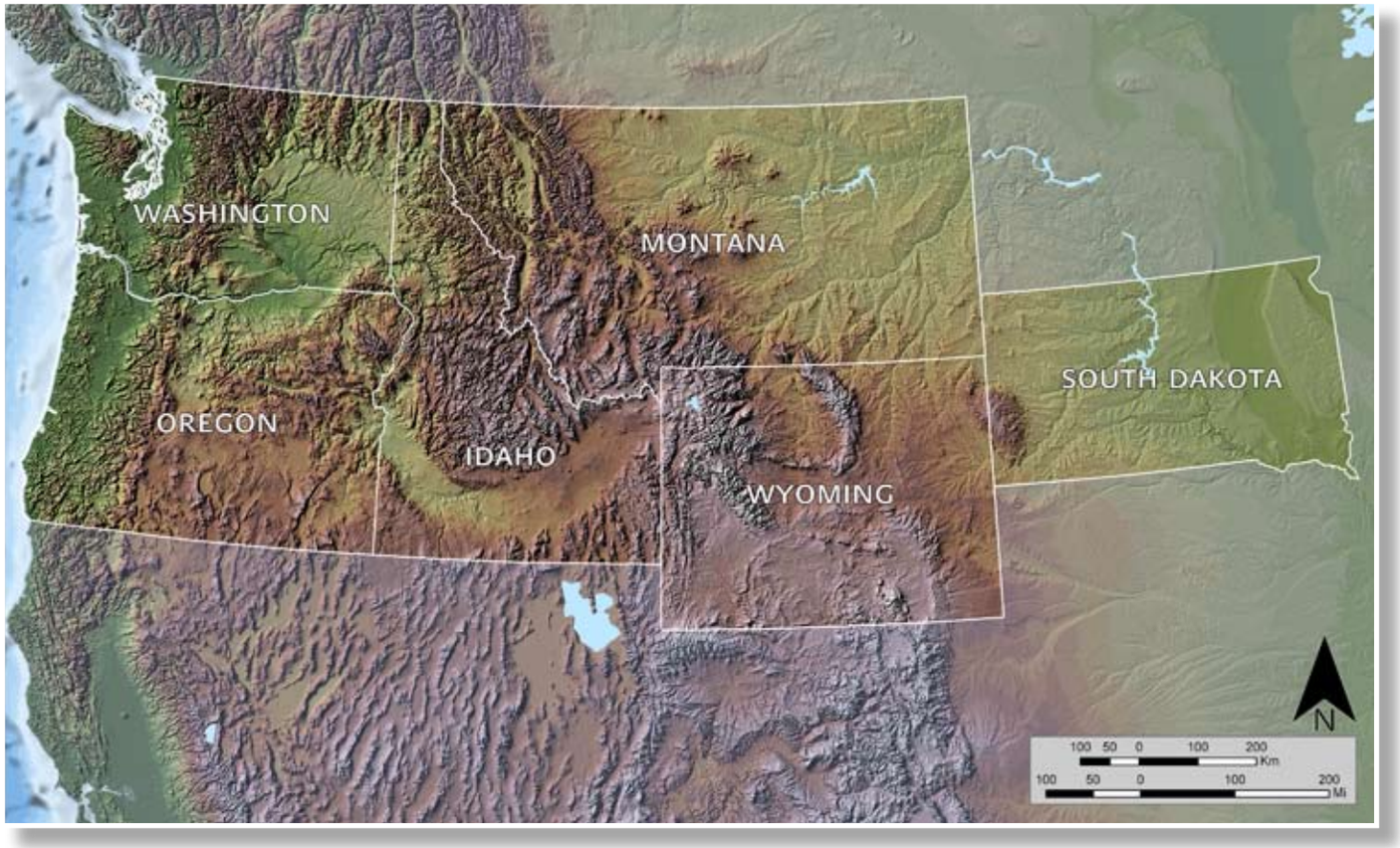


BIG SKY CARBON SEQUESTRATION PARTNERSHIP

The Big Sky Carbon Sequestration Partnership (BSCSP) is working on developing effective, safe, and economical approaches for capturing and permanently storing CO_2 to reduce the nation's greenhouse gas emissions. The BSCSP relies on existing technologies from the fields of engineering, geology, chemistry, biology, GIS, and economics to develop novel approaches for both geologic and terrestrial carbon storage in this Region. The BSCSP also engages in economic and regulatory analyses, public education and outreach, and regional demonstration projects to deploy and evaluate new technologies.

The BSCSP is a coalition of more than 60 organizations including universities, national laboratories, private companies, state agencies, Native American tribes, and international collaborators. BSCSP partners are engaged in several aspects of the Validation Phase and Development Phase projects and contribute to Partnership efforts to deploy carbon sequestration in the BSCSP Region.

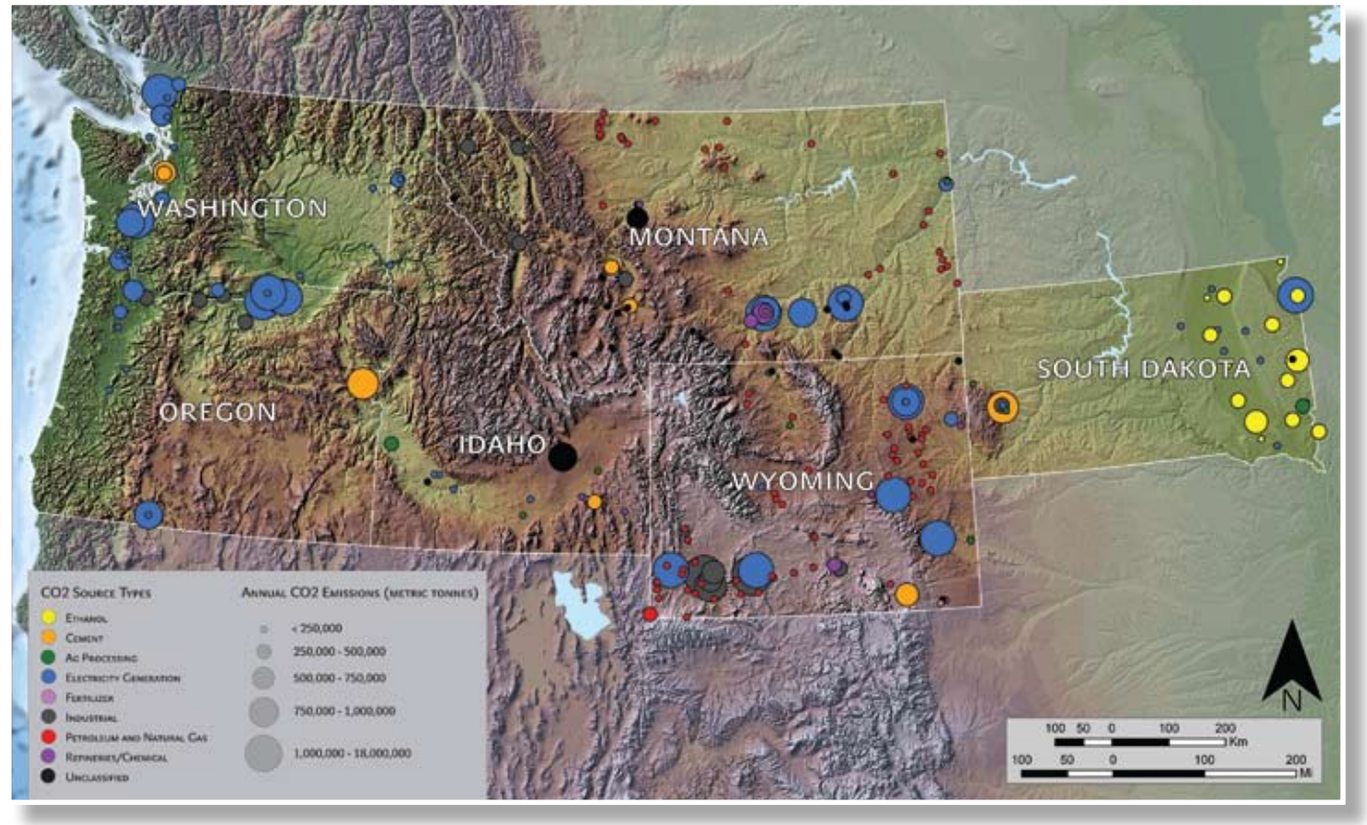
The BSCSP Region encompasses Montana, Wyoming, Idaho, South Dakota, and eastern Washington and Oregon. The regional characterization of potential CO_2 storage options conducted during Characterization Phase efforts confirmed that the Region holds a wealth of potential carbon sequestration sites. East of the Rockies there are large saline formations capable of sequestering large volumes of CO_2, while the western part of the Region has basalt formations which also have the potential to sequester many hundreds of years of regional CO_2 emissions. In addition, the BSCSP land area includes vast acreage of agricultural, range, and forest lands that can be managed for greater storage of soil carbon and carbon in biomass. The BSCSP Region is also rich in energy resources including coal, oil and gas, and renewable sources of energy.

