

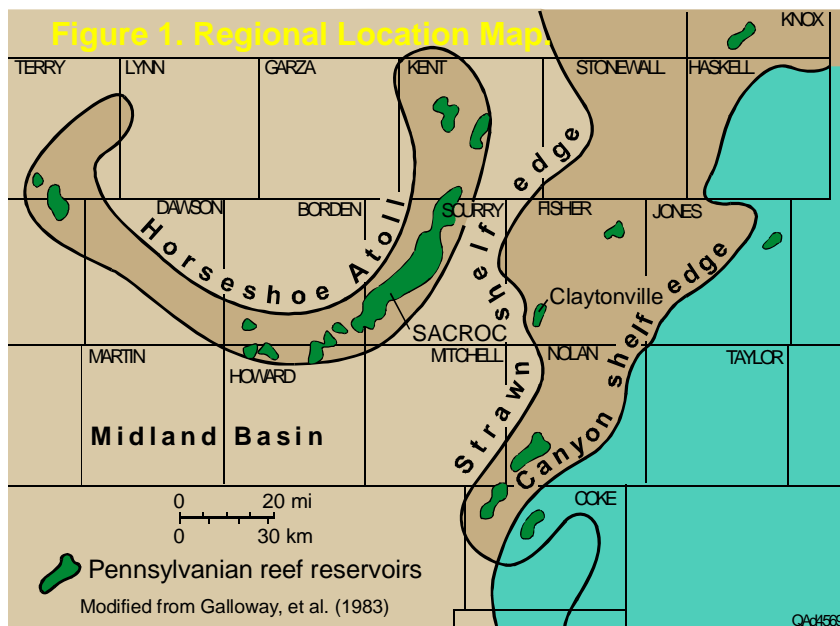
FACTSHEET FOR PARTNERSHIP FIELD VALIDATION TEST

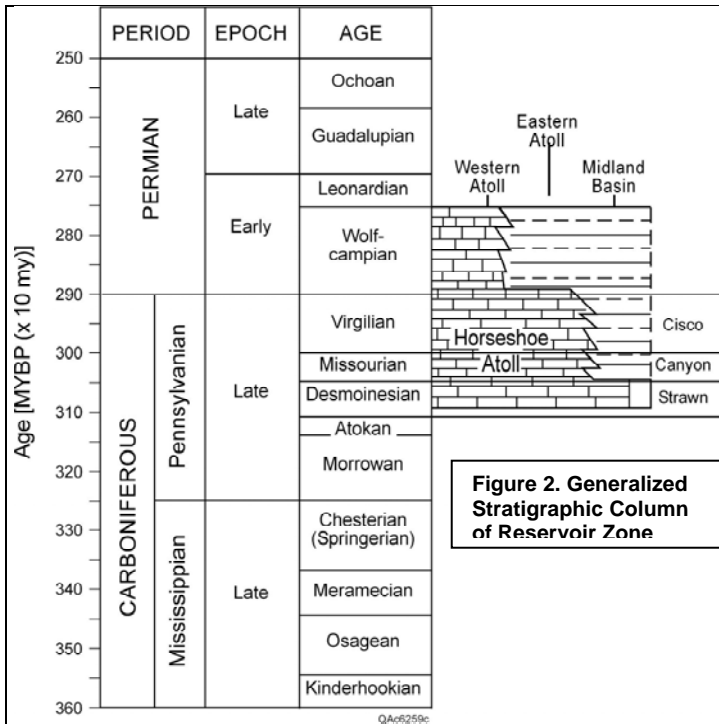
Partnership Name	Southwest Regional Partnership on Carbon Sequestration		
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Field Test Information: Field Test Name	Permian Basin, Texas: SACROC EOR-Sequestration Test		
Test Location	Near Snyder, Texas		
Amount and Source of CO ₂	Tons	Source	
	300,000 tons/year for 3 to 5 years; CO ₂ sourced from McElmo Dome, CO		
Field Test Partners (Primary Sponsors)	KinderMorgan CO ₂ Company, L.P.		

