Geologic CO_2 Storage Options for California

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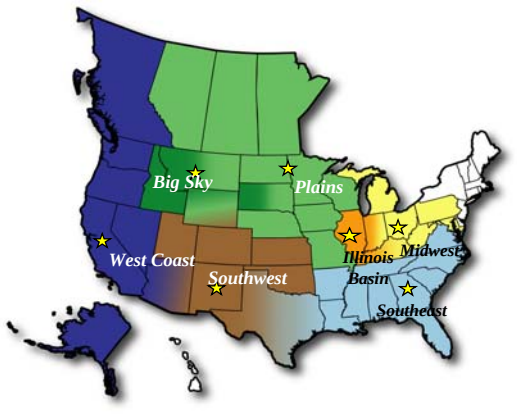
Outline

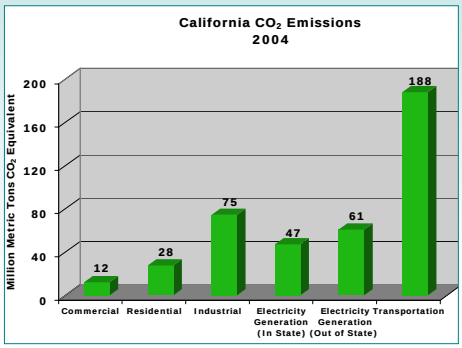
- California CO_2 emissions
- Geologic storage opportunities in California
- What about faults?
- Need for field pilot studies
- Summary

WESTCARB Is One of Seven DOE Regional Carbon Sequestration Partnerships

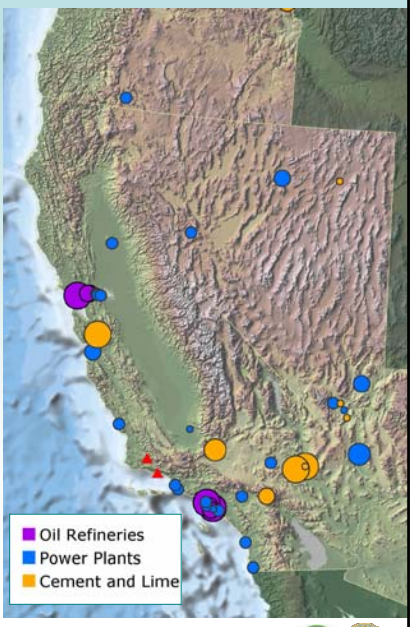
- Opportunities for terrestrial and geologic CO_2 storage are being evaluated
- DOE program represents 40+ states, 4 provinces, and over 240 organizations
- Phase I (complete): focus on regional assessments
- Phase II (under way, 4-year duration): focus on small-scale field tests
- Phase III (upcoming, 10-year duration): pre-commercial geologic field tests



California CO_2 Emissions



(Source: EPA)

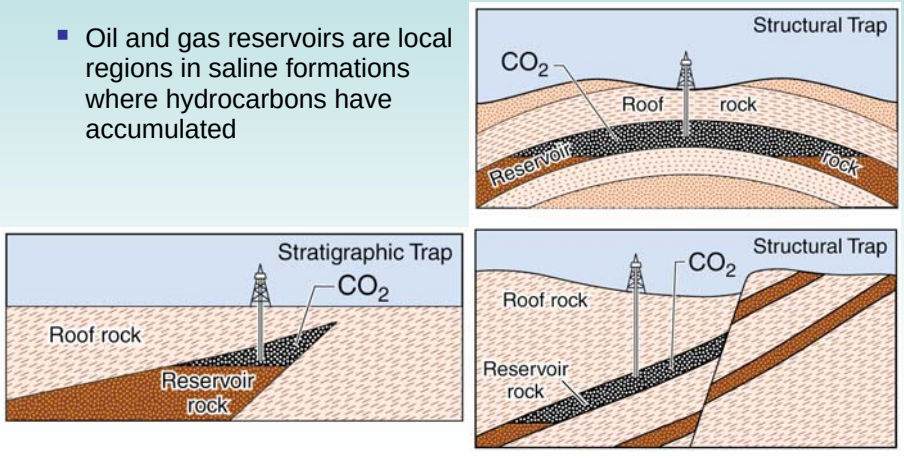


Primary Geologic CO_2 Storage Options for California

- Oil and gas reservoirs
  - Storage with Enhanced Oil Recovery (EOR) or Enhanced Gas Recovery (EGR)
  - Storage only
- Saline formations
  - Storage only