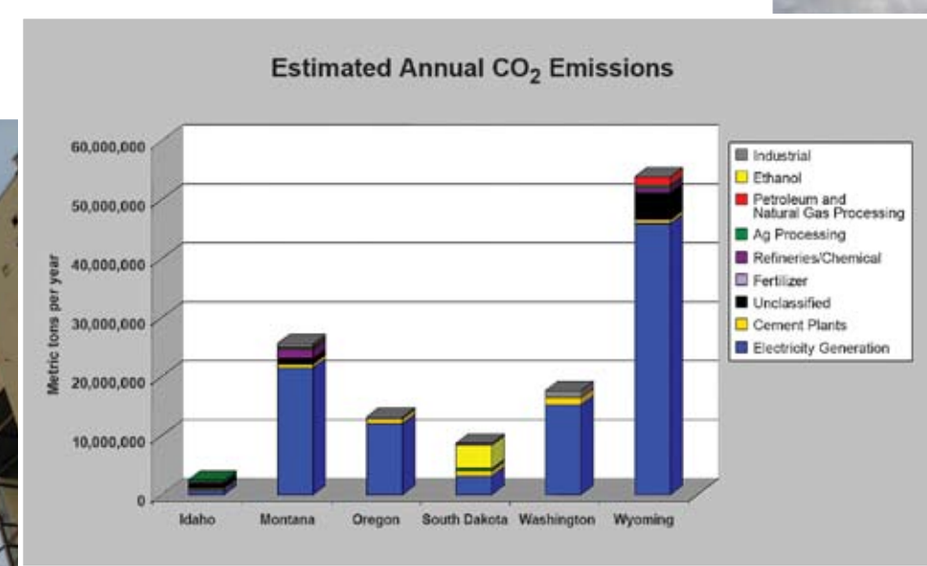
BSCSP Sources

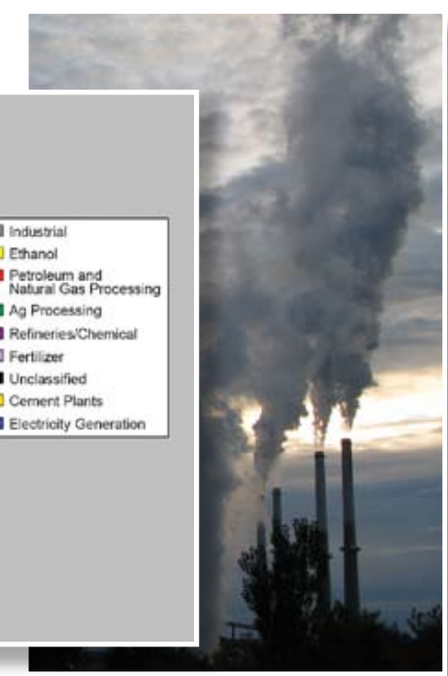
The BSCSP estimates that their Region produces more than 119 million metric tons (131 million tons) of CO_2 from stationary sources annually, totaling approximately 4 percent of U.S. emissions. While the BSCSP Region currently produces only a small fraction of the CO_2 emissions in the United States, it is a key area for fossil fuel energy development and has one of the largest population growth rates in the nation. According to U.S. 2000 census data, the Region has a population of about 13 million people and has increased 16 percent from 1990 to 2000, with the greatest growth occurring in Idaho, Oregon, and Montana. South Dakota is the least populous state in the Region and also has the lowest CO_2 emissions. Washington State is the most populous state in the Region, but because of low industrial emissions and reliance on hydroelectric power, it only ranks third in CO_2 emissions. While Montana and Wyoming have relatively low populations, they are the greatest emitters of CO_2 because of numerous mining, industrial, and fossil fuel operations, in addition to a high dependence on coal-fired electric generation.

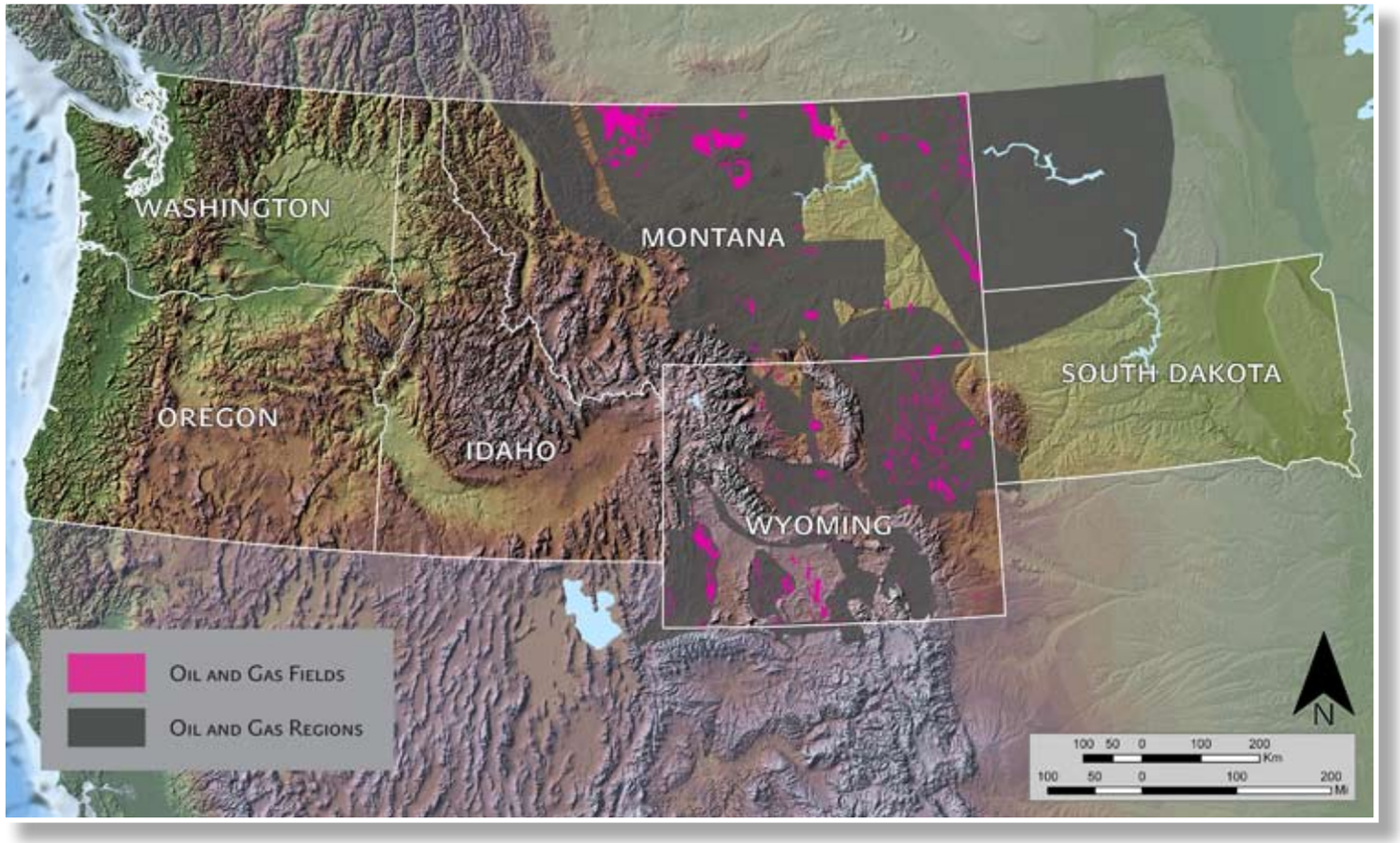
Eighty-one percent of estimated CO_2 emissions in the BSCSP Region are produced by coal-fired electric generation facilities, which produce 97 million metric tons (107 million tons) of CO_2 emissions annually. Montana and Wyoming combined produce 70 percent of these emissions. In these two states, cement production, ethanol production, and other industrial processes, such as aluminum production, emit 14 million metric tons (15 million tons) annually, accounting for 12 percent of the Region's emissions. Idaho, Oregon, and Washington contribute 28 percent of the Region's emissions from power generation plus cement, lime, and aluminum production. South Dakota produces about 4 million metric tons (4.3 million tons) annually from ethanol production. Unclassified sources, including diesel fuel use, production by-products from mining operations, and self-contained coal and natural gas power plants for large institutions account for an additional 8 million metric tons (9 million tons) of CO_2 annually which represents 6.5 percent of the Region's total. Mining of trona ore for soda ash, which is a commodity naturally occurring in the United States only in Wyoming's Green River Basin, produces 4.6 million metric tons (5.1 million tons) of CO_2 annually.

