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### Authors

Myer, Larry R.  
Benson, Sally M.  
Byrer, Charles  
[et al.](#)

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# THE GEO-SEQ PROJECT: A STATUS REPORT

Larry R. Myer<sup>1</sup>, Sally M. Benson<sup>1</sup>, Charles Byrer<sup>2</sup>, David Cole<sup>3</sup>, Christine A. Doughty<sup>1</sup>, William Gunter<sup>4</sup>, G. Michael Hoversten<sup>1</sup>, Susan Hovorka<sup>5</sup>, James W. Johnson<sup>6</sup>, Kevin G. Knauss<sup>6</sup>, Anthony Kavscek<sup>7</sup>, David Law<sup>4</sup>, Marcelo J. Lippmann<sup>1</sup>, Ernest L. Majer<sup>1</sup>, Bert van der Meer<sup>8</sup>, Gerry Moline<sup>3</sup>, Robin L. Newmark<sup>6</sup>, Curtis M. Oldenburg<sup>1</sup>, Franklin M. Orr, Jr.<sup>7</sup>, Karsten Pruess<sup>1</sup>, Chin-Fu Tsang<sup>1</sup>

<sup>1</sup>Lawrence Berkeley National Laboratory, Berkeley, California

<sup>2</sup>National Energy Technology Laboratory, Morgantown, West Virginia

<sup>3</sup>Oak Ridge National Laboratory, Oak Ridge, Tennessee

<sup>4</sup>Alberta Research Council, Edmonton, Alberta, Canada

<sup>5</sup>University of Texas at Austin, Austin, Texas

<sup>6</sup>Lawrence Livermore National Laboratory, Livermore, California

<sup>7</sup>Stanford University, Stanford, California

<sup>8</sup>Netherlands Institute of Applied Geoscience, Utrecht, The Netherlands

## ABSTRACT

The goals of the GEO-SEQ Project are to reduce the cost and risk of geologic sequestration and decrease the time to implementation. In order to lower costs, it has been shown that enhanced oil recovery (EOR) methods can be optimized for sequestration, and enhanced gas recovery (EGR) with sequestration is feasible. An evaluation of the effects of SO<sub>x</sub> and NO<sub>x</sub> on geochemical reactions between CO<sub>2</sub>, water, and reservoir rocks, has been done to assess the use of impure waste streams as a means to reduce overall sequestration costs. In order to lower sequestration risks a methodology for site-specific selection of subsurface monitoring technologies has been demonstrated, baseline data needed for interpretation of isotopic tracers used to monitor reservoir processes have been developed, and a new definition of formation capacity factor for use in assessing sequestration efficiency has been developed. Code comparison studies are underway for oil, gas, brine and coalbed reservoir simulators for predicting the fate of CO<sub>2</sub> in the subsurface. The GEO-SEQ Project has conducted field tests of monitoring technology at CO<sub>2</sub> EOR projects in California and New Mexico, and is collaborating on a pilot test to sequester CO<sub>2</sub> in a brine formation in Texas.

## INTRODUCTION

Initiated in May of 2000, the GEO-SEQ Project is an applied research and development program with the overall goals of: (1) lowering the cost of geologic sequestration; (2) lowering the risk of geologic sequestration; and (3) decreasing the time to implementation of geologic sequestration by pursuing early opportunities for pilot tests and gaining public acceptance. The Project is supported by the U. S. Department of Energy, Fossil Energy (DOE FE) Carbon Sequestration Program through the National Energy Technology Laboratory (NETL). Research is conducted by a core team of scientists and engineers from five research institutions in the United States, one in Canada, and one in Europe, working with four

private-sector partners: BP, ChevronTexaco, En Cana, and Statoil. In addition, through ongoing collaborations and an advisory committee, the team includes other universities and public and private research organizations. Accomplishments to date of the main activities of the Project are summarized in the following sections. Additional information, including publications prepared by the GEO-SEQ team to date, can be found at <http://www-esd.lbl.gov/GEOSEQ/>.

