California Energy Commission's R&D Activities in CCS for California

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PIER CCS R&D and Techno-Economic Summaries of Key Activities

- California Carbon Capture and Storage Review Panel (2010), including Technical Advisory Team
- WESTCARB – West Coast Regional Carbon Sequestration Partnership (2003−2015); collaborative R&D with DOE NETL, state agencies, national labs/universities, EPRI, industry, and others
- PIER projects on potential for induced seismicity, groundwater impacts, etc., from CO_2 injection (some ongoing)
- *Geologic Carbon Sequestration Strategies for California: Report to the Legislature* (2008) and *Assessment of the Barriers and Value of Applying CO_2 Sequestration in California* (2015)
- Staff workshop on CCS for natural gas power plants (2015)
- CEC Siting Division-siting activities with HECA

California Agencies Convene Expert Panel to Examine CCS Policy

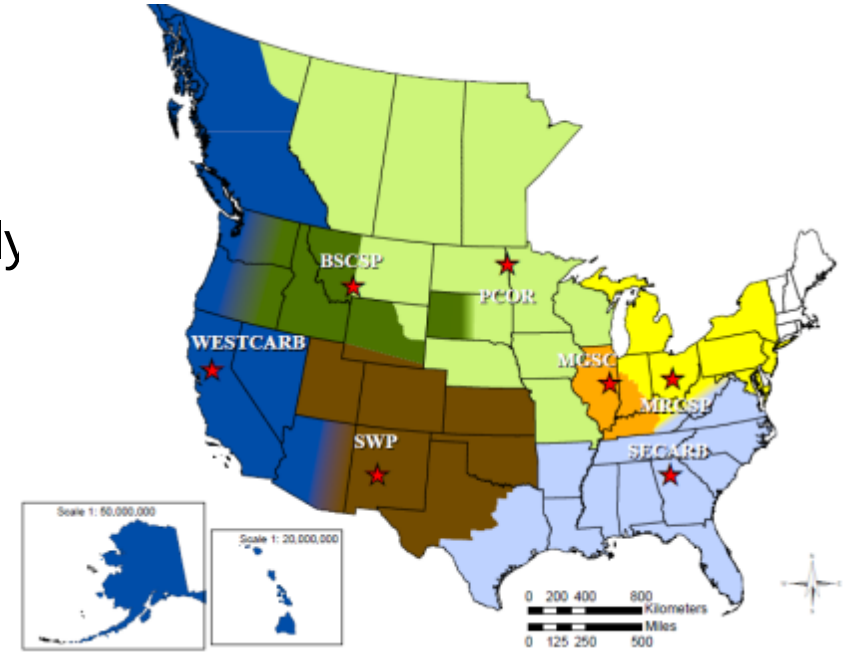
- California Carbon Capture and Storage Review Panel was created in 2010 by the Energy Commission, CPUC, and ARB, with involvement of DOGGR, Dept. of Water Resources, and others
- Panelists included experts from academia, NGO, utilities, industry associations, law firms, and a former state legislator. Chaired by Carl Bauer, former Director of DOE's National Energy Technology Laboratory
- Five public meetings held; Energy Commission team developed topical white papers for panelists
- Panel developed recommendations to guide CCS policy formulation and regulatory role coordination in California
- http://www.climatechange.ca.gov/carbon_capture_review_panel/index.html

Key Recommendations of CCS Review Panel

- Determine and coordinate permitting and regulatory authority for CCS projects including CEQA lead, site operations, and CO_2 pipelines
- Establish GHG “accounting protocols” for sequestered CO_2 to facilitate inclusion in AB 32 compliance programs
- Develop performance standards for the design and operation of CCS sites for environmental, health, and safety protection
- Clarify ownership and use of subsurface pore space for CO_2 storage
- Assign financial responsibility for long-term stewardship of CO_2 storage sites
- Establish cost allocation mechanisms and/or incentives to support early CCS projects
- Develop public education materials and programs

West Coast Regional Carbon Sequestration Partnership (WESTCARB)

