EFRC: CENTER FOR FRONTIERS OF SUBSURFACE ENERGY SECURITY (CFSES)

UPDATED: AUGUST 2016

AWARDS: $15.5M (August 2009 – July 2014); $11.2M (August 2014 – July 2018)	
WEBSITES: http://science.energy.gov/bes/efrc/centers/EFRC/; http://www.utefrc.org/	
TEAM: **The University of Texas at Austin (Lead):** Larry W. Lake (Director), Hilary Olson, Tip Meckel, Matthew Balhoff, M. Bayani Cardenas, David DiCarlo, Nicolas Espinoza, Nick Hayman, Marc Hesse, Susan Hovorka, Keith Johnston, Masa Prodanovic, Mary F. Wheeler, Changbing Yang; **Sandia National Laboratories**: Grant Heffelfinger, Susan Altman, Thomas Dewers, Mario Martinez, Anastasia Ilgen, Pania Newell, Hongkyu Yoon	

SCIENTIFIC MISSION AND APPROACH

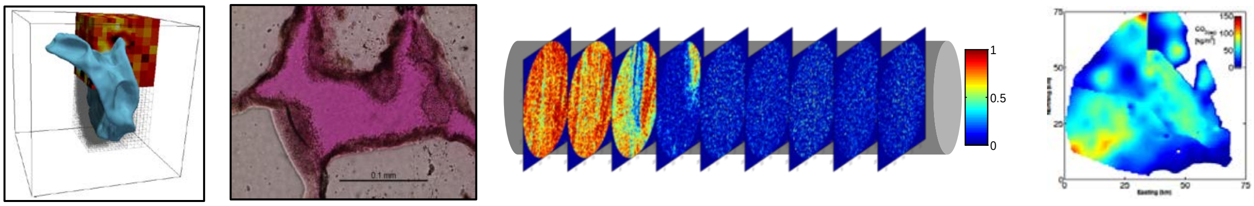
The mission of CFSES is to understand and control emergent (unexpected) behavior arising from coupled physics and chemistry in heterogeneous geomaterials, particularly during the years to decades time scales. The research is tackling three technical challenges: sustaining large storage rates, using pore space with unprecedented efficiency, and controlling undesired or unexpected behavior in geostorage. CFSES is organized into two themes:

1) **Fluid-Assisted Geomechanics:** Through investigations of the surface-controllable variables of pore pressure, injectate chemistry, and behavior of subsurface heterogeneity, the research efforts focus on coupled hydro-mechano-chemical processes that address the GCS challenges of storage efficiency, sustaining injection rates, and avoidance of emergent, unwanted behaviors.

2) **Buoyancy-Driven Multiphase Flow:** Uses an aligned combination of field observation, laboratory experimentation and model development aimed at understanding and exposing emergent patterns and control strategies for multiphase flow in heterogeneous geomaterials.

SELECTED SCIENTIFIC ACCOMPLISHMENTS

- Developed numerical models that describe the size and shape of fractures caused by arbitrary stimulation and loading. Based on a novel phase field approach and when coupled with injectate chemistry, the models estimate the likelihood of a breach in the confining layer(s) of a storage site.
- Used invasion percolation modeling (a different type of model from above) of buoyant and capillary forces to analyze and predict the storage efficiency of CO_2 trapping at a given site. The work relates immobilization of CO_2 to traditional geologic characteristics of grain size and grain sorting. The method developed becomes one of several that can screen candidate storage sites.
- Used the Bravo Dome CO_2 field in New Mexico as a natural laboratory to understand the CO_2 behavior in the subsurface. Averaged across the reservoir, only 20% of the CO_2 had dissolved into the field's saline brine over 1.2 million years. The rest remained as a free gas trapped by the cap-rock. This study was the first field evidence for the safe long-term storage of very large amounts of CO_2 in saline aquifers.
- Developed and experimentally validated models that can predict the growth of a single fracture in the presence of subsurface stress and reactive water. This model should enable the anticipation and prevention of unwanted fracturing and the ability to control the fracture pathway.
- Showed that injecting surface-treated nanoparticles into heterogeneous reservoirs causes more uniform CO_2 spreading than without them, thereby increasing CO_2 storage efficiency by as much as 30%.