As part of ongoing activities, the BSCSP continues to update annual emissions estimates and stationary sources as new information becomes available. Work also continues to characterize the proximity of potential geologic sequestration sites in the vicinity of these stationary sources. This information, in conjunction with available infrastructure data (pipelines, EOR sites, right-of-ways, etc.), will be used to develop an interactive mapping tool for evaluating potential sequestration sites.









BSCSP Oil and Gas Reservoirs

Within the BSCSP Region mature oil and gas reservoirs have contained crude oil and natural gas for millions of years. These reservoirs are primarily located in the sedimentary basins of Wyoming and Montana. Based on cumulative oil production to date from these reservoirs, the Region could sequester an estimated 1.6 billion metric tons (1.8 billion tons) of CO_2.

The major oil and gas producing regions within the BSCSP area are: (1) the Williston Basin that covers the northeastern region of Montana as well as parts of South and North Dakota; (2) the Central Montana Uplift; (3) the Sweetgrass Arch in north-central Montana; (4) the Wind River Basin in central Wyoming; (5) the Bighorn Basin in north-central Wyoming and south-central Montana; (6) the Powder River Basin (PRB) that spans southeastern Montana and northeastern Wyoming; (7) the Laramie Basin in southeastern Wyoming; and (8) the Greater Green River Basin (GRB) in southwestern Wyoming. There are over 500 oil and gas fields in Montana and more than 1,400 in Wyoming. The largest of these fields could potentially sequester 129 million metric tons (142 million tons) of CO_2 which is greater than the Region's current annual CO_2 emissions.

Enhanced oil recovery offers an economic incentive for carbon sequestration in oil and gas reservoirs. Current EOR operations within the BSCSP Region include individual projects in the Green River, Wind River, and Powder River Basins that utilize CO_2 produced from a natural gas processing plant on the Moxa Arch in the western Green River Basin. Plans are in progress to expand the delivery of this CO_2 to many other fields within the Big Horn Basin, the Williston Basin, and the Laramie Basin. Additionally, the presence of large reservoirs trapping naturally occurring CO_2 in the BSCSP Region further demonstrates the long-term suitability of these basins for CO_2 storage.

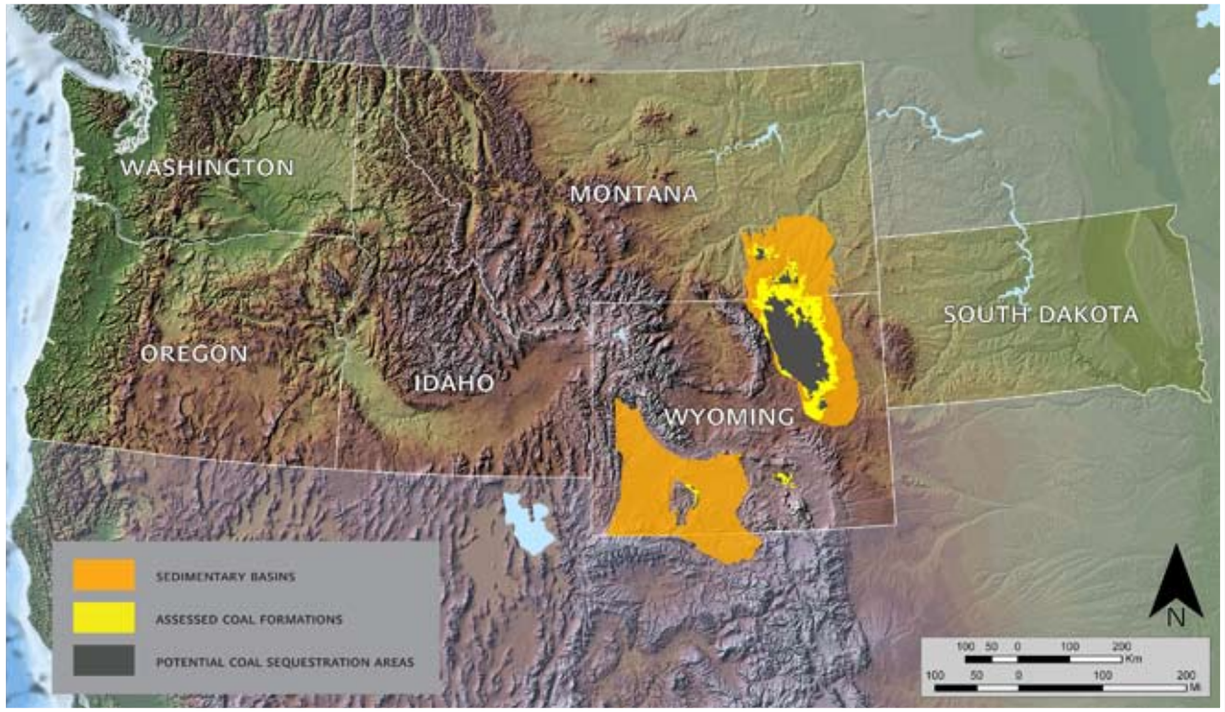
BSCSP Coal Seams

The BSCSP has many coal seams throughout the Region that can be used for CO_2 sequestration. Although there are many coal basins within the Region, CO_2 storage resource estimates were focused on basins with the largest coal resources including the PRB and the GRB. Unmineable coal is generally defined as coal buried under 305 m (1000 ft) or more of overburden. The salinity of the water in a coal deposit is sometimes used as a guide for determining depth. However, the coal seams in the PRB, for example, have exceptionally fresh water and thus water salinity cannot be used as a reliable tool for determining coal depth or the unmineability of the coal.

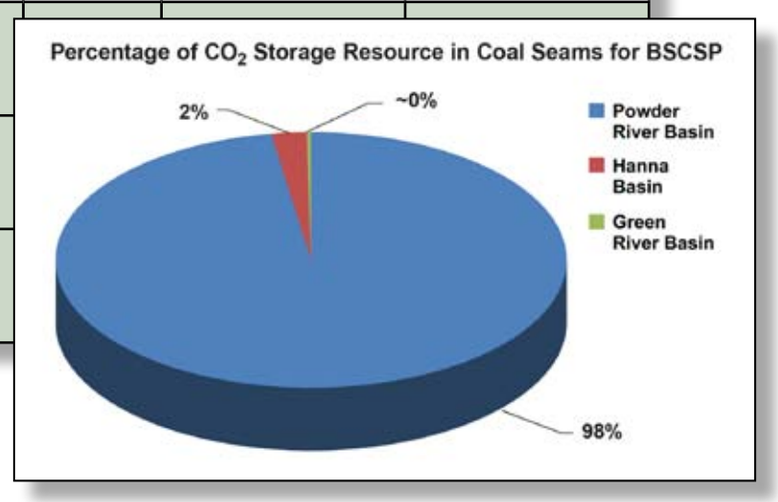
The nature of the PRB coal zone makes this basin exceptionally important for CO_2 sequestration in the BSCSP Region. The large unmineable area (below 305 m (1000 ft) has an average thickness of 22 m (73 ft). In addition to being thick, the coal seam also has high natural permeability, which describes how connected the pore spaces are within the coal deposit. High permeability ensures that once injected, CO_2 can flow throughout the pore network and fill all available pore spaces within the deposit. Also, during the CO_2 sequestration process, CO_2 molecules displace methane (CH_4) molecules from adsorption sites within the coal matrix. The CO_2/CH_4 displacement ratio for the subbituminous coal of the PRB is much higher than coals of higher rank, which suggests that the PRB may be an ideal location for a CO_2-sequestration-in-coal site. Carbon dioxide storage in unmineable coal seams is an attractive economic prospect due to ECBM recovery through injection of CO_2 into coal seams. The increased methane production resulting from this process helps to offset the cost of CO_2 capture and sequestration.

The PRB and GRB both contain significant coalbed methane resources. These resources are important economically for power generation; however, there is significant CO_2 storage potential within coal seams that are too deep or too thin to be economically viable as mineable resources. Coal formations in the PRB include the Knobloch and Rosebud coals in Montana, and the expansive Wyodak-Anderson coal formation which underlies most of northeastern Wyoming. Coal formations in the GRB, and Hanna Basin where assessed, include the Ferris, Hanna, Black Butte, Point of Rocks, and Johnson coalbeds.