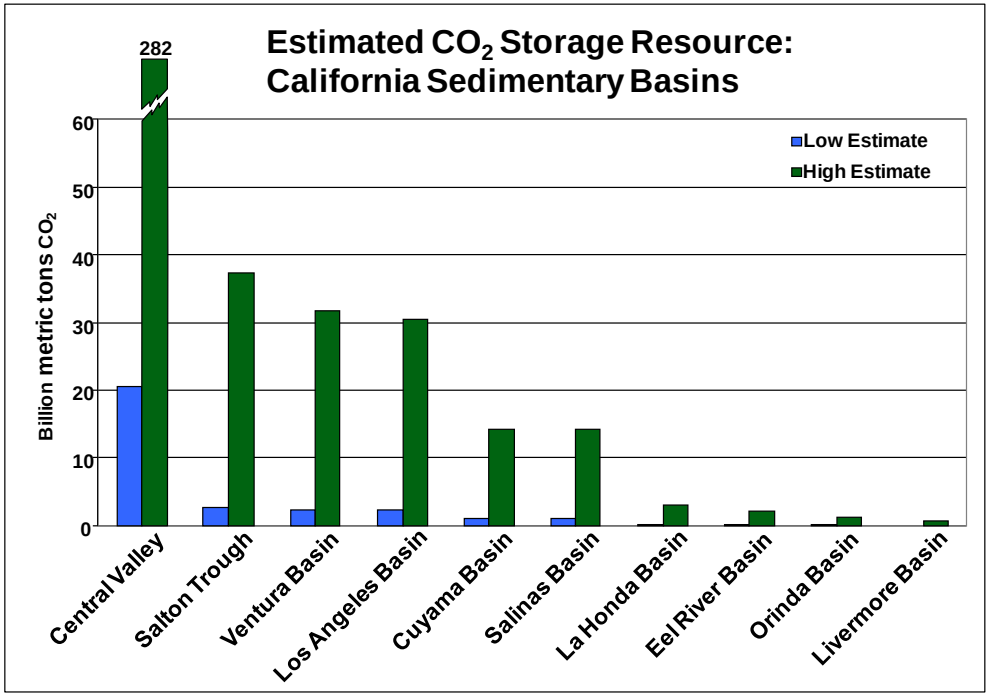
- Collaborative R&D team with >100 partners, led by Energy Commission
- One of 7 DOE “regional partnerships,” each charged with conducting regionally focused research and public outreach
- Basic questions answered for geologic and terrestrial carbon storage:
  - Is there ample, affordable, widely distributed storage capacity for the types of emission sources in the region?
  - Will storage be secure given the region’s seismicity (geologic storage) and history of wildfires (terrestrial storage)?
  - Does geologic storage pose any risk to hydrocarbon or groundwater resources?
  - California applications are promising
- Pilot-scale field tests validate technology



WESTCARB territory includes AK, AZ, BC, CA, HI, NV, OR, and WA

California's Geologic CO_2 Storage Capacity Is Very Large

- On-shore sedimentary basins conducive to storage represent capacity for roughly 1000 years of current point source CO_2 emissions
- Central Valley's Sacramento and San Joaquin Basins have the largest capacity
- Opportunities for CO_2 storage also exist in the state's oil and natural gas fields – many have potential for CO_2-enhanced oil recovery
- Off-shore basins identified and partially characterized



30–460 Gt onshore saline formation capacity
3.3–5.7 Gt natural gas reservoir capacity
1.4–3.7 Gt oil reservoir capacity

WESTCARB Drilled Wells to Validate Formation Permeability at Promising Sites (CA and AZ)

- Site screening and selection
- Project planning; industry host engagement
- Subsurface modeling and injection simulation
- Risk assessment
- Monitoring plan
- Permitting
- Community outreach
- Safety plan and training
- Field measurements, laboratory analysis of core samples
- Site closure and restoration

