WEST COAST REGIONAL CARBON SEQUESTRATION PARTNERSHIP
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WESTCARB Annual Meeting

September 15-17, 2009
Scottsdale, Arizona

Northern California CO_2 Reduction Project

Edward Hymes
Project Manager
Shell International Exploration and Production

Sean McFadden
Technical Team Leader
Shell International Exploration and Production

John Henry Beyer
WESTCARB Program Manager
Lawrence Berkeley National Laboratory

Shell / Lawrence Berkeley Lab Collaboration

- LBNL and Shell project teams first met in June 2008 to discuss the possibility of working together
- We agreed on a new project site in Solano County near the SW edge of the Sacramento Basin
- Shell has worked on regional and site-specific geologic characterization, CO_2 injection, well design, and field logistics and operations
- LBNL has developed a detailed test plan adapted to the site and depth of interest

Permits & Agreements

- Surface and subsurface access – Agreement signed between landowner and Shell in mid April 2009
- UIC permit for Class V, Experimental – With support from Sandia Technologies, Shell submitted application to EPA Region 9 in August 2009 after data gathering, subsurface modeling, and well design
- DOE Environmental Questionnaire – Aspen Environmental is finalizing the NEPA documentation
- Land use permits – Shell has clarified requirements and are developing the application for submission

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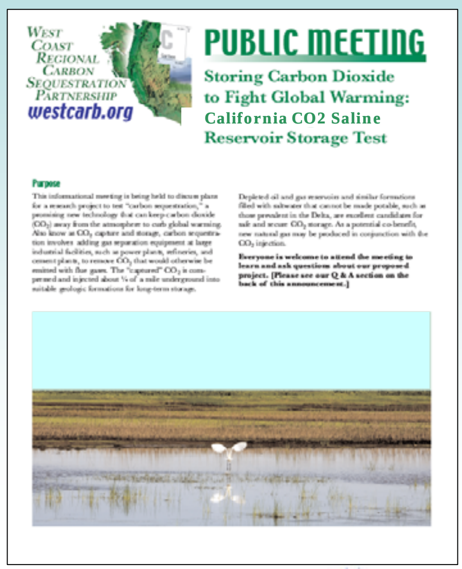
Public Outreach

- Conducted research to gain an understanding of the community
- Issued a press release
- Engaged with local stakeholders
- Developed information materials
- Updated WESTCARB website with project information
- Established an information phone line



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WESTCARB Program Objectives for the Northern California CO_2 Reduction Project

Overall goal: Gain practical experience in and demonstrate the potential for CO_2 storage in deep geologic formations in settings with large CO_2 sources and storage potential.

- Demonstrate the safety and feasibility of CO_2 storage in saline formations in the northern regions of California's vast Central Valley
- Analyze chemical interactions among CO_2, formation brine, and reservoir rock
- Demonstrate and test methods for monitoring geologic CO_2 storage
- Gain experience with regulatory permitting, landowner issues, and public outreach associated with geologic storage of CO_2 in California

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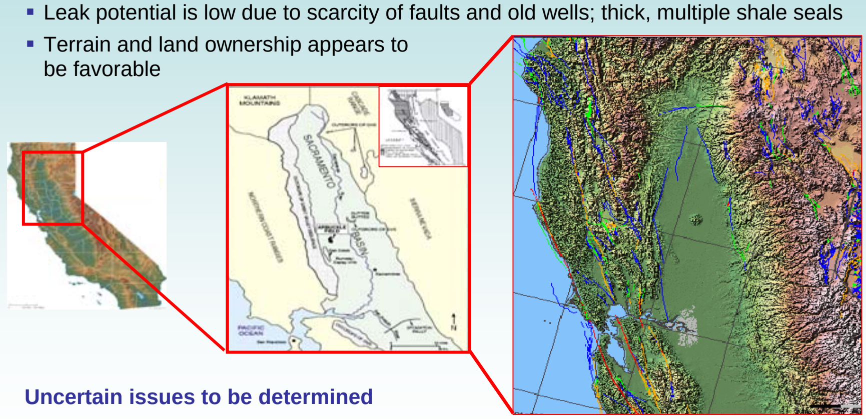
Western Sacramento Valley Location

