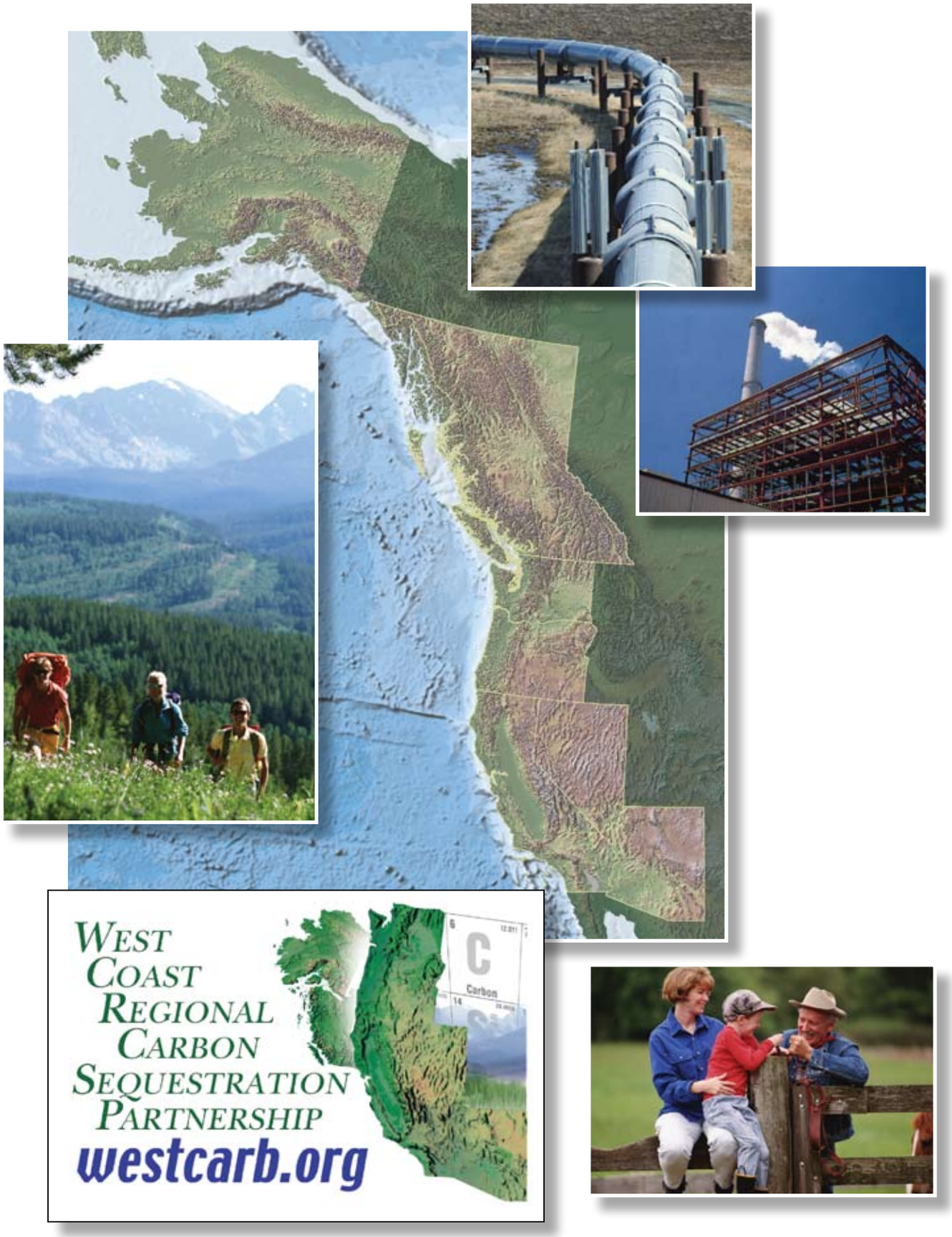


West Coast Regional Carbon Sequestration Partnership

The West Coast Region, consisting of the states of Alaska, Arizona, California, Hawaii, Nevada, Oregon, Washington, and the Canadian province of British Columbia, is characterized by a wealth of natural resources, varied ecosystems, and a large and growing population imbued with an entrepreneurial spirit. In addition to cultural, economic, and geographic diversity, the Region has one of North America's broadest mixes of CO_2 sources and an equally broad array of opportunities to curb atmospheric CO_2 buildup through carbon sequestration.

The West Coast Regional Carbon Sequestration Partnership (WESTCARB), led by the California Energy Commission, comprises researchers from more than 80 public agencies, private companies, and nonprofits. WESTCARB's goal is to identify and map the regional opportunities for geologic and terrestrial carbon sequestration and to validate the feasibility, safety, and efficacy of some of the best regional opportunities through field tests.

Results of WESTCARB characterization studies to date show excellent carbon sequestration potential throughout the Region. Numerous EOR and enhanced gas recovery (EGR) opportunities, as well as ECBM, offer the potential for geologic sequestration to be coupled with economic incentives. In addition, broadly distributed sedimentary basins believed to contain saline formations have the potential to store hundreds of years' worth of the Region's CO_2 stationary source emissions. Terrestrial sequestration opportunities are among the best in North America and provide a viable approach to offsetting some of the Region's relatively large transportation-related CO_2 emissions.

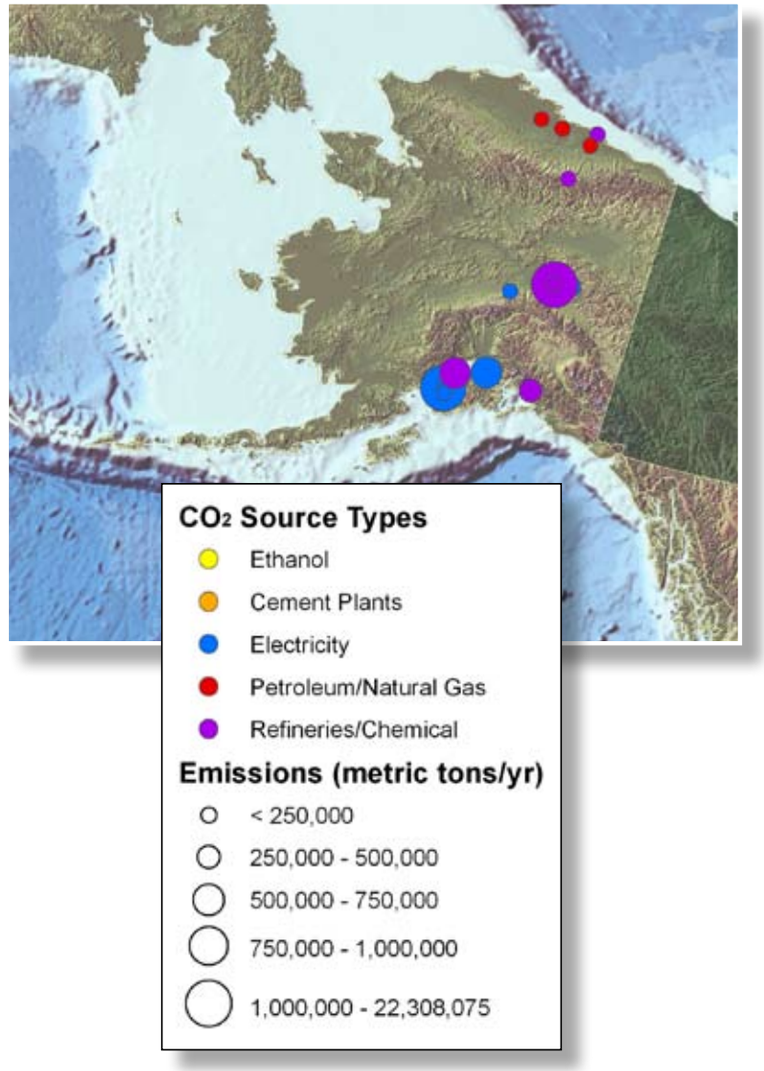
WESTCARB researchers believe that carbon sequestration can play an important role in state and provincial efforts to address climate change as policymakers and the public seek ways to protect the environment and ensure healthy economies.