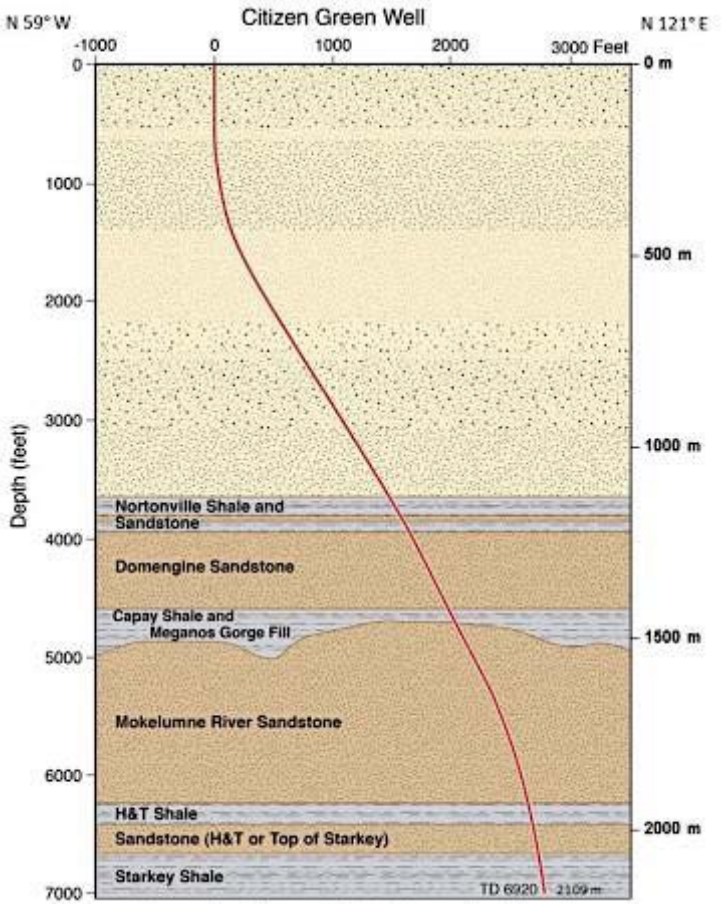
Rock core collected at Citizen Green well (above) sent to LBNL scientists for laboratory analysis of CO_2 behavior in pore spaces (below)

WESTCARB Criteria for Site Selection

- Well-defined stratigraphy or geologic structure to confine CO_2 to target strata
- No impact on low-salinity (<10,000 mg/L TDS) aquifers
- Location unlikely to cause public nuisance (noise, traffic, dust, etc.)
- Proximity to large CO_2 point sources (future commercial potential)
- Available hydrogeologic, well log, seismic, and rock/fluid properties to inform site suitability and initial modeling
- Major faults understood for evaluating potential leakage pathways
- Depth of storage greater than ½ mile to keep CO_2 in dense (low buoyancy) phase

