

SUMMARY OF FARNHAM DOME FIELD TEST SITE & OPERATIONS

Era	System and Series	Stratigraphic unit	Hydrogeologic unit		
Cenozoic	Quaternary	Unnamed alluvium		Local aquifers	
	Tertiary	Miocene	Browns Park Formation		
		Oligocene	Bishop Conglomerate		
		Eocene	Bridger Formation		Confining unit
	Green River Formation		Laney Member		Laney aquifer
			Wilkins Peak Member		
			Tipton Shale Member Lyman Member		Confining unit
	Paleocene	Wasatch Formation	Saline aquifer		Wasatch-Fort Union aquifer
		Fort Union Formation			Mesaverde aquifer
	Mesozoic	Cretaceous	Mesaverde Group		Saline aquifer
Baxter Shale			Confining Shales		
Frontier Formation					
Mancos and Mowry					
Bear River Formation				Muddy Sandstone	
				Thermopolis Shale	
Dakota Sandstone		Saline aquifer			
Jurassic		Morrison Formation	Confining shale		
		Curtis-Stump Formations	Saline aquifer		
		Entrada Sandstone	Confining shales		
		Gypsum Spring Formation	Saline aquifer		
Triassic		Navajo-Nugget Sandstones	Confining unit		
		Chugwater Formation	Saline aquifers		
	Dinwoody Formation	Confining unit			
Paleozoic	Permian	Phosphoria Formation	Confining unit		
		Tensleep Sandstone		Pennsylvanian Sandstone aquifer	
		Amsden Formation		Saline aquifer	
	Mississippian	Mississippi Carbonate-rock aquifer	Saline aquifer		
		Madison Limestone	Mississippian aquifer		
	Devonian	Darby Formation	Confining unit		
		Ordovician	Bighorn Dolomite	Local aquifer	
	Gallatin Limestone		Confining unit		
	Gros Ventre Formation				
	Cambrian	Flathead Sandstone	Local aquifer		
Precambrian		Igneous and metamorphic rocks	Precambrian confining unit		

Figure 1. Generalized stratigraphic column for the SWP region of interest.

The SWP intends to accomplish a major deep saline sequestration deployment in an area known as Farnham Dome in central Utah. This test will follow an injection schedule over 4 years, leading up to 900,000 tonnes (1,000,000 U.S. tons) of CO₂ per year. The target formations include deep Jurassic and older geologic formations in the Farnham Dome of Utah. We will maintain at least two injection intervals at the site, to maximize capacity testing and evaluation of monitoring efficacy. By carrying out two injections in the different stratigraphic intervals, we can begin to evaluate portability of science and engineering results.

Injection Site Description

The Farnham Dome injection site is located just southwest of the Uinta basin, near Price, Utah, 120 miles south of Salt Lake City, in central Utah. Farnham Dome is an elongated surface anticline located along the northern plume of the San Rafael uplift.

Drilling along the crest of Farnham Dome in the 1920s and 1930s resulted in the discovery of significant deposits of carbon dioxide (CO₂) in the Jurassic Navajo Sandstone and small shows of CO₂ in Triassic, Permian, and Pennsylvanian reservoirs. Given that the more shallow Jurassic units hold significant CO₂, the deeper Triassic and Permian units appear promising with respect to large CO₂ capacities and low-risk with respect to leakage. The area provides an

excellent deployment test opportunity for analysis of high injection rates and high-resolution monitoring of CO₂ in multiple rock layer horizons. These deep saline formations are major targets for commercial-scale sequestration associated with future coal-fired power plants planned for the area. For this research project, no profits will be earned, and no CO₂ will leave the site. Much of the Farnham Dome site falls under jurisdiction of the U.S. Bureau of Land Management.

