Northern California CO_2 Storage Pilot

WESTCARB Annual Meeting
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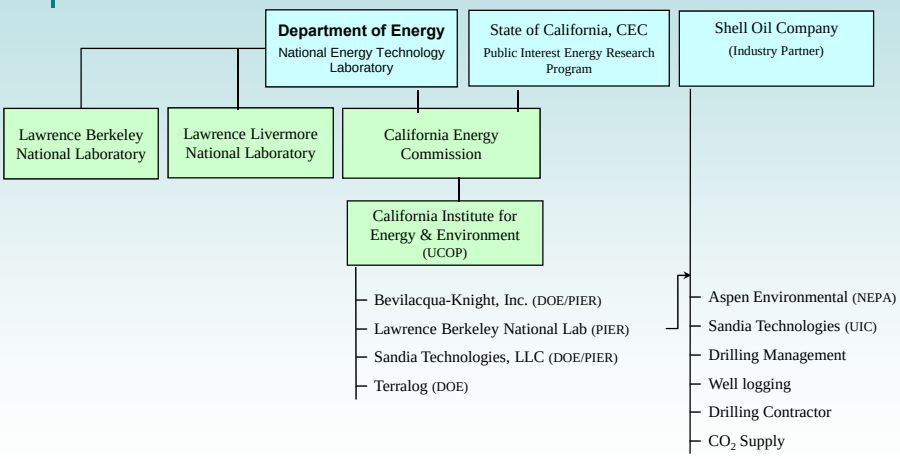
Industry Partner: Shell Oil Company

A welcome industry partner

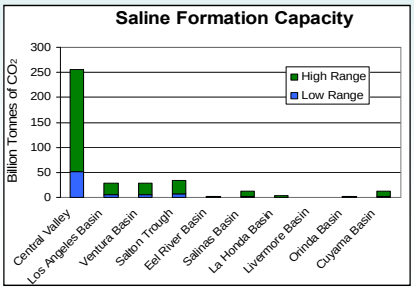
- Committed to reducing global CO_2 emissions
- Extensive technical expertise in:
  - Geologic evaluation
  - Well log analysis
  - Porosity and permeability evaluation
  - Geophysics
  - Deep well drilling
  - CO_2 injection

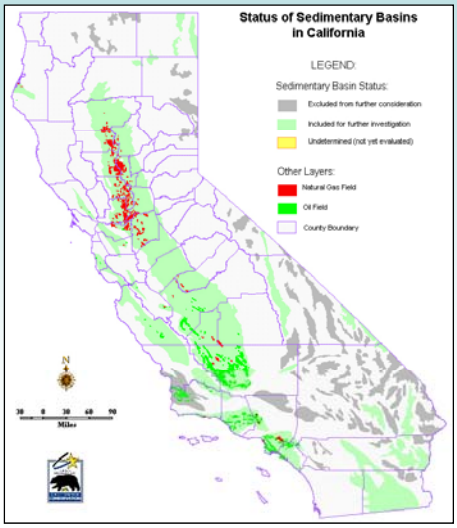
Northern California CO_2 Storage Pilot Contracting and Funding Flow



WESTCARB Phase I – Preliminary estimate of CO_2 storage capacity in California

- Oil reservoirs – 121 fields
  - 3.4 billion tonnes
- Gas reservoirs – 128 fields
  - 1.8 billion tonnes
- Saline formations – 27 basins
  - 75-300 billion tonnes