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



Source: Shell

Uncertain issues to be determined

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

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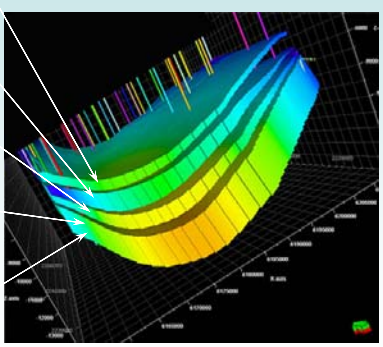
Site Characterization by Shell Technical Team

- **Geologic characterization**: stratigraphy, hydrogeology, salinity estimates. Offset log data: reservoir structure, thickness, sand/shale ratios, porosity, permeability, overlying seals (shales), lateral continuity, temperature, mechanical/rock properties, pore pressure
- **CO_2 injection simulation** for a range of permeabilities, porosities, and CO_2 quantities: injectivity, plume size, injection volume and duration, distance between injection and monitoring wells.
- **Analyze water injection tests**: mini/micro frac, step rate test, and pressure transient test at different permeabilities
- **Logging and coring program**
- **Model time-lapse walk-away VSP**: data acquisition, survey geometry, cost, signal-to-noise
- **Well design options and costs**: monitor well placement; directional control during drilling, well separation control
- **Logistics for completions and testing**: completion design, scheduling and sequence of field operations, with cost implications

Analysis of offset log and core data

Type Stratigraphy

- Nortonville shale
- Domengine sand
- Ione/Capay shale
- Hamilton sand
- Meganos shale
- Anderson sand
- Anderson shale
- Martinez sand
- Martinez Shale
- Martinez Complex sands
- Deeper sands and Seals



Model showing general thickening along the axis of the syncline

Source: Shell

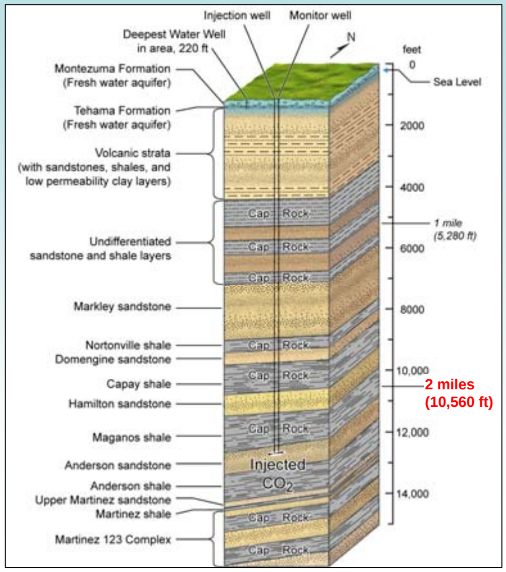
Attributes of target formation extrapolated from nearby wells (2 miles)

- Thick sand package with thick shale above
- Multiple clean sands with low shale content
- Caliper and resistivity logs show fluid invasion indicating permeability
- Average porosity 18%
- Laterally continuous sands
- Sands are compacted and do not wash out
- Likely high salinity
- Good regional containment, no nearby outcrops or known faults
- Option to plug back to shallower formations if needed

Concerns

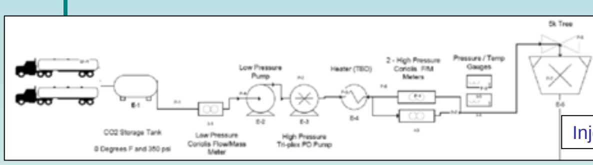
- Deep, >10,500 feet
- Possible low permeability & porosity