Summary of Field Test Site and Operations

General Geology and Target Reservoirs: The SACROC oil field unit, the main part of the Kelly-Snyder field, lies along a trend of fields described by Galloway et al. (1983) as the Horseshoe Atoll Play (Figure 1). Hydrocarbons are produced from Pennsylvanian-age strata, including the Cisco and Canyon groups, which represent an isolated platform depositional environment (Figure 1). The Cisco and Canyon formations are carbonates that vary in observed facies, including interbedded pellet, crinoid, algal, and intraclast grainstones and boundstones.

Seal Strata: The section overlying the productive oil zone are Permian-age strata, the Triassic age Dockum formation, and the Paleocene/Eocene Ogallala Formation. Permian strata include cyclic shallow-water ramp carbonates sequences bracketed by cycle-base shales, and evaporite tops. The carbonate mudstones and evaporite beds are very low permeability. Immediately overlying the injection zone, the Wolfcamp formation within the Wichita-Albany Group is a high-stand sea level rise flooding surface composed of marine shales. Thus, there are both primary and secondary seals between the injection zone and potable water zones above.





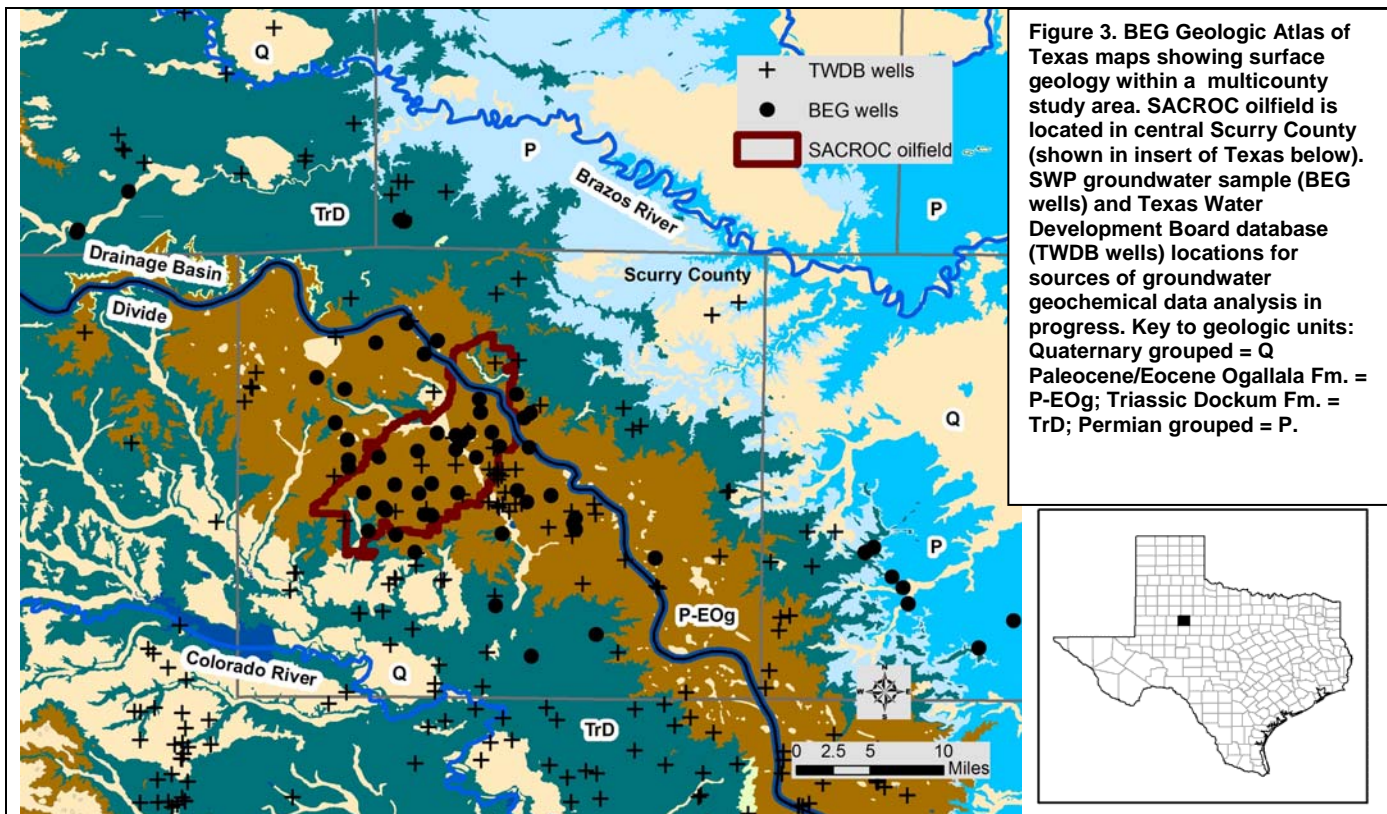
Potential Leakage Areas: The Pennsylvanian Reef strata at SACROC (Figure 2) have low leakage potential. The structural closure is not formed by faulting and no major faults are mapped in the area. Fracturing is prevalent within the injection zone, but because the origin of fractures is non-tectonic, the fractures seem to be confined to the injection interval and do not result in potential leakage paths. Fractures are a result of paleo low-stand exposures that formed karsts of varying sizes. SACROC is highly developed, with numerous wellbores and production-related infrastructure. Potential leakage from wellbores is a field -management issue that can be addressed by robust engineering practices. Well -drilling in these fields is documented and indicates little potential for unknown wellbores.