Geologic Structures That Trap CO_2 Underground—Each Is Present in California

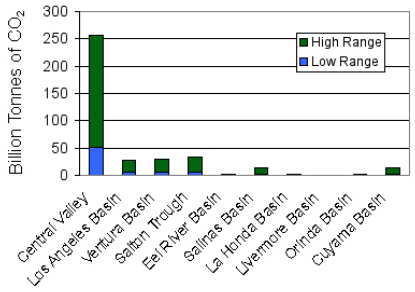
- Oil and gas reservoirs are local regions in saline formations where hydrocarbons have accumulated

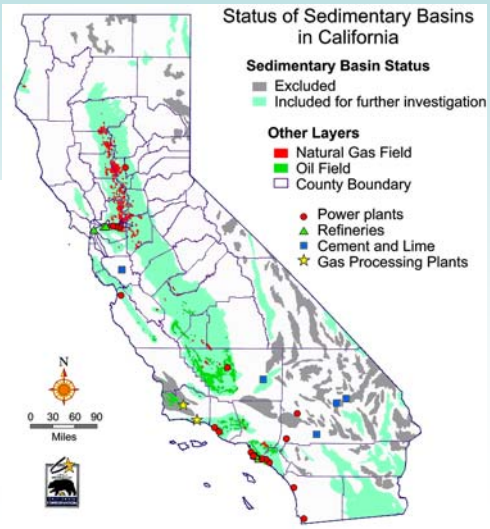


Typical geological structures ideal for trapping CO_2
(Source: W Gunter, ARC)

Major Geologic Storage Opportunities in California

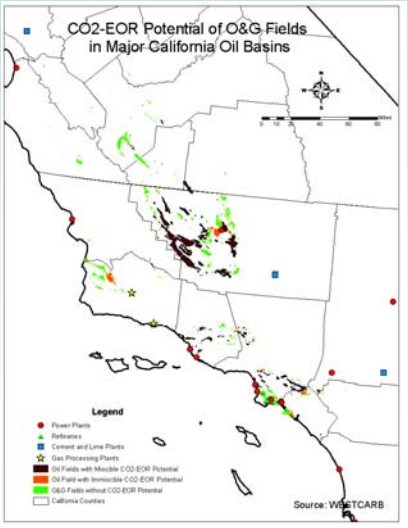
California Saline Formation Resource Estimate





Significant Opportunities for EOR and EGR

- 121 oil fields met depth and miscible EOR criteria
  - 3.4 Gt CO_2 storage capacity, using production as a basis
  - Other studies suggest 5.4 billion barrels oil technically recoverable
- 128 gas fields met depth criteria
  - 1.8 Gt CO_2 storage capacity

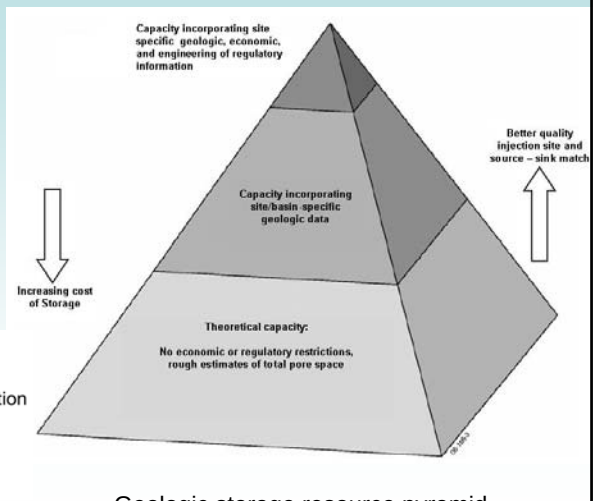


Many Factors Affect Storage Capacity Estimates

Resource capacity calculated by:

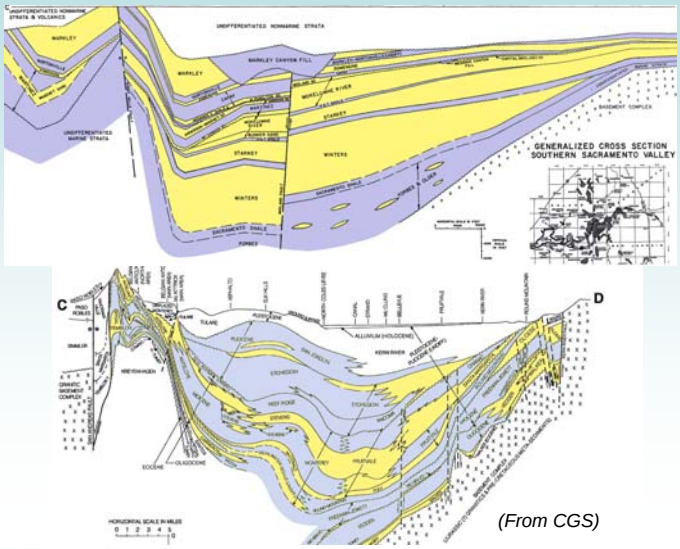
$$G_{CO2} = A\, h_g\, \varphi_{tot}\, \rho\, E$$

G_{CO2} = Mass of CO_2
A = Basin Area
h_g = Gross thickness of porous formation
φ_{tot} = Porosity of porous formation
ρ = CO_2 density
E = CO_2 storage efficiency factor



Geologic storage resource pyramid
(Modified from Bradshaw et al, 2006)

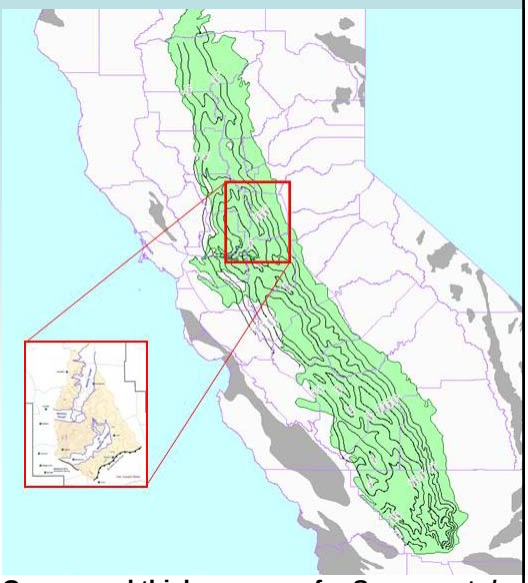
Each Promising Sedimentary Basin Must Be Characterized for CO_2 Storage Potential



(From CGS)

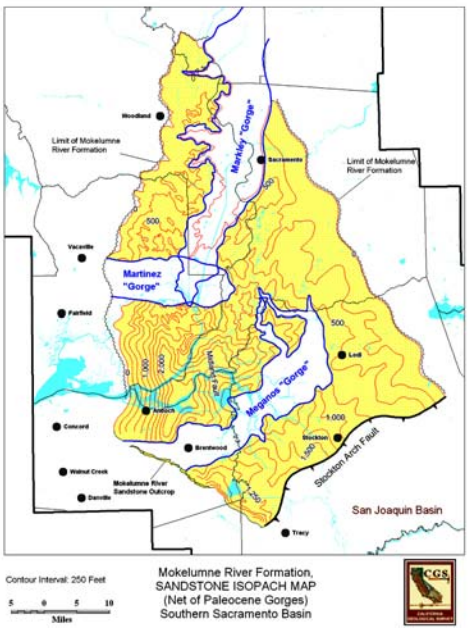
WESTCARB Phase II Studies Are Improving CO_2 Storage Resource Estimates

