California Carbon Capture and Storage Review Panel

TECHNICAL ADVISORY COMMITTEE REPORT

Review of Saline Formation Storage Potential in California

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CALIFORNIA CARBON CAPTURE AND STORAGE REVIEW PANEL

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Monitoring, Verification, and Reporting Overview

Options for Permitting Carbon Capture and Sequestration Projects in California

Long-Term Stewardship and Long-Term Liability in the Sequestration of CO2

Enhanced Oil Recovery as Carbon Dioxide Sequestration

Carbon Dioxide Pipelines

Approaches to Pore Space Rights

Sequestration Risk History

Introduction

One of the prerequisite conditions for consideration of CCS as a method for reducing CO_2 emissions is that there be appropriate geologic conditions and sufficient capacity for storage of the CO_2 in the deep subsurface. This paper presents a brief review of the geologic attributes which make a site suitable for storage, a summary of the locations in California suitable for storage, and indications of the ample resource available for storage.

Background and Storage Basics

Although the idea of intentionally storing large quantities of CO2 in underground geologic formations for extended periods is relatively new, natural CO2 reservoirs, as well as oil and gas reservoirs—many containing large percentages of CO2—have existed for millions of years. Relevant industrial experience includes natural gas injection and storage, which has been successfully practiced for many decades. For more than 30 years, the oil industry has re-injected produced gas for various purposes, including reservoir pressure maintenance, avoidance of sour gas processing in locations without markets for sulfur by-products, disposal of gas processing by-products, and to eliminate flaring. Salty water co-produced with oil has been similarly re-injected. The oil industry also commonly uses CO2, water/steam, and nitrogen for enhanced oil recovery (EOR), wherein injected fluids mobilize residual oil to producing wells.

In California, suitable geologic formations for CO2 storage include depleted or near-depleted oil and gas reservoirs and saline formations (rocks containing non-potable salty water). These targets are common in deep sedimentary basins, places where sand and mud have accumulated to great thickness over many millions of years and lithified (compacted under pressure into rock). These types of layered rocks are potentially good storage sites because they have the capacity to hold or trap large amounts of CO2 in the pore spaces of permeable layers such as sandstone, while overlying impermeable mud-rock layers form good seals that prevent the gas from escaping upward. Both oil and gas reservoirs and saline formations derive from the same lithified sand and mud in a sedimentary basin, so the physical properties of the rocks of relevance to CO2 storage, such as the porosity and permeability of the sandstones, and impermeability of the mud-rock seals, are the same in both cases. Oil and gas reservoirs can be thought of as local regions within saline formations where hydrocarbons fill most of the pore space between the sand grains.

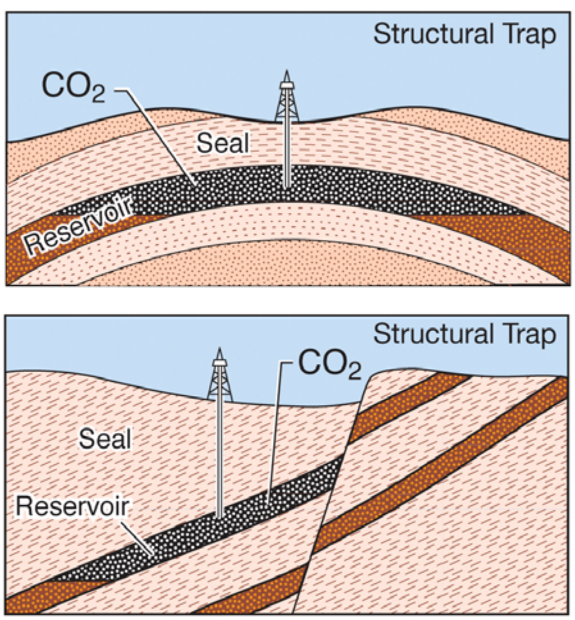

Figure 1: Illustration of sealing mechanisms created by formation deformation (top) and by faulting (bottom).

