the ENERGY lab

PROJECT FACTS

Carbon Storage – Geologic Storage Simulation

Analytical-Numerical Sharp-Interface Model of CO_2 Sequestration and Application to Illinois Basin

Background

Through its core research and development program administered by the National Energy Technology Laboratory (NETL), the U.S. Department of Energy (DOE) emphasizes monitoring, verification, and accounting (MVA), as well as computer simulation and risk assessment, of possible carbon dioxide (CO_2) leakage at CO_2 geologic storage sites. Computer simulation can be used to estimate CO_2 plume and pressure movement within the storage formation as well as aid in determining safe operational parameters; results from computer simulations can be used to refine and update a given site's MVA plan. Risk assessment research focuses on identifying and quantifying potential risks to humans and the environment associated with geologic storage of CO_2, and helping to ensure that these risks remain low.

Project Description

This three-year project — performed by New Mexico Institute of Mining and Technology (New Mexico Tech) and partners — is developing a new multi-layer basin-scale hybrid analytical-numerical multilayer model that will explicitly represent the freshwater, brine, and CO_2 phases of carbon storage using sharp-interface theory to overcome computational limitations of scale. The model is being developed to simulate an injection of about 100 million metric tons of CO_2 annually into the Mount Simon sandstone and Knox Dolomite within the Illinois Basin at dozens of power plant locations across Indiana, Kentucky, and Illinois (Figure 1). The project team is characterizing the petrophysical and mineralogical properties of the Eau Claire confining unit of the Cambrian-Ordovician aquifer system using newly acquired cores. The project will make this model available to the geosciences community for application to a wide variety of sedimentary basins.

Goals/Objectives

The primary goal of this project is to develop a new, multi-scale hybrid analytical-numerical simulator of CO_2 injection using sharp-interface theory to assess environmental and seismic risks associated with large-scale CO_2 injection of up to 100 million tons of CO_2 annually within the Illinois Basin (Figure 1A). The project team's intended application of this model focuses on both programmatic and scientific risks, including: 1) determination of effective, basin-scale hydrologic parameters for reservoirs, confining units, and faults; 2) determination of safe injection rates in different parts of the Illinois Basin; and 3) assessment of probable leakage rates of CO_2 from the Mount Simon sandstone formation into overlying formations and, ultimately, to the atmosphere. The project's effort to address these risks will help meet the Carbon Storage Division's goals of ensuring permanent CO_2 storage in the subsurface and estimating storage capacity.

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PARTNERS

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PROJECT DURATION

Start Date	End Date
9/30/2009	9/30/2012

COST

Total Project Value
$970,824

DOE/Non-DOE Share
$758,877 / $211,947

PROJECT NUMBER

DE-FE0001161

Code development efforts center on use of sharp-interface theory to extend the current Princeton code — which represents two fluids, CO_2 and brine — by adding a third fluid, freshwater, to the system. An additional sub-scale analytical model will be developed for leakage along fault zones. This will allow more general problems to be studied, with the focus on leakage of fluids outside the injection formation.

In the area of data compilation and interpretation, project team members are supporting the modeling effort by determining porosity-effective stress and log (permeability)-porosity relations for Paleozoic carbonate and non-carbonate (siliciclastic) units; compiling existing pressure, salinity, temperature, and hydrologic stress data for the Illinois Basin; and determining fault systems and assessment of fault properties. Efforts are also focused on determining the mineralogy and the petrophysical parameters of the Eau Claire confining unit. Model calibration and prediction efforts focus on developing a quasi-three-dimensional model of the Illinois Basin. A data set is being constructed that includes the positions of major faults, changes in sedimentary layer thickness, and land surface elevations for the basin. Control volume finite-difference grids are being developed for sandstone, shale, carbonate units, and coal measures. Three-dimensional grids also are being constructed for model testing purposes.

The project addresses the need for physical measurements by developing a hybrid analytical-numerical multiscale simulator for CO_2 injection and leakage up oil and gas wells, and by implementing these kinds of simulations to allow for wide-ranging explorations of parameter spaces and sensitivities by taking into account uncertainties regarding effective hydraulic properties for leaky wells and faults.