- Mapping of key storage formations aids in site selection

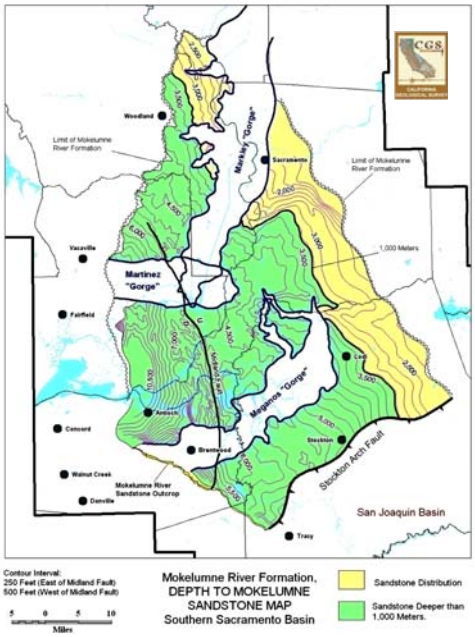


Gross sand thickness map for Sacramento/ San Joaquin Basin (From CGS)

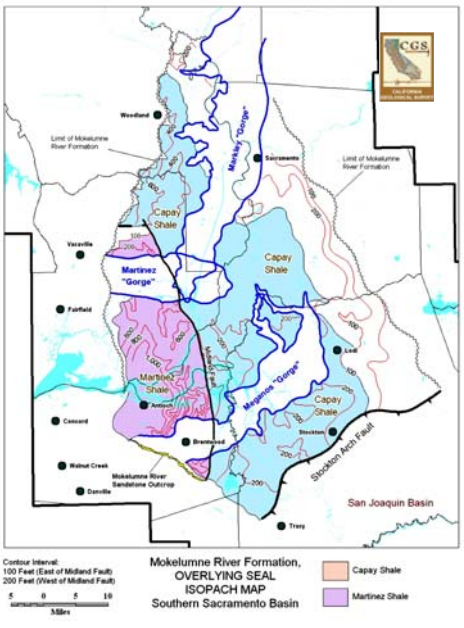
Mokelumne River Formation Is a Large Potential Storage Reservoir Near Major CO_2 Sources



Mokelumne River Formation Is Mostly Deeper than 3300 Feet (1000 Meters)—CO_2 Would Stay in the "Dense Phase" Good for Storage



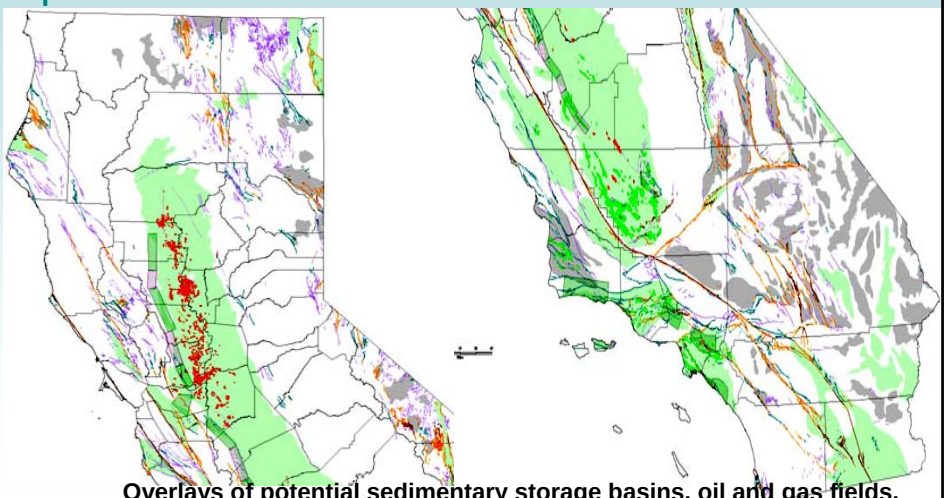
Many Mokelumne River Formation Seals Are Thick (>100 feet or 30 m)—Good for CO_2 Storage