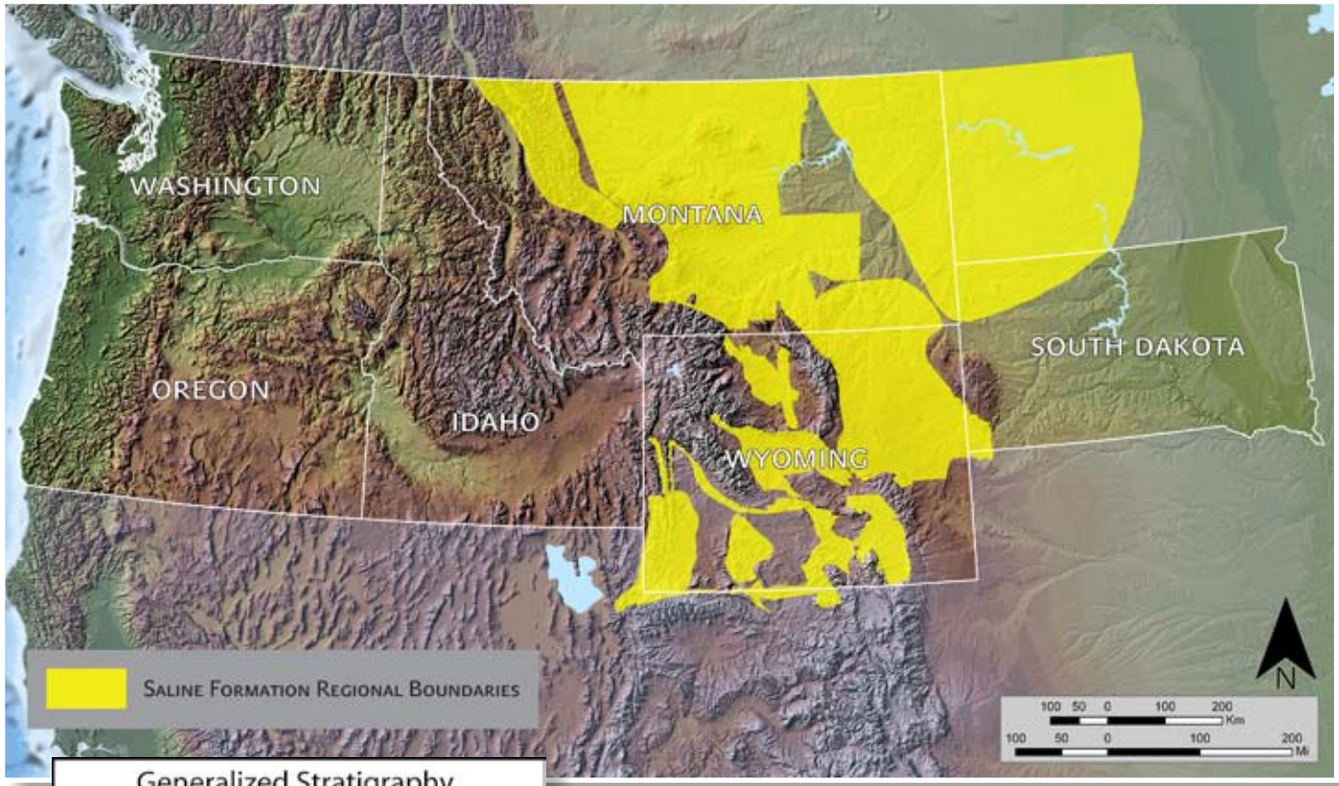
BSCSP calculations estimate that the total CO_2 storage resource in unmineable coal seams in the PRB is around 12 billion metric tons (13 billion tons), most of which represents storage area in the expansive Wyodak-Anderson coal field. Carbon dioxide storage resource estimates for the Hanna Basin are around 250 million metric tons (276 million tons), while the GRB has the potential to sequester 44 million metric tons (49 million tons) of CO_2.

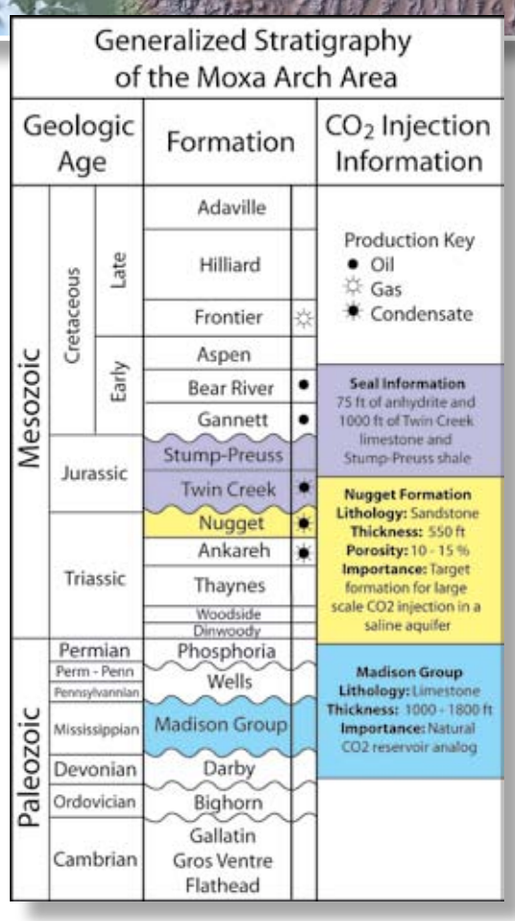


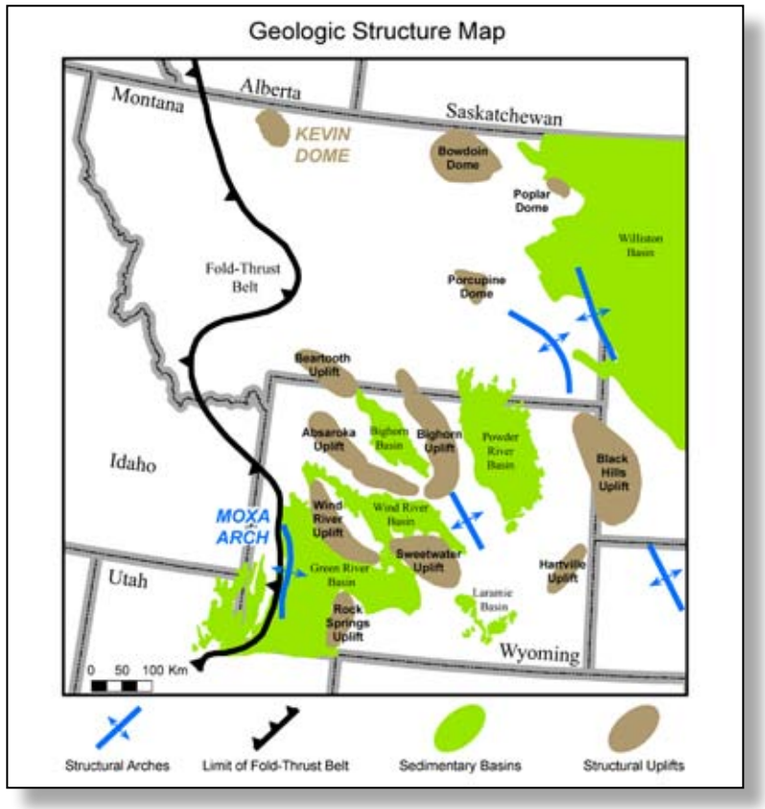
Coal Seam	Basin	State	Storage Volume (million metric tons)	Storage Volume (million tons)
Knobloch	Powder River Basin	Montana	133	147
Rosebud	Powder River Basin	Montana	140	154
Black Butte	Green River Basin	Wyoming	28	31
Point of Rocks	Green River Basin	Wyoming	16	18
Ferris	Hanna Basin	Wyoming	391	431
Hanna	Hanna Basin	Wyoming	180	198
Johnson	Hanna Basin	Wyoming	11	12
Wyodak-Anderson	Powder River Basin	Wyoming	11,500	12,701
Powder River Basin *Total million metric tons (Total million tons)*	11,800 (13,001)			
Hanna Basin *Total million metric tons (Total million tons)*	582 (641)			
Green River Basin *Total million metric tons (Total million tons)*	44 (49)			



The Rosebud coal seam in the northern Powder River Basin.