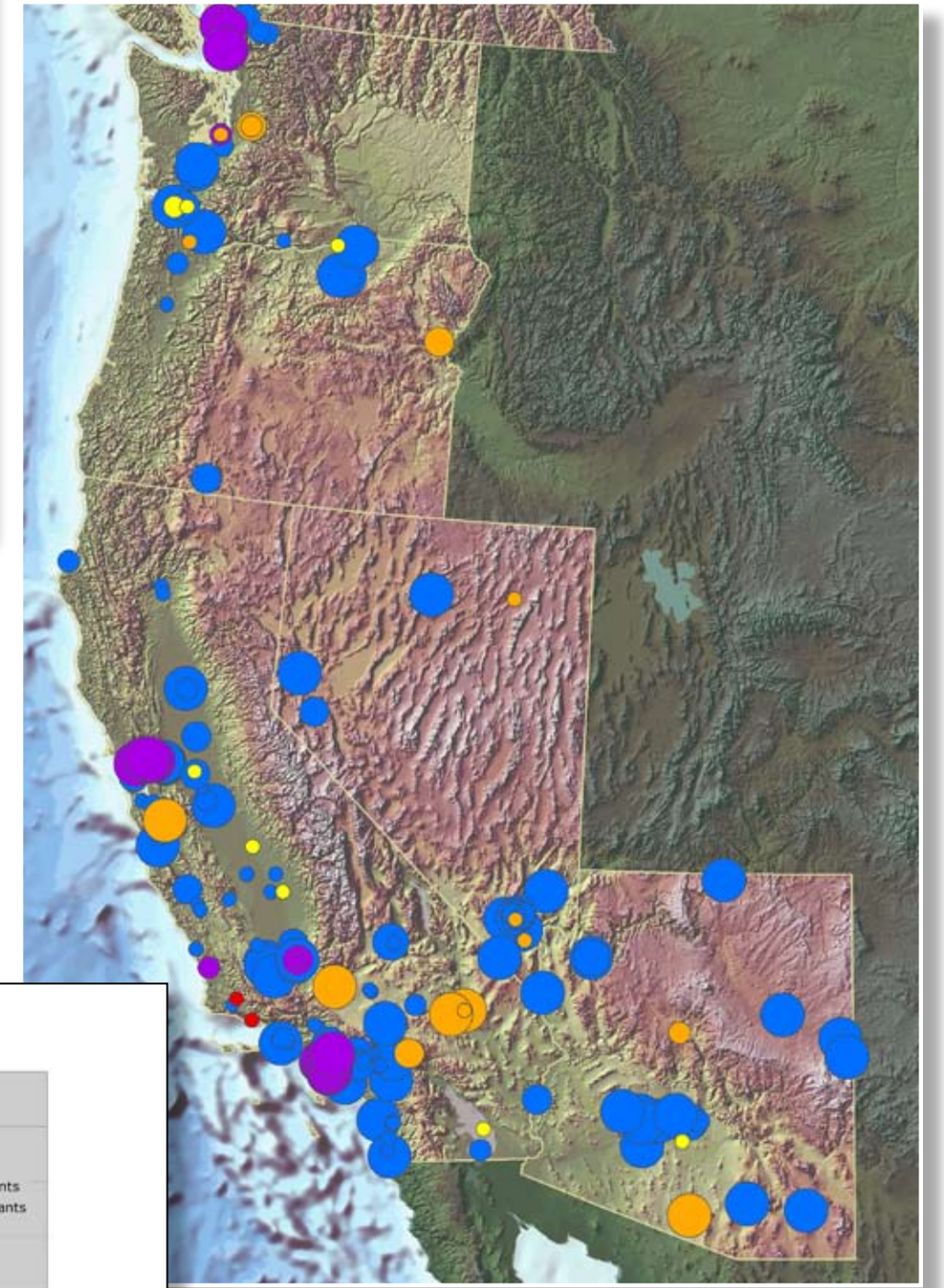
WESTCARB CO_2 Emission Sources

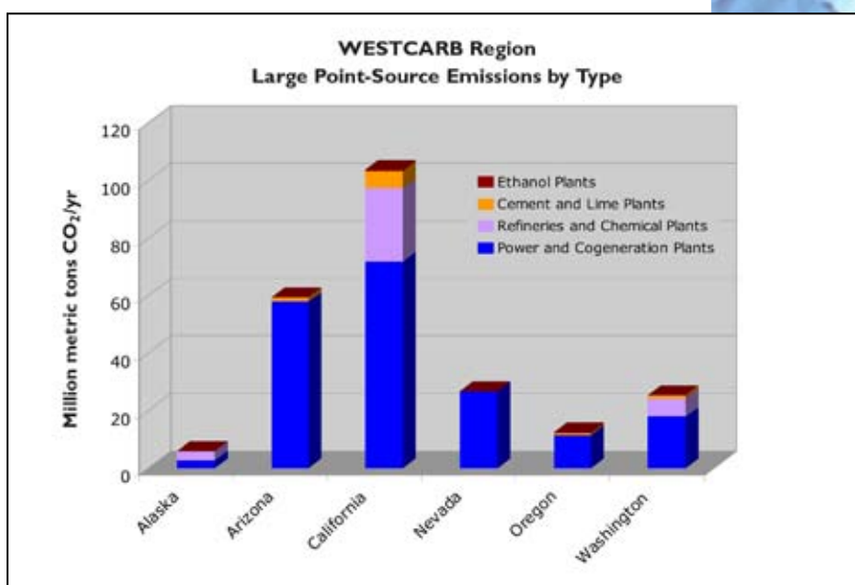
The WESTCARB states account for approximately 11 percent of U.S. CO_2 emissions. About half of the Region's emissions come from the transportation sector, while more than a third come from industrial and electric power sectors. California ranks second among all states in CO_2 emissions, with the transportation sector accounting for the majority of the state's total. The large percentage of emissions from mobile sources underscores the importance of developing terrestrial sequestration options (as well as biofuels plants with geologic sequestration) to provide a mechanism for offsetting these hard-to-capture emissions.