Fault and Fracture Primer

- Faults are fractures which have moved
- Faults and fractures are ubiquitous
- Faults and fractures exist at all scales
- Faults and fractures can be fluid conduits or seals
- Fluid pressure changes from CO_2 injection can cause movement on faults and fractures even if new fractures are not formed
- **Faults and fractures should be respected, but not feared**

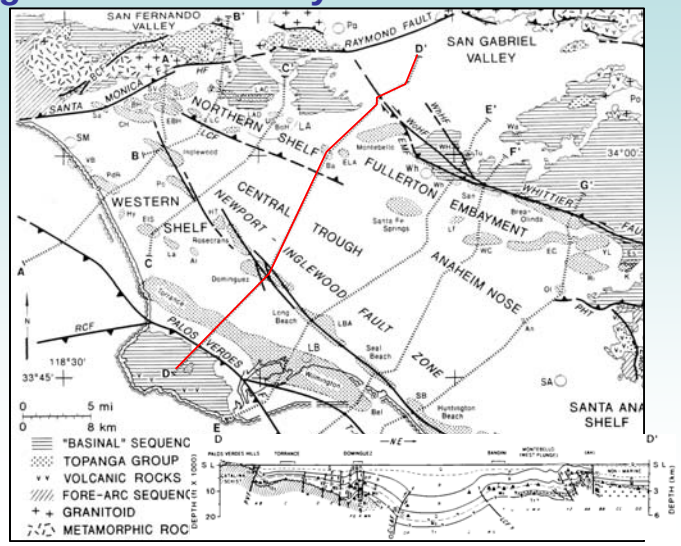
New Faults Warrant More Study than Old Faults—Many California Basins Have Few Faults <2 Million Years Old



Overlays of potential sedimentary storage basins, oil and gas fields, and faults <2 million years old (From CGS)

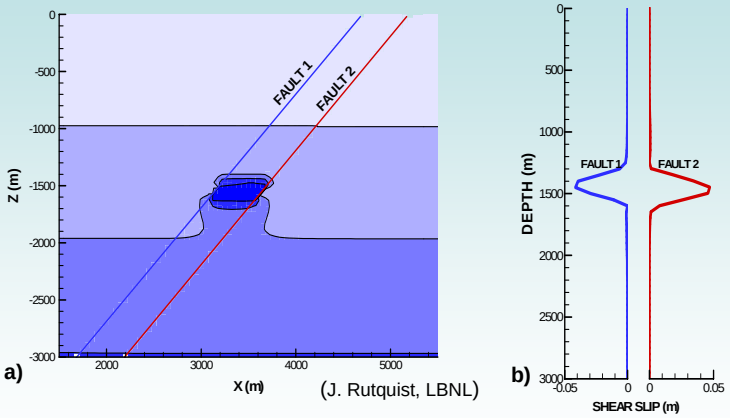
Active Seismic Faults Cross Oil Reservoirs in the Los Angeles Basin—They Don't Leak

- Multiple reservoirs along the Newport-Inglewood fault have retained hydrocarbons over geologic time



(From Wright, 1991)

Site Characterization Includes Geomechanical Fault Analysis—Answering the Question "Will They Slip?"



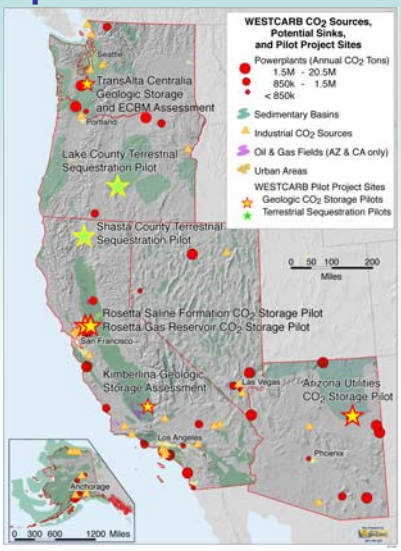
(J. Rutquist, LBNL)

Numerical simulation of slip on discontinuities resulting from a pressurized region