In order to make the most efficient use of underground pore space, and to maximize the vertical separation between storage formations and potable water, CO2 storage takes place at depths below 800 meters, about 2500 feet, where ambient pressures and temperatures result in CO2 as a liquid-like, supercritical phase, which occupies much less volume than gaseous phase CO2 captured at industrial facilities. Under supercritical conditions, the density of CO2 will range from 50 to 80 percent of the density of water. Because it's still lighter than the native formation water, a buoyant force will tend to lift the CO2 upward, (hence, the need for impermeable overlying seals as discussed earlier). Over time, several additional trapping mechanisms work to immobilize the CO2 in the reservoir, including physical (capillary trapping) and chemical (solubility and mineral trapping) processes. Collectively, these are referred to as "secondary" trapping mechanisms.

One geologic attribute that is necessary for the existence of oil and gas reservoirs, but not necessarily required for CO2 storage because of secondary trapping, is structural closure, wherein geologic layers have been deformed or altered in a way that prevents lateral and upward movement of the hydrocarbons. The "classic" hydrocarbon reservoir is exemplified by seal rocks deformed into the shape of a dome, or inverted bowl (see Figure 1), under which the hydrocarbons have collected. In California, stratigraphic traps where the reservoir rock pinches out or terminates laterally in an impermeable rock "sandwich" are common. Another very common structural closure mechanism in California is faulting. As rocks on one side of a steeply dipping fault are moved relative to those on the other side, reservoir rocks are brought into contact with impermeable rocks, preventing lateral movement of fluids. In some instances, however, faults can act as leakage paths. If faults are present, a necessary part of site characterization is to assess if they are seals or not.

The California CO_2 Storage Resource

As part of the WESTCARB project, the California Geological Survey (CGS) conducted screening studies to identify California sedimentary basins having the greatest potential for long-term geologic CO2 storage. CGS initially identified and cataloged 104 onshore sedimentary basins that collectively underlie approximately 33 percent of the area of the state. These basins include all large oil- and gas-producing basins, as well as numerous smaller basins. These basins were then screened, using available data, to make preliminary determinations of their geologic suitability for CO2 sequestration. Screening criteria included the presence of significant porous and permeable units in which to store CO2, thick and pervasive seals to restrict migration of CO2, and sufficient basin depth to provide the confining pressure required to keep injected CO2 in its high-density (low-volume) supercritical phase. Accessibility was also considered, and basins overlain by national and state parks and monuments, wilderness areas, Bureau of Indian Affairs administered lands, and military installations were excluded. Most of the basins excluded for these reasons are located in eastern and southeastern California.

Of the 27 onshore basins that met the screening criteria, the most promising are the larger basins, including the San Joaquin, Sacramento, Los Angeles, Ventura, and Salinas basins, followed by the smaller Eel River, La Honda, Cuyama, Livermore, and Orinda basins. Favorable attributes of these basins include (1) geographic distribution; (2) thick sedimentary fill with multiple porous and permeable zones; (3) thick, laterally persistent sealing units; (4) availability of good datasets to characterize the subsurface; and (5) numerous abandoned or mature oil and gas fields that might be reactivated for CO2 sequestration or benefit from CO2 enhanced oil and gas recovery operations.

Using the methodology developed to support NETL's Carbon Sequestration Atlas of the United States and Canada, the CO2 storage "resource" for the 10 onshore basins was calculated to be between 75 and 300 gigatonnes of carbon dioxide (GT CO2). For oilfields, preliminary estimates are on the order of 0.3 to 1.3 GT CO2, and for natural gas fields, from 3.0 to 5.2 GT CO2. The preliminary estimates indicate that the resource for geologic storage of CO_2 is ample. For comparison, the CO_2 emissions from power and industrial sources in California is currently about 0.08GT per year.

Californians may also find candidates for CO2 storage in nearly all of the 20 offshore basins identified by CGS, however, a lack of available data has limited the quantification of their CO2 sequestration potential to areas where oil and gas exploration has occurred. A CGS study of the oil and gas fields of the Los Angeles and Ventura offshore basins estimated 0.24 GT of capacity in depleted hydrocarbon reservoirs.