Reservoir Properties: The geology of the injection zone is comparable to a large class of potential brine storage reservoirs. Depth of the flooded zones range from ~6300–7100 ft (1900–2200 m) with average reservoir pressures of ~2600 psig. The Wolfcamp shale is extremely low

permeability, but the reservoir units approach 10s of millidarcies with porosity ranging from ~2 to ~15%. The oil residing in the field is of high quality. Some free gas was most likely released into the reservoir during initial production, as inferred by increasing producing gas-oil ratios. Pore types include vugs, interparticle, intercrystalline, and fractures. Because the relationship between porosity and permeability is dependent on the pore type, it can be quite variable. Although storage and flow capacity are low, the reservoir has been interpreted to be in fairly good vertical and horizontal communication, based on the consistency of bottom-hole pressure measurements.

In sum, the target reservoir physical properties and character of its oil make the Pennsylvanian carbonates (Figure 2) a good candidate for CO₂ enhanced oil recovery as well as concomitant storage of CO₂. Good injectivity is also observed by the field operator, and elucidation of potential injectivity reduction following CO₂ injection is among SWP goals.

Data Quality: Formation characterization is ongoing at SACROC. The field was discovered in the early 1950's and quickly developed. Thus, much of the well data and wireline logs are quite old. Newly acquired data have increased the quality of subsurface characterization.



Surface Description and Land Use: The Ogallala Formation (Figure 3, P-EOg) crops out at the surface over most of the SACROC unit and is underlain by the Dockum Formation (Figure 3, TrD at depths between 50 and 150 ft). Together water-bearing units of the Ogallala and Dockum comprise the Dockum aquifer, which is the primary supply of drinking water in the region. Undifferentiated Permian units (Figure 3, P) underlie the Dockum at depths of ~400 ft underneath the SACROC unit and crop out to the east. Wells sampled for water chemistry parameters range in depth from 30 to 500 ft. All these wells are classified by the TWDB as being completed in the Dockum aquifer but they are completed in different water-bearing units of the aquifer. This is one source of variability in water chemistry. A surface water divide bisects the Ogallala outcrop. Regional groundwater analyses indicate a possible groundwater divide at the same location. These divides are an additional source of regional groundwater variability because there are likely changes in groundwater chemistry along flow-paths to the northeast toward the Brazos River and to the southwest toward the Colorado River. Surface topography is relatively flat compared to other SWP pilot areas, with only gentle hills and mild terraces associated with surface water erosion. Land-usage in the area is dominated by farming and oilfield infrastructure with some residential areas. Differential recharge associated with differing land use practices is another source of groundwater variability.

Nearest Underground Drinking Water Source: Drinking water resources in Scurry County (Figures 3) come from a combination of Dockum groundwater and surface water piped from reservoir southwest of SACROC oilfield. Water wells in Fisher County, immediately east of Scurry County, are completed in Permian, the Triassic Dockum, or Quaternary units. In general water quality in Scurry County is better than in Fisher County; however, total dissolved solids in Scurry County water usually exceeds the drinking water standard of 500 milligrams per liter. Results of the SWP groundwater sampling in Scurry and surrounding counties show that there is no degradation of drinking water resources overlying the SACROC oilfield compared to areas outside of SACROC from CO₂ injection operations.