Stratigraphic column

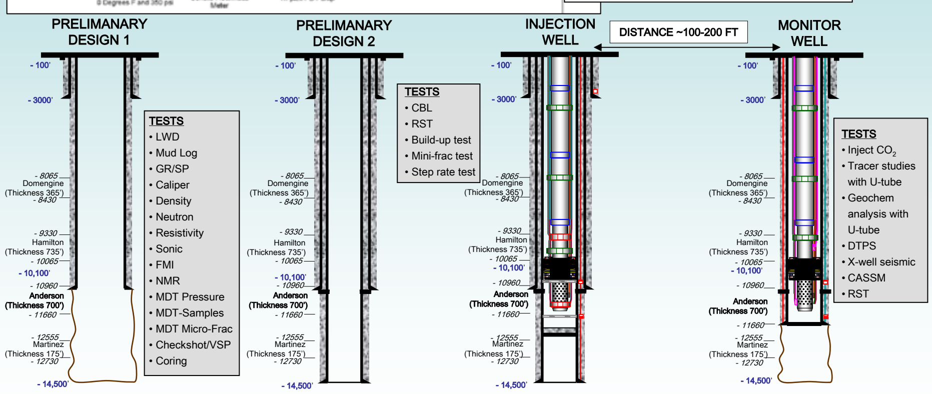


Source: Shell

Project Scope



Inject 2,000 - 6,000 Tons of CO_2



Appraisal → **Run Casing** → **Pilot Injection Test**

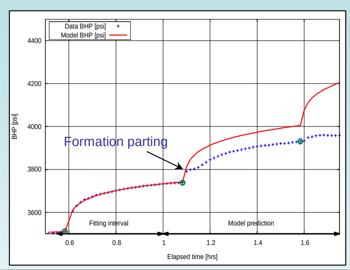
Source: Shell

Pilot Project Test Plan

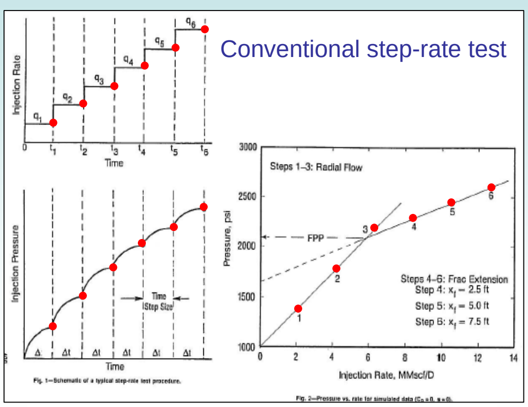
- Model CO_2 injection and multiphase CO_2 / formation water movement
- Assess injectivity and safe injection pressure with analysis of downhole pressure from step-rate injection, micro frac, and build-up tests
- Obtain fluid samples in rapid succession at reservoir pressure with U-Tube system during CO_2 injection test
- Use tracers to assess supercritical and dissolved phases of CO_2
- Measure geochemical interactions of CO_2 with reservoir brine and rock
- Monitor subsurface CO_2 movement and trapping using VSP and cross-well seismic before and after CO_2 injection
- Lab study of seismic velocity of CO_2-saturated core
- Run RST and DTPS logs to monitor CO_2 and demonstrate well integrity
- Analyze geomechanics and monitor possible induced seismic activity
- Estimate reservoir storage capacity
- Calibrate and validate multiphase flow models

Transient analysis of step-rate test (SRT) data

SRT used to define the formation parting pressure (FPP), the maximum injection pressure without fracturing the formation



Conventional step-rate test



Singh, P. K., R. G. Agarwal, and K. D. Krase, 1987, Systematic design and analysis of step-rate tests to determine formation parting pressure, SPE paper 16798, 62nd ATCE of SPE, Dallas, TX, September 27-30, 1987.

Transient analysis of SRT

- Use the same SRT data
- More accurate identification of FPP
- Reduce the maximum injection pressure during test
- Reduce the volume of fluid injected
- Produce estimates of the storativity transmissivity, skin factor

Silin, D. and G. Robin, 2009, Combining step-rate well test with transient pressure test: is it possible?, SPE paper 121425, 2009 SPE Western Regional Meeting, San Jose, CA, March 24-26, 2009.

