THE NORTH AMERICAN CARBON STORAGE ATLAS

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CANADA

Natural Resources Canada | Ressources naturelles Canada | Canada

MEXICO

Gobierno Federal | SENER | CFE

UNITED STATES

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Foreword

Natural Resources Canada (NRCan), the Mexican Ministry of Energy (SENER), and the U.S. Department of Energy (U.S. DOE) are proud to release the North American Carbon Storage Atlas (NACSA), which was produced under the leadership of the North American Carbon Atlas Partnership (NACAP). Production of this Atlas is the result of cooperation and coordination among carbon storage experts from local, state, provincial, and Federal government agencies, as well as industry and academia. This Atlas provides a coordinated overview of carbon capture and storage (CCS) potential across Canada, Mexico, and the United States. The primary purpose of the Atlas is to show the location of large stationary carbon dioxide (CO_2) emission sources and the locations and storage potential of various geological storage sites. This Atlas is a first attempt at providing a high-level overview of the potential for large-scale carbon storage in North America. As each country makes progress in the dynamic technology of CCS, additional resources will become available that allow for a more thorough effort to identify large stationary CO_2 emission sources and potential storage sites.

A key aspect of CCS is the amount of carbon storage potential available to effectively help reduce greenhouse gas emissions. As shown in this Atlas, CCS holds great promise as part of a portfolio of technologies that enables Canada, Mexico, the United States, and the rest of the world to effectively address climate change while meeting the energy demands of an ever increasing global population. This Atlas includes the most current and best available estimates of potential CO_2 storage resource determined by each of the three countries' selected methodology. A CO_2 storage **resource** estimate is defined as the volume of porous and permeable rocks available for CO_2 storage and accessible to injected CO_2 via drilled and completed wellbores. Carbon dioxide storage resource assessments do not include economic or regulatory constraints; only physical constraints to define the accessible part of the subsurface are applied.

All data in this Atlas were collected before April 2011. These data sets are not comprehensive; however, it is anticipated that CO_2 storage resource estimates, as well as geological formation maps, will be updated when sufficient new data are acquired. Furthermore, it is expected that, through the ongoing work of NRCan, SENER, and U.S. DOE, data quality and conceptual understanding of the CCS process will improve, resulting in more refined CO_2 storage estimates.

About The North American Carbon Storage Atlas

The North American Carbon Storage Atlas contains five main sections: (1) Introduction, (2) North American Perspectives, (3) Carbon Capture and Storage in Canada, (4) Carbon Capture and Storage in Mexico, and (5) Carbon Capture and Storage in the United States. The Introduction section contains an overview of CCS and the North American Carbon Atlas Partnership efforts. The North American Perspectives section describes North American geology as it pertains to the potential storage of CO_2 and provides maps that show the number, location, and magnitude of large stationary CO_2 emission sources and the location and areal extent of sedimentary basins and geological formations within those basins that have been assessed to date. This section also provides summaries of the estimated CO_2 storage resource in the assessed formations in Canada, Mexico, and the United States. The remaining three sections provide more details on CO_2 sources and storage resources in oil and gas reservoirs, unmineable coal, and saline formations in each of the three countries.

Carbon dioxide storage resource estimates were derived from data available in each country. These data are representative of potential storage formations in the three countries and are needed to estimate key parameters, such as area (A), thickness (h), and porosity (ϕ) of a formation. Carbon dioxide emission and storage resource maps were compiled for this Atlas by U.S. DOE's National Energy Technology Laboratory (NETL) from information provided by the three countries.

The CO_2 geological storage information in this Atlas was developed to provide a high-level overview of CO_2 geological storage potential across Canada, Mexico, and the United States. The location and areal extent of promising geological storage formations and the CO_2 resource estimates presented in this Atlas are intended to be used as an initial assessment of potential geological storage opportunities. This information provides CCS project developers with a starting point for further investigations. Furthermore, the information provided by this Atlas will help quantify the extent to which CCS technologies can contribute to the reduction of CO_2 emissions, **but it is not intended to serve as a substitute for site-specific assessments and testing**.

