

FACTSHEET FOR PARTNERSHIP FIELD VALIDATION TEST

Partnership Name	Southwest Regional Partnership on Carbon Sequestration		
Contacts: DOE/NETL Project Mgr.	Name William O'Dowd	Organization NETL	E-Mail William.ODowd@NETL.DOE.GOV
Principal Investigators	Brian McPherson (brian@nmt.edu) and Reid Grigg (reid@prcc.nmt.edu) New Mexico Tech		
Field Test Information: Field Test Name	Paradox Basin, Utah: Aneth Field – Combined Enhanced Oil Recovery with Concomitant CO ₂ Sequestration		
Test Location	Aneth Oil Field near Bluff, Utah, in extreme southeast corner of the state.		
Amount and Source of CO ₂	150,000 tons/year/square-mile of field area; CO ₂ sourced from McElmo Dome, CO		
Field Test Partners (Primary Sponsors)	Resolute Energy Company		
	Navajo Nation Oil and Gas Company		

Summary of Field Test Site and Operations

General Geology and Target Reservoirs: The Aneth oil field, discovered in 1956, is one of the largest in the nation. Because the field is on Navajo Nation land, mineral royalties go to the Navajo Nation and are utilized in many ways, including a broad scholarship fund. Aneth is located on the McElmo-Cortez CO₂ pipeline system, and the sheer size of the field makes it a possible target for larger-scale sequestration operations. Petroleum production interests were previously owned by ChevronTexaco and ExxonMobil, and are now jointly owned by Resolute Natural Resources Company (Resolute) and the Navajo Nation Oil and Gas Company. Both companies operate the field together, and the SWP is pleased to partner with Resolute and the Navajo Nation OGC in a combined enhanced oil recovery (EOR) and sequestration pilot test.

The Aneth Unit is part of the greater Aneth field and is located in the Paradox Basin of southeastern Utah (Figure 1). Aneth is a stratigraphic trap with fractures and minor faults. The Aneth Unit covers about 16,800 acres of the northern section of greater Aneth and has produced about 149 million barrels of oil in place (Figure 2). Secondary recovery by waterflood started in 1962. The planned CO₂ flood began in August 2007. The monitor area for this field validation study covers about 2 square mile sections on the western edge of the Aneth Unit. CO₂ injection over the 2 mi² area is accomplished with approximately 16 wells with total injection rates of about 300,000 tons per year. The pilot test site is located within the Aneth mound complex (Figure 3), which formed on a weak structural nose. The present-day structural relief of about 150

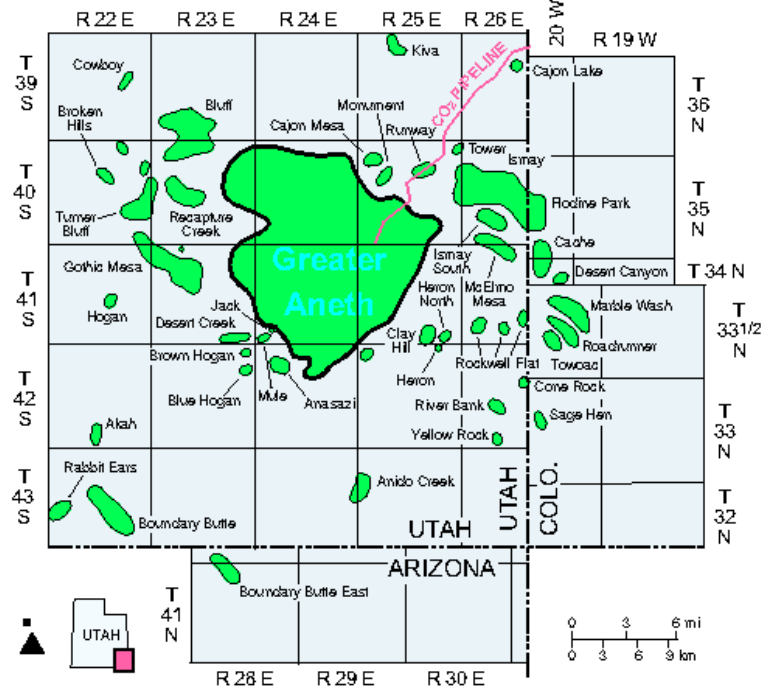


Figure 1. Location of greater Aneth and surrounding oil fields of the Paradox Basin.