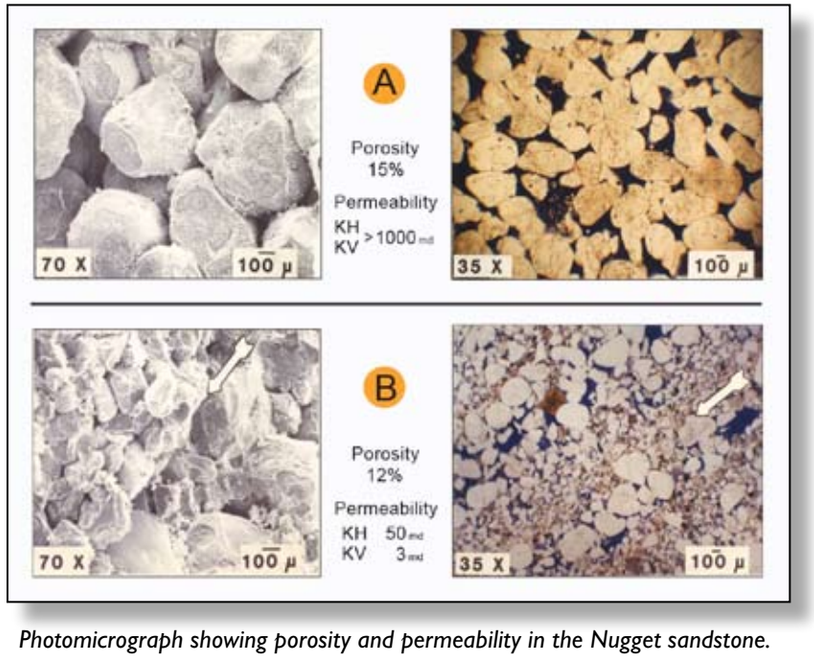




BSCSP Saline Formations

Saline formations throughout the BSCSP Region offer great potential for future sequestration activities. Extensive deep saline formations are present in Paleozoic and Mesozoic formations of Montana's and Wyoming's sedimentary basins. These basins account for greater than 3 million km^2 (750 million acres) underlain by sedimentary units potentially suitable for sequestration. BSCSP estimates that greater than 400 billion metric tons (441 billion tons) of CO_2 could be sequestered in the Region's saline formations, which is adequate for storing the Region's cumulative anthropogenic CO_2 for many years. Several of these formations currently host vast naturally occurring accumulations of CO_2, demonstrating the potential of these units to efficiently trap CO_2. BSCSP is studying naturally occurring CO_2 reservoirs in the Duperow Formation at Kevin Dome in northern Montana and the Madison Formation of the Moxa Arch in southwestern Wyoming as potential analogs for sequestration.

The Triassic / Jurassic Nugget Sandstone in southwest Wyoming is the target for the BSCSP Development Phase large-scale injection test. The Development Phase project will geologically characterize the site, construct pre-injection models of CO_2 flow in the sub-surface, inject up to 0.91 million metric tons (1 million tons) per year of CO_2 for 3 years, and monitor the injected CO_2. This saline formation is important regionally in that it has tremendous potential storage and is geologically similar to many other deep saline formations throughout the BSCSP Region and much of the West. This test will provide critical data towards developing a commercial-scale sequestration site in the Region.



Photomicrograph showing porosity and permeability in the Nugget sandstone.

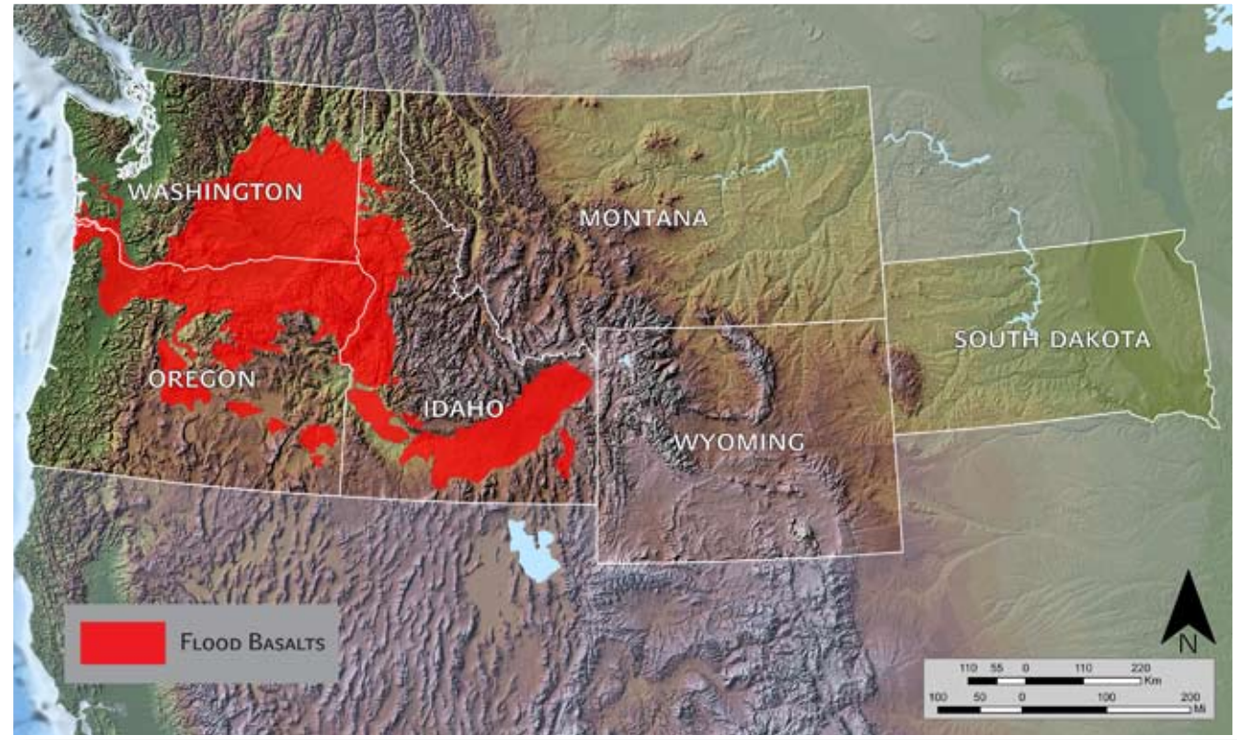
BSCSP Basalts

Regionally extensive mafic rock formations, flood basalts, are a distinguishing feature of the geology of the Pacific Northwest. The Region's Columbia River Basalt Group (CRBG) covers approximately 164,000 km^2 (63,300 mi^2). The CRBG, which is part of the larger Columbia Plateau Province, is probably the most well-studied igneous province in the world. There are over 300 lava flows that comprise CRBG. Each flow is from a few tens of meters to 100 m (328 ft) thick. Combined, the basalt formations offer significant long-term storage potential, with CO_2 storage estimates that range between 33–134 billion metric tons (36–148 billion tons). Large basalt formations are globally distributed, with estimates that the five largest basalt provinces could sequester 10,000 years of global CO_2 emissions. Basalt formations have a number of characteristics that are favorable for CO_2 storage including:

- Conducive mineralogy and chemical makeup for rapid *in situ* mineralization of CO_2
- Multiple very low permeability flow interior sections acting as caprock seals
- High porosity and permeability in interflow zones suitable for CO_2 injection