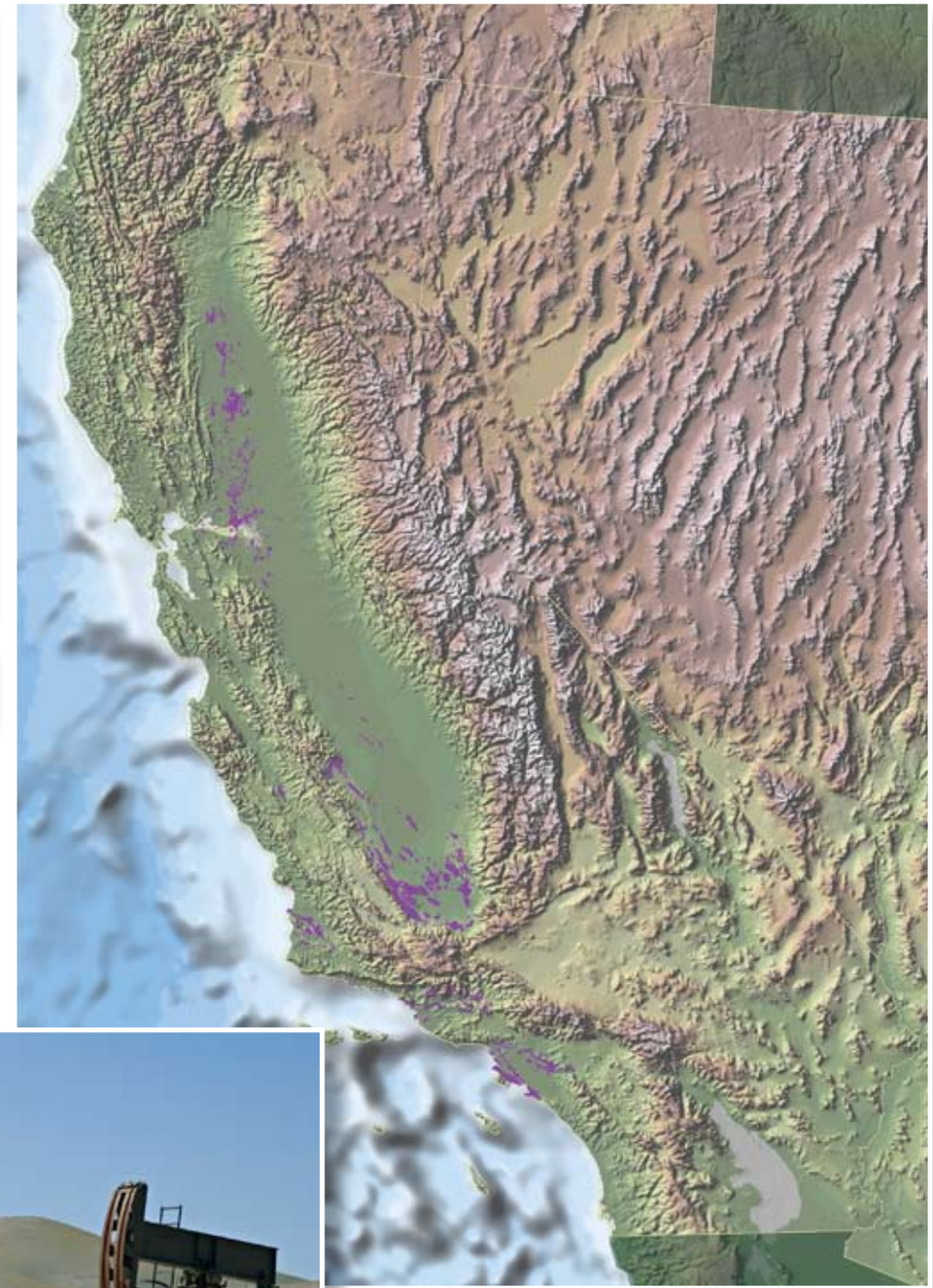
The largest stationary sources in the Region are electric power and co-generation plants, oil refineries, and cement and lime plants. Electric power plants are the single largest CO_2 stationary source type, with California and Arizona electric power/co-generation plant CO_2 emissions considerably higher than other states in the Region. Arizona's power plants are mostly coal-fired, whereas California's are predominantly natural-gas-fired, which makes the cost of CO_2 capture generally higher in California. Additionally, without adoption of carbon sequestration measures, CO_2 emissions from ethanol and other biofuel plants (currently small) have the potential to grow rapidly as the alternative fuel industry expands.

The WESTCARB CO_2 sources database (which is also served to NATCARB) includes information for more than 250 of the largest emitting power and industrial facilities in the WESTCARB Region.









In conjunction with geologic sequestration, additional production may be achieved in some oil fields through CO_2 EOR, even when secondary recovery methods have already been applied.

WESTCARB Region Oil and Gas Fields

In the WESTCARB Region, major oil and gas fields represent both sequestration targets and EOR/EGR opportunities—especially in California and Alaska.

In California, most oil reservoirs are found in the southern San Joaquin Basin, Los Angeles Basin, and southern coastal basins. Estimates made by WESTCARB investigators suggest a potential CO_2 EOR storage resource of 3.7 billion metric tons (4.1 billion tons), based on a screening of reservoirs using depth, crude oil gravity, and cumulative oil produced. A DOE study of CO_2 EOR potential in California suggests that technically recoverable reserves exceed 0.3 million m^3 (5.6 billion barrels).

Researchers also estimated an additional 2.5 billion metric tons (2.7 billion tons) of potential CO_2 storage in California non-EOR (i.e., depleted reservoir) storage applications.

The Sacramento River Delta is home to some of California's largest natural gas fields, which have been major producers since the 1930s. WESTCARB estimates the CO_2 sequestration potential in California natural gas reservoirs at 1.8 billion metric tons (1.9 billion tons).

In Alaska, the oil and gas fields on the North Slope are of prime interest because of the large potential for CO_2 EOR. The hydrocarbon reservoirs of the Cook Inlet offer potential for CO_2 enhanced recovery given their proximity to industrial CO_2 sources.

WESTCARB Coal Basins

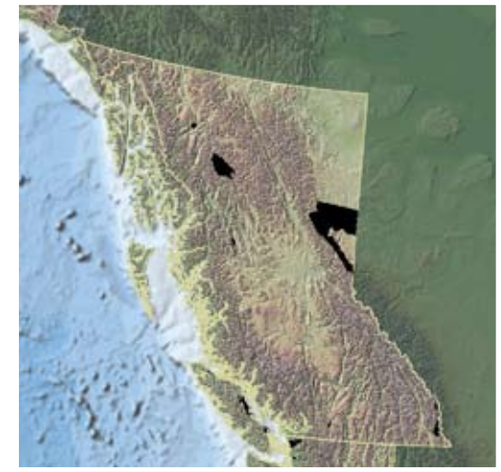
Opportunities for geologic CO_2 storage in unmineable coal basins within the WESTCARB Region are found predominantly in the Pacific Northwest and Alaska. In the Pacific Northwest, three deep coal bed deposits offer promise: the Bellingham Basin in northwestern Washington; the coals of the upper Puget Sound Region, south and east of the Seattle-Tacoma metropolitan area; and small, deep coal deposits in southwestern Oregon.

