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**PUT IT BACK – AN EXPERIMENT IN RETURNING CARBON FROM
BURNING OF FOSSIL FUEL TO THE SUBSURFACE AS CARBON DIOXIDE**
By Susan D. Hovorka

CO₂: The Issue

Combustion of fossil fuel in air moves 7 billion tons annually of carbon from storage in the crust in the form of oil, gas, and coal into the atmosphere in the form of carbon dioxide [1]. Observed atmospheric concentrations have been increasing [2] suggesting that rates of CO₂ production exceed the assimilative capacity of the terrestrial-ocean system. Although the atmospheric concentrations produced are not thought to be directly harmful to life, credibility is increasing that this sudden excursion in global atmosphere composition can cause or contribute to various potentially negative effects, from direct damage to habitat as a result of ocean acidification to contributing to global climate change and resulting perturbations [3]. In recognition of the significance of these risks, 126 countries have ratified the Kyoto Protocol [4], by which they agree to implement policies that reduce greenhouse gas emissions.

Residents and industries of the Gulf Coast are involved in a carbon issues in several ways: as producers and refiners of fossil fuels, as consumers of fossil fuels, and as inhabitants of a low-lying warm-climate region for which risks such as increased tropicalization, higher sea level, and increased severity of storms have significance. A number of options have been suggested to reduce the transfer of carbon to the atmosphere, including increased use of now available technologies such increased efficiency, increased use of non-fossil energy sources, and capture and storage of CO₂ either from the atmosphere by vegetation or by engineered processes from large combustion sources [1].

Geologic Storage in the Gulf Coast

One option to atmospheric release of CO₂ that is particularly attractive to the Gulf Coast is long-term disposal of CO₂ in geologic formations, so called geologic sequestration. This mitigates the impact of use of fossil fuels on the atmosphere by closing the loop, and putting the carbon back underground as compressed CO₂. In this mechanism the CO₂ is separated from fuels before combustion or from other flue gasses after combustion, compressed, and injected underground below and isolated from potable water resources, a process known as carbon capture and storage (CCS).

Geologic storage is especially suitable for use in the Gulf Coast because it builds in existing expertise's in the region in characterizing the subsurface and predicting the subsurface behaviors of buoyant fluids. Geologic storage builds on a nearly a century of oil and gas exploration and production experience, on decades of experience in the Permian basin and elsewhere for pipeline transport and injection of CO₂ for enhanced oil recovery (EOR). Last but not least, the implementation of carbon capture and storage as a method for reducing atmospheric release of CO₂ would create a significant opportunity for development of much more widespread use of the CO₂ for EOR. Beneficial use of CO₂ in the subsurface for EOR would increase domestic oil supply and provide revenues

in the form of taxes and jobs that could offset some of the costs of CCS. It would also provide career options for geoscientists and engineers in to support this potential growth area.

Underground storage of fluids is not widely understood outside of the geologic community. Most non-geologists express preferences for methods of reducing atmospheric releases that they are more familiar with, even though some of those methods are more expensive or less effective than geologic storage. Therefore education and dialog between the geoscience community and the public is needed if the opportunities are to be realized.

Frio Brine Pilot

As one of the first steps toward developing knowledge about and interest in CCS, an international team of 16 research organizations led by the Bureau of Economic Geology (BEG) undertook a field experiment to document the performance of the subsurface in storing CO₂. This experiment was designed to be transparent, rigorous, and focused on monitoring the subsurface behavior of CO₂ during and after CO₂ injection. The purpose was to educate both the researchers on critical technical issues and the public on the potential of the geologic storage option, and supply information in a timely manner to the CCS research community. The US Department of Energy National Energy Technology Laboratory (NETL) provided \$4.1 million dollars to support the project, additional support of about \$2 million was supplied by research collaborators from federal and private sources.

The experiment site, known as the Frio Brine Pilot, is 4 mi south of Dayton, Texas in the South Liberty oil field. The oil field was developed in the 1950's and is on the lower coastal plain on marginal wetlands on a terrace above the Trinity River, and remains in production. However, the selected test interval in the upper Frio Formation "C" sandstone at depths of 5,053 to 5,073 ft below surface is a brine-rock system with no hydrocarbon accumulation. Selection of a zone above the reservoir optimizes the focus of the study on modeling and monitoring, because the complex interactions of CO₂ with oil do not dominate the system. Pressure at this depth is 2,211 psi, salinity is 125,000 ppm and temperature 134.5° F. The injection interval is the mineralogically complex, reworked fluvial sandstone of the Oligocene upper Frio Formation. Average porosity in the injection sandstone 32%, and measured permeability is 2.5 Darcys. The sandstone test interval is isolated by numerous thick shales above and below the interval and fault compartmentalization on the sides. Dip in the injection sandstone is steep, about 16° toward the south. The site is representative of a broad area that is an ultimate target for large-volume storage because it is part of a thick, regionally extensive, thick sandstone trend that underlies a concentration of industrial sources and power plants along the Gulf Coast of the United States. Development of geologic storage in this region has excellent potential to upscale to impact U.S. releases.