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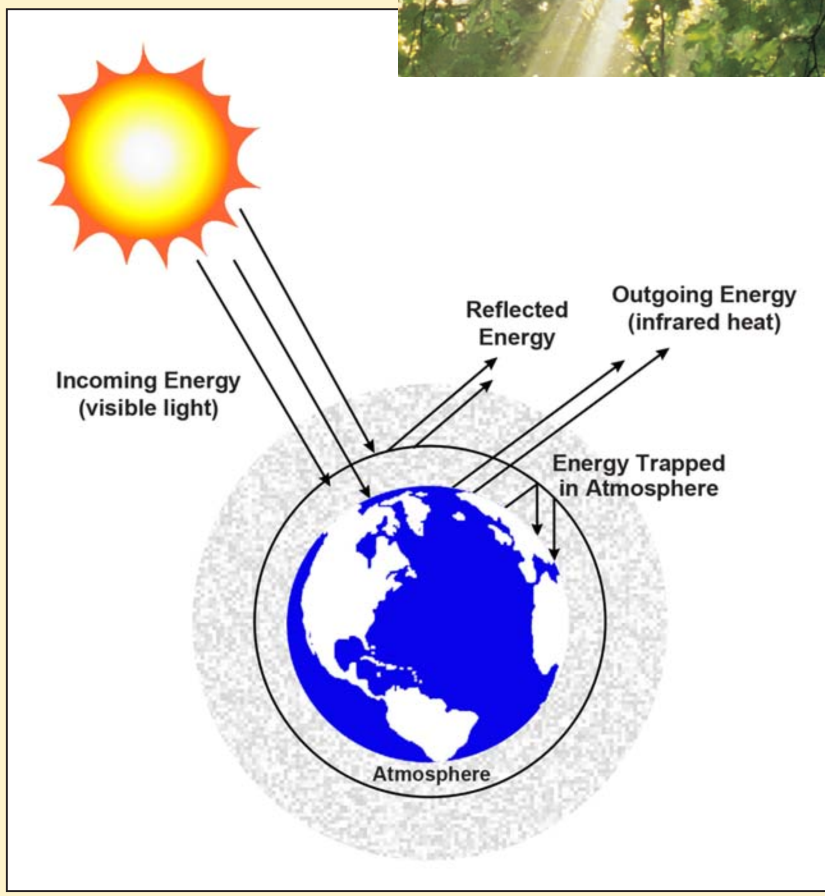
Carbon Dioxide Emissions

Greenhouse gases (GHGs) in the atmosphere contribute to the greenhouse effect, which is the trapping of radiant heat from the sun in Earth's atmosphere. Carbon dioxide (CO_2) is of particular interest, because it is one of the most prevalent GHGs. Carbon dioxide is a colorless, odorless, nonflammable gas that provides a basis for the synthesis of organic compounds essential for life. Atmospheric CO_2 originates from both natural and manmade sources. Natural sources of CO_2 include volcanic outgassing, the combustion and decay of organic matter, and respiration. Manmade, or anthropogenic, CO_2 primarily results from the burning of various fossil fuels for power generation and transportation. In addition, industrial activities (ethanol plants, refineries, chemical plants, etc.) contribute to anthropogenic CO_2 emissions.

The greenhouse effect is a natural and important process in the Earth's atmosphere. However, GHG levels have significantly increased above pre-industrial levels. According to the Energy Information Administration (EIA), annual global energy-related CO_2 emissions have reached approximately 32 gigatonnes. Many scientists consider the resulting increase in the atmospheric CO_2 concentration to be a contributing factor to global climate change.