Puget Sound seams have been tested by several coal bed methane exploration companies, and WESTCARB investigators are characterizing their CO_2 sequestration potential. Preliminary results show that the subsurface extent of the coal basins represents an area greater than 2,500 km^2 (950 mi^2). Initial analysis indicates prospective coal seam reservoir properties of 30 m (100 ft) coal thickness, a CO_2 sorption capacity of 20–24 m^3 (700–850 ft^3) CO_2 per ton of coal, and a permeability of approximately 5 millidarcies. The estimated CO_2 storage potential in this area is 2.8 billion metric tons (3.1 billion tons), and the estimated recoverable CBM is 57–570 billion m^3 (2–20 trillion ft^3).

Although coal mining in Alaska has been very limited, the state contains major coal deposits that range from shallow to over 2,000 m (6,500 ft) deep. Essentially all of the CO_2 storage potential in unmineable coal beds lies in the North Slope and Cook Inlet regions, which have coals of suitable thickness, depth, and permeability.

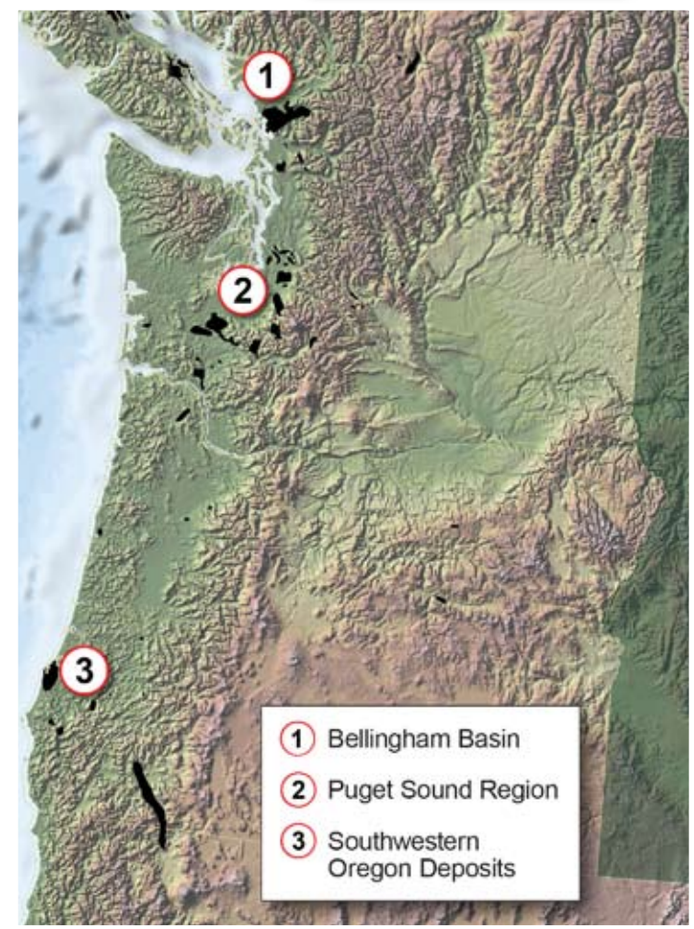
Preliminary estimates of geologic CO_2 storage resource in Alaska suggest that about 80 billion metric tons (90 billion tons) could be stored in deep coal seams. It is likely, however, that only a portion this total would be considered favorable for CO_2 sequestration, due to permeability, seam geometry, surface access, faulting, and other site-specific (but currently unknown) conditions. WESTCARB is continuing its analysis and expects to refine initial estimates as studies progress. Alaska's coal bed methane resources are estimated to be approximately 22 trillion m^3 (780 trillion ft^3), which is comparable to the CBM resources in all of the lower 48 states.

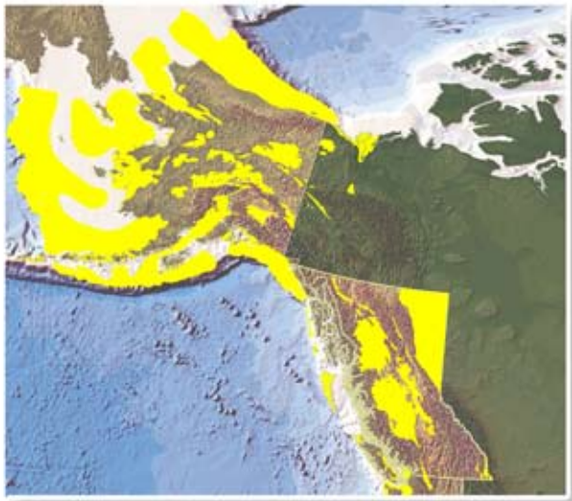
Map Credit: Flores, R., Stricker, G., and Kinney, S., "Alaska Coal Geology, Resources, and Coalbed Methane Potential." U.S. Geological Survey, DDS 77, 2004.