## **CO-OPTIMIZATION OF CARBON SEQUESTRATION AND ENHANCED OIL RECOVERY (EOR) AND ENHANCED GAS RECOVERY (EGR)**

Two studies are focused on reducing sequestration costs by production of oil and gas in conjunction with CO<sub>2</sub> sequestration. One effort is focused on modifying existing, and developing new, CO<sub>2</sub> EOR methods to increase the amount of CO<sub>2</sub> stored in the reservoir relative to the amount of oil produced. As a first step, new criteria were developed for selection of candidate oil reservoirs for combined EOR and CO<sub>2</sub> sequestration (Kovscek, 2002). Work next focused on specific approaches that could increase CO<sub>2</sub> storage while at the same time enhancing oil recovery. Five initial methods are identified: (1) adjust injection gas composition to maximize CO<sub>2</sub> concentration while maintaining an appropriate minimum miscibility pressure; (2) design well completions (or consider horizontal wells) to create injection profiles that reduce the adverse effects of preferential flow of injected gas through high permeability zones; (3) optimize water injection to minimize gas cycling and maximize gas storage; (4) use aquifer injection to store CO<sub>2</sub> that would flow rapidly to producing wells if reinjected in the oil zone; and (5) consider reservoir repressurization after the end of the producing life of the field. Reservoir heterogeneity has a major impact on selection and implementation of specific approaches. Current work is focused on quantifying these relationships as well as developing additional co-optimization methods. A second effort focuses on injection of CO<sub>2</sub> into depleted gas reservoirs while simultaneously enhancing CH<sub>4</sub> recovery and offsetting sequestration costs. The feasibility of carbon sequestration enhanced gas recovery (CSEGR) has been assessed through numerical simulations performed with the TOUGH2 code, incorporating a new equation of state for H<sub>2</sub>O-CO<sub>2</sub>-CH<sub>4</sub> mixtures. Initial 2-D simulations were based on the Rio Vista Gas Field, the largest on-shore-dry-gas field in California. Results showed that significant CH<sub>4</sub> recovery could be achieved before CO<sub>2</sub> breakthrough and that breakthrough was controlled more by reservoir heterogeneity than mixing (Oldenburg and Benson, 2002). Subsequent 3-D simulations of a more realistic five-spot well configuration similarly yielded results that were positive for feasibility of CSEGR. Current work is focused on an economic assessment of CSEGR (Oldenburg, Stevens and Benson, this volume). A depleted gas reservoir which has undergone CSEGR could also be used for gas (CH<sub>4</sub>) storage. Preliminary simulations suggest that 30% more CH<sub>4</sub> can be stored using CO<sub>2</sub> as a cushion gas as compared to the conventional approach.

## **EVALUATION OF THE IMPACT OF CO<sub>2</sub> AQUEOUS FLUID AND RESERVOIR ROCK INTERACTIONS ON THE GEOLOGIC SEQUESTRATION OF CO<sub>2</sub>**

Another approach to lowering costs is to sequester less-pure CO<sub>2</sub> waste streams that are less expensive or require less energy to separate from flue gas. The objective of this study is to evaluate the impact of this impure CO<sub>2</sub> waste stream on geologic sequestration. To date, the influence of SO<sub>2</sub>, NO<sub>2</sub>, and H<sub>2</sub>S on CO<sub>2</sub>/rock/water interactions has been evaluated for a feldspathic-sandstone and a carbonate reservoir. Simulations equivalent to batch-type (closed-system) reactions have been performed. The impact of the contaminants on mineral dissolution/precipitation and changes in porosity is primarily due to the increase in acidity caused by their addition. The relative impact is given as: SO<sub>2</sub>>NO<sub>2</sub>>>H<sub>2</sub>S≥CO<sub>2</sub>. Reactive chemical transport modeling is currently being carried out to assess spatial and temporal impact of the chemical processes identified in the closed-system modeling study.

## **OPTIMIZATION OF GEOPHYSICAL MONITORING TECHNOLOGIES**

Monitoring the location and movement of CO<sub>2</sub> in the subsurface will lower risks of sequestration. This effort focuses on assessing the sensitivity of geophysical methods and demonstrating their applicability for monitoring. The first phase of this effort involved implementation of a numerical simulation-based, three-step, interactive process of reservoir simulation, forward, and inverse geophysical modeling, to evaluate the sensitivity of candidate techniques and design optimum sensor configurations (Hoversten and Myer, 2001). The second major element of this effort is field demonstration of candidate methods. Four different methods are currently being evaluated: crosswell seismic, single well seismic, crosswell electromagnetic (EM), and electrical resistance tomography (ERT). A CO<sub>2</sub> EOR pilot operated by ChevronTexaco in Lost Hills, California, provided an early opportunity to test crosswell seismic and EM techniques. High-resolution crosswell seismic and EM surveys were made before and after CO<sub>2</sub> injection. Data from three time-lapse surveys were the basis of a joint seismic/EM inversion providing quantitative estimates of gas saturation change resulting from CO<sub>2</sub> injection (Hoversten et al, this volume). In a parallel activity, the ERT method is being applied in a CO<sub>2</sub> EOR project at the ChevronTexaco Vacuum Field, New Mexico. This use of well casings as electrodes for crosswell measurements is being tested. Time-lapse measurements have been made and are currently being analyzed.