Accomplishments

- Completed code development of a fully three-dimensional, multi-layer, finite difference model based on sharp-interface theory as well as Los Alamos Laboratory's finite element heat and mass transfer (FEHM) model grid.
- Developed a preliminary quasi-three-dimensional grid for the Illinois Basin (Figure 1D). Permeability and porosity were allowed to decrease with depth in each layer (Figure 1B). Calibrated model to drawdown patterns around Chicago (Figure 1C). Compared model to a TOUGH2 simluation example with 8 layers. New model grids have also been developed to to integrate water wells present in the Chicago study area.
- Completed a study of basin-scale porosity-depth and permeability-porosity relationships for sands, shales, and carbonate rocks for the Illinois Basin using salinity, noble gas, and oxygen isotope tracer data.

Benefits

As carbon capture, utilization, and storage (CCUS) capacity increases and projects become commercial beyond 2020, the importance of accurate geologic models and robust risk assessment protocols will become increasingly important to project developers, regulators, and other stakeholders. NETL's Carbon Storage Program aims to continue improvements to the models and risk assessment protocols. Specific goals within the Simulation and Risk Assessment Focus Area that will enable the Carbon Storage Program to meet current programmatic goals are to (1) validate and improve existing simulation codes which will enhance the prediction and accuracy of CO_2 movement in deep geologic formations to within ± 30 percent accuracy, (2) validate risk assessment process models using results from large-scale storage projects to develop risk assessment profiles for specific projects, and (3) develop basin-scale models to support the management of pressure, CO_2 plume, and saline plume impacts from multiple injections for long-term stewardship in major basins of the United States.

To effectively evaluate the risk of large-scale deployment and injection of large volumes of CO_2 into many widely distributed well fields over long periods, modeling of the details of the petrophysical character of the target reservoirs and the effectiveness of the seals on a regional scale is needed. The results of this project will be critical for those planning the assessment and permanent storage of large-scale CO_2 injection into the deep saline aquifers of the Illinois Basin.

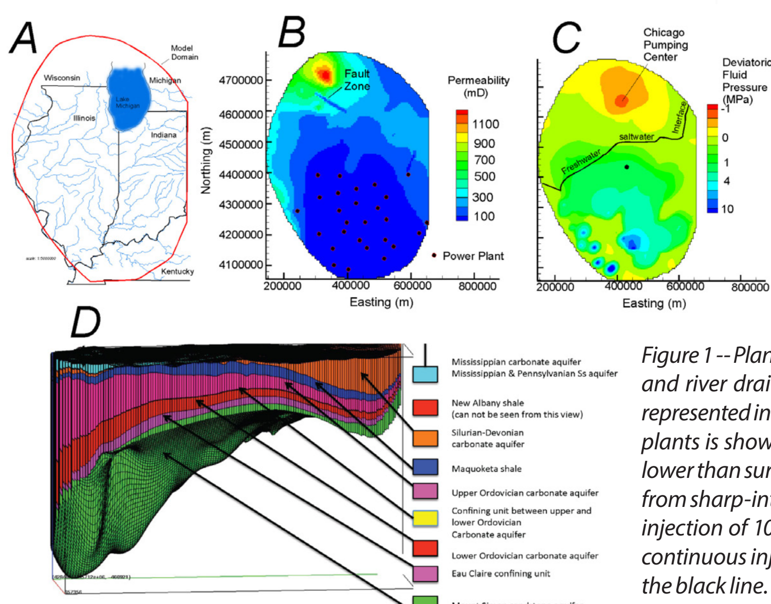

Figure 1 -- Plan-view map showing location of model domain (red line), state boundaries, and river drainage network across Illinois Basin (A). Permeability variations (in mD) represented in sharp-interface model for Mount Simon Formation (B). Location of power plants is shown with red circles. Fault zones were assigned permeability 10-100 times lower than surrounding rocks. Preliminary computed deviatoric fluid pressures (in MPa) from sharp-interface model due to freshwater withdraws in the Chicago area and from injection of 100 MTons of CO_2 at dozens of power plants. Results are after 90 years of continuous injection (C). The position of the freshwater-saltwater interface is shown by the black line. Three-dimensional view of Illinois Basin Stratigraphy looking to the west (D). The grid was generated using the Los Alamos LaGrit mesh generator.