It is largely the result of differential compaction. The primary CO₂ sequestration target is the Pennsylvanian Desert Creek and overlying Ismay members of the Paradox formation, the primary producers in the Greater Aneth Field. These carbonate strata were deposited on the southwestern flank of the Paradox evaporite basin, and are laterally equivalent to the more basinward anhydrites and salts.

The Aneth Unit was originally developed with vertical wells drilled on 80-acre spacing. The field was infill-drilled in the 1970s to 40 acre spacing. The field has been managed with water injection that began with unitization in the early 1960s. In 1996, Texaco drilled 43 multi-lateral horizontal wells (23 producers and 20 injectors). In 1998, the injectors in section 14 were converted to a CO₂-WAG project to pilot the possibility of a fieldwide CO₂ injection program.

Brief Summary of Target Reservoirs and Seals:

- **Producing Formations:** Desert Creek and Ismay Zones of the Paradox Formation (Pennsylvania). Depth to top approximately 5600 to 5800 ft. Bottomhole temperature ~125°F (Figure 3).
- **Deepest fresh water aquifer:** Navajo Sand (Jurassic) 500 to 1000 ft.
- **Lithology:** limestones, both oolitic and algal.
- **Type of trap and reservoir geometry:** stratigraphic, partly dolomitized algal carbonate mound on a weak structural nose (Figure 4).
- **Seal and source rocks:** The “seal” unit above the sequestration target is the low-permeability Gothic Shale, and the underlying seal is an organic-rich mud deposit, the Chimney Rock Shale (Figures 3 and 4). Both shales are seals as well as original oil source rocks. Oil generation began during the Cretaceous, as these strata were buried to depths greater than 10,000 feet. Later tectonic uplift and gentle structural development had only minor effects on redistribution of the accumulation.
- **Potential leakage points:** Not a strongly faulted reservoir, gross structure is depositional (algal mound). Planned 3D seismic survey may provide details of small-scale faulting, if any. Well spacing in the Aneth Unit is generally at 40 acres.
- **Pay zone thickness:** 130 to 200 ft. Net pay average 50 ft.
- **Porosity:** ~10 %
- **Permeability:** 5 to 30 millidarcies
- **Water saturation and water characteristics:** 23.3%, salt water 125,000 to 175,000 ppm NaCl concentration

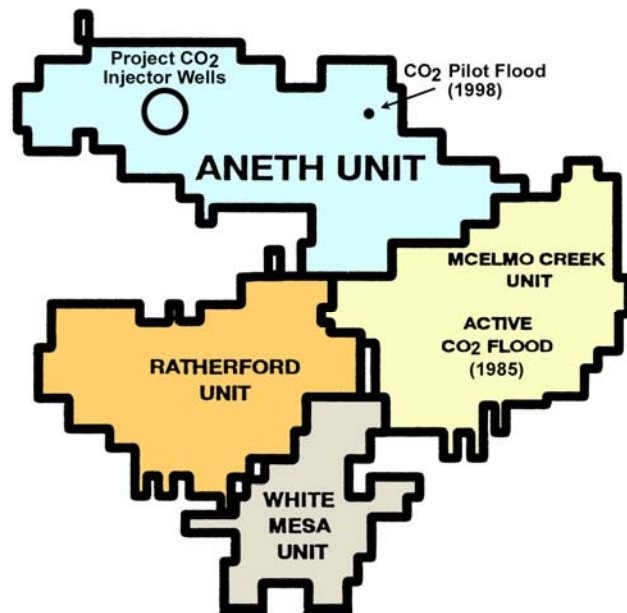


Figure 2. Units within the greater Aneth field.