Canada, Mexico, and the United States are signatories to the United Nations Framework Convention on Climate Change (UNFCCC). This treaty was approved in 1992 and calls for the stabilization of atmospheric CO_2 concentrations at a level that could minimize impact on the world's climate. No single approach is sufficient to stabilize the concentration of CO_2 in the atmosphere, especially considering the growing global demand for energy and the associated potential increase in CO_2 emissions. Conservation, renewable energy, carbon capture and storage (CCS), and improvements in the efficiency of power plants, automobiles, and other energy consuming devices are all important steps that must be taken to mitigate GHG emissions. In an analysis by the International Energy Agency (IEA), CCS provides 19 percent of the reduction in CO_2 emissions required until 2050 to stabilize the atmospheric CO_2 concentration at 450 parts per million. Technological approaches such as CCS are needed that will effectively reduce CO_2 emissions, while allowing economic growth and prosperity with its associated energy use.

The greenhouse effect describes the phenomenon whereby Earth's atmosphere traps solar radiation caused by the presence of gases, such as CO_2, methane, and water vapor, in the atmosphere that allow incoming sunlight to pass through and absorb heat radiated back from Earth's surface, resulting in higher temperatures.



In Earth's natural greenhouse effect, sunlight enters the atmosphere and is either reflected, absorbed, or simply passes through. The sunlight that passes through the atmosphere is either absorbed by the Earth's surface or reflected back into space. The Earth's surface heats up after absorbing this sunlight, and emits long wavelength radiation back into the atmosphere. Some of this radiation passes through the atmosphere and into space, but the rest of it is either reflected back to the surface or absorbed by GHGs, which re-radiate longer wavelength radiation back to Earth's surface. These GHGs trap the sun's energy within the atmosphere and cause the planet to warm.

GHGs, such as CO_2, methane, water vapor, and nitrous oxide, trap indirect heat from the sun. Without the greenhouse effect, Earth's climate would be approximately -18 °C (0 °F).

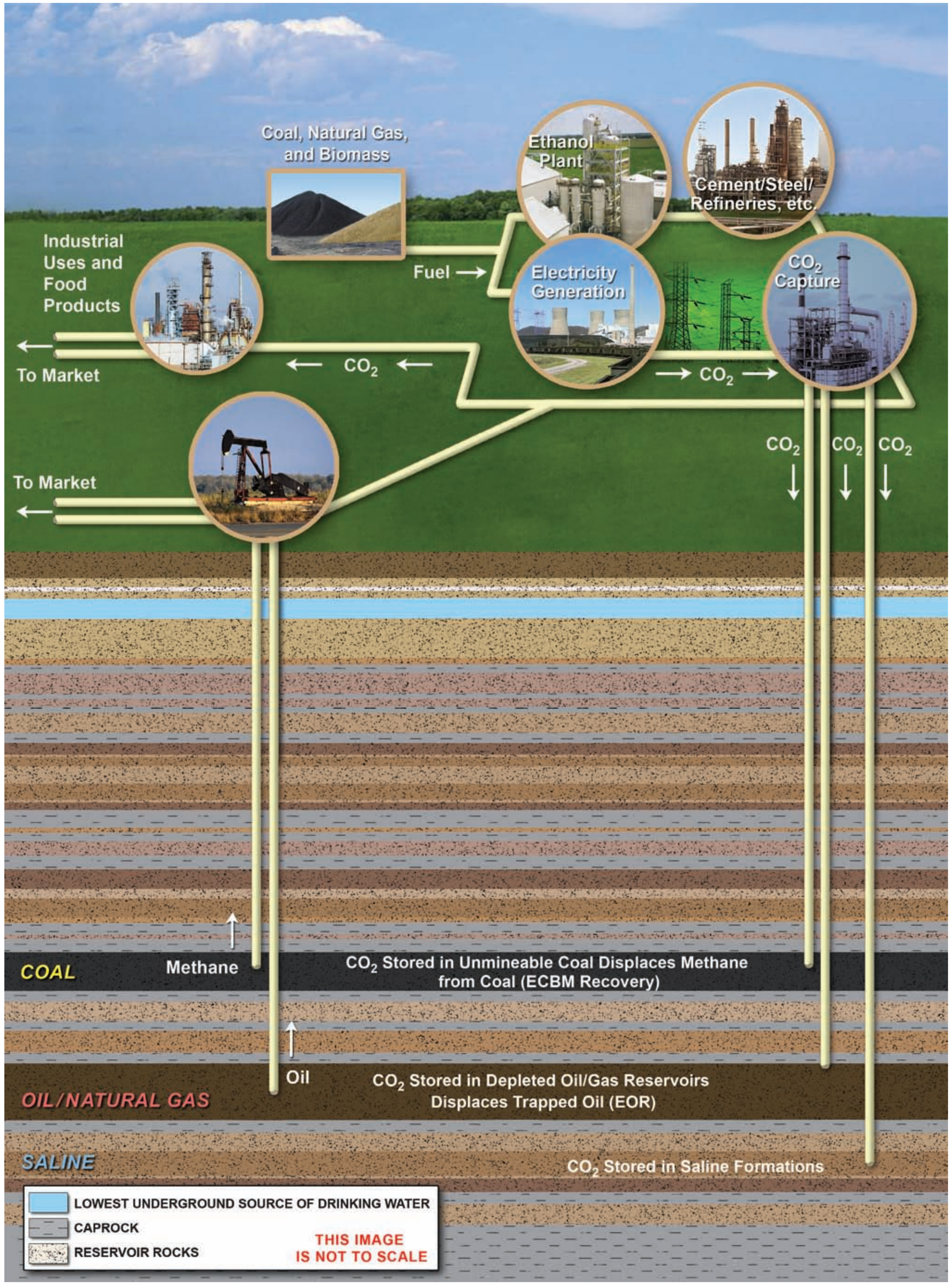
What Is Carbon Capture and Storage?