Description of Geology

The target formations are deep saline units present throughout the Southwest Partnership region, as well as in many states outside the region. Figure 1 summarizes the regional stratigraphy. In all candidate sites under consideration at

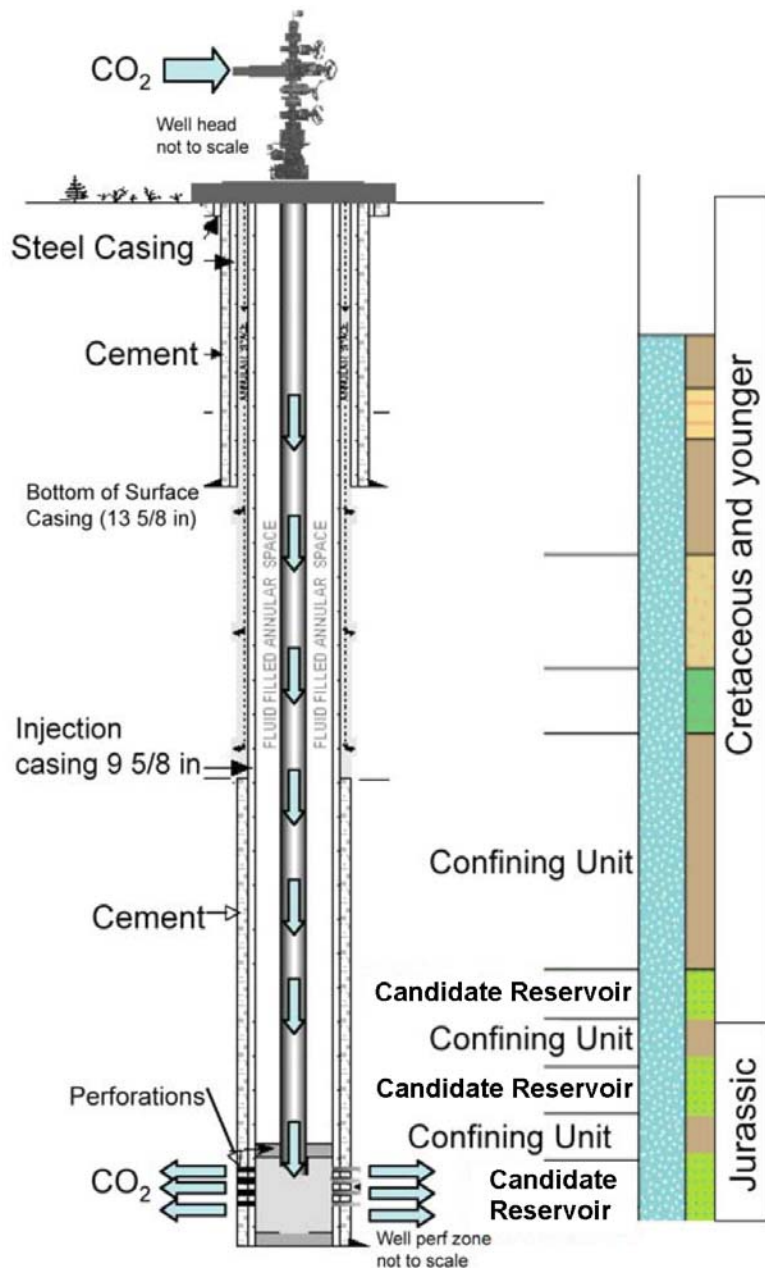


Figure 2. Schematic of injection well design. Note the relative locations of candidate sequestration target reservoirs versus confining units, providing a “stacked system” of reservoirs/seals.

this time, the seal is the Morrison Formation, a thick (400 feet) shale/gypsum/siltstone of Jurassic age, also regionally present throughout the Southwest Partnership states. The target units lie within a true “stacked” system—above the Morrison formation lies the Dakota formation, a Cretaceous-aged sandstone similar to the deep Triassic and Permian sands, and capped by the Pierre/Mancos shale, a very thick (1,500 feet to 5,000 feet) shale unit. The SWP has gathered porosity, permeability, mechanical, compositional, and geophysical data associated with these target reservoirs and seals.