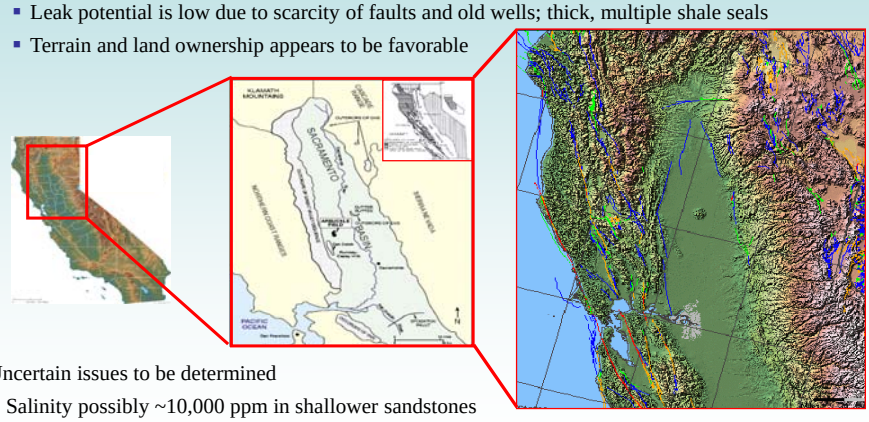




Western Sacramento Valley Location

Viable Pilot Test Site

- Capacity to trap CO_2 is adequate for planned volume
- Leak potential is low due to scarcity of faults and old wells; thick, multiple shale seals
- Terrain and land ownership appears to be favorable



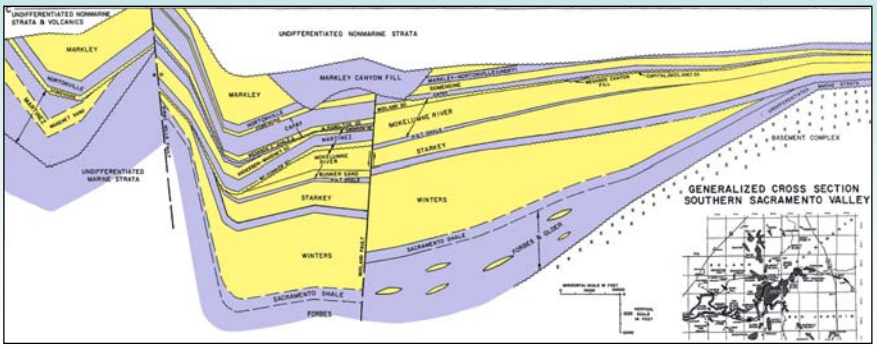
Uncertain issues to be determined

- Salinity possibly ~10,000 ppm in shallower sandstones
- Permeability uncertainty at injection depth – axis of syncline is very deep
- Sand continuity in the syncline is unknown

Source: Shell

Sacramento Valley geologic cross-section

Numerous stacked sandstone (yellow) and shale (purple) formations



Source: California Geological Survey

California Central Valley Geologic Column

- Three main depositional periods:
  - Jurassic
  - Cretaceous
  - Tertiary
- Rocks are mostly:
  - clastic sandstone
  - siltstone
  - claystone/shale

Source: Shell

ERA	PERIOD	EPOCH	FORMATIONS	DEPOSITIONAL ENVIRONMENTS		BASIN COVERAGE	MAJOR SEDIMENT SOURCE	EVENT
CENOZOIC	QUARTER.	Holocene				MORE RESTRICTED BASIN, NARROW AND LIMITED CONECTIONS TO OPEN SEA	SIERRA NEVADA & KLAMATH MT., WESTERN COASTAL RANGES, MARINE	
		Pleistocene						
	TERTIARY	Pliocene						
		Miocene						
		Oligocene	Markley Canyon fill					
			UNCONFORMITY					EROSION/FILL
		EOCENE	Markley fm	Deep water slopes	MARINE / CONTINENTAL			RENEWED TRANSGRESSI
			Nortonville Shale					
			Domengine Sandstone / Ione Clay	Deltaic complex				SUNSIDENCE / MAJOR SEA INVASION
			Capay shale / Meganos Canyon fill					
			UNCONFORMITY					UPLIFT/REGRESSION
			Hamilton sand					
			Meganos shale / Martinez Canyon fill					
		PALEOCENE	ANGULAR UNCONFORMITY	MOSTLY SUB_AREIAL EROSION, MARINE ENVIRONMENTS IN THE REGION OF DELTA DEPOCENTERS				
			Anderson sand					
			Anderson shale					
			Upper Martinez sand					
			Martinez shale					
			1st Martinez sand					
			shale					
			UNCONFORMITY					
MESOZOIC	CRETACEOUS	UPPER	2nd Martinez sand	Fluvial delta-slope	FLUVIAL, DELTAIC, PROGRADATION, SHELF & SLOPE SEDIMENTS	BASIN COVERED A GREATER AREA	SIERRA NEVADA & KLAMATH MT., MARINE	
			Moreno shale					
			3rd Martinez sand					
			H&T shale					
			Starkey sands	Fluvial delta-slope				
			Winters formation	Deep sea fan				
			Lower delta shale					
			Sacramento Shale					
			UNCONFORMITY					
			Forbes shale (source rock)	Marine				
			Kione sand (Wild Goose)	Distal pro-Delta / Slope systems				
			Guinad					
			Dobbins (source rock)					
			Sites					
			Funks					
			Yolo shale					
			Vernado					
		EARLY	Shasta	Shallow marine				
	JURASSIC		Knoxville					
			Franciscan Assemblage / Basement	Submarine				