Carbon capture and storage involves the separation and capture of CO_2 from the atmospheric emissions of industrial processes and transporting the CO_2 to deep underground geological formations for safe, permanent storage.

Carbon capture and storage is typically targeted at industrial facilities that emit large amounts of CO_2. These facilities include power plants, petroleum refineries, oil and gas production facilities, iron and steel mills, cement plants, and various chemical plants.

Geological storage is defined as the placement of CO_2 into a subsurface formation so that it will remain safely and permanently stored. Five storage types for geological carbon storage are currently under investigation in North America, each with unique challenges and opportunities: (1) oil and gas reservoirs, (2) unmineable coal, (3) saline formations, (4) organic-rich shales, and (5) basalt formations.

The storage process includes technologies for measurement, monitoring, verification, accounting, and risk assessment at the storage site. Effective application of these technologies will provide a high level of confidence that the CO_2 will remain safely and permanently stored and ensure an accurate accounting of the stored CO_2, thus providing the basis for establishing carbon credit trading markets for stored CO_2. Risk assessments focus on identifying and quantifying potential risks to humans and the environment associated with carbon storage, and identifying appropriate measures to ensure that these risks remain low.



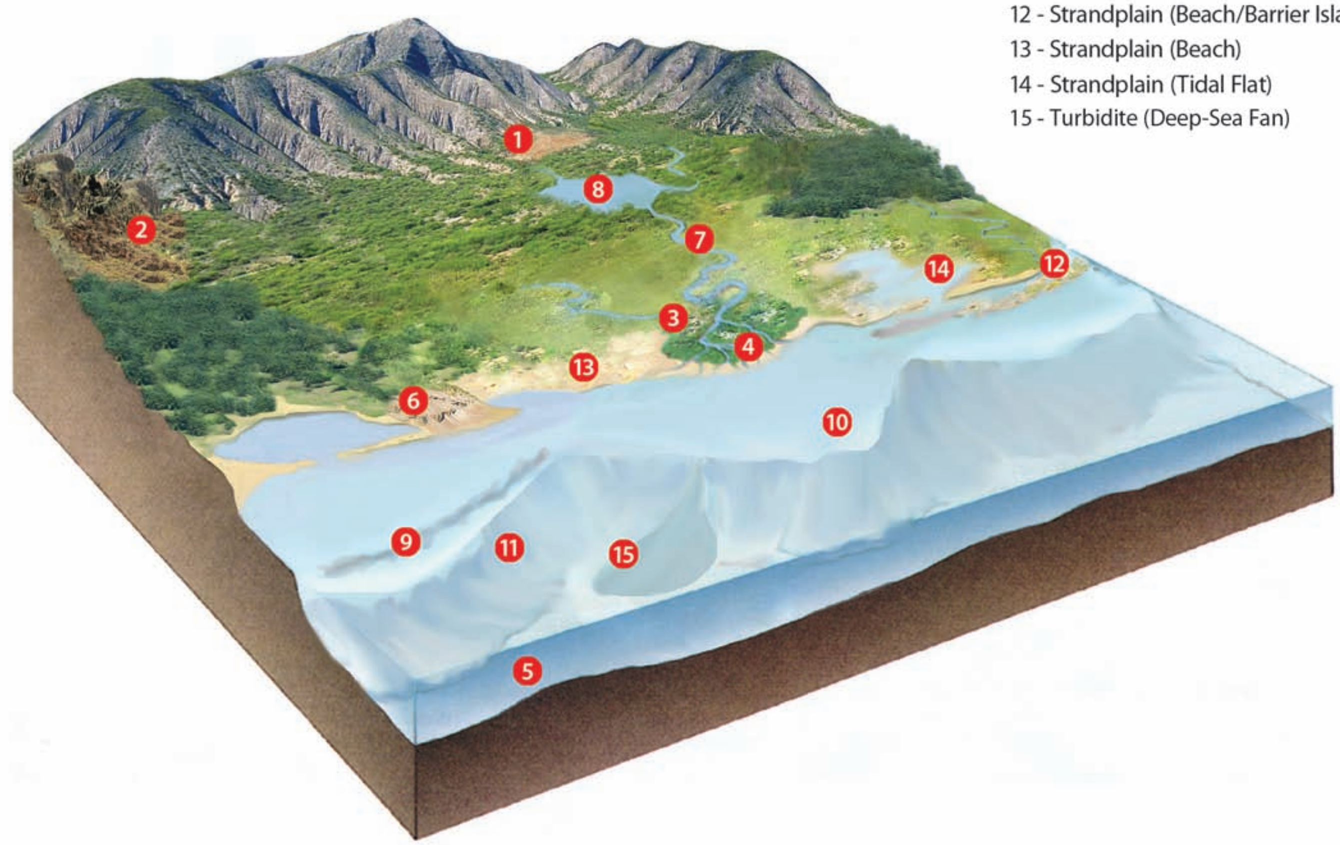
Geological Storage Environments

The process of identifying suitable geological storage sites involves a methodical and careful analysis of both technical and non-technical aspects of potential sites. This process is analogous to the methods used in the petroleum industry to advance a project through a framework of resource classes and project status subclasses until the project produces hydrocarbons.

Each type of geological formation has different opportunities and challenges. While geological formations are infinitely variable in detail, geologists and engineers in the petroleum industry characterize potential reservoirs by their lithology, depositional environment, trapping mechanism, and hydrodynamic conditions. The physical, chemical, and biological processes associated with deposition of a particular type of sediment influences how formation fluids are held in place, how they move, and how they interact with other formation fluids and solids (minerals). Certain geological properties may be more favorable to long-term containment of liquids and gases typically needed for geological storage.

Several types of depositional environments are currently being evaluated for CO_2 storage in North America. The different classes of reservoirs include: deltaic, coal/shale, fluvial, alluvial, strandplain, turbidite, eolian, lacustrine, clastic shelf, carbonate shallow shelf, and reef. Basaltic interflow zones are also being evaluated as potential reservoirs.

