Interdisciplinary Investigation of CO$_2$ Sequestration in Depleted Shale Gas Formations

Background

The overall goal 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 2020 and 2030. 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: oil and gas reservoirs, saline formations, unmineable coal seams, basalts, and organic-rich shales. Technologies being developed 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. These technologies will lead to future CO$_2$ management for coal-based electric power generating facilities and other industrial CO$_2$ emitters by enabling the storage and utilization of CO$_2$ in all storage types.

The DOE Carbon Storage Program encompasses 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. The first three Technology Areas comprise the Core Research and Development (R&D) that includes studies ranging from applied laboratory to pilot-scale research focused on developing new technologies and systems for GHG mitigation through carbon storage. This project is part of the Core R&D GSRA Technology Area and works to develop technologies and simulation tools to ensure secure geologic storage of CO$_2$. It is critical that these technologies are available to aid in characterizing geologic formations before CO$_2$-injection takes place in order to predict the CO$_2$ storage resource and develop CO$_2$ injection techniques that achieve optimal use of the pore space in the reservoir and avoid fracturing the confining zone (caprock). The program’s R&D strategy includes adapting and applying existing technologies that can be utilized in the next five years, while concurrently developing innovative and advanced technologies that will be deployed in the decade beyond. The ability to determine the feasibility of large-scale geologic storage of CO$_2$ in depleted shale gas reservoirs is important when looking for alternative storage formations. Should carbon storage in such reservoirs prove feasible, the number and total capacity of geologic formations for storage of CO$_2$ will increase significantly.
Project Description

Stanford University is investigating the feasibility of geologic carbon storage in depleted shale gas reservoirs. Shale is one of the most common types of sedimentary rock, and is characterized by thin, horizontal layers of rock with extremely low permeability. Many shale types contain approximately 1–2 percent organic material in the form of waxy kerogen, which, along with the abundant clay in shales, provide an adsorption substrate for CO\textsubscript{2} storage similar to that in coal seams (Figure 1). Current shale-related carbon capture and storage (CCS) research is focused on achieving economically viable CO\textsubscript{2} injection rates, given the shale’s low permeability. The potential for the geologic storage of CO\textsubscript{2} in these formations is attractive for several reasons:

- Organic-rich shales are widely distributed (unlike depleted-oil and gas reservoirs).
- Existing infrastructure of wells, pipelines, etc. is available (unlike saline aquifers).
- Pore pressure in the shale formations prior to CO\textsubscript{2} injection will be reduced by gas production, thereby decreasing the potential for induced seismicity, which is potentially another challenge in many saline aquifers.

The focus of this work is to determine how the physical and chemical processes associated with CO\textsubscript{2} storage in organic-rich shales affect injectivity and storage capacity (over long periods of time), and the ability of the shale to store CO\textsubscript{2} (as both a free and adsorbed phase) for thousands of years. This project elucidates mechanisms of CO\textsubscript{2} injectivity, the formation’s geomechanical response, CO\textsubscript{2} transport through fractures and matrix, storage security through a trap and seal framework, and lays the foundation for accurate estimates of storage rates and capacity. Experiments provide data for the verification and validation of models to estimate CO\textsubscript{2} storage capacity and effectiveness of injection into gas shales under realistic conditions.

Goals/Objectives

The over-arching objective of the study is to conduct a series of multiscale, multiphysics, interdisciplinary laboratory and theoretical studies to assess the feasibility of using depleted organic-rich shale reservoirs for large-scale carbon storage. All rock sample analyses, simulations, and modeling will be performed at the laboratory facilities at Stanford University. The scientific objectives of this study are to determine how the physical and chemical processes associated with CO\textsubscript{2} interaction with organic-rich shales affect the following: (1) the ability to inject CO\textsubscript{2} over a long period of time, (2) the ability to store CO\textsubscript{2} as a free phase, and (3) the ability of the shale to adsorb and permanently store CO\textsubscript{2}. Four main focus areas related to the utilization of organic shales as CO\textsubscript{2} geologic storage formations are addressed in this study:

- The physical and chemical interactions between injected CO\textsubscript{2} and shale within the pore spaces of the reservoir rock.
- Understanding how critical-state CO\textsubscript{2} migrates through hydrofractures (man-made fractures generated during injection well development), naturally occurring fractures, and pore spaces within the reservoir rock.
- The chemical interactions that occur between injected CO\textsubscript{2} and groundwater.
- Understanding how injected CO\textsubscript{2} is trapped and sealed within the reservoir rock.

These four areas address the principal scientific objectives of this work, which are to determine how the physical and chemical processes associated with CO\textsubscript{2} injection into organic-rich shales affect the ability to inject CO\textsubscript{2} over long periods of time, and the ability of the shale to store CO\textsubscript{2} for thousands of years. The study will include the examination of shales from a number of basins in the United States where shale gas is produced, including the Barnett shale, the Haynesville shale, the Woodford shale, the Marcellus shale, and Devonian age shales from the Illinois and Appalachian basins in Kentucky.

Figure 1. Scanning electron microscope images of gas shale: (a) pores are 14-1,590 nm in diameter and (b) silica rich regions with organic kerogen (darkly shaded) in the lower left corner. Smaller pores might be either a tip of either a larger pore body or a pore throat (constrictor between two pore bodies).

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Accomplishments

- To evaluate physical and chemical interactions between CO₂ and shale, researchers furthered attempts to image in real time movement in situ of gas through shale cores. Gas porosity of shale cores was also imaged using X-ray CT scanning at micron scale (Figure 2), and investigated sorption, swelling and viscous creep in clays.

- Effective pore size in shales, which dictates permeability and can affect injectivity, has been shown to decrease with increasing effective stress.

- In order to evaluate CO₂ transport in hydrofractures, researchers designed and investigated model systems for simulating sorption and transport at micro and mesoscales. In addition, researchers determined the extent of Knudsen diffusion on the transport mechanism at the nanoscale through application of the a gas slippage (Klinkenberg) effect and determined the difference in gas viscosity and density parameters from nano to micron scales.

Benefits

If the research demonstrates the feasibility of using depleted shale gas formations for carbon storage, the number of sites where storage of CO₂ can be carried out will increase dramatically as will the storage capacity of geologic formations to geologic store large volumes of CO₂. Additionally, depleted shale gas reservoirs will already have much of the infrastructure (pipelines, wells, and developed well sites that were used to remove natural gas) needed to perform CO₂ injection available for immediate use. This project supports the Carbon Storage Program’s efforts to identify and utilize geological formations capable of storing appreciable volumes of CO₂ with 99 percent storage permanence in addition to laying the groundwork for estimating the storage capacity of gas shales within 30 percent.

![Figure 2. Results of a porosity 3D image reconstruction using cores and CT imaging.](image)