Characterization Well Results for the Sacramento Basin

Citizen Green well on King Island near Lodi

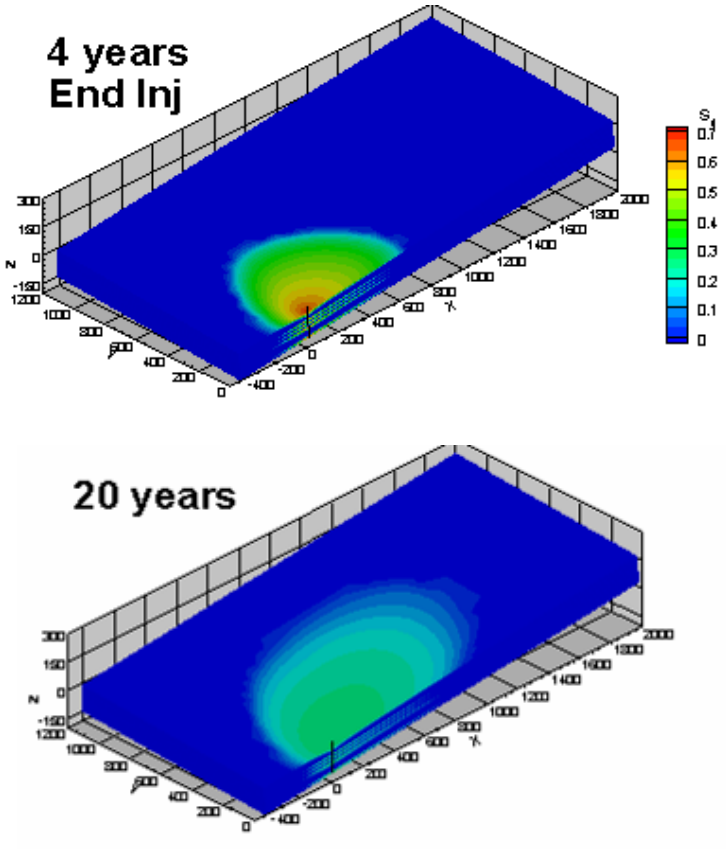


- Location in northern California's natural gas producing region allowed use of experienced local drillers, mudloggers, etc.
- Reuse of pad and surface casing from an inactive natural gas well saved money and simplified CEQA
- Deviated well drilled to 7000 foot depth
- Core samples and logging data showed unconsolidated sands with high permeability in primary target formation, as well as good sealing properties in the shales
- Laboratory analyses of core samples at LBNL indicated good CO_2 injectability

Modeling and Simulation Results for the San Joaquin Basin

Kimberlina Power Plant north of Bakersfield

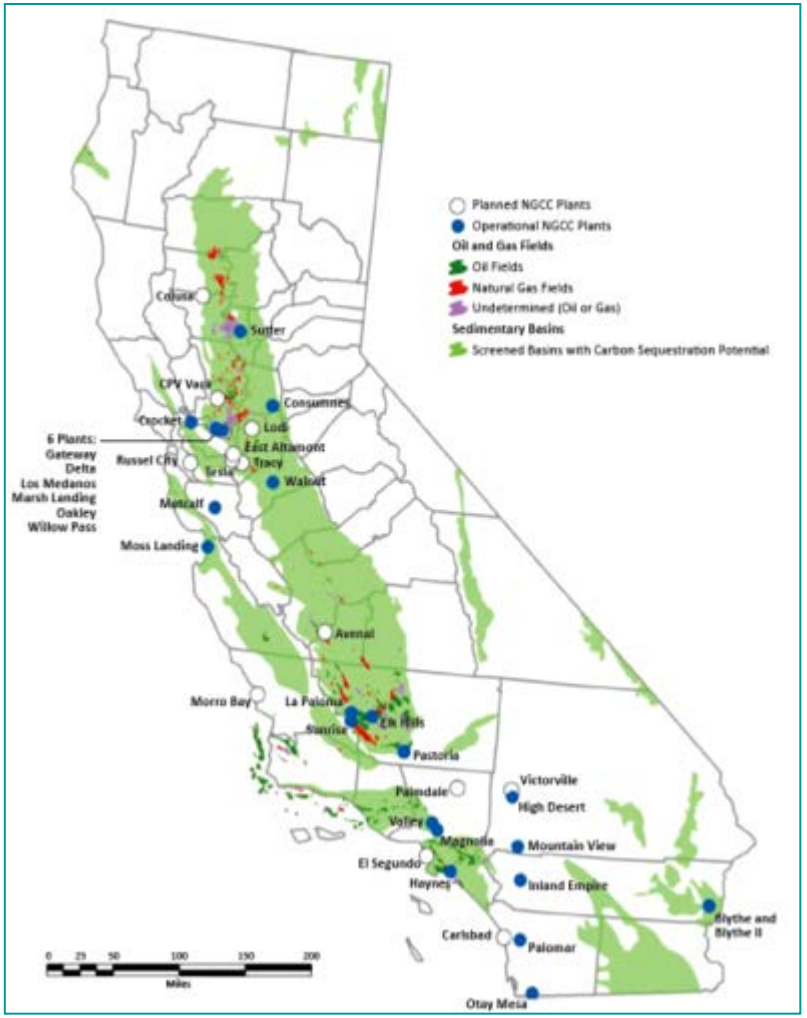
- Site of Clean Energy Systems' 5 MW oxy-combustion power plant with inherent CO_2 separation; on-site injection well planned but not drilled
- 85-square-mile geologic model developed by Lawrence Livermore; regionally continuous Vedder Formation at a depth of 8000 feet appears best storage site
- Lawrence Berkeley simulation of a 4-year, 1 million-ton CO_2 injection showed plume stabilization within 20 years with little migration