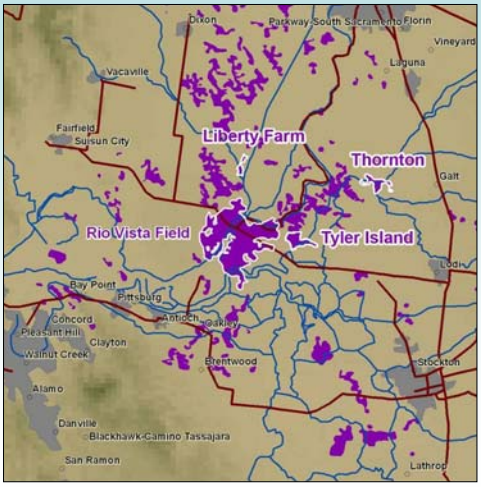
a) The model, showing a maximum pressure increase in the region of 2.6 times original pressure
b) Shear slip on the faults

Field Tests Provide Regional Knowledge Base Essential for Commercial Implementation

- Field tests examine prime storage locations
- Pilot projects involve site-specific focus for:
  - Testing injection technologies
  - Assessing storage capacity
  - Determining costs
  - Assessing leakage risks and demonstrating the effectiveness of safety measures
  - Validating monitoring methods
  - Establishing regulatory procedures



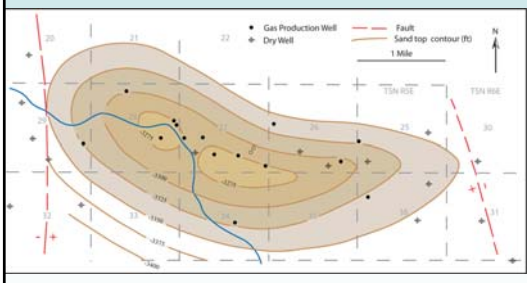
Rosetta Resources CO_2 Storage Pilot Test



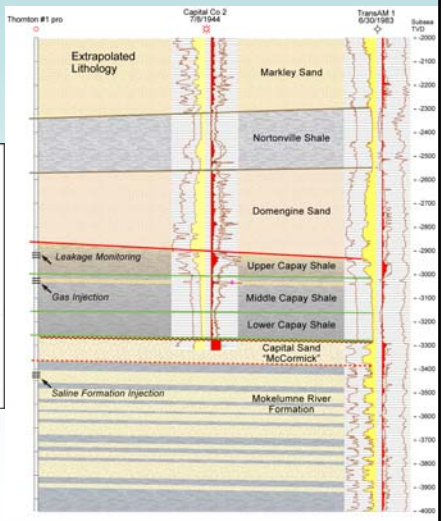
Major Sacramento–San Joaquin River Delta natural gas fields shown in purple

- Lead industrial partner: Rosetta Resources
- Validate sequestration potential of California Central Valley sediments
- Gain insight into viability of CO_2 storage and Enhanced Gas Recovery
- Inject up to 2000 tons at about 3400 ft (1000 m) depth
- Focus on monitoring

Existing Wells Provide Data for Geologic Model



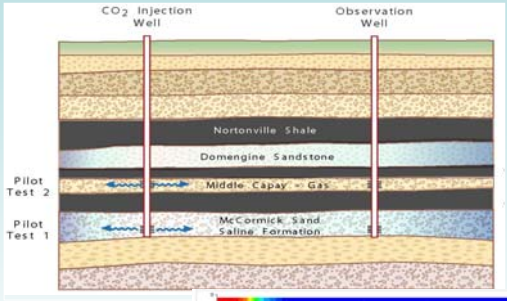
Structure on top of target reservoir



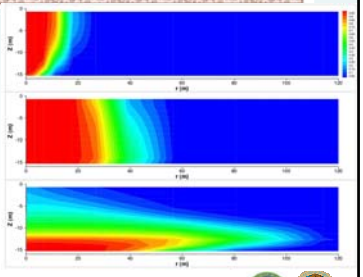
(R. Trautz, LBNL)