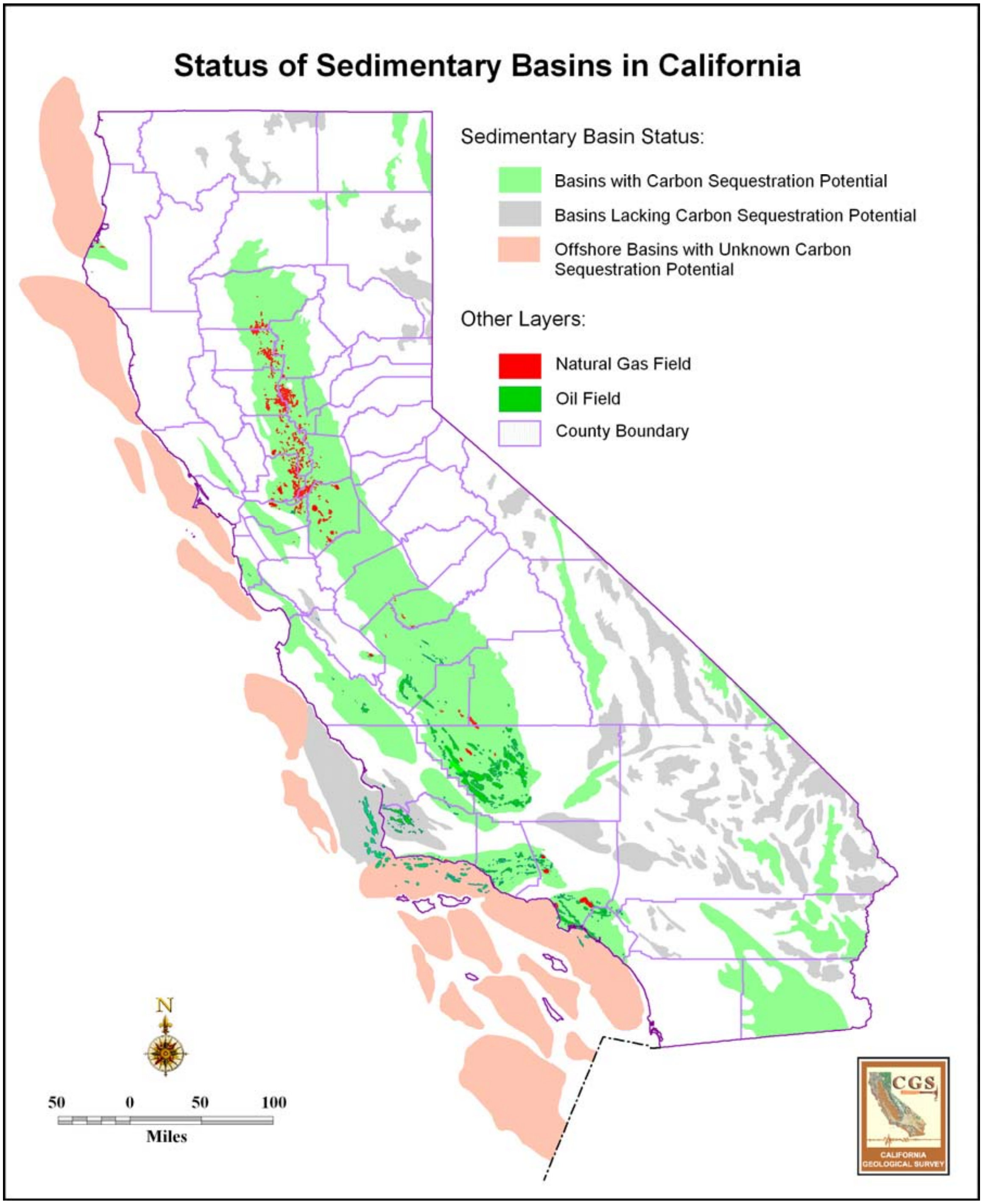

Figure 2: Map of sedimentary basins in California showing those currently identified as having CO2 storage potential. Oil and gas fields are co-located is several basins with high storage potential, suggesting opportunities for CO2-enhanced recovery.