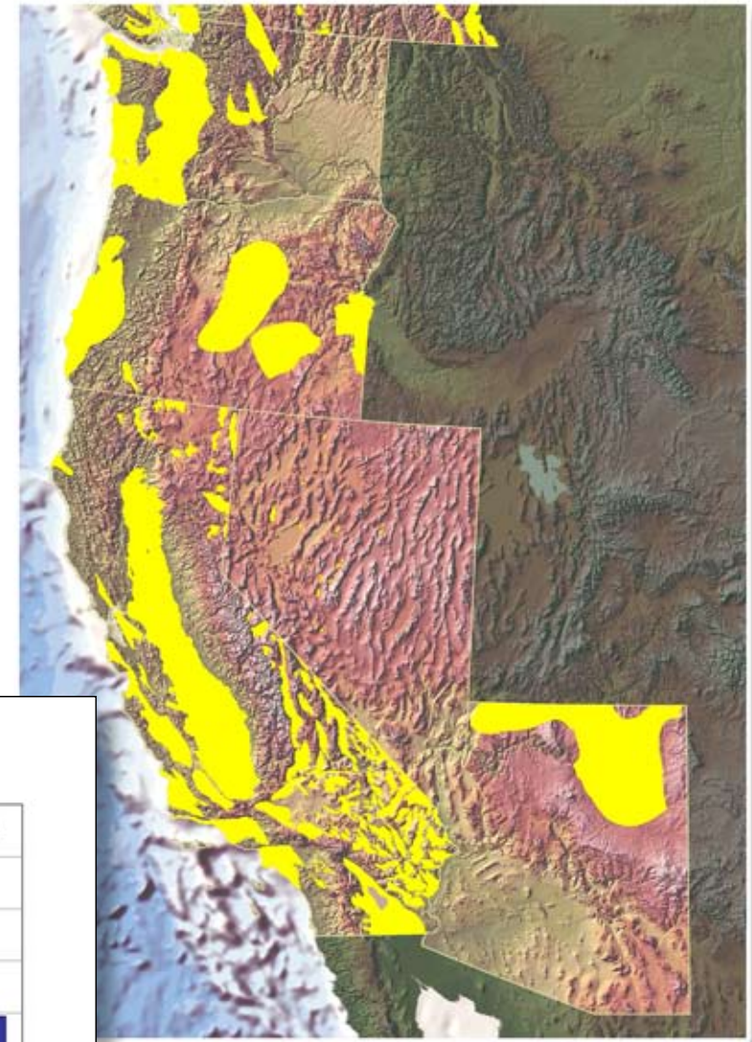


Coal Basins

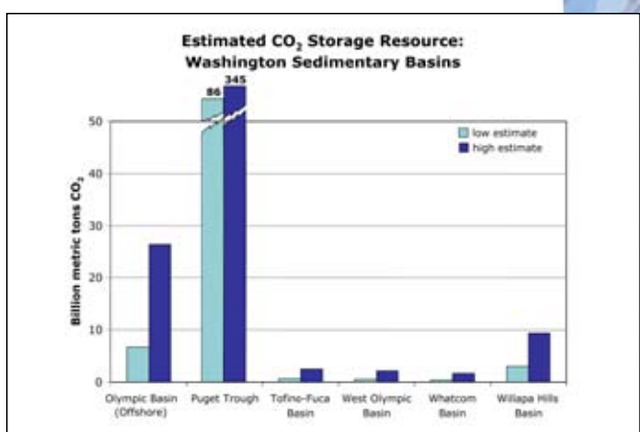
TransAlta's 1400 MW coal-fired power plant in Centralia, Washington.

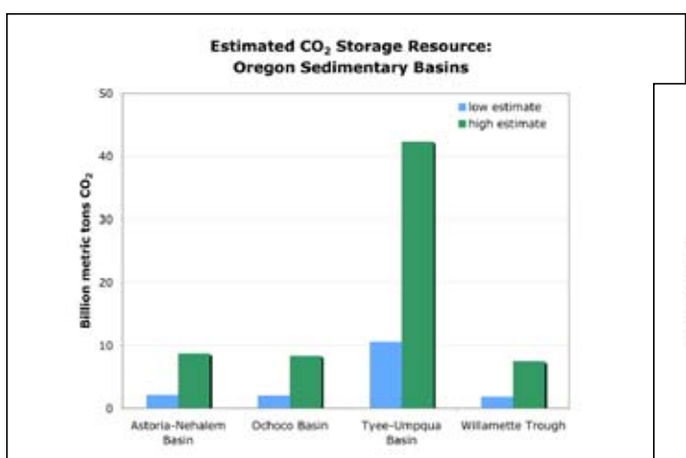


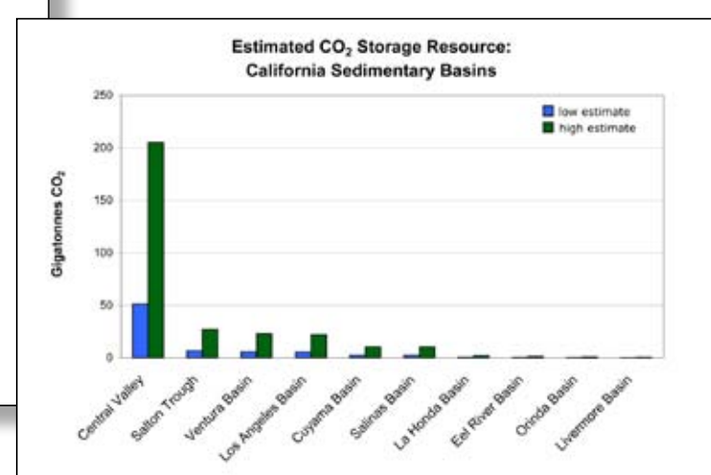




Deep Saline Formations







WESTCARB Saline Formations

Deep sedimentary basins are broadly distributed throughout the WESTCARB Region. Most are believed to be saline formations, and research is ongoing to bolster confidence in their salinity and to estimate their potential to store large volumes of the Region's industrially produced CO_2.

In California, for example, WESTCARB researchers consider Cenozoic marine sedimentary basins as offering the best potential for geologic sequestration. These basins exhibit a wide areal distribution, thick sedimentary sections containing multiple widespread saline-saturated sandstones, and thick and laterally persistent shale seals. Petrophysical data from past oil and gas development in many basins support researchers' assessments. In terms of potential CO_2 storage resource, WESTCARB ranks the San Joaquin, Sacramento, Ventura, Los Angeles, and Eel River basins as the most promising. Researchers estimate the aggregate CO_2 storage resource of the 10 largest basins at approximately 80–300 billion metric tons (90–330 billion tons) CO_2.

In Oregon and Washington, 10 western coastal basins offer potential sequestration opportunities. These basins contain sandstone and shale sequences up to 9,000 m (30,000 feet) thick. The largest in terms of potential CO_2 storage resource is Washington's Puget Trough. The total CO_2 storage resource for the 10 sedimentary basins is approximately 120–450 billion metric tons (130–500 billion tons).

Areas of potential for CO_2 sequestration in Nevada are Granite Springs Valley in Pershing County, Antelope and Reese River Valleys in Lander County, and Ione Valley in Nye County. Each appears sufficiently large areally and is filled with sediments and volcanic rocks. Site characterization studies will be needed to determine if CO_2 storage capacity exists beneath these valleys.

In Arizona, the sediments underlying the Colorado Plateau in Arizona, including the Naco and Martin formations, represent sequestration opportunities and are in the vicinity of several large coal-fired power plants. Both the potential storage targets and seals are laterally extensive and up to hundreds of feet thick.