Experiment Objectives

- Demonstrate that CO₂ can be injected into a brine formation without adverse health, safety, or environmental effects

- Determine the subsurface distribution of injected CO₂ using diverse monitoring technologies
- Demonstrate validity of conceptual models
- Develop experience necessary for success of large-scale CO₂ injection experiments.

Experiment Progress

Early in 2004 well construction was approved by the Texas Commission for Environmental Quality (TCEQ) as a class 5 experimental well. Field services operator Sandia Technologies, LLP completed workover of an existing well as an observation well May 13, followed by drilling of a new injection test well 100 ft downdip of the observation well, which was completed June 4, 2004, at a total depth of 5,753 ft. The upper Frio “C” sandstone at a depth of 5053 to 5073 feet was selected for the test. Texas American Resources donated well access and the preinjection 3-D seismic survey used for characterization. Local property owners have donated land access for the experiment. BP has provided project review and advice. The Australian CO₂CRC is and Alberta Research Council contributed substantial expertise to the project team.

Research team members from the BEG USGS, Corelabs, Schlumberger, Lawrence Berkeley National Labs (LBNL), Lawrence Livermore National Lab (LLNL), Oak Ridge national Lab (ORNL) completed preinjection baseline core sampling, wireline logging, aqueous geochemistry, crosswell seismic, cased hole cross-well electromagnetic imaging, vertical seismic profiling, two well hydrologic testing, and surface water and gas monitoring were completed during July-September of 2004. October 4-13, 1,600 tons of CO₂ from a Baytown refinery and a Louisiana ammonia plant were injected into the test zone. Four types of tracers were introduced by the national lab researchers to tag the CO₂ so that it can be distinguished from other CO₂ in the subsurface, soil, and atmosphere: introduced noble gasses, perfluorocarbon, and SF₆ tracers, and the natural stable isotopic composition of carbon and oxygen. CO₂ transport in the Frio “C” sandstone from the injection well to the observation well 100 feet away took 51 hours, and tracers were detected and sampled for more detailed analyses. A “U-tube” sampling device designed and operated by Lawrence Berkeley National Lab (LBNL) was instrumental in obtaining high quality, high frequency fluid samples. Measurement of CO₂ saturation using the Schlumberger RST tool detected saturation and plume thickness. Post injection saturation changes observed as CO₂ migrated through the steeply dipping sandstone under gravitational forces appears to reverse the trend observed during injection. Continued observation will yield information about saturation history significant to understanding CO₂ trapping mechanisms. Downhole pressure and temperature proved to be sensitive indicators of plume behavior, showing changes in plume as CO₂ saturation changed before and after breakthrough. The hydrologic performance of the two-phase (brine+ CO₂) system was tested using transient pressure testing. VSP and crosswell seismic and EM will be repeated in December, and wireline logging, aqueous and gas geochemistry, and surface monitoring have been repeated at intervals and will be repeated for several months into 2005 to document conditions returning toward baseline.

Modeling by both LBNL using TOUGH2 and by UT Department of Petroleum Engineering with parameters based on detailed study of petrophysics predicted that breakthrough of CO₂ to the observation well would occur in 2.5 to 6 days. Breakthrough of CO₂ occurred 30 percent earlier than predicted. Logging using the Schlumberger reservoir saturation tool determined that by the fourth day after the initiation of injection, the plume thickness was half what and that saturation in preferred flow zones was higher than had been predicted by the model showing that factors favoring rapid flow such as high permeability zones or gravity override were larger than predicted. As injection continued for 9 days, plume thickness increased by addition of CO₂ in the lower part of the plume, culminating with an observed saturation profile similar to that predicted by the model. CO₂ saturation was variable but was estimated to be in excess of 50% of porosity.

Some of the key variables that control CO₂ injection and postinjection migration, including thickness and heterogeneity of the injection interval, residual brine saturation during injection, and residual CO₂ saturation during gravity drainage. Measurements made over a short time frame and small distance during the Frio Brine Pilot experiment help define the correct value of these variables. Resulting better conceptualized and calibrated models will then be available for developing larger scale, longer time-frame injections.

The project has contributed unique data sets to help us document the viability of using geologic storage as a mechanism for reducing atmospheric emissions of greenhouse gasses. The small-volume and short-term injection with closely spaced wells allowed intensive monitoring using multiple methodologies and early results useful to develop the next stage of experiments and field demonstrations.