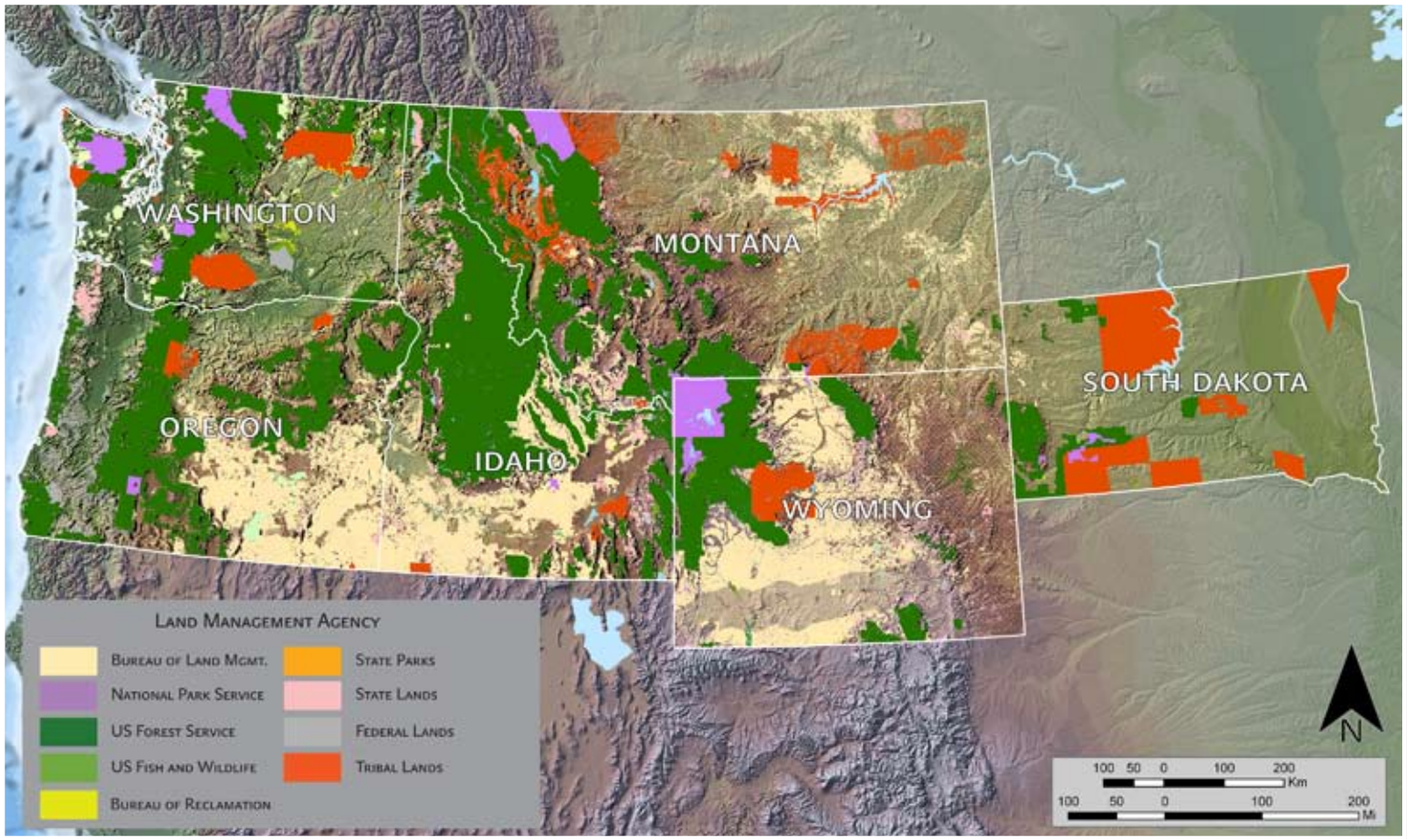
Although flood basalts have an inherently heterogeneous structure, there is ample evidence of km-scale lateral continuity in interflow zones where basalts serve as regional aquifer systems. For example, the CRBG contains several regional aquifer systems serving eastern Washington and north-eastern Oregon that consist of a layered series of highly conductive aquifer zones (darcy-level permeability) alternating with dense basalt zones of very low hydraulic conductivity. Wells have penetrated the thick sequence of basalt flow tops to meet irrigation, industrial, and public water supply needs since the early 1900s. These examples from shallow basalt aquifer systems are important because deeper basalts that are potential targets for CO_2 sequestration are expected to have similar regional-scale connectivity in some interflow zones that would be required for any commercial-scale CO_2 sequestration operation.

A specialized three-component, quasi 3-dimensional seismic survey was completed in December 2007 at the proposed field site. Tomographic refraction statics, velocity analysis, and preliminary migration of the P-wave data show no evidence of significant faulting or vertical displacement within the image area. The results of the seismic processing reduce uncertainty with regard to the basalt structure and provide confidence for proceeding with the pilot in the proposed test area.



Thumper trucks deliver seismic energy to the subsurface to detect underground faults.

Basalt core sample.



BSCSP Land Ownership

The core states of the BSCSP Region consist of a variety of land ownership and management entities which can affect carbon sequestration activities. The Region contains a high proportion of federal- and state-owned lands managed by various government agencies, all of whom retain different policies and regulations for permitting sequestration related activities on these lands. Private lands with split surface and subsurface estates further complicate this issue. Because of this, the sequestration potential of a specific site is not governed solely by geologic or technical issues but must engage the myriad of competing regulations and policies that govern both surface and subsurface regulatory frameworks.

The BSCSP Region contains large areas of federal land managed by the BLM, Bureau of Indian Affairs, DoD, DOE, FS, FWS, and U.S. Bureau of Reclamation, as well as many national parks, state parks, state wildlife management areas, and federal wildlife refuges. Many of these lands demonstrate the potential for carbon sequestration activities, but such activities will be unique to each site based on surface and subsurface ownership and regulatory frameworks that have only recently begun to emerge.

All of the core states in the BSCSP Region are in different stages of policy development for carbon sequestration activities on both private and public lands in addition to various split estate scenarios. The legislation governing these activities will be important for the viability of carbon sequestration in the Region. The BSCSP continues to work with state and federal agencies to develop a regulatory and policy framework that will ensure the safe and reliable storage of CO_2 under suitable geologic, social, economic, and environmental constraints.

National Parks, private farms, and large tracts of National forests demonstrate land ownership diversity in the Big Sky Region.

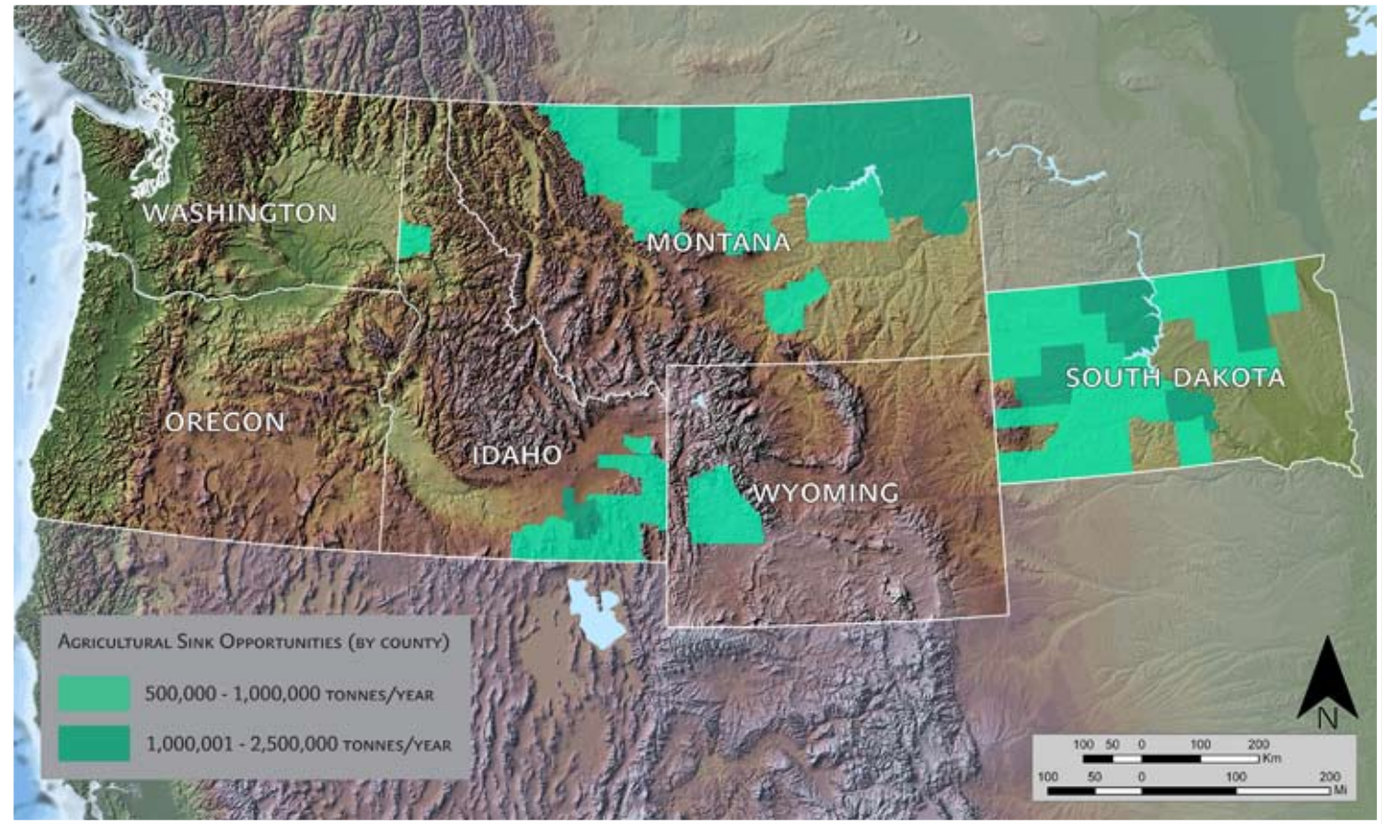
BSCSP Terrestrial Opportunities

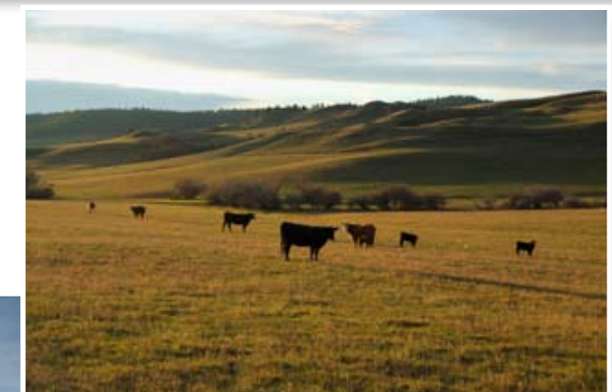
The BSCSP Region has extensive land area that provides tremendous potential for greenhouse gas offsets through terrestrial carbon sequestration in forests, rangelands, and agricultural croplands. Based on current land use practices, the Region can potentially sequester 6.7 million metric tons (7.4 million tons) of CO_2 per year in agricultural lands. BSCSP has developed a market-based approach to carbon storage and verification protocols that includes: (1) establishing terrestrial pilots in cropland, forestland, and rangeland; (2) designing carbon portfolios in conjunction with industry, tribal members, and landowners; and (3) conducting a remote sensing study of management practices and adoption trends in north-central Montana.