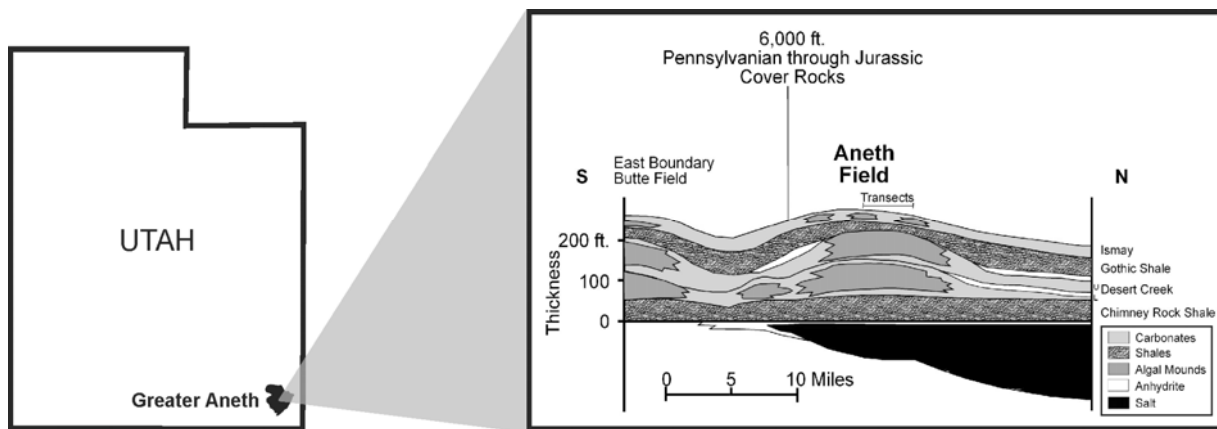


Figure 3. Location map of Aneth field and pilot site (left) and representative cross-section (right). The area indicated by "transects" is the location of a profile of CO₂ flux measurements the Partnership conducted in January 2005.

Data Quality: Most geophysical well logs are available from the Utah Division of Oil, Gas and Mining (DOGDM) for the Aneth and other units in Greater Aneth field; only a few mudlogs have been preserved. They consist of 1950s vintage through 1990s logs, both in hard copy and as scanned images; LAS files are generally not available. To date, the SWRP has digitized approximately 460 logs, mostly neutron porosity, density and gamma-ray logs. Well log quality is good to very good.

An estimate of 70% of logs have coverage along the length of the entire bore hole, with roughly 30% covering the reservoir section only. Correlation of formation tops was achieved by interpreting gamma ray and formation density/compensated neutron logs of each well; porosity was also determined from a variety of well logs. The general petroleum geology of Greater Aneth field has been summarized in numerous publications since the field was discovered.

The location of conventional cores through the Paradox Formation reservoir from wells is variable. The UGS has seven cores from Aneth Unit wells. Other cores are either owned by Resolute or unknown. Core-derived porosity and permeability, thin sections, and core descriptions are available from the Utah Geological Survey and Resolute. Further, using a 16 ft interval of the core representing the field's entire Gothic shale interval, extensive analysis of the reservoir seal has been conducted.

Cumulative production data and completion reports data is available from DOGDM's Web site, including old and abandoned producers.

High-quality water well information, groundwater quality, and surface water data is readily