U-Tube System for fast fluid and tracer sampling

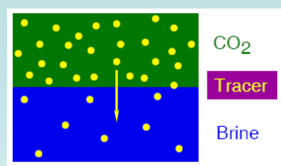
U-Tube surface module

High pressure control valves

Pressurized sample storage

U-tube and check valve strapped to production tubing

Geochemistry of geologic sequestration: CO_2-brine-mineral interactions



- Multiple phase partitioning tracers (noble gases [Kr, Xe], SF_6, volatile organic chemicals) injected with CO_2. From known phase partitioning behavior (solubility, volatility):
  - Infer the average volume fractions of different fluid phases along the flow path
  - Determine reservoir processes and conditions (phase saturations, fracture-matrix interaction, exchange geometry)
  - Identify fast preferential paths
- Geochemical interactions of CO_2 with formation brine and rock
  - Changes in chemical and isotopic composition of fluid along a flow path reflect
    - Mixing
    - Mineral dissolution
    - Precipitation
  - Reactive transport models quantify these competing processes

Source: Mack Kennedy, LBNL

Model (Code) Complexity

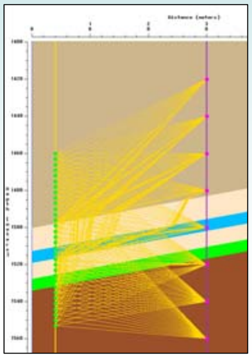
Fluid dynamics: TOUGH2
- Multiphase flows of water/NCGs/dissolved solutes/non-isothermal
- Investigate reservoir dynamics and testing

Geochemistry: TOUGHREACT
- Reactions between gas - aqueous - solid phases
- Study natural and induced chemical evolution of fluid-rock system

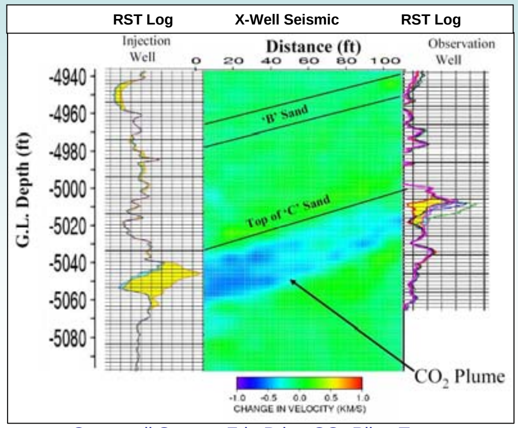
Geomechanics: TOUGH-FLAC
- TOUGH2 coupled to commercial FLAC3D geomechanics code
- Stress-strain: analyze uplift and subsidence, permeability change

Seismic Imaging of the CO_2 Plume

- Time-lapse crosswell
- Time-lapse vertical seismic profile (VSP)
- Resonance bar study of core samples



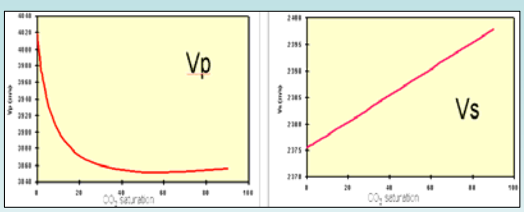
Crosswell raypaths



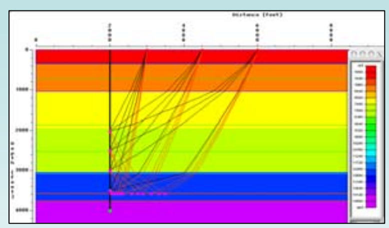
Crosswell Survey, Frio Brine CO_2 Pilot, Texas

Source: Tom Daley, LBNL

VSP Survey Analysis

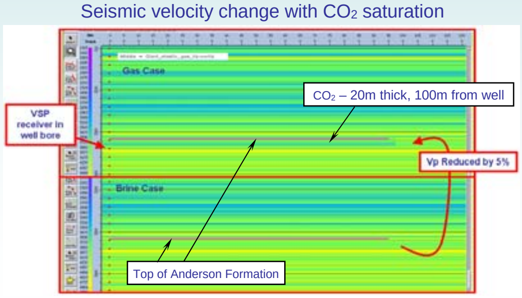


Seismic velocity change with CO_2 saturation



Ray tracing for VSP offset planning

Source: Tom Daley, LBNL



Velocity model for CO_2 simulation

Source: Shell

At the Frio Brine CO_2 Pilot, VSP detected the plume extent at a depth of 5,000 feet.