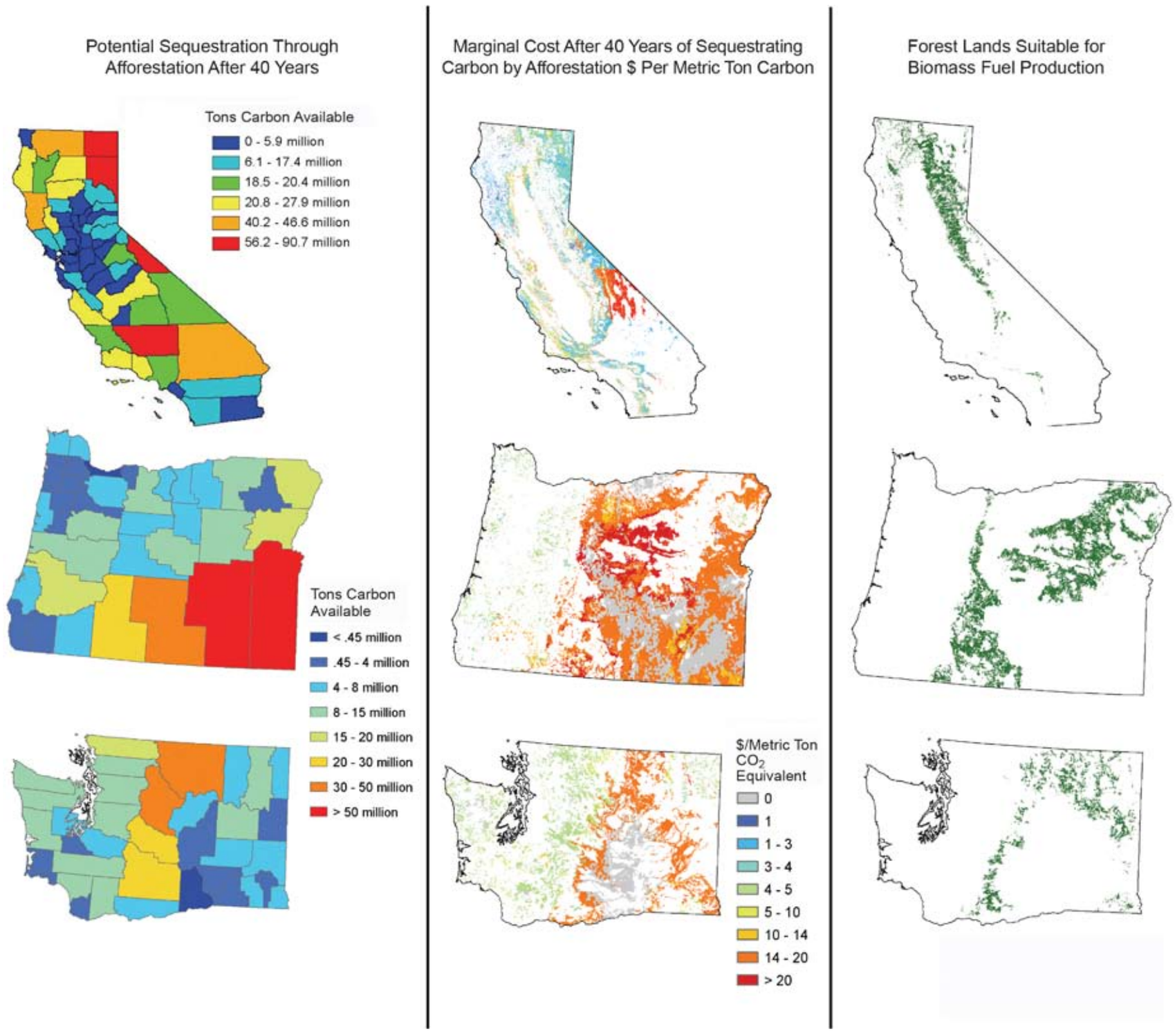
In Alaska, the potential CO_2 storage resource may be massive, but researchers are focusing on the Cook Inlet Basin because of its proximity to industrial CO_2 sources.

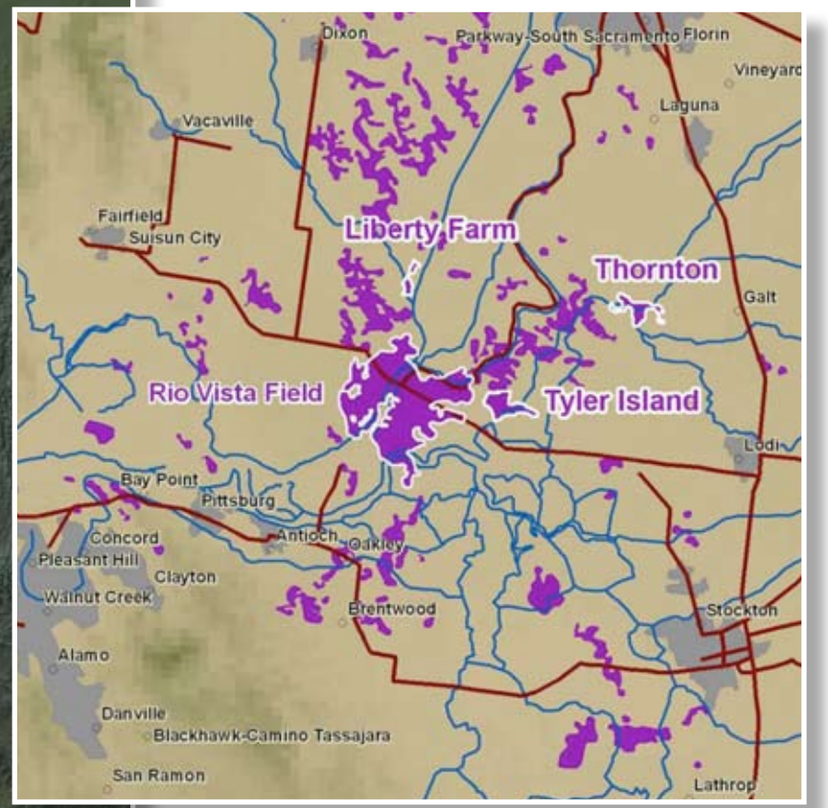
WESTCARB Terrestrial Carbon Sequestration Opportunities

Major terrestrial sequestration opportunities in the WESTCARB Region include afforestation of rangelands and agricultural lands, changes in forest management to increase carbon stocks, improved management of forest fuels to reduce emissions from wildfires, and (where practical) the use of these fuels in biomass energy facilities.

WESTCARB researchers evaluated afforestation of rangelands for California, Oregon, and Washington over 20-, 40-, and 80-year time periods. On a dollar per ton of CO_2-equivalent basis, costs are lowest for the longer timespans because the planted trees have more time in their prime growing years, and the initial costs of land preparation and planting are amortized over a larger quantity of sequestered carbon. Successful project development entails analysis of forest suitability of candidate lands; a thorough understanding of total costs, including opportunity, conversion, maintenance, measurement, and monitoring costs; gauging the potential variability in sapling survival and tree growth rates; and the aggregate area and geographic distribution of potentially afforested lands. Afforestation of Oregon and Washington lands currently in hay and wheat production was also evaluated.

Forest management options examined by WESTCARB include widening riparian buffer zones, lengthening harvest rotations in commercial forests, and (for California only) variable retention techniques in commercial forestry operations. Also analyzed was the feasibility of removing fuels from wildfire-prone forests for transport to biomass energy plants. This assessment took into account the suitability of lands for fuel reduction, treatable area, and biomass yield under typical treatment programs.





Major Sacramento Delta natural gas fields (in purple) in the vicinity of the proposed California CO_2 storage pilot attest to extensive potential storage capacity and commercialization opportunities.

Assessment of coal seams in Washington state.