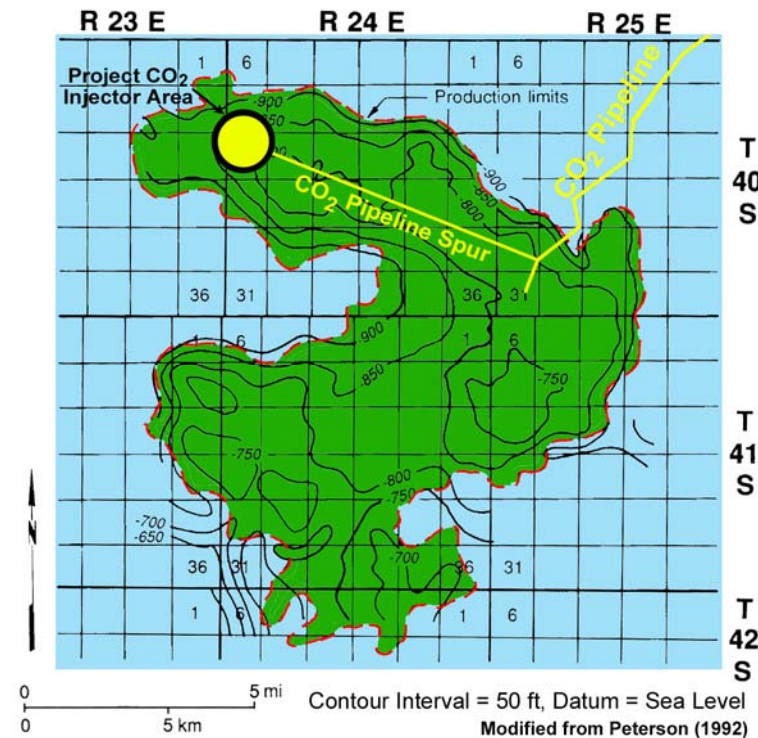


Figure 4. Structure map of top of the Desert Creek zone.

available on the Utah Division of Water Rights' website and various publications.

Surface Description and Land Use: The topography of the area consists of washes and dissected buttes and mesas formed in response to downcutting by the San Juan River. The surface geology of the area consists of rocks of the Cretaceous Dakota Sandstone and Burrow Canyon Formation, and the upper Jurassic Morrison Formation. Quaternary alluvial deposits occur in valleys, washes, and along the floodplain of the San Juan River. The only perennial tributary to the San Juan River is McElmo Creek; a few springs are also present.

Most of the area is part of the Navajo Indian Reservation, although most of the Aneth Unit sequestration analyses will be conducted on Bureau of Land Management lands. The largest communities in the area are Montezuma Creek and Aneth, with a combined population of about 1000 people. Land use in the area consists of livestock grazing and limited agriculture, which relies on water wells powered by windmills.

Research Objectives

EOR-Sequestration Testing: The field has the capacity to take delivery of an estimated 20 MMCF per day of CO₂ and re-injection capacity of a similar amount. The CO₂ is sourced from McElmo Dome, and arrives at a pressure of about 2750 psi, which is sufficient to inject it into the wells without compression. For our combined EOR/sequestration program, individual well CO₂ injection rates are planned and expected to approach 300 MCF per day per well. The process of displacing approximately 20% of the reservoir pore volume will take about five to eight years. Carbon dioxide will be injected for a period of several years and the SWP will intensely monitor CO₂ movement for 24 months. Injection commenced in August 2007, and will continue for many years. State-of-the-art reservoir modeling is being used to simulate flow and chemical processes and forecast ultimate CO₂ storage capacities. Given the previous success of EOR in this and other western U.S. sedimentary 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. Finally, it is our goal to develop a rigorous risk assessment framework that will help identify the optimum storage sites in this and other similar oilfield reservoirs that are ubiquitous throughout the Rocky Mountain western states.

Summary of Modeling and MVA Efforts

Table 1 provides a summary of our ongoing and future monitoring activities for the Aneth EOR-sequestration test. Data from these monitoring activities are being used to parameterize state-of-the-art mathematical reservoir models. These models include coupling of multiphase CO₂-groundwater flow, rock deformation, and chemical reactions to evaluate residence times, migration patterns and rates, and effects of CO₂ injection on fluid pressures and rock strain, and effects of chemical diagenesis, including variations in solubility, dissolution, and precipitation.

We are also developing state-of-the-art seismic models to assist with optimization of different seismic methods for imaging CO₂ in the subsurface. Most methods are 2-D, but we developed both 2-D and 3-D models for optimized analysis and interpretation.

Our first reservoir modeling objective was to elucidate the origin of subsurface brines and the hydraulic communication among different aquifers required to form those brines. This was intended to provide insight about how pressures induced by CO₂ injection might “communicate” hydraulically with other units, and to help identify potential migration pathways.