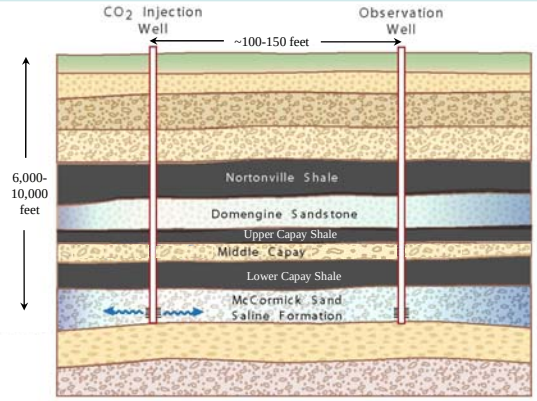
WEST COAST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

7

Northern California CO_2 Storage Pilot

Site Geologic Attributes
- Multiple seals
- High permeability saline reservoir


20-ton CO_2 tankers



Representative cross-section

Field Operations
- Drill two wells penetrating reservoir
- Inject 2,000 tonnes of CO_2 into a saline formation
- Assess injectivity and storage capacity
- Monitor subsurface CO_2 movement
- Test for leakage

WEST COAST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

8

Pilot Objectives

Identify Pilot Test Objectives

Rank Objectives
- Scientific
- Public
- Industry
- Likelihood of Success

- Determine the injectivity of the reservoir
- Determine the storage capacity of the reservoir
- Model and monitor the trapping of the injected CO_2
- Assess seal integrity
  - Caprock
  - Faults
- Evaluate and manage environment

Pilot Project Test Plan

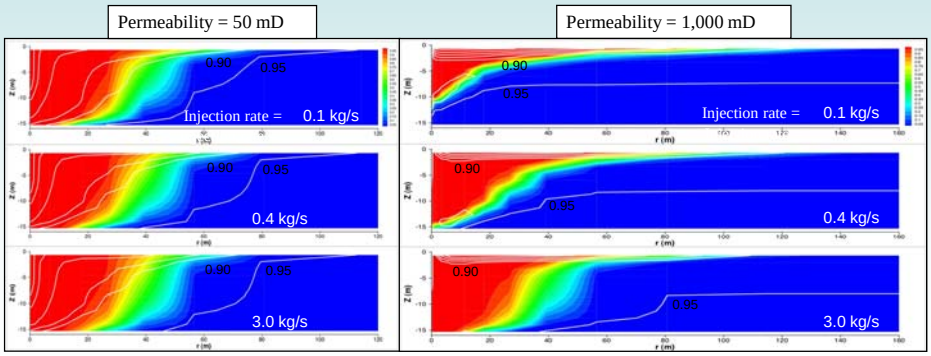
- Model CO_2 injection and CO_2 movement
- Assess injectivity with step-rate injection test
- Assess storage capacity
- Use tracers in CO_2 to assess gas (supercritical) and liquid (dissolved) phases
- Monitor subsurface CO_2 movement using time-lapse VSP and cross-well seismic
- Run Reservoir Saturation Tool (RST) logs to monitor near wellbore
- Use a Distributed Thermal Perturbation Sensor to monitor CO_2 near wells
- Monitor CO_2 at surface near wells
- Validate models