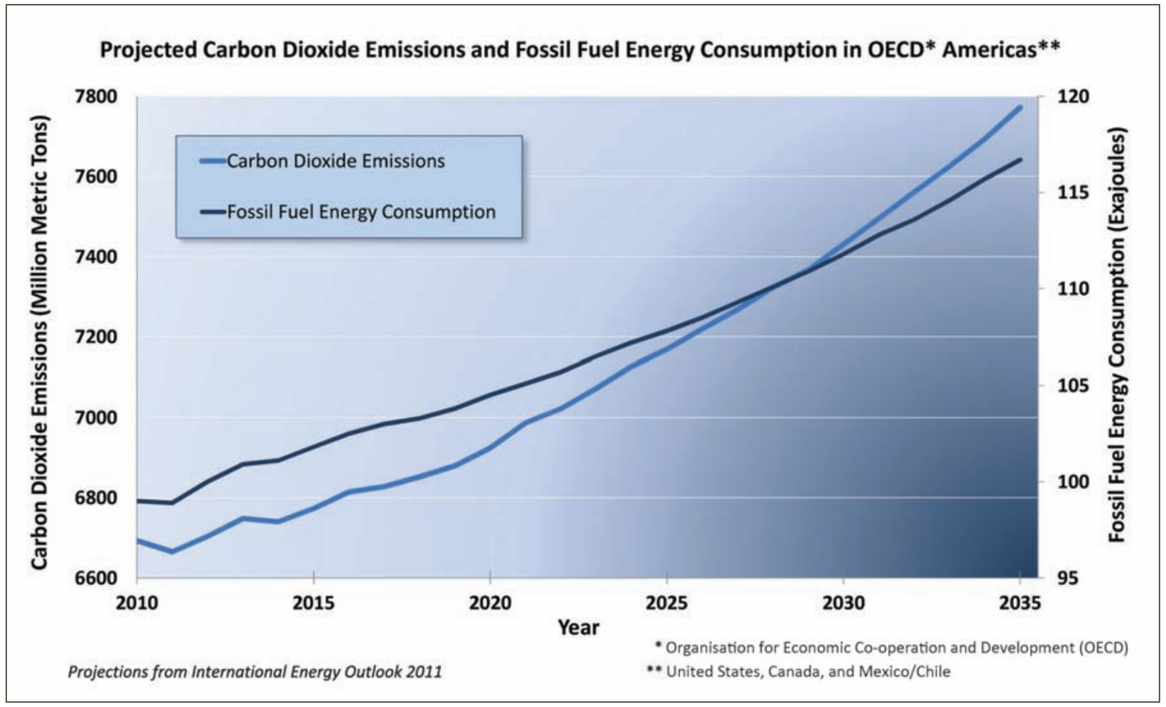
Although the flow paths of the original depositional environment may have been degraded or modified by mineral deposition or dissolution since the geological units were deposited, the basic stratigraphic framework created during deposition remains. Geological processes working today also existed when the sediments were initially deposited. Analysis of modern day depositional environment analogs, paired with evaluation of core, outcrops, and well logs from ancient subsurface formations provide an indication of how formations were deposited and how CO_2 within the formation is anticipated to flow.



Types of depositional environments.

Importance of Carbon Capture and Storage to North America

Increased GHG emissions and potential global climate change represent a critical challenge to North America. In 2012, North America is projected to emit approximately 20 percent of the world's CO_2. Most of these CO_2 emissions come from fossil fuels used for energy. However, at least for the foreseeable future, we will continue to rely on fossil fuels to sustain our economy and quality of life.



Energy demand is expected to grow in North America in the coming decades with concurrent increases in the demand for inexpensive, reliable, and available energy sources, including coal. The coal reserves in North America are substantial and will provide a reliable energy source well into the future. However, coal combustion releases the most CO_2 per unit of energy produced of all fossil fuels. Without an effective way to limit and reduce CO_2 emissions from coal, further increases in CO_2 emissions could lead to consequences resulting from climate change.

Innovation and research have already produced successful pilot projects demonstrating that CCS can help reduce GHG emissions, while minimizing negative impacts on our economy and lifestyle. The abundance of coal reserves in North America provides the incentive to implement CCS technologies, and, in doing so, to develop more sustainable power production methods. In addition to sustainable power and environmental benefits, enhanced oil recovery (EOR), enhanced coalbed methane recovery (ECBM), stronger and more stable local economies, and better partnerships between nations are all benefits North Americans can expect from the implementation of CCS technology.