Pilot Involves One Injection and One Observation Well

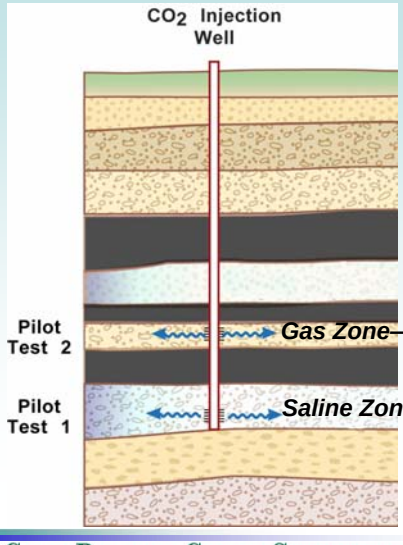
- Assess seal integrity, underground spread of CO_2, storage capacity, and injectivity
- Study mixing and methane displacement in gas reservoir
- Measurements include downhole pressure and temperature, fluid sampling, wireline logging, vertical seismic profiling and crosswell seismic, and shallow groundwater and surface CO_2 sensors



Above: schematic cross-section Right: computer simulation of CO_2 in gas reservoir *(R. Trautz, C. Oldenburg, LBNL)*



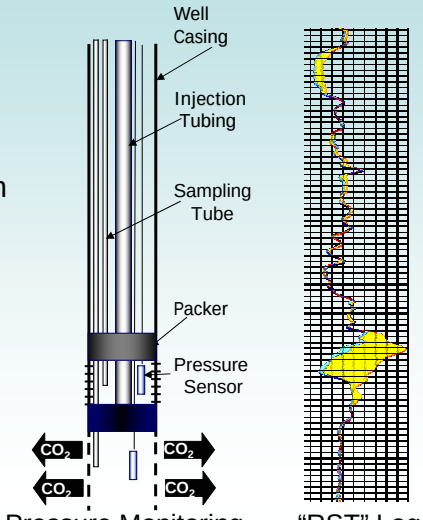
Pilot Tests Help Clarify Regulatory Framework



- California is an underground injection control (UIC) "mixed primacy" state, meaning federal and state regulators have a say
- Both agencies have been supportive

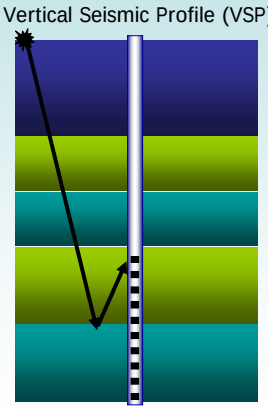
Pilot Tests Assess Geologic Seal Integrity—Answering the Question "Will It Leak?"

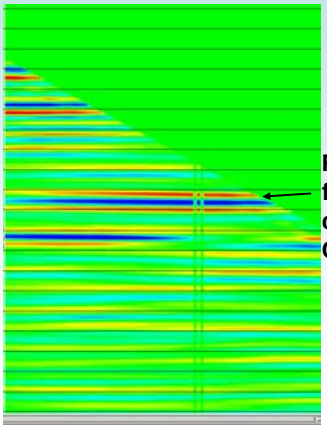
- Geomechanical analysis
  - Safe injection pressure
- Monitor pressure and water quality in a shallow formation above the injection zone (for early detection of any leaks)
- Obtain geophysical well logs from injection and observation wells before and after CO_2 injection



Pilot Tests Will Map the Underground Spread of Injected CO_2 Within Intended Storage Zone