Identify Measurement and Monitoring Approaches

Prioritize Pilot Program Test Plan

TOUGH2* simulation of CO_2 injection into saline reservoir

- CO_2 plume 1 year after injection of 2,000 tonnes
- High residual water saturation: S_W = 95%, S_G = 5%
- Supercritical CO_2 is buoyant; displaces water
- Sensitive to injection rate only at high permeability



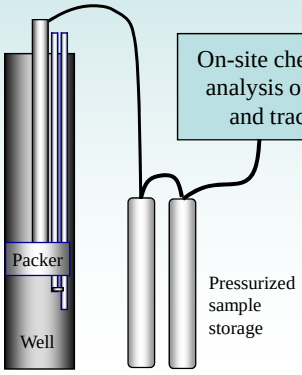
Color contours: Weight % CO_2 in supercritical (gaseous) phase. White contours: Water saturation ($1 - S_g$).

* Transport Of Unsaturated Groundwater and Heat

Source: C. Doughty, LBNL

Water sampling at injection and monitoring wells with the U-Tube System

Continuous pressurized samples of water and gas during and after CO_2 injection



Frio CO_2 Test Site, Texas

Source: B. Freifeld, LBNL

U-Tube System for fluid and tracer sampling

pH, Ec, temperature monitors

Pressure control valves

Control room

Sample collection chambers

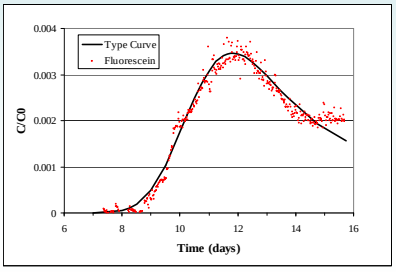
U-tube and check valve strapped to production tubing

Source: B. Freifeld, LBNL

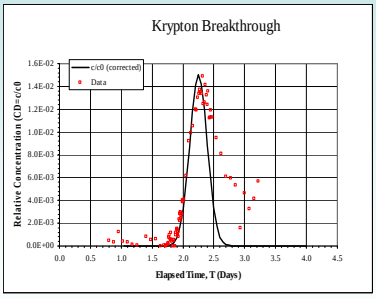
Tracer analysis to estimate CO_2 sweep efficiency in the reservoir

Single-phase and two-phase tracer test in Frio Sandstone at the Frio CO_2 Test Site in Texas, using two wells with 30-meter separation

- Water pumped from one well was tagged with fluorescein dye and injected into the 2nd well.
- Data analysis yielded the porosity-thickness product of the swept reservoir region.



Source: B. Freifeld, LBNL



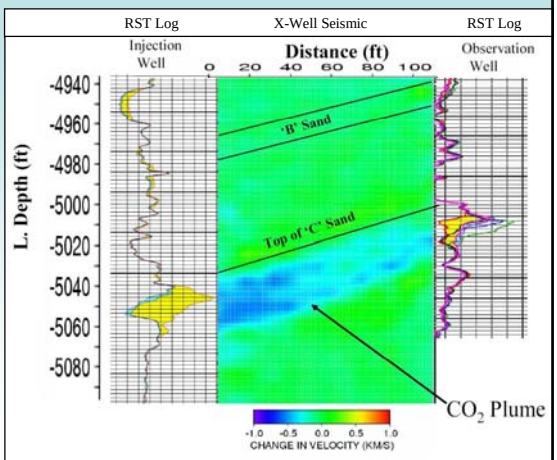
- CO_2 tagged with Krypton was injected into one well and its arrival monitored at the 2nd well.
- Data analysis showed that CO_2 followed high permeability paths and accessed only ~20% of the reservoir.

Source: B. Freifeld, LBNL

Monitoring the CO_2

- Seismic imaging
  - Time lapse VSP
  - Time lapse crosswell
  - Controlled-Active-Source Seismic Monitoring (CASSM)
  - Correlate seismic with fluid and tracer samples obtained with U-tube
- Time lapse Reservoir Saturation Tool (RST)* log

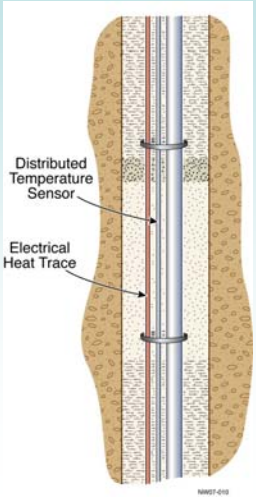
*Schlumberger tool that measures thermal neutron absorption to infer water saturation, and C/O ratio with an induced gamma ray spectrometer.