Figure 2 shows all the sedimentary basins in California, along with those currently identified as having CO2 storage potential.

Although early carbon capture and sequestration projects may take advantage of the opportunities for storing CO2 in conjunction with CO2-enhanced hydrocarbon recovery projects in depleting oil and gas fields, such applications will not be sufficient to accommodate all of the CO_2 that must ultimately be captured from California industrial sources. Commercial application of geologic sequestration in California will require use of the state's saline formations.

The saline formation storage resource numbers quoted above arise from estimates made with limited geologic data, and without any constraints due to technology, cost, or regulations. As both geologic and non-geologic constraints are added, storage resource values, while still quite large, will be decreased. This can be seen in the continued work by the California Geological Survey to better define the state's CO_2 storage resource.

CGS has completed a more detailed, formation-specific mapping of the southern portion of the Sacramento Basin, representing a little more than 22% of the area of the Central Valley. CGS used information from about 6,200 wells to better define the thickness, extent, and continuity of potential reservoir sands and seals in the Mokelumne River, Starkey, and Winters formations. Using the NETL methodology for calculation of CO_2 storage resource yielded a total of 3.5–14.1 GT for the mapped formations. On a percentage area basis, this represents about a factor of 3 decrease in the preliminary storage resource quoted above, though still very large relative to current California emissions.

Final selection of a sequestration site in any of the California basins will require more detailed, site-specific data and detailed analysis of the subsurface. Thorough knowledge of the geologic structure and properties is key to minimizing the risk of leakage. From this perspective, storage locations in saline formations that are located vertically between, or laterally adjacent to, existing oil/gas reservoirs have an advantage over other locations because of the large body of pre-existing subsurface knowledge gained from the oil/gas exploration and production activities. A disadvantage of existing oil/gas reservoirs is that the existence of old wells, potentially not constructed or closed to modern standards, increases the risk of leakage. Generally, this risk increases with the age of the wells. Therefore, identification and assessment of existing deep wells at or near a proposed CO_2 storage project will need to be an element of site characterization. Whether targets are depleted hydrocarbon reservoirs or saline formations, site characterization must be followed by detailed study of appropriate monitoring systems, potential health and environmental risks, transport issues, and economics in order to assess a potential site.

Connecting Sources to Storage Sites

Locations of many of the largest CO_2 point sources appear to match well with geologic storage sites in saline formations for key areas of the state: the Los Angeles Basin, the southern San Joaquin Valley, and the Sacramento-San Joaquin river delta. Co-location of major CO_2-producing sources with suitable sinks is not a given, however, so the lack of a CO_2 pipeline infrastructure in California could present a barrier to early commercialization in some instances. In total, some 30 California industrial facilities each produce over 1 million metric tons of CO_2 per year. Most are natural gas-fired power plants, along with several oil refineries and cement kilns. The few coal- and petroleum coke-fired power plants in California are relatively small because they were mostly non-utility generators built as cogeneration qualified facilities.

Summary

In summary, work to date has shown that the CO_2 storage resource in California is ample and well matched with major industrial point sources. Saline formations represent the largest CO_2 storage resource, by far. Depleted oil and gas reservoirs represent a smaller fraction of the total storage resource, but are attractive for early projects because of the greater availability of data for site characterization and the prospect of offsetting revenue from hydrocarbon sales. Though existing geologic data is generally more limited than for existing oil and gas reservoirs, saline formation storage is attractive because these formations are more broadly distributed relative to sources, and the risks of leakage due to leakage from existing wells is less. Ultimately, saline formation storage will be necessary to accommodate all of the CO_2 that must be captured from industrial point sources to enable California to meet its long-term goals for reducing greenhouse gas emissions. Because California's saline formations have not been extensively studied, further work is needed to better define the best storage sites within areas defined as storage resources. Selection of any specific storage site will require site-specific data acquisition, geologic modeling and analysis of potential health and environmental risks, monitoring system design, and analysis of transport issues and economics.