Initial LBNL simulation of CO_2 plume in the Vedder formation at end of the 4-year, 1 million ton injection period (top) and after 20 years (bottom)

California NGCC Plants Align Well with Sedimentary Basins Screened for CO_2 Storage

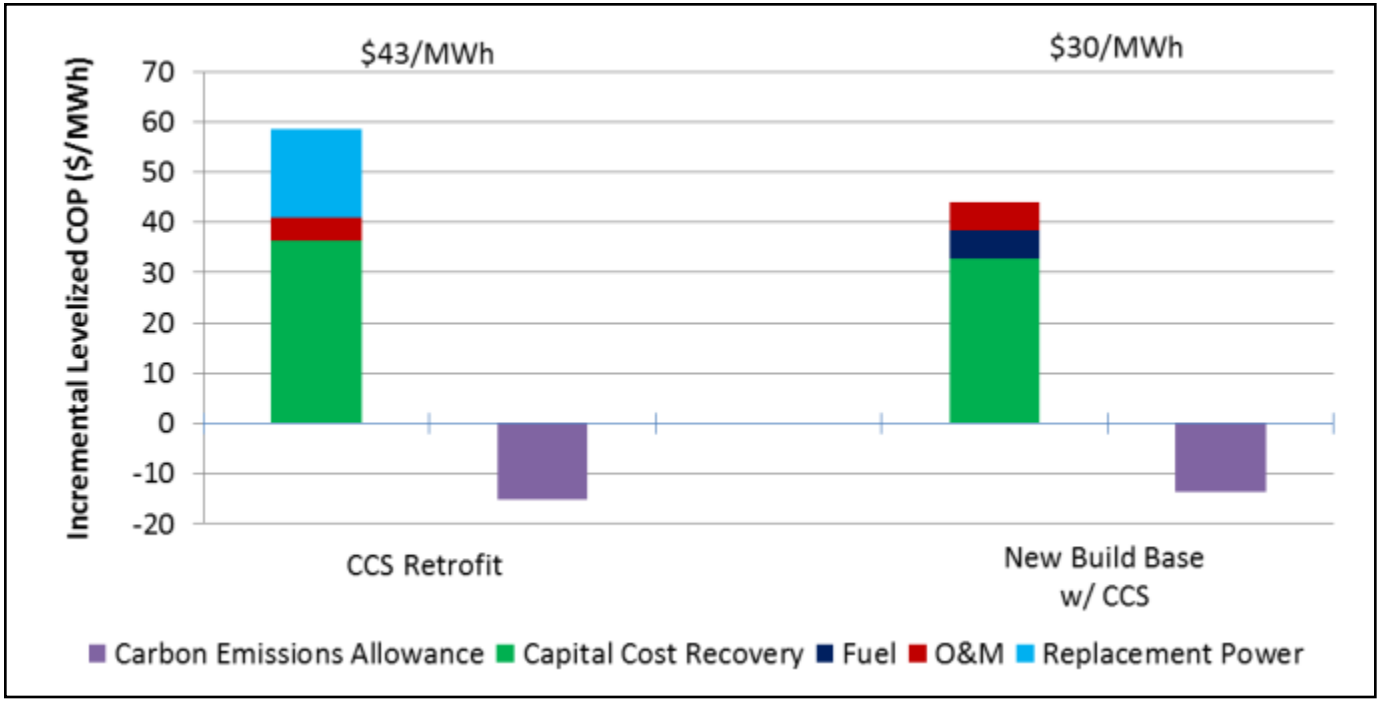
- Initial review of geology beneath 42 NGCC plant sites found 33 with underlying sedimentary basins having sand thickness and depth suitable for CO_2 storage
- About 20 sites also had oil and gas fields within 12 miles
- Most are in flat, rural terrain, suggesting CO_2 pipeline construction may be feasible
- Similar result expected for cement, biofuels, and ag processing plants