CFSES research, from left: Phase-field model of propagating fracture in a three dimensional heterogeneous media; Photomicrograph showing diffuse chlorite grain boundary after exposure to CO_2 (pink is the pore space between the grains); X-Ray computerized tomographic image of a core showing the uniform flow of CO_2 with surface-treated nanoparticles through a sandstone core; Distribution of dissolved CO_2 in the subsurface at Bravo Dome natural analog site.

IMPACT

- CFSES collaboration resulted in two successful National Energy Technology Laboratory (NETL) grants totaling over $2.5M. One project is on the geomechanics of CO_2 reservoir seals and the other on a nanoparticle injection technology for remediating CO_2 storage.
- CFSES collaboration resulted in funding of a Sandia-University of Texas Academic Alliance grant on induced seismicity in CO_2 reservoirs. This project is closely aligned and integrated with induced seismicity research funded by the State of Texas through a $4.5 million project to build a statewide earthquake monitoring system in Texas and to conduct earthquake research.
- Researchers have an ongoing applied research project stemming from the CFSES research on surface-treated nanoparticles. An oil production company is planning a pilot project where the nanoparticles that help control the movement of CO_2 in the subsurface will be co-injected at an oil reservoir with CO_2 for enhanced oil recovery.

PUBLICATIONS AND INTELLECTUAL PROPERTY

As of May 2016, CFSES had published 107 peer-reviewed publications cited over 900 times and filed 3 disclosures and one US patent application. One patent has been issued. The following is a selection of impactful papers:

- Cygan, R. T., Romanov, V. N. and Myshakin, E. M. Molecular Simulation of Carbon Dioxide Capture by Montmorillonite Using an Accurate and Flexible Force Field. *Journal of Physical Chemistry C* **116**, 13079-13091, doi:10.1021/jp3007574 (2012). [**50 citations**]
- Yoon, H., Valocchi, A. J., Werth, C. J. and Dewers, T. Pore-scale simulation of mixing-induced calcium carbonate precipitation and dissolution in a microfluidic pore network. *Water Resources Research* **48**, doi:10.1029/2011wr011192 (2012). [**31 citations**]
- Zhang, Y. P. *et al.* Hydrogeologic Controls on Induced Seismicity in Crystalline Basement Rocks Due to Fluid Injection into Basal Reservoirs. *Ground Water* **51**, 525-538, doi:10.1111/gwat.12071 (2013). [**31 citations**]
- Chaudhary, K. *et al.* Pore-scale trapping of supercritical CO_2 and the role of grain wettability and shape. *Geophysical Research Letters* **40**, 3878-3882, doi:10.1002/grl.50658 (2013). [**28 citations**]
- Worthen, A. J. *et al.* Nanoparticle-stabilized carbon dioxide-in-water foams with fine texture. *Journal of Colloid and Interface Science* **391**, 142-151, doi:10.1016/j.jcis.2012.09.043 (2013). [**29 citations**]
- Altman, S. J. *et al.* Chemical and Hydrodynamic Mechanisms for Long-Term Geological Carbon Storage. *Journal of Physical Chemistry C* **118**, 15103-15113, doi:10.1021/jp5006764 (2014) [**10 citations**]
- Sathaye, K. J., Hesse, M. A., Cassidy, M. and Stockli, D. F. Constraints on the magnitude and rate of CO_2 dissolution at Bravo Dome natural gas field. *Proceedings of the National Academy of Sciences of the United States of America* **111**, 15332-15337, doi:10.1073/pnas.1406076111 (2014). [**11 citations**]
- Rinehart, A. J., Dewers, T., Broome, S. T. and Eichhubl, P. Effects of CO_2 on mechanical variability and constitutive behavior of the Lower Tuscaloosa Formation, Cranfield Injection Site, USA. *International Journal of Greenhouse Gas Control* **53**, 305-318, doi:10.1016/j.ijggc.2016.08.013 (2016). [**0 citations**]