Ash pond near Cholla Power Plant in Arizona, site of the Arizona Utilities CO_2 Storage Pilot.

WESTCARB Geologic Field Tests

WESTCARB is conducting three pilot-scale geologic CO_2 injection tests and two site characterization pilots.

The Arizona Utilities CO_2 Storage Pilot will test the storage capability of a saline formation in the northeast portion of the state, part of the extensive Colorado Plateau. The area's naturally occurring CO_2 accumulations attest to the feasibility of safe, long-term geologic storage. The potential CO_2 storage resource within the Colorado Plateau is estimated to be large because of the thickness—more than 100 m (330 ft)—of deep-lying, porous saline formations and the presence of good seals. Available data suggest that suitable storage sites may be found beneath or near Arizona's coal-fired power plants. The Arizona pilot will help define the feasibility of using these sites for future commercial CO_2 storage projects.

A geologic CO_2 storage pilot in a saline formation is planned for the Sacramento River Delta in central California. Decades of experience with natural gas production and storage have provided excellent knowledge of local geology, and evidence suggests that the area's sandstone formations can safely store CO_2 for extremely long periods.

CO_2 injection into depleting gas reservoirs could potentially enhance gas recovery, after which the injected CO_2 could remain stored.

WESTCARB's site characterization pilots are evaluating (1) the CO_2 injectivity and storage potential of deep Puget Sound (Washington state) coal seams and other geologic formations near TransAlta's Centralia coal-fired power plant, and (2) the potential for CO_2 storage in the saline formations and depleting oilfields in the southern San Joaquin Valley of California. The latter pilot is providing important initial data and modeling for WESTCARB's Development Phase large-volume CO_2 storage test at Clean Energy Systems' Kimberlina facility in Kern County.

WESTCARB Terrestrial Field Validation Tests

WESTCARB's terrestrial carbon sequestration field tests are under way in Shasta County, California, and Lake County, Oregon.

In Shasta County, afforestation activities entail restoring native conifer and oak species to rangelands and fire-damaged forest lands on about a dozen plots ranging from 10 to 100 acres each.

In Lake County, researchers are studying the feasibility of establishing plantations of fast-growing trees, such as hybrid poplars, on suitable agricultural or grazing land, which could be harvested on short rotations to fuel biomass power plants.

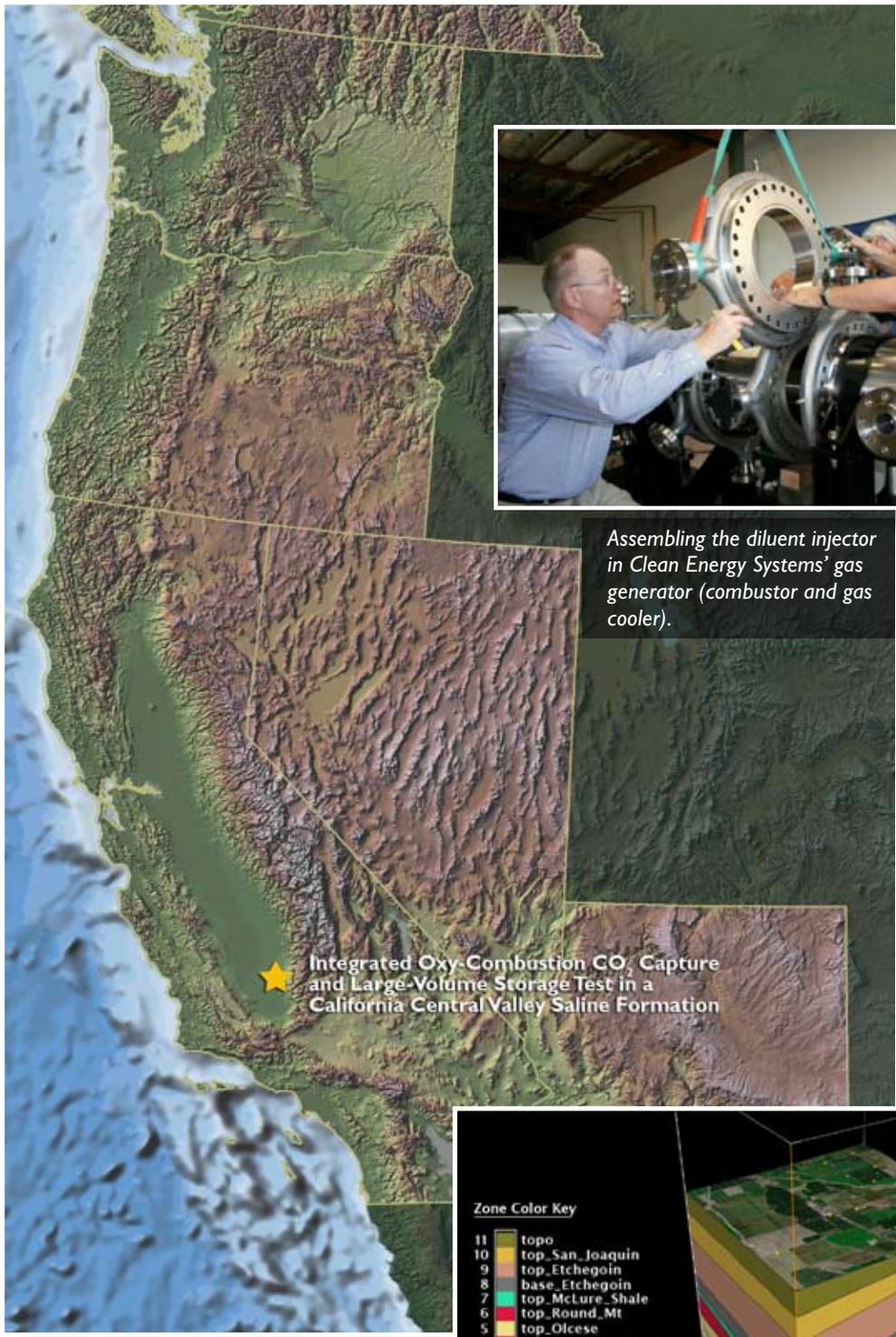
Both the California and Oregon pilots also involve research into carbon sequestration coupled with fire risk management through forest fuel reduction. Fire-prone forests are being treated to restore forest health by removing understory trees, brush, and other fuels that could contribute to catastrophic wildfires and the associated large GHG emissions. Where feasible, the removed fuel in Shasta County is being transported to a local biomass power plant to generate electricity, which can offset power demand that may otherwise be met by fossil fuel combustion.

The Shasta County pilot also features a conservation-based forest management project where a conservation group and timber company are working together to restore and maintain high-quality forest habitats and test the practicality and effectiveness of forest carbon accounting protocols.