Source: Lawrence Livermore National Lab and California Geological Survey

Capital Cost Is the Most Significant Economic Variable for Adding CCS to NGCC Plants

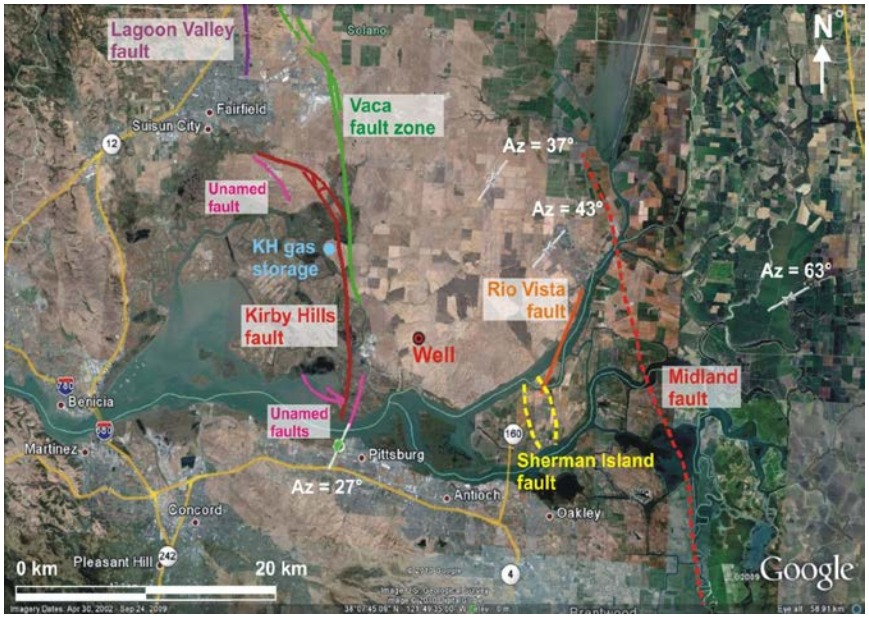
- Adding CO_2 capture and compression reduced net output by 11% and increased net heat rate by 12%
- Cost for full CCS system is $900 million for 600 MW plant; for retrofits, replacement power is also costly



Source: CB&I

CO_2 Storage Integrity and Seismicity

- Could earthquakes release CO_2 or could CO_2 injection cause earthquakes? Both have been studied.
- California Geological Survey issued seismic hazard map classifying faults according to age since last activity
- WESTCARB analyzed the risk of induced seismicity from small-scale CO_2 injection in the Montezuma Hills of Solano County. Results yielded an approach to risk assessment for induced seismicity as part of the permitting process.
- LBNL examined the potential for induced seismicity in the San Joaquin Valley from geologic CO_2 storage and historic basin pressure changes



Active faults in the vicinity of a proposed pilot CO_2 injection well in the Montezuma Hills were identified and the pressure change effects simulated by LBNL

WESTCARB Outreach to California Communities

- Thornton – pilot-scale CO_2 injection proposed; CEQA declaration published
- Rio Vista – pilot-scale CO_2 injection proposed; draft permit issued
- Bakersfield – 1 million ton CO_2 injection proposed; permit application developed
- Well attended public meetings in all three communities; no formal comments to CEQA or draft permit
- WESTCARB also conducted public official and business/civic/EJ group briefings, science teacher training, opinion surveys, media interviews, etc.
- Citizen Green well videos at http://www.westcarb.org/videos.html

How WESTCARB Results Can Support ARB Storage Protocol Development

- Project site geologic characterization procedures
- Risk, EHS, and surface and subsurface monitoring plans
- Geologic models and CO_2 injection simulations
- Data from permit applications and CEQA declarations
- Stakeholder network and engagement experience

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