- Seismic imaging
  - Vertical seismic profiling (VSP)
- Fluid sampling



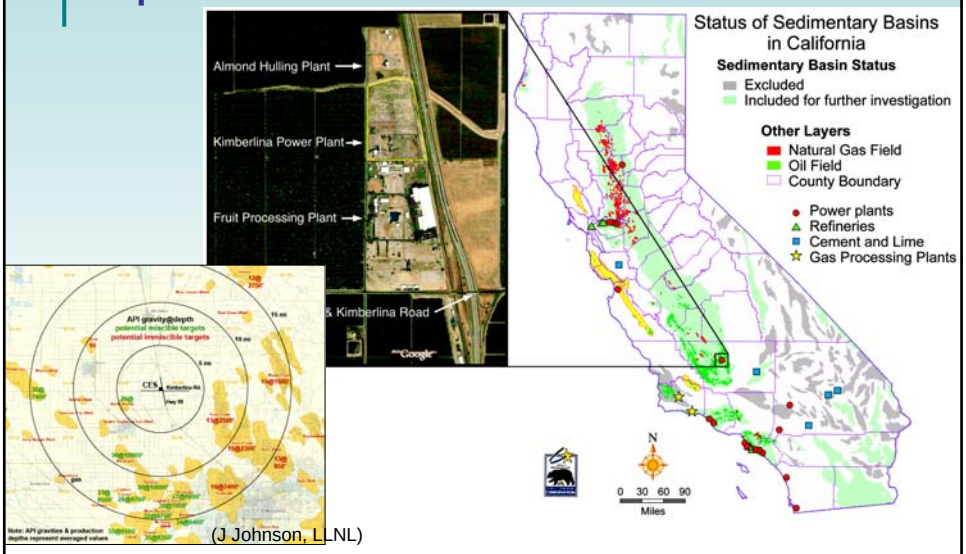


VSP result from Frio CO_2 Injection pilot test (Daley, 2005)

WESTCARB "Large-Volume Test" (Phase III) Objectives

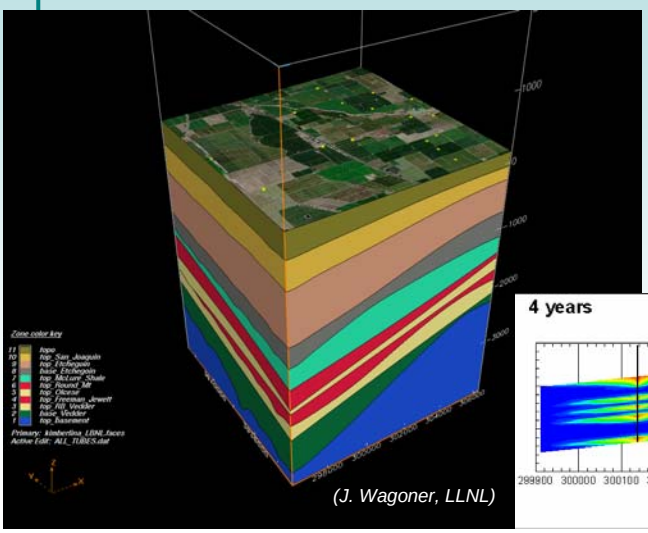
- Conduct a commercial-scale CCS test in California
  - Accessing the best geologic target in the state
  - 1 million tons CO_2 to be injected
- Demonstrate advanced, commercial "sequestration friendly" power generating technology (Clean Energy Systems)
- Demonstrate commercial-scale sequestration methodologies for site characterization and monitoring (Schlumberger)
- Conduct research supporting subsurface sequestration methodologies, and advancing technologies in reservoir engineering, risk assessment, and monitoring
- Exercise, and provide important experience for, evolving regulatory and legal frameworks

Project Is Representative of Major California Sequestration Potential

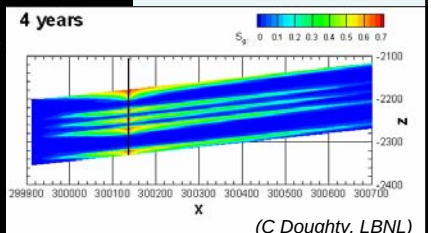


(J Johnson, LLNL)

Initial Geologic Model and Reservoir Simulations for Phase III Test



(J. Wagoner, LLNL)



(C Doughty, LBNL)

Summary

- The CO_2 storage resource in California is very large
- Hydrocarbon reservoirs have demonstrated the ability of geologic structures to securely hold buoyant fluids for very long times
- Refinement of initial resource estimates will greatly aid site selection
- Geologic faults must be assessed as part of site characterization; their mere existence does not disqualify a site for CO_2 storage
- Field tests at different scales provide essential experience and knowledge needed for informed policy making and accelerated commercial readiness of CO_2 storage technologies