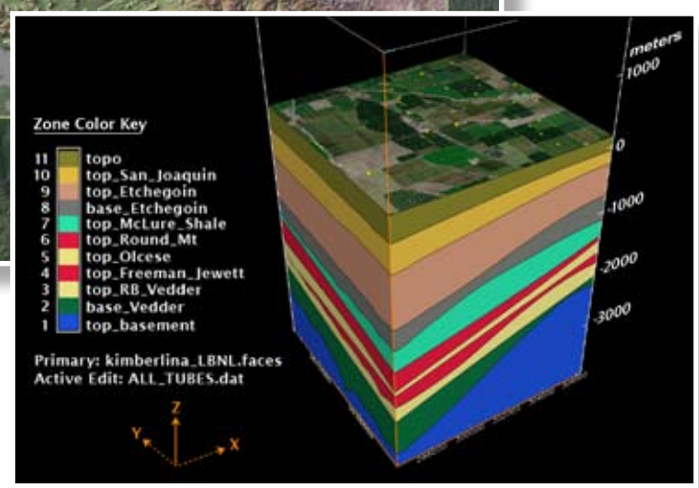
Measuring and monitoring activities are an important component of all WESTCARB terrestrial sequestration field tests. Overall objectives are to quantify the CO_2 emission reductions/sequestration attributable to each activity; gather information on costs and benefits to landowners; design measurement, monitoring, and verification methods; evaluate the practicality of existing reporting protocols to quantify verifiable reductions; and explore questions of market validation for terrestrial sequestration activities.

Measuring and monitoring activities establish carbon baselines and quantify carbon stored through terrestrial sequestration projects.

Replanting after a fire can re-establish a forest (left side of fence) and prevent colonization by invasive brush (right side of fence).



Assembling the diluent injector in Clean Energy Systems' gas generator (combustor and gas cooler).



Initial geomodel developed by Lawrence Livermore National Laboratory for the formations underlying the Kimberlina Site.

WESTCARB Large-Volume Geologic Field Validation Test

WESTCARB is preparing to inject 0.9 million metric tons (1 million tons) of CO_2 to validate the secure, large-volume storage capability of the saline formations prevalent in the Central Valley of California. Storage operations will be conducted in parallel with a commercial demonstration of a "rocket engine" oxy-combustion power plant with CO_2 capture by Clean Energy Systems.

The Kimberlina project site, located 29 km (18 mi) north of Bakersfield, currently houses Clean Energy Systems' 5 MW oxy-combustion pilot unit, which was funded in part by DOE and the California Energy Commission. Clean Energy Systems is ready to build a 49 MW power plant that could be the prototype for commercial clean power projects in the United States and Europe.

Starting in 2011 and continuing for four years, the entire CO_2-rich exhaust stream from the new power plant will be compressed to a liquid-like "supercritical" state and injected ~2,100 m (~7,000 feet) beneath the site. The test will allow researchers to better determine the storage opportunities in the saline formations of California's Central Valley, which are one of the largest potential CO_2 storage resources in WESTCARB's territory.

Two sandstone units are suitable candidates, and the deeper of the two—the Vedder—is currently the primary injection target. Its thickness at the site is up to 500 ft (150 m) and it is believed to have good injectivity. Both candidate units are regionally continuous, with thick shale units providing good overlying seals at the site and surrounding areas.

Throughout the project, WESTCARB researchers will deploy multiple monitoring and modeling methods, including proven oil industry techniques and new research-grade instruments to monitor the injected CO_2 as it is distributed underground. Results will be compared with computer models that simulate underground behavior of the CO_2, allowing for the validation and improvement of modeling techniques, which can subsequently be applied to potential commercial projects in the area. Researchers will continue to monitor the site after the conclusion of injection operations as part of the environmental stewardship phase of the project.

The technical information and experience gained from the Kimberlina project will allow researchers to better quantify the storage potential of the Region's saline formations and will help policymakers and the public assess the role that industrial CO_2 capture and geologic sequestration can play in achieving greenhouse gas emission reductions.

Commercial Opportunities for CCS in the WESTCARB Region

A strong commitment to mitigating climate change is evidenced within the WESTCARB Region. Some WESTCARB states have policies to lower greenhouse gas emissions, and most are active in various climate change initiatives and in efforts to spur clean energy technology development. As the Western Region strives to meet emission targets in the coming years, commercial deployment of geologic and terrestrial carbon sequestration stands to become increasingly important.

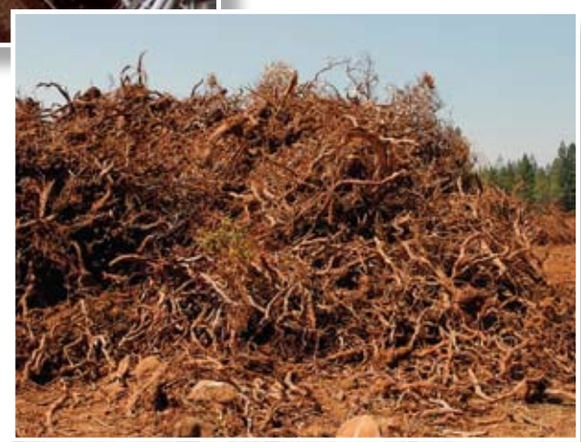
With this setting in mind, WESTCARB has sited its geologic field tests in areas suitable for commercial deployment of CCS. This involves consideration of the potential storage capacity of geologic formations, their proximity to major sources, and possible economic co-benefits such as ECBM production, EOR, and EGR.

For example, WESTCARB has studied the potential for CO_2 storage in the depleting oil and natural gas fields in California's Central Valley. Enhanced recovery techniques are already being deployed in many of these fields, and even greater recovery rates may be realized through injection of CO_2. Recently, two power generators have announced plans to build plants with CO_2 capture in Kern County, and it is anticipated that CO_2 EOR will receive a boost once local supplies of CO_2 become available.

Biofuel plants may also provide a readily captured source of CO_2 in the Central Valley. Several have been proposed in response to California's Low-Carbon Fuel Standard.

California's Central Valley and Washington's Puget Sound contain the largest known saline formation storage potential in the WESTCARB region. The goal of WESTCARB's Large-Volume Geologic Storage Test in Kern County is to validate the storativity of a typical Central Valley saline formation at a scale that will demonstrate how a commercial operation would function.

WESTCARB examined the Pacific Coal Region in Washington to identify areas with the potential for ECBM production. More detailed characterization of CO_2 storage resource estimates for coal-bearing sub-basins in the Puget Sound in Washington is still being carried out. ECBM in this area could be facilitated by the proximity of a major stationary source for CO_2.



Fuels removed from forests and brushlands to help prevent catastrophic wildfires can be used by biomass power plants to generate electricity.

The western region affords significant potential for increased terrestrial carbon sequestration, and WESTCARB has been working with state entities in Oregon and California to develop protocols for terrestrial carbon sequestration projects. Research into the costs and carbon storage rates associated with afforestation, forest conservation, and forest fuels reduction to prevent catastrophic wildfires helps lay the groundwork for the introduction of these types of projects into carbon credit markets. Fuels removed from forests can also be used for biomass electricity generation, thereby decreasing fossil fuel consumption.