Table 1. Measurement Technologies Employed at Aneth, Utah Test Site

<u>Measurement technique</u>	<u>Measurement parameters</u>	<u>Applications</u>
Introduced and natural tracers	- Travel time	- Tracing movement of CO ₂
	- Partitioning of CO ₂ into brine or oil	- Quantifying solubility trapping
	- Identification sources of CO ₂	- Tracing leakage
	- CO ₂ , HCO ₃ , CO ₃ ²⁻	- Quantifying solubility & mineral trapping
Water composition	- Major ions	- Quantifying CO ₂ -water-rock interactions
	- Trace elements	- Detecting leakage into shallow groundwater aquifers
	- Salinity	- Control of formation pressure below fracture gradient
Subsurface pressure	- Formation pressure	- Wellbore and injection tubing condition
	- Annulus pressure	- Leakage out of the storage formation
	- Groundwater aquifer pressure	- Tracking CO ₂ movement in and above storage formation
Well logs	- Brine salinity	- Tracking migration of brine into shallow aquifers
	- Sonic velocity	- Calibrating seismic velocities for 2D seismic surveys
	- CO ₂ saturation	

Time-lapse 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
Passive seismic monitoring	- Location, magnitude and source characteristics of seismic events	- Development of microfractures in formation or caprock - CO ₂ migration pathways
Electrical techniques	- Self-potential monitoring	- Tracking movement of CO ₂ in and above the storage formation - Detecting migration of brine into shallow aquifers
Visible and infrared imaging from satellite	- Hyperspectral imaging of land surface	- Detect vegetative stress
CO ₂ land surface flux monitoring using flux chambers or eddy covariance	- CO ₂ fluxes between the land surface and 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 and repeat surface fluxes measured.
- Baseline reservoir groundwater (brine) compositions assessed.
- Water-based interwell tracer test conducted in 2007.
- CO₂-based interwell tracer test in progress since July 2009.
- 3-D reservoir model grids assembled and simulations ongoing.
- Surface and subsurface geologic maps and cross-sections refined through new mapping.
- Digitizing porosity logs and derived porosity/permeability relationship for core plug analysis.
- Injection in Phase I area began in August, 2007.
- Injection in MVA area started January, 2008.
- Geophone array installed in an observation well, October 2007.
- Baseline and two repeat VSP survey completed; basic data processing completed, time-lapse analysis started.
- Development of interferometry method developed for VSP using Frio as test bed data set.
- Electrical self-potential monitoring underway since November 2007. Data analysis in progress.
- Microseismic monitoring (passive seismic) continuous since November 2007
- Microseismic sources reveal significant NW-SE striking reservoir structures in study area
- Microseismicity activity was initially sporadic; however event rates are becoming higher and more persistent.
- Approximately 3800 microseismic events detected over 1st year of monitoring, approximately ½ can be located.
- Analysis of Gothic shale seal completed by Terra Tek and Sandia National Labs
- Compilation of all injection and production data from MVA study area.

Summary of Target Sink Storage Opportunities and Benefits to the Region

- The Desert Creek Formation is representative of many oil/gas fields throughout the Colorado Plateau, 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.

<p>Cost:</p> <p style="text-align: center;">Total Field Project Cost: Approximately \$5.5M</p> <p>DOE Share: Approximately \$4.4M or 80%</p> <p>Non-DOE Share: Approximately \$1.1M or 20%</p>	<p>Field Project Key Dates:</p> <p>Baseline Completed: January, 2007</p> <p>Drilling Operations Begin: October, 2006</p> <p>Injection Operations Begin: August, 2007</p> <p>MVA Events: August, 2007 and ongoing</p> <p>Total CO₂ Injected as part of SWP Demonstration Purposes: 24,465,248 mcf or 1,414,176 tons over 2 years t</p>
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Field Test Schedule and Milestones

Major field operations, including well-drilling, pipeline planning, reservoir engineering and baseline MVA operations, began in winter and spring of 2006. Safety training, initial reservoir model grids, and other essential SWP activities also began during this past year. First injection was originally scheduled for September 2006, but was rescheduled to August 2007, because of permitting delays. A general summary of the SWP's schedule for the Utah project is provided in the Gantt chart below.

