Center for Frontiers of Subsurface Energy Security (CFSES)
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Mission Statement*: To understand and control emergent behavior arising from coupled physics and chemistry in heterogeneous geomaterials, particularly during the years-to- decades time scales over which injection for geologic CO_2 storage will drive natural systems far-from-equilibrium.*

Geologic CO_2 storage (GCS) is key for mitigating greenhouse gas emissions, but to be effective GCS must overcome three primary technical challenges: sustaining large storage rates for decades, using underground space efficiently, and controlling undesired or unexpected behavior. To meet these challenges the *Center for Frontiers of Subsurface Energy Security* (CFSES) pursues scientific advances with the goal to (i) establish scientific understanding of far-from-equilibrium processes in heterogeneous geologic media, and (ii) develop novel materials and methods for controlling those processes. Specific examples of our **science goals** are:

- Understand *chemical-mechanical coupling* by identifying mechanisms and time/length scales for self-reinforcing fracture propagation and fluid leakage through those fractures.
- Combine experiments and computational chemistry to examine the *structural (mechanical) and chemical interactions* between wet supercritical CO_2 and clays. We also seek advanced models of noble gas and isotope partitioning between immiscible fluid phases.
- Understand and predict *modes* (compact viscous flow vs. capillary channels) *and fluxes* of reactive CO_2 migration through brine-saturated geomaterials with cm-to-m scale heterogeneity.
- Capitalize on the improved understanding of these processes to design, develop and apply *novel materials* that will alter fluid-assisted perturbations in heterogeneous geomaterials.

The **impact** of the proposed research will be a new scientific foundation for defining the physical constraints on challenges for GCS, and for identifying novel materials and strategies to overcome these constraints. The science will be valuable for broader policy considerations associated with greenhouse gas emissions, the risks in operating storage sites, and the appropriate mix of incentives and regulation for GCS operation.

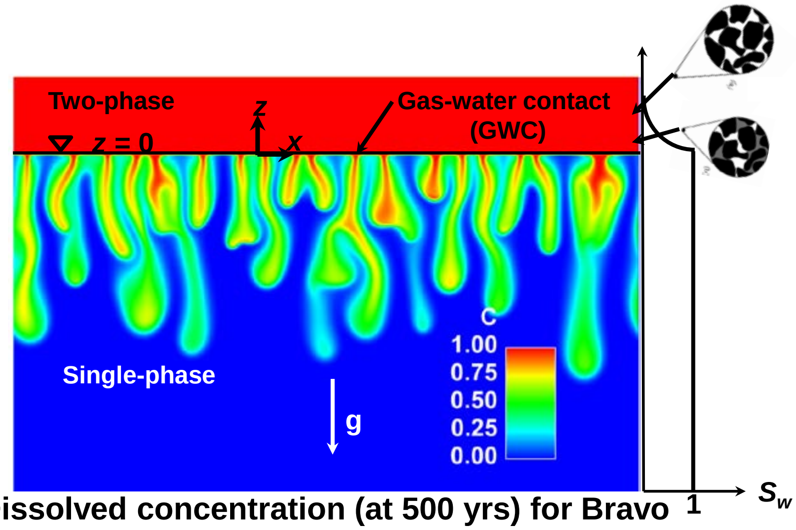
Keywords: Geomechanics, geological CO_2 storage, relative permeability, primary drainage, hydraulic fracturing, phase-field fracture formulation, adaptive finite elements, porous media, caprock, fractures, multiphase flow, reservoir rock, noble gases, migration-fractionation, geochemical tracers, hydration energy, Bravo Dome, porous media, , micromechanics , chemo-mechanical coupling, saline aquifers, mineral trapping, lattice Boltzmann method, pore network modeling

CFSES has already addressed science questions underlying two current concerns for GCS: storage security and risk assessment. Example projects include the following.

Science to Inform Storage Security

Far-from-equilibrium states during CO_2 displacement of brine: CFSES has developed an advanced model for buoyancy driven convective dissolution of CO_2 into brine. CO_2 is normally lighter than water and will hence float on top of it. However, mixtures of CO_2 and water are denser than either causing there to be

a local instability—heavy fluid over light—that forms instabilities (figure) that vastly increase the surface area between CO_2 and water; hence increasing the rate of dissolution.
Impact: Dissolution into water is one of the main mechanisms for storing CO_2. Modeling the fingers suggests the storage rate is 3 times faster than previous estimates.



Dissolved concentration (at 500 yrs) for Bravo Dome properties with 50 kPa entry pressure.

Science to inform GCS risk assessment

Far-from-equilibrium CO_2-mediated geochemistry and caprock integrity: Work within CFSES has quantified mineral dissolution and precipitation on the time scale of a field test (11 days) and long-term storage (1000 years). The work provides insight into the impact of geochemical reactions on injectivity, trapping of CO_2 and caprock integrity. The work can guide potential site selection based on the geochemistry of the site. **Impact:** Other CFSES projects are investigating the effects that chemical interactions will have on storage site mechanical properties. The results of this project will frame this work and provide calibration.

Emergent phenomena during CO_2 plume migration: signature of heterogeneous fluid/rock properties: Modeling of flow through permeable media is normally done in the viscous-dominated flow regime. However, buoyancy forces are likely to dominate viscous flow in the majority of the storage domain because of small fluid pressure gradients caused by the very long storage times. Modeling of this type of flow represents a paradigm shift in the way in which such modeling is normally done. Meso-scale heterogeneity that is typically under represented in conventional flow simulations will strongly influence flow paths, saturations, geochemical reactions, and long-term fate. **Impact:** This project experimentally investigates the combined effect of heterogeneity, viscous forces and buoyancy.

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