Multi-scale Evaluation of Theoretical and Pressure-Constrained Capacity for Site Selection in the Appalachian Basin Region of the United States of America

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Abstract

Several basins across the world are being actively explored to determine the potential and associated risk of carbon dioxide (CO₂) storage by investigating various characterization, modeling and monitoring technologies related to Carbon Capture, Utilization, and Storage (CCUS). The upper Ohio River Valley region in the United States has a history of strong dependence on coal for its industrial base, which includes power generation and steel manufacturing sources. However, understanding of potential reservoirs and containment zones for effectively sequestering the emitted CO₂ in the region is rudimentary at best due to lack of extensive deep well data. The objective for this project includes the development of a CO₂ storage framework to estimate the feasibility and potential for CO₂ storage in nine Cambrian-Ordovician saline formations of interest in eastern Ohio. The presented subsurface analysis and modeling work complement past and ongoing efforts to prove CO₂ storage and utilization options in Ohio and surrounding regions. Our methodology supports systematic initial screening and selection of potential storage sites, using limited geologic characterization data, typical of early exploratory project stages.

Systematic multiscale, multisystem assessment methodology is crucial to resolve the physical processes and geological heterogeneity for exhaustive feasibility determination in any given basin for large-scale CCUS implementation. Preliminary CO₂ capacity and injection performance are evaluated at different scales namely, regional or formation scale, site scale, and near-well or local scale. Multiple target injection systems such as single formation injection zone and multiple formation stacked injection zones are explored. The reservoir feasibility assessment determined (a) volumetric capacity and (b) dynamic capacity and injectivity for CO₂ storage in the ~61,000 sq. km study region. This paper presents the reservoir feasibility assessment methodology which applied novel visual interpretation of potential target locations for CO₂ storage, systematic performance-based screening and ranking workflow for potential storage sites, and numerical investigation of key operational constraints in select potential saline sites. While the methodology is thorough and robust, the presented results are considered preliminary estimates due to the inherent geologic uncertainty associated with limited available data in the study region.

Structural and petrophysical data such as porosity and permeability were used to develop a three-dimensional (3D) Static Earth Model (SEM) in Petrel® for a representative, adequately resolved, model of the regional geologic heterogeneity in the Cambrian-Ordovician interval of interest. Prospective storage resources were estimated with considerations for the total storage efficiency of CO₂ in these modeled saline formations. Varying levels of input data resolution were tested, typical
of advancing project phases, from representative average formation property values to detailed 3D property grid in the SEM to determine their impact on the calculated volumetric estimates. Potential areas within each of the nine formations of interest were screened using connected volumes analysis and ranked based on three performance criteria namely, capacity, injectivity and storage integrity. A single injection zone system in a sandstone formation (Figure 1) and a stacked storage system with a column of multiple carbonate formations were chosen as two illustrative examples to demonstrate the feasibility assessment methodology. Numerical modeling scenarios in these screened sites, representing different lithologies and target injection systems, used key performance metrics, such distribution of injected CO₂ and pressure, to provide insights into acceptable well spacing, pressure buildup, and CO₂ plume distribution. Simplified equivalent near-well models and heterogeneous site models were implemented for insights into operational considerations such as injection well locations, rates etc. on pressure-constrained CO₂ capacity and injectivity between the two systems considered.

This work has resulted in the successful identification of areas in different formations with high potential for geologic CO₂ storage in the eastern Ohio study region. P₅₀ results were used as representative (median) metric of the calculated prospective CO₂ storage resource and mapped for visual representation and geospatial evaluation of potential injection locations in the study region. Notable areas with high storage resource potential can be observed on prospective storage resource maps in northeastern Ohio, east-central Ohio, and along the western margin of the study area in central Ohio. The potential for stacked storage reservoirs is suggested by the reoccurrence of local highs in similar locations on prospective storage resource maps for many of the formations evaluated. Both single injection zone and stacked storage systems appear to provide the much-needed pore volume to accommodate CO₂. Comparison between the volumetric and dynamic estimates for CO₂ storage highlight the effects of operational considerations such as rates, well locations, etc. typical of realistic site conditions.

The dynamic modeling exercise showed that transmissivity of the injection zones identified (permeability-thickness product), which can be estimated using field tests, determines the injection and hence storage efficiency that can be achieved. Significant injectivity potential is also proven by the presence of several high-performance brine injection wells in the region. The porosity-permeability of the injection zone are significant factors for the CO₂ injection amounts as well as the extent of the injected plume in the subsurface. Preliminary pressure-constrained CO₂ capacity in both the example systems suggests that a significant portion of the prospective storage resource estimates remains unutilized, thus suggesting that potential operational optimization for efficiency improvement remains to be explored.

Integration of results from three different scales provides cumulative insights into the practical feasibility of commercial CO₂ storage in deep saline formations in eastern Ohio. Complex geology of the storage resource being investigated calls for advanced and extensive geologic characterization to improve confidence in current performance estimates for CCUS implementation in the region. By methodically narrowing down potential injection locations using the presented methodology, acquiring detailed site characterization data would help eliminate critical uncertainties and provide more robust insights to relate to monitoring aspects during injection operations in the system of interest.
Figure 1. Illustration of the results of static storage resource estimation leading to the CO_2 capacity comparison in the single injection zone example system.

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