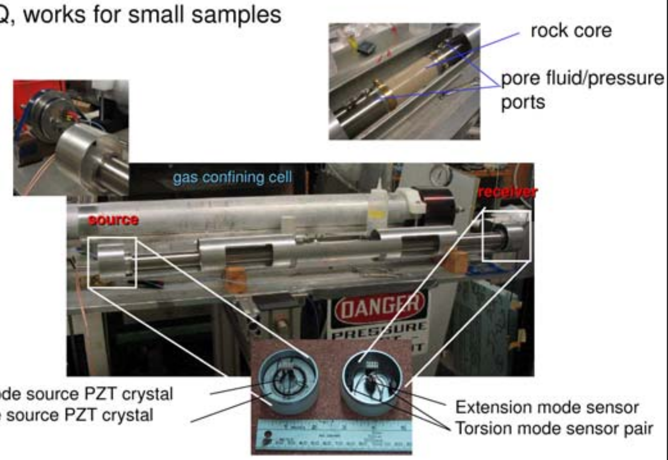
Modeling results: At a depth of 11,000 feet, the acoustic impedance change from CO_2 saturation should be detectible using VSP surveys.

Modified Split Bar Hopkinson Pressure Bar Apparatus

Measures resonance of bar + sample system

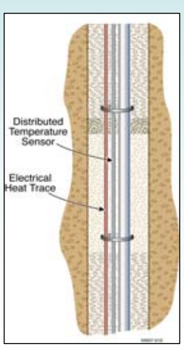
Measurements of elastic moduli in the 500-1000 Hz range

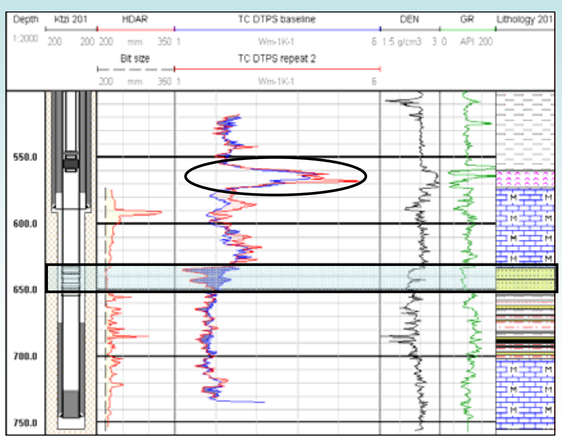
Can extract Q, works for small samples



Source: Seiji Nakagawa, LBNL

Distributed Thermal Perturbation Sensor (DTPS) for Tracking CO_2 Migration in the Subsurface





Good overall fit to baseline results (e.g., anhydrite marker horizon).

Distinct zone with decrease in thermal conductivity: main zone of CO_2 injection

From Jan Henninges, GFZ, Barry Freifeld, LBNL, and the CO_2SINK Scientific Monitoring Team

Contact Information

Edward Hymes
Project Manager
Shell International Exploration and Production
Houston, Texas
edward.hymes@shell.com
281-544-4972

Sean McFadden
Technical Team Leader, EP Solutions
Shell International Exploration and Production
Houston, Texas
s.mcfadden@shell.com
281-544-3890

John Henry Beyer, Ph.D.
WESTCARB Program Manager, Geophysicist
Lawrence Berkeley National Laboratory
Earth Sciences Division
One Cyclotron Road, MS 90-1116
Berkeley, CA 94720
jhbeyer@lbl.gov
510-486-7954