Injection Operation: The total volume of CO₂ injected at the SACROC oilfield between 1972 and October 2009 is over 175 million metric tons. Current CO₂ injection at SACROC exceeds approximately 18 million metric tons per year (Mt/yr). Hence, this site is a perfect field “laboratory” for studying the fate of CO₂ injected into the subsurface. A new stage of injection that the SWP has been specifically monitoring at site 56-17 began in October 2008; this includes a WAG (water injection alternating with gas injection) period where CO₂ injection will be partially offset

by water. Site 56-17 is composed of a central oil production well surrounded by four WAG injection wells. KM has provided access to three monitoring wells, located between 200 and 300 ft from corresponding injection wells. SWP MVA activities were conducted through April 2009, resulting in an approximate 6-month period of observation that took place during CO₂-injection only.

Figure 4. Results of an extensive history-match analysis to evaluate trapping mechanisms at SACROC for 100 years starting in 1972.

Research Objectives

The SACROC Unit in the Texas Permian Basin is the oldest CO₂-EOR operation in the United States, with CO₂ injection dating from 1972—only one CO₂-EOR project in Hungary is older, dating from ~1969. SWP research objectives are multi-fold. Objectives of the regional groundwater studies are (1) Have drinking water resources been impacted by over 37 years of CO₂ injection at SACROC? And (2) Can CO₂ that has been injected at depths of 6,000 to 7,000 ft be detected in the Dockum aquifer, which extends as deep as 500 ft within the study area? Our first effort at SACROC was an intensive post-audit modeling analysis to understand the fate of the CO₂ injected over 30 years' time, including a forecast of decades to follow. Results suggest that during injection, hydrostratigraphic trapping dominates, but for the 70 years to follow, residual-gas trapping is the dominant mode of CO₂ storage (Figure 4). KinderMorgan maintains a vast database of CO₂ injection/production data that facilitated this analysis. The SWP also began extensive MMV studies at SACROC during its ongoing injection operations. The SACROC pilot represents an unprecedented opportunity for CO₂ storage history-matching in tandem with large-scale MMV operations.

EOR-Sequestration Testing: The CO₂ at SACROC is sourced from the McElmo Dome. The SWP will monitor the new stage of CO₂ injection for a period of at least 18 months. State-of-the-art reservoir modeling is being used to simulate flow and chemical processes and forecast ultimate CO₂ storage capacities. Given the historical success of EOR in this and other southern U.S. basins, our primary research objective of the EOR-sequestration test is to evaluate and maximize efficacy of CO₂ subsurface monitoring technologies, and to improve our ability to track the fate of injected CO₂ and to calculate ultimate storage capacity. A particular focus is the efficacy of 2-D and 3-D seismic imaging methods and investigation of ways to optimize interpretation using other geophysical data. Finally, another major goal, ultimately, is to develop a rigorous risk assessment framework that will help identify optimum storage sites in this and other similar oilfield reservoirs located throughout the southwestern U.S.

Summary of Modeling and MVA Efforts:

Table 1 summarizes our ongoing and future monitoring activities for the SACROC EOR—sequestration testing. Data from these monitoring activities are being used to parameterize state-of-the-art basin reservoir models that include coupling of multiphase CO₂-groundwater flow with rock deformation and chemical reactions. These

models are being used to conduct continuing post-audit (history match) simulations of SACROC and to evaluate ranges of residence times, migration rates and patterns. We are also examining the effects of CO₂ injection on fluid pressures and rock strain (e.g., potential reactivation of fracture permeability). Model simulations are being conducted to examine potential reservoir diagenesis to follow CO₂ injection, including variations in solubility, dissolution, and precipitation. Seismic models, including 3-D reflection, vertical seismic profiling, passive seismic monitor, and repeat borehole geophysical logging are helping us evaluate different geophysical methods for imaging CO₂ in the subsurface.