The BSCSP is working directly with landowners to provide guidance on land-management practices that maximize carbon storage and to develop initial portfolios. The potential development and design of carbon markets is being explored by two parallel efforts: (1) the development of carbon market portfolios with individual landowners and land managers led by the National Carbon Offset Coalition (NCOC), and (2) the use of a computer simulation model to assess terrestrial carbon storage potential and carbon market opportunities at a county level led by a team from the South Dakota School of Mines and Technology.

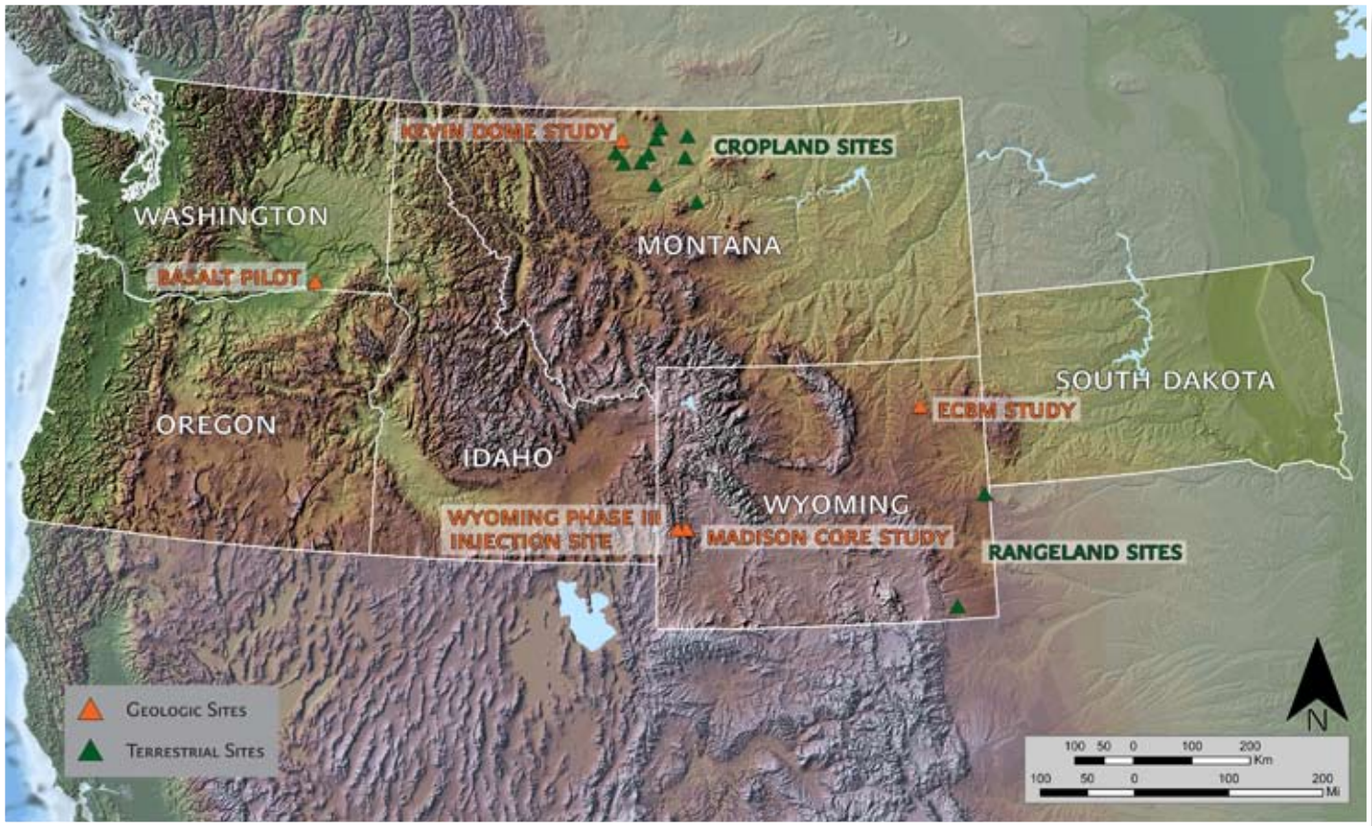
Currently, a total of 5,700 metric tons (6,300 tons) of CO_2 on tribal lands have been traded from the Nez Perce account for reforestation projects. Continued collaboration with the Fort Peck Tribe on a range offset project for 1,480 km^2 (366,000 acres) and the Northern Cheyenne tribe on a proposed forestry project for approximately 61 km^2 (15,000 acres) further utilizes tribal lands for CO_2 activities in the BSCSP Region.

A total of 73,402 metric tons (80,900 tons) of CO_2 was traded this quarter for 66 Montana landowners on 447 km^2 (110,379 acres) of no-till and grass plantings. The second pool of no-till and grass planting projects is now being organized with landowners in Montana, Colorado, and Nebraska. The first New Mexico Range pool with 8 landowners on 1,165 km^2 (287,979 acres) has contracted for 202,245 metric tons (223,000 tons) of CO_2 and is scheduled to undergo third-party verification in May. A second range pool of 23 landowners from Montana, Wyoming, Colorado and Texas are now being organized and contracted. This pool is scheduled to undergo third-party verification in June. To date NCOC has also signed up 13 affiliate organizations (organizations agreeing to assist landowners in completing project applications).

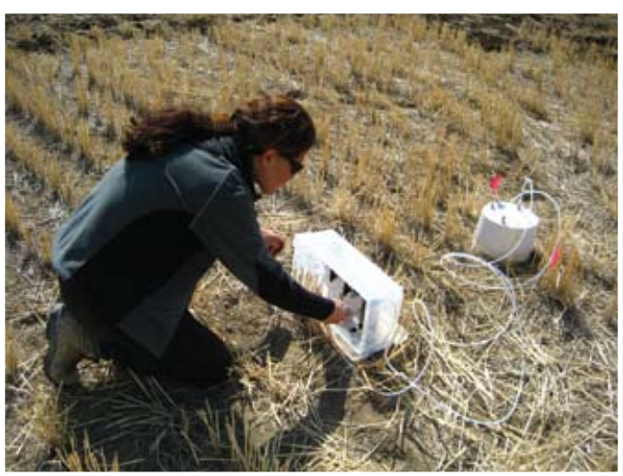




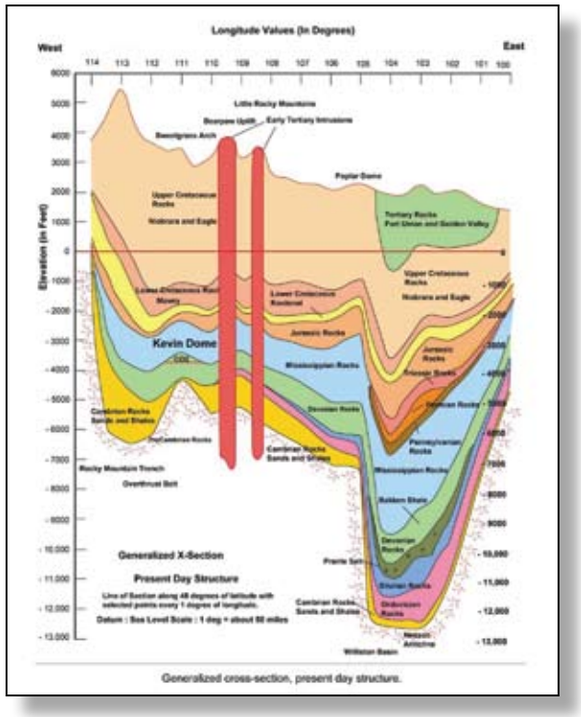
BSCSP is assessing land management practices to best facilitate terrestrial sequestration.



