hydro-chemo-thermo-mechanical (HCTM) processes related to the injection of CO_2 into the subsurface. This work expanded the results from a

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PARTNERS

None

PROJECT DURATION

Start Date End Date
12/01/2009 05/31/2013

COST

Total Project Value
$300,000

DOE/Non-DOE Share
$300,000/$0

PROJECT NUMBER

DE-FE0001826

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previous study on the interactions of groundwater acidification and dissolution of minerals and precipitation on pore-scale processes. The scope of work included general analyses in the governing parameter domain, interfacial properties of water, mineral, CO_2 and/or surfactant system, interaction between clay particles and CO_2, reactive fluid flow as a result of CO_2 dissolution, two-phase flow between immiscible CO_2 and formation fluid, CO_2 break through and sealing strategies, and CH_4-CO_2 hydrate replacement and hydro-mechanical implications. The project team explored coupled phenomena, identified different zones in the storage reservoir, and investigated their implications in CO_2 geological storage. In particular, the research: (1) Explored spatial patterns in mineral dissolution and precipitation (comprehensive mass balance formulation); (2) experimentally determined the interfacial properties of water, mineral, and CO_2 systems, including CO_2-water-surfactant mixtures to reduce the CO_2-water interfacial tension in view of enhanced sweep efficiency (Figure 1); (3) analyzed the interaction between clay particles and CO_2, and the response of sediment layers to the presence of CO_2 using specially designed experimental setups and complementary analyses; (4) coupled advective and diffusive mass transport of species, together with mineral dissolution to explore pore changes during advection of CO_2-dissolved water along a rock fracture; (5) upscaled results to a porous medium using pore network simulations; (6) measured CO_2 breakthrough in highly compacted fine-grained sediments, shale and cement specimens; (7) explored sealing strategies; and (8) experimentally measured CO_2-CH_4 replacement in hydrate-bearing sediments. Analytical, experimental and numerical results obtained in this study can be used to identify optimal CO_2 injection and reservoir-healing strategies to maximize the efficiency of CO_2 injection and to attain long-term storage.

Goals/Objectives

The goal of this project was to gain a better understanding of the fundamental processes and couplings that may either hinder or enhance the long-term geological storage of CO_2. To reach this goal, GT explored the consequences of HCTM processes on geological storage, identified emergent phenomena, and bound the parameter-domain for the efficient injection and safe long-term geologic storage of CO_2 in underground reservoirs. Specific project objectives included:

- Combining unique pore and particle-scale experimental studies.
- Numerically evaluating the experimental studies and upscale the pore- and particle-scale processes.
- Utilizing the data to develop a fully coupled, macroscale numerical HCTM model.

Accomplishments

- By the end of the project, four students had accumulated 6,080 training related hours under the program.
- CO_2-water interfacial tension decreases significantly from 72mN/m to ~25mN/m as pressure increases to reservoir pressure-temperature conditions. Contact angle varies with CO_2 pressure in response to changes in CO_2-water interfacial tension.
- Experimental CO_2 injection tests in pore micro-models and parallel network model simulations demonstrate that the sweep efficiency of CO_2 invasion can be effectively enhanced by lowering the capillary factor. In particular, the sweep efficiency can double with the addition of surfactants.
- The complex interplay between chemo-hydro-mechanical processes may lead to positive feedback mechanisms that can either degrade or self-stabilize the caprock seal capacity, or alter CO_2 injectivity in the reservoir.
- Leaks in most storage sites will be advection-controlled once percolation takes place (in the absence of high conductivity geological features). Diffusive and advective CO_2 leaks through non-fractured caprocks will be minor and will not compromise the storage capacity of CO_2 injection sites.
- CH_4-CO_2 replacement within the stability field occurs without loss of stiffness in the granular medium. CO_2-flooded sandy reservoirs can remain mechanically stable during and after CH_4 gas production.

Benefits

Overall the project made a vital contribution to the scientific, technical, and institutional knowledge necessary to establish frameworks for the development of commercial-scale CCS. This project also contributed to the Carbon Storage Division programmatic goal of ensuring 99 percent storage permanence and improving the efficiency of carbon storage operations. The research delivered unprecedented particle and pore-scale data, up-scaled implications, emergent phenomena, injection strategies and storage performance.

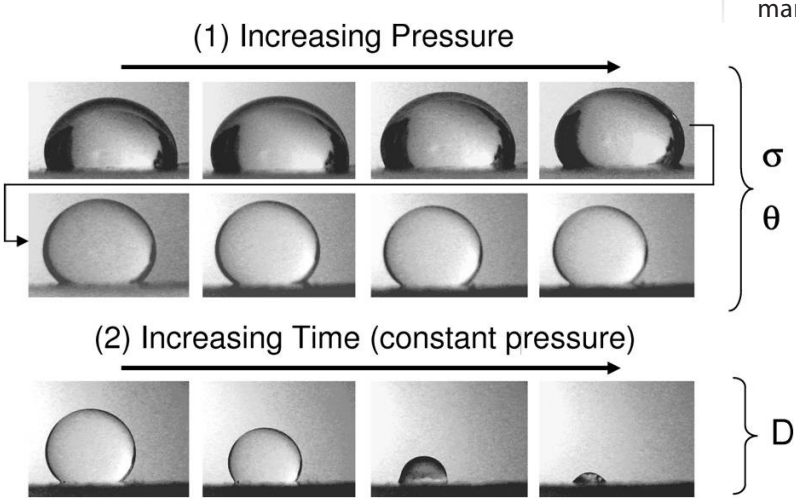

Figure 1. A water droplet on polytetrafluoroethylene (PTFE) substrate surrounded by CO_2. (1) Changes in interfacial tension and contact angle as CO_2 pressure increases from 0.1 to 18.5 MPa. (2) droplet size reduction as water diffuses into the surrounding liquid CO_2 (Duration ~400 min).