To move toward a larger scale, longer time CO₂ storage experiment, an industry-academic partnership, the Gulf Coast Carbon Center (www.gulfcoastcarbon.org), an initiative of the Jackson School of Geosciences, is working to develop economically viable, environmentally effective options for reducing carbon emissions in the region. GCCC is a member of the DOE Southeast and Southwest Regional Sequestration Partnership. Goals include developing a vision for how sources and sinks can be aggregated to form a network for capture and storage and to develop a first project that is likely to match a hydrogen or ethylene oxide plant with a reservoir that will be used for CO₂-enhanced oil production plus storage.

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Figure 1.

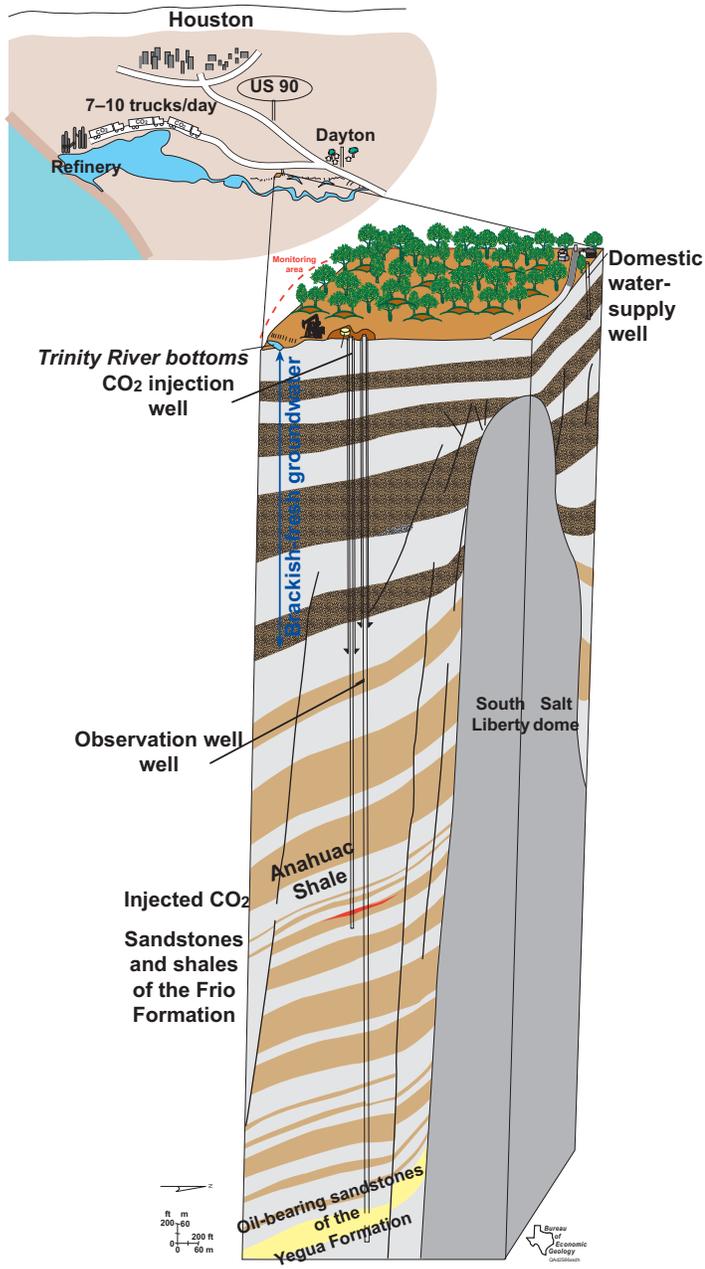


Figure 2

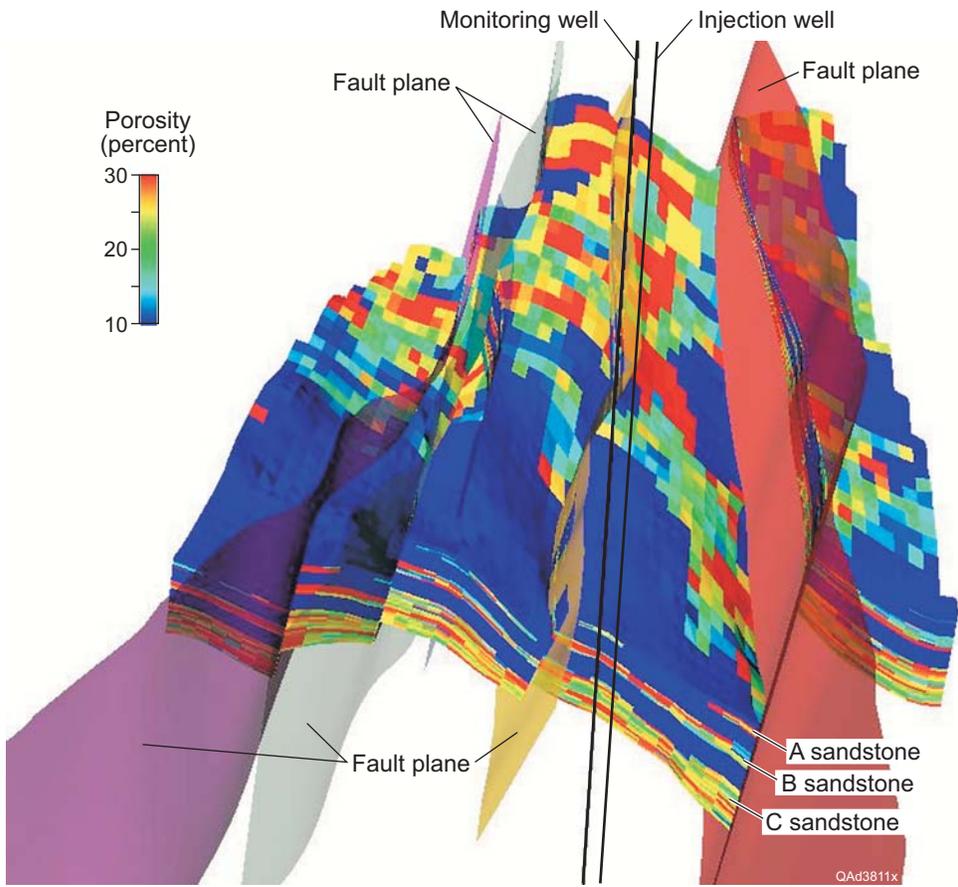


Figure 3



Figure 4

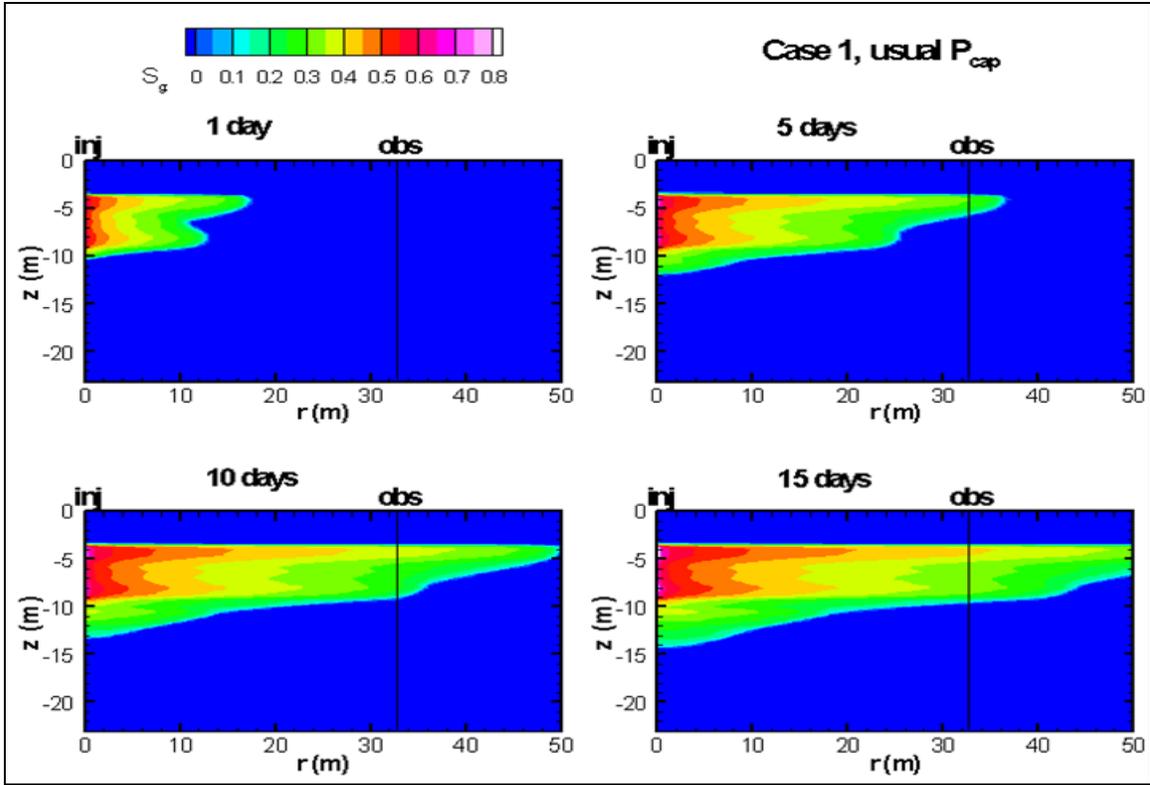


Figure 5