The map shows the locations of the geologic and terrestrial pilots and studies that the BSCSP is undertaking in the Validation and Development Phases. The paragraphs below provide brief descriptions of the projects.



Field tests are conducted on cropland to measure naturally occurring CO_2 fluctuations.



BSCSP Pilot Tests

Validation Phase Geologic Tests and Characterization Efforts

Madison Core Study, SW Wyoming—The objective of this study is to perform a detailed core and structural analysis of the Madison Formation in the Moxa Arch to help understand changes in rock properties resulting from CO_2 exposure and to determine the potential leakage pathways and the best MVA technologies.

Enhanced Coal Bed Methane Recovery (ECBM) and CO_2 Sequestration, East Wyoming—A reservoir simulation in a Powder River Basin coalfield in Wyoming found that there can be significant recovery of coal-bed methane with injection of pure CO_2 versus injection of flue gas. The results indicate that pure CO_2 does not mix with methane and eliminates the need for gas separation facilities.

Montana Kevin Dome Characterization Study, Northern Montana—The purpose of this study is to understand the reservoir and trapping characteristics of Kevin Dome, a geologic structure that contains naturally occurring CO_2.

Basalt Hosted Saline Formation Characterization and Pilot Test, SE Washington—A small scale CO_2 injection 900–2700 metric tons (1000–3000 tons) into the Columbia River flood basalts will confirm feasibility of safe, permanent storage of CO_2 by addressing technical issues associated with the transport and injection of supercritical CO_2 in deep flood basalt formations.

Development Phase Geologic Test

Nugget Sandstone Large Volume Injection Test, SW Wyoming—With the cooperation of industry partners, Cimarex and Schlumberger, the BSCSP plans to inject up to 2.7 million metric tons (3 million tons) of CO_2 from a Cimarex Energy gas processing plant into the Nugget Sandstone on the Riley Ridge Unit on the LaBarge Platform in southwest Wyoming. The injection into the Nugget saline formation will be at depths of 3,350 m (11,000 ft), which is substantially deeper than most pilot tests to date. The Nugget sandstone represents a key opportunity for sequestration in the region because it can potentially store more than 100 years of current emissions from power plants in Wyoming and is similar to other sequestration target saline formations in the region. Additionally, the area has access to the state-wide CO_2 pipeline infrastructure, making it the basis for an economic evaluation at commercial scale.

Validation Phase Terrestrial Tests

Carbon Market Explorations—Efforts include developing initial portfolios with landowners and working with potential buyers and other partners to establish prices, contract terms, MVA procedures and responsibilities of participants.

Cropland Field Validation Test—The objective of this test is to quantify and determine cropland management practices that optimize carbon sequestration and develop MVA protocols to evaluate carbon sequestration for enrolled farms.

Rangeland Sequestration Potential Assessment—Field studies are being conducted at three sites in the northern mixed-grass prairie of Wyoming. The purpose of these studies is to determine the effect of grazing intensity (none, light, heavy) and seasonality of grazing (early-season, late-season) on rangelands.

Placement of survey equipment at a proposed basalt field site.

BSCSP Region Commercialization Opportunities

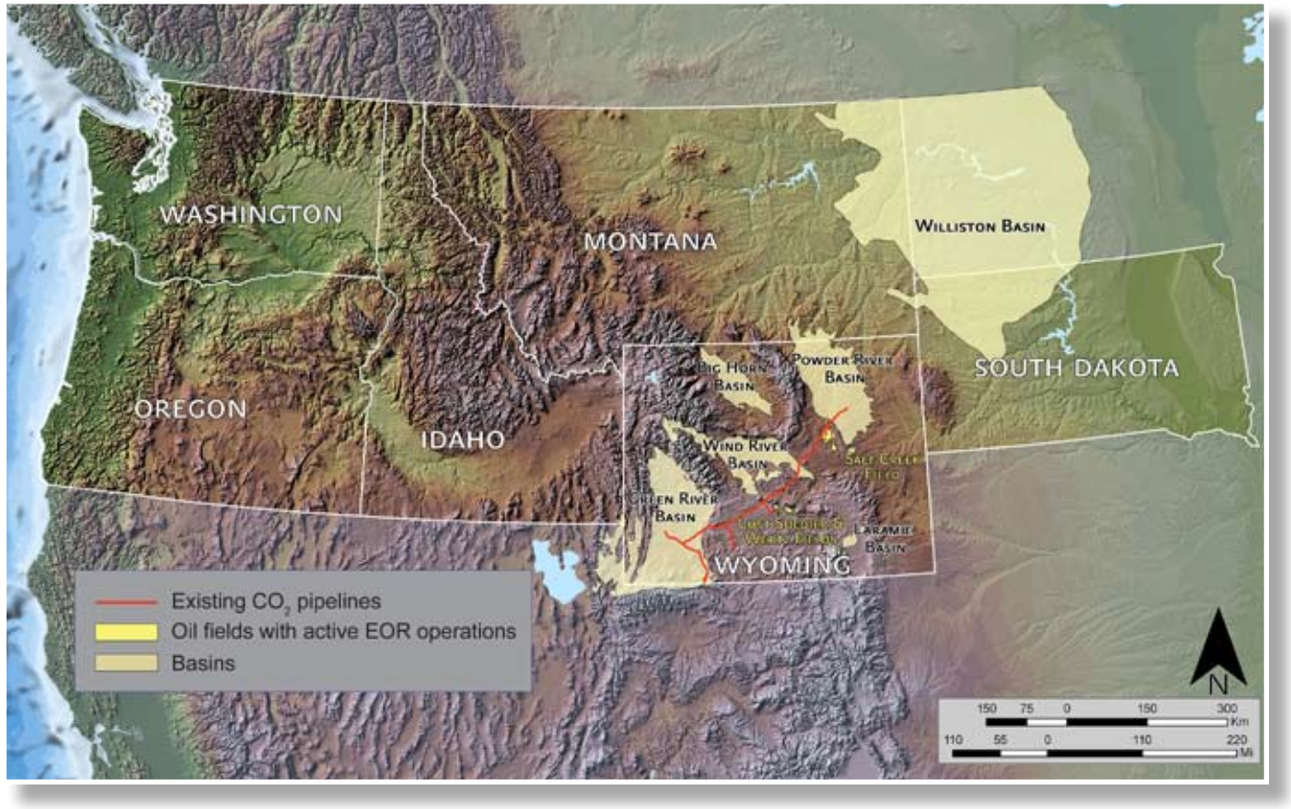
Early Opportunities for Commercialization in the BSCSP Region

The BSCSP Region has several ongoing and proposed projects, existing infrastructure, and regional initiatives that are helping move CCS forward in the Region.

Currently, there are several power plants being proposed in the Region with CCS. In northern Montana, a 250 MW plant with fluidized bed combustion technology is being proposed with capture that would meet California's AB 32 emission performance standards. Also in Montana, research is being conducted to evaluate Kevin Dome as a potential CO_2 sequestration site for proposed plants in the Region. In Washington, a 900 MW IGCC plant is being proposed with 65 percent CO_2 capture and permanent sequestration with injection in basalt flow targets.

EOR and Infrastructure

Active EOR operations within the BSCSP Region include projects in the GRB and PRB. The Exxon-Anadarko CO_2 pipeline system delivers CO_2 from a gas processing plant to the Salt Creek, Lost Soldier, and Wertz oil fields for EOR. Wyoming is continuing to develop its CO_2 pipeline infrastructure to make CO_2 transportation more efficient and to access other depleted oil reservoirs in the Big Horn, Williston, Wind River, and Laramie Basins. The Devon CO_2 pipeline will extend the existing pipeline from Bairoil to Beaver Creek oil fields and should be operational in 2008. Construction of a CO_2 pipeline to Glenrock, WY has also been proposed.

Regional Initiatives

All of the states in the BSCSP Region have committed to participate in regional greenhouse gas initiatives. Washington, Oregon, Montana, Wyoming, and Idaho are participating as partners or observers with the Western Climate Initiative (WCI). The WCI's overall goal is to reduce regional greenhouse gas emissions. South Dakota is an observer with the Midwest Greenhouse Gas Accord, an agreement to establish regional initiatives to increase energy security, promote renewable energy, and reduce greenhouse gas emissions. Additionally, states within the BSCSP have passed bills to incentivize CCS, to determine pore space ownership, and to set performance standards and establish oversight and authority of CCS operations. Several states have also formed legislative committees to focus on implementing a regulatory framework and drafting new bills.