the ENERGY lab

PROJECT FACTS

Carbon Storage – ARRA - GSRA

Modeling and Risk Assessment of CO_2 Sequestration at the Geologic-Basin Scale

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 risk assessment and modeling tools for CO_2 storage in saline formations on a basin scale.

Project Description

NETL partnered with the Massachusetts Institute of Technology (MIT) to develop tools to better understand and model CO_2 storage permanence in geologic formations at the basin scale. This research contributed to deploying carbon capture and storage (CCS) at a gigatonne per year injection scale over the course of several decades, by providing robust simulation tools on a very large scale. Continuous CO_2 injection of

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PARTNERS

None

PROJECT DURATION

Start Date	End Date
12/01/2009	8/31/2013

COST

Total Project Value
$299,045
DOE/Non-DOE Share
$299,045 / $0

PROJECT NUMBER

DE-FE0002041

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this magnitude must be understood at the geologic basin scale in order to better understand storage permanence and capacity. The project performed fundamental research on CO_2 migration, fate, and displaced brine at the geologic basin scale. Additionally, MIT developed analytical sharp-interface models of the evolution of CO_2 plumes over the duration of injection (decades) and after injection (centuries).

MIT has experience in investigating closed-form analytical solutions that account for plume shape during CO_2 injection and for regional groundwater flow. From accomplishments obtained in this past research, MIT extended the modeling use in this project to include the essential physics governing plume migration: (1) induced pressure gradients, (2) capillary trapping, (3) buoyancy, (4) regional groundwater flow, (5) aquifer slope, (6) dissolution into the brine (due to both diffusion from residual CO_2 and convective mixing from mobile CO_2), and (7) loss through the confining unit (Figure 1).

MIT applied the analytical solutions of CO_2 plume migration and pressure evolution to specific geologic basins to estimate the maximum footprint of the plume, and the maximum injection rate that can be sustained during a given injection period without fracturing caprock. These results have led to more accurate resource estimates, based on fluid flow dynamics, rather than ad hoc assumptions of an overall "efficiency factor" typically used in storage capacity estimation calculations. In addition, MIT used risk assessment methodologies to evaluate the uncertainty in their predictions of storage capacity and leakage rates. The results of the research were incorporated into the short course titled "Carbon Capture and Storage: Science, Technology, and Policy" offered through the MIT Professional Institute to train the present and future CCS workforce.

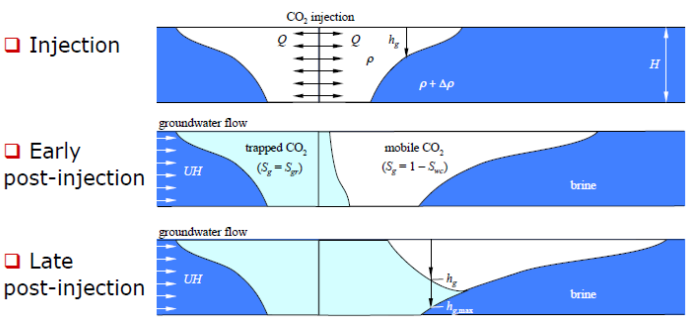

Figure 1. Conceptual model of work to be undertaken that will take into consideration the effects of: capillary and dissolution trapping; injection and post-injection periods; and the regional groundwater flow and slope of the geological formation.

Goals/Objectives

The main objective of the project was to develop tools to better understand modeling and risk assessment of CO_2 storage permanence in geologic formations at the geologic basin scale, and to understand CCS at the gigatonne per year injection scale required to have an impact on the abatement of CO_2 emissions. To meet this objective, the project developed mathematical models of storage resources and injectivity at the basin scale, building quantitative risk assessment methodologies, and obtaining quantitative estimates of storage resources, potential leakage risks, and injectivity of geologic basins across the continental United States. The specific technical objectives of the project included:

- The development of mathematical models of capacity and injectivity at the basin scale
- The application of risk assessment methodologies that will inform on CO_2 permanence
- The application of the models to geologic basins across the continental United States

Accomplishments

- By the end of the project, seven students have accumulated 10,044 training related hours under the program.
- The project team has developed several mathematical models for the evaluation of CO_2 migration at the basin scale. These basin scale models focus on the pressure evolution of the CO_2 plume during and after injection, the evaluation of the effects of capillary trapping mechanisms on CO_2 migration and permanence within the storage formation, and a model evaluating both capillary and solubility trapping mechanisms within the storage formation.
- The project developed methodologies to apply the basin scale mathematical models to a variety of basins in the continental U.S. The geologic storage data to be used in these models were evaluated and validated against existing model structure, with paths for improved modeling parameters also being investigated.
- The project team worked to refine the determination of basin-specific storage resource estimates based on CO_2 storage capacity and infectivity. The project team conducted a sensitivity analysis on basin scale modeling parameters, and probability distributions for model parameters with the most significant effect on model outputs. Additionally, an uncertainty analysis for modeling parameters and outputs was conducted. The basinal data and refined storage capacity estimates for several carbon storage formations were applied to the CO_2 migration models.

Benefits

Overall the project made a vital contribution to the scientific, technical, and institutional knowledge base needed to establish frameworks for the development of commercial-scale CCS. More specifically, the mathematical models and uncertainty quantification methodologies developed by the project offer a physically-based approach for estimating storage resources and potential leakage risk at the basin scale. This research will further the Carbon Storage Division programmatic goals of optimizing storage operations and ensuring 99 percent storage permanence in the subsurface. The simplified model of pressure evolution accounts for non-uniform injection rates and different boundary conditions of the geologic stratum. The capillary trapping model accounts for the combined effect of the injection period, groundwater flow, geological formation slope, and caprock undulations. The models of CO_2 migration along layers considered discrete events of potential leakage through the caprock, representing flow through active faults. Additionally, the project helped to train students in the skills and competencies that will be required from a workforce needed to implement CCS technologies on a commercial-scale.