Table 1. Measurement Technologies Employed at SACROC, Texas Test Site

Measurement technique	Measurement parameters	Applications
Tracers	- Travel time - Partitioning of CO ₂ in brine/ oil - Identification sources of CO ₂ - CO ₂ , HCO ₃ ⁻ , CO ₃ ²⁻	- Tracing movement of CO ₂ - Quantifying solubility trapping - Tracing leakage - Quantifying solubility & mineral trapping
Water composition	- Major ions - Trace elements - Salinity	- Quantifying CO ₂ -water-rock interactions - Detecting leakage into shallow groundwater aquifers
Subsurface pressure	- Formation pressure - Annulus pressure - Groundwater aquifer pressure	- Control of formation pressure below fracture gradient - Wellbore and injection tubing condition - Leakage out of the storage formation - Tracking CO ₂ movement in and above storage formation
Well logs	- Brine salinity - Sonic velocity - CO ₂ saturation	- Tracking migration of brine into shallow aquifers - Calibrating seismic velocities for 2-D seismic surveys
2-D seismic imaging	- P and S wave velocity - Reflection horizons - Seismic amplitude attenuation	- Tracking CO ₂ movement in and above storage formation
Vertical seismic profiling	- P and S wave velocity - Reflection horizons - Seismic amplitude attenuation	- Detecting detailed distribution of CO ₂ in the storage formation - Detection leakage through faults and fractures
CO ₂ land surface flux monitoring using flux chambers	- CO ₂ fluxes between the land surface and atmosphere Atmosphere	- Detect, locate and quantify CO ₂ releases
Soil gas sampling	- Soil gas composition Isotopic analysis of CO ₂	- Detect elevated levels of CO ₂ - Identify source of elevated soil gas CO ₂ - Evaluate ecosystem impacts

Accomplishments to Date

- Baseline surface fluxes measured
- Baseline reservoir groundwater (brine) compositions assessed
- 3-D reservoir model grids assembled
- surface and subsurface structure contour maps and cross-sections refined through new mapping using recently acquired geophysical logs that span the shallow (100 to 3,000 ft) subsurface.
- identification of shallow groundwater flow paths
- identification of regional trends in groundwater chemistry
- identification of impacts to shallow groundwater from old (pre-1975) produced water (brine) evaporation pits
- initial history match simulations completed, and updates continue as data is collected
- obtained 3-D seismic data volume collected by Kinder Morgan in 2003 over the northern section SACROC for use as baseline for new surface seismic data

- completed pre-injection borehole geophysical logs in multiple monitoring wells within injection pilot site
- completed pre-injection vertical seismic profiling
- CO₂ injection started in first two wells 9/2008, second two wells commenced in 10/2008.

Summary of Target Sink Storage Opportunities and Benefits to the Region

- The SACROC pilot will be an initial high resolution analysis of the potential for CO₂ storage in the broader carbonate “Horseshoe Atoll” system, a huge (area and volume) system with potentially enormous CO₂ capacity (Figure 1). Given that most of the western side of the atoll is below the oil-water contact, it is particularly appealing for large-scale sequestration, as suggested by our Phase I analysis of the region.
- The SACROC field is also representative of many oil/gas fields throughout the southwestern U.S., and results will be applicable to many such fields.
- Typically, EOR with CO₂ is carried out with an objective to maximize re-production and recycling of CO₂ for further EOR. Among the SWP goals is to maximize sequestration, or leaving CO₂ in the ground rather than recycling, while not compromising efficacy of EOR.

Cost:

**Total Field Project Cost:
Approximately \$5.5M**

DOE Share: Approximately \$4.4 or 80%

Non-DOE Share: Approximately \$1.1 or 20%

Field Project Key Dates:

Baseline Completed: January, 2008

Drilling Operations Begin: October, 2007

Injection Operations Begin: September, 2008

MVA Events: September, 2008

**Total CO₂ Injected as part of SWP Demonstration
Purposes: 311,400,000 mcf or approximately 18,000,000 million tons**

Field Test Schedule and Milestones (Gantt Chart):

Major field operations at SACROC have been under way since the start of the project in late 2005. Safety training, initial reservoir model grids, and other essential SWP activities also began during this past year. A general summary of the SWP’s schedule is provided in the Gantt chart below.