Frio CO_2 Test Site, Texas

Source: T. Daley, LBNL

Distributed Thermal Perturbation Sensor (DTPS) for tracking CO_2 migration in the subsurface



Thermal conductivity measurements during and after CO_2 injection monitor the distribution of CO_2 near the well

- The DTPS consists of a borehole-length electrical resistance heater and fiber optic distributed temperature sensor.
- Constant heating is applied along the borehole, then is turned off. The temperature sensor measures the decay.
- The low thermal conductivity of CO_2 versus water allows for estimates of CO_2 saturation.
- The DTPS has been successfully tested at the CO_2SINK project in Germany.

Source: Barry Freifeld, LBNL

Regulatory Agencies & Permits

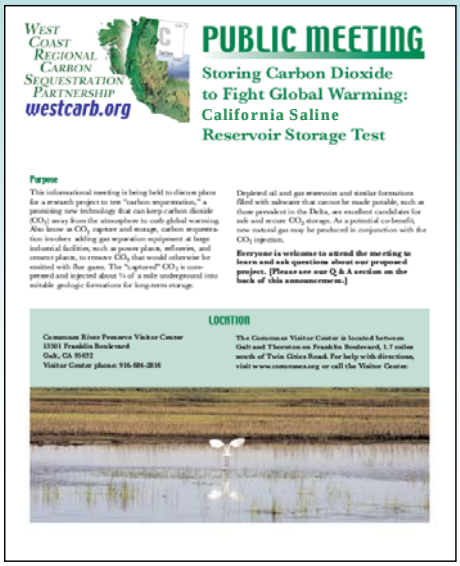
- Injection permit: US EPA Underground Injection Control (UIC) Program – Class V, Experimental
  (New draft regulations for Class VI, CO_2 wells)
- Drilling permit: County agency
- (Drilling permit in oil/gas field: CA Department of Oil, Gas, and Geothermal Resources)
- NEPA: DOE Environmental Questionnaire
- CEQA: Lead state or local agency; CEC approval

Agreements & Contracts

- Surface owner
- Mineral rights owner
- Mineral rights leaseholder
- Pore space owner *(surface owner in Wyoming)*
- Agreements among project partners
- Contracts with subcontractors and suppliers
- Adjacent surface owners for VSP source points

Public Outreach

- State-wide and local information
- Public meetings
- Input on test plans and monitoring



West Coast Regional Carbon Sequestration Partnership
westcarb.org

PUBLIC MEETING

Storing Carbon Dioxide to Fight Global Warming: California Saline Reservoir Storage Test

Purpose

This informational meeting is being held to discuss plans for a research project to test "carbon sequestration," a promising new technology that can keep carbon dioxide (CO_2) away from the atmosphere to curb global warming. Also know as CO_2 capture and storage, carbon sequestration involves adding gas separation equipment at large industrial facilities, such as power plants, refineries, and cement plants, to remove CO_2 that would otherwise be emitted with flue gases. The "captured" CO_2 is compressed and injected about ½ of a mile underground into suitable geologic formations for long-term storage.

Depleted oil and gas reservoirs and similar formations filled with saltwater that cannot be made potable, such as those prevalent in the Delta, are excellent candidates for safe and secure CO_2 storage. As a potential co-benefit, new natural gas may be produced in conjunction with the CO_2 injection.

Everyone is welcome to attend the meeting to learn and ask questions about our proposed project. [Please see our Q & A section on the back of this announcement.]

LOCATION

Cosumnes River Preserve Visitor Center
13501 Franklin Boulevard
Galt, CA 95632
Visitor Center phone: 916-684-2816

The Cosumnes Visitor Center is located between Galt and Thornton on Franklin Boulevard, 1.7 miles south of Twin Cities Road. For help with directions, visit www.cosumnes.org or call the Visitor Center.