Source of CO₂

For the Farnham Dome deployment site, the sources of CO₂ include natural CO₂ from the Jurassic-aged Nugget Sandstone. A second potential source is a coalbed methane (CBM) production field northwest of Price, Utah; the CBM operation currently vents over 100,000 tons of CO₂ per year. A short pipeline will need to be added to facilitate injection of captured CO₂ into the deep saline reservoirs at Farnham Dome. All CO₂ captured will be 97% pure, with the remainder nitrogen (air). No CO₂ will leave the site. No commercial purposes or profit will be garnered under this research project.

Injection Operations

A relatively standard well-design will be used for injection at Farnham (Figure 2). A minimal length of pipeline will be added in order to deliver the CO₂ for deep injection. Blue Source LLC, a SWP partner, and Savoy Energy LLC, the field operator, are completing designs for necessary

pipelines. Upon completion of the deployment phase test, this pipeline will be used to transport the captured CO₂ from the Farnham Dome site to the Uinta Basin enhanced oil recovery market.

Characterization Data

Because the Farnham Dome site is very close to areas of active petroleum generation, the amount and quality of characterization data is fairly good.

Research Objectives

SWP's overall goal is to validate the information and technology developed under the Characterization and Validation Phases relative to research and field activities, public outreach efforts, and regional characterization. Specific objectives include:

- Develop an overall methodology that optimizes engineering and planning for future commercial-scale sequestration projects.
- Conduct successful large-scale CO₂ injection projects targeting deep saline formations present throughout the western U.S.
- Achieve a more thorough understanding of the science, technology, regulatory framework, risk factors, and public opinion issues associated with large-scale injection operations.
- Validate monitoring, mitigation, and verification (MMV) activities; modeling, and equipment operations.
- Refine capacity estimates of the target formation in the region, using results of the test.

Summary of Monitoring of CO₂

Simulation and Monitoring of CO₂

The project will require extensive monitoring and simulation to determine if the storage operations are effective in trapping the injected CO₂ for millennia. Vertical seismic profiling and microgravity methods will be particularly utilized, given their proven ability to resolve the size of the CO₂ plume. Monitoring, mitigation and verification (MMV) techniques that will be used include repeat 3D seismic surveys, pressure monitoring, groundwater chemistry monitoring, pressure and fluid sample monitoring from other locations, soil gas sampling, and other methods. A variety of "in house" and commercial/public simulation tools will be used, including GEM, TOUGH2, TOUGHREACT, FEHM, CO₂-PENS, COMSOL, THRUST3D, MRKEOS and SWEOS. The table below summarizes monitoring technologies that will be used in tandem with these simulation tools.

Measurement Technologies Employed at Field Test Site

Measurement technique	Measurement parameters	Application
Introduced and natural tracers	Travel time Partitioning of CO ₂ into brine or oil Identification sources of CO ₂	Tracing movement of CO ₂ in the storage formation Quantifying solubility trapping Tracing leakage
Water composition	CO ₂ , HCO ₃ ⁻ , CO ₃ ²⁻ Major ions Trace elements Salinity	Quantifying solubility and mineral trapping 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
Well logs	Brine salinity Sonic velocity CO ₂ saturation	Tracking CO ₂ movement in and above storage formation Tracking migration of brine into shallow aquifers Calibrating seismic velocities for 3D seismic surveys

Time-lapse 3D seismic imaging	P and S wave velocity Reflection horizons Seismic amplitude attenuation	Tracking CO ₂ movement in and above storage formation
Vertical seismic profiling and crosswell seismic imaging	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 and electromagnetic techniques	Formation conductivity Electromagnetic induction	Tracking movement of CO ₂ in and above the storage formation Detecting migration of brine into shallow aquifers
Time-lapse gravity techniques	Density changes caused by fluid displacement	Detect CO ₂ movement in or above storage formation CO ₂ mass balance in the subsurface
Land surface deformation	Tilt Vertical and horizontal displacement using interferometry and GPS	Detect geomechanical effects on storage formation and caprock Locate CO ₂ migration pathways
Visible and infrared imaging from satellite or planes	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 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