## **APPLICATION OF NATURAL AND INTRODUCED TRACERS IN GEOLOGIC SEQUESTRATION**

The overall goal of this effort is to provide methods that use natural carbon and oxygen isotopes, and introduced tracers to determine the fate and transport of CO<sub>2</sub> injected into the subsurface. Isotopic work has focused on assessing carbon and oxygen isotope changes as CO<sub>2</sub> reacts with formation fluids and minerals. Results show that the light isotopes (<sup>12</sup>C; <sup>16</sup>O) are preferentially adsorbed onto mineral surfaces resulting in an enriched free CO<sub>2</sub>. This partitioning is large when the solid is coated with hydrocarbons. As CO<sub>2</sub> moves through an EOR environment it may become progressively enriched in the heavy isotopes. Model calculations indicate that typical CO<sub>2</sub> gas from anthropogenic injection sources will exhibit increases in <sup>13</sup>C/<sup>12</sup>C ratios due to interaction with rocks and brines because most geological reservoirs are isotopically heavier. Current work is focused on analysis of gas and carbon isotope compositions of samples obtained from the Lost Hills CO<sub>2</sub> EOR pilot. Work on introduced tracers has focused on development of a laboratory flow system for study of sulfur hexafluoride (SF<sub>6</sub>) and a suite of perfluorocarbon (PFC) tracers.

## **ENHANCEMENT OF NUMERICAL SIMULATORS FOR CO<sub>2</sub> SEQUESTRATION IN DEEP UNMINEABLE COAL SEAMS, AND IN OIL, GAS, AND BRINE FORMATIONS**

Two studies are underway to improve simulation models for capacity and performance assessment of CO<sub>2</sub> sequestration. The first is focused on coal bed methane (CBM) numerical codes. Work began with definition of the physical processes that need to be included in CBM codes. Benchmark problems were then developed, incorporating increasing levels of complexity. The numerical models being tested are CMG's, STARS, CMG's GEM, GeoQuest's ECLIPSE, BP's GCOMP, CSIRO's SIMEDII and ARI's COMET2. Testing of the first two sets of numerical problems has been completed. These numerical problems have now been repeated assuming injection of flue gas (Law et al, this volume). Further information can be found at <http://www.arc.ab.ca/extranet/acbml> (user name and password can be obtained by contacting David Law; [law@arc.ab.ca](mailto:law@arc.ab.ca)). The second effort is a code intercomparison study which has the goal of stimulating further development of models for predicting, optimizing and verifying

CO<sub>2</sub> sequestration in oil, gas, and brine formations. In Phase I, a set of eight benchmark problems were developed which incorporate a variety of processes of importance in sequestration. In subsequent phases, test problems will evolve to address greater complexity and validate experimental data. The Phase I problems have been widely distributed to the scientific community, and researchers from ten organizations in six countries (including France, Canada, Germany, New Zealand, Australia, and the U.S.) are participating. A first comparison of results has been made (Oldenburg et al, this volume and Pruess et al, this volume).

## **IMPROVING THE METHODOLOGY AND INFORMATION AVAILABLE FOR CAPACITY ASSESSMENT OF SEQUESTRATION SITES**

One of the important factors in determining the suitability of sites for sequestration will be the CO<sub>2</sub> storage capacity of the formations. This effort first focused on developing a methodology for calculating capacity. Capacity depends not only upon porosity, but also on multiphase flow properties, formation geometry and gravity, and geologic heterogeneity. The concept of a capacity factor, which could be used to quantitatively compare the sequestration capacity of specific sites, was introduced. Initial efforts focused on performing an assessment of the sequestration capacity of oil and gas fields and brine formations in California (Benson 2001). More detailed assessments were then carried out for specific sites in the Frio and Oakville Formations in Texas. Results show that gravity-driven buoyancy flow causes a decrease in the capacity of a given volume. Layer-type heterogeneities tend to counteract these effects by causing lateral spreading of the CO<sub>2</sub> plume.

## **FRIO PILOT TEST**

The Frio Test is a collaboration with the Texas Bureau of Economic Geology to conduct a pilot CO<sub>2</sub> injection experiment in a brine formation. The overall objectives of the pilot test are to: (1) adequately characterize a site for CO<sub>2</sub> disposal; (2) monitor the behavior and migration of CO<sub>2</sub>; (3) develop conceptual models of CO<sub>2</sub> behavior; (4) develop expertise in design and performance of CO<sub>2</sub> storage facilities; and (5) provide information needed to characterize conditions adverse to long-term containment of CO<sub>2</sub>. Current work is focused on test design. GEO-SEQ investigators are performing reservoir and geophysical simulations as well as geochemical calculations in support of the design of the CO<sub>2</sub> injection strategy and selection of monitoring techniques.

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