As the world economies globalize in scope, boundaries between countries can blur, especially when the world faces issues of GHG emissions. For the countries in North America, geological storage resources may need to supersede national boundaries to accomplish CCS technology implementation. Already, carbon pipelines transcend North America's national borders. Jointly pursuing and documenting scientific data related to reducing the impact of energy production and use in North America is vital to the future.

This Atlas is the first attempt between Canada, Mexico, and the United States to jointly publish information on CO_2 stationary source and storage resource data. With active collaboration, consensus, and resources, North America can demonstrate a partnership in addressing unique challenges on this continent that will affect the world. This Atlas represents the beginning of that collaboration.

North American Energy Working Group

The North American Energy Working Group (NAEWG) was established in the spring of 2001 by the Canadian Minister of Natural Resources, the Ministry of Energy of Mexico, and the Secretary of Energy of the United States. The goals of NAEWG were to foster communication and cooperation among the governments and energy sectors of the three countries on energy-related matters of common interest, and to enhance North American energy trade and interconnections consistent with the goal of sustainable development for the benefit of all. This trilateral process fully respects the domestic policies, divisions of jurisdictional authority, and existing obligations of each country.

As a part of NAEWG, Canada (NRCan), Mexico (SENER), and the United States (U.S. DOE) initiated the North American Carbon Atlas Partnership (NACAP). NACAP is a mapping initiative designed to disseminate and exchange CCS-related information between Canada, Mexico, and the United States in order to effectively speed up the development of a geographic information system (GIS)-based CO_2 sources and storage resource database in North America. The development of this GIS system supports the Carbon Storage Program in U.S. DOE's Office of Fossil Energy, the objectives of NAEWG, current initiatives under the Canada-United States Clean Energy Dialogue, and the Mexico-United States Bilateral Framework on Clean Energy and Climate Change. It is expected that this initiative will serve as a key opportunity to foster collaboration among the three countries in CCS.

In August 2009, at the North American Leaders Summit in Guadalajara, Mexico, it was formally announced that the three countries had agreed to produce an atlas that would result in uniform mapping methodology and data sharing of large sources of CO_2 emissions and potential storage sites in North America. The overall effort will—

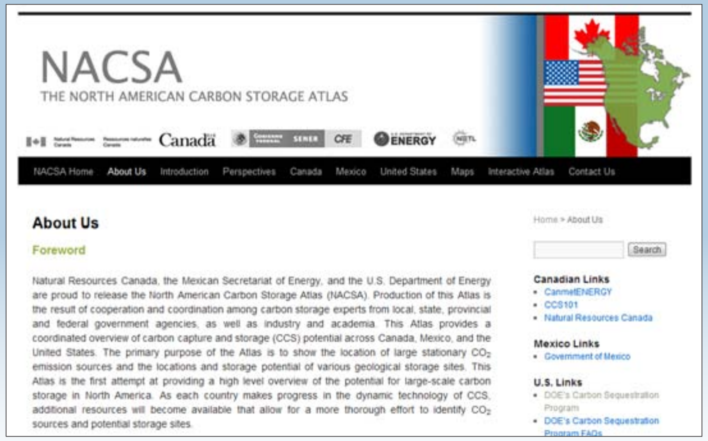
- Facilitate the sharing of information to foster and enhance data exchange on CO_2 sources and storage formations in support of a GIS system, which is typically used to convey information in map form. The aim is to create a distributed database, rather than a central repository, where data from different states, provinces, or organizations can be accessed via a common portal and in similar format.

- Form a consensus on the methodology to be used in estimating the CO_2 storage potential of various types of CO_2 storage systems in North America. This will be particularly relevant for cross-border storage to eliminate international "fault lines" and ensure compatible estimates of storage potential in North America.

- Promote potential collaboration on research, development, and demonstration (RD&D) related to CCS. This includes sharing efforts to evaluate alternative uses of CCS technologies, such as EOR or ECBM recovery.

North American Carbon Storage Atlas Website

The NACSA website (www.nacsap.org) serves as a resource for information on CO_2 stationary sources and CO_2 storage resources in North America. The website houses full storage resource estimation methodologies and links to valuable information from the three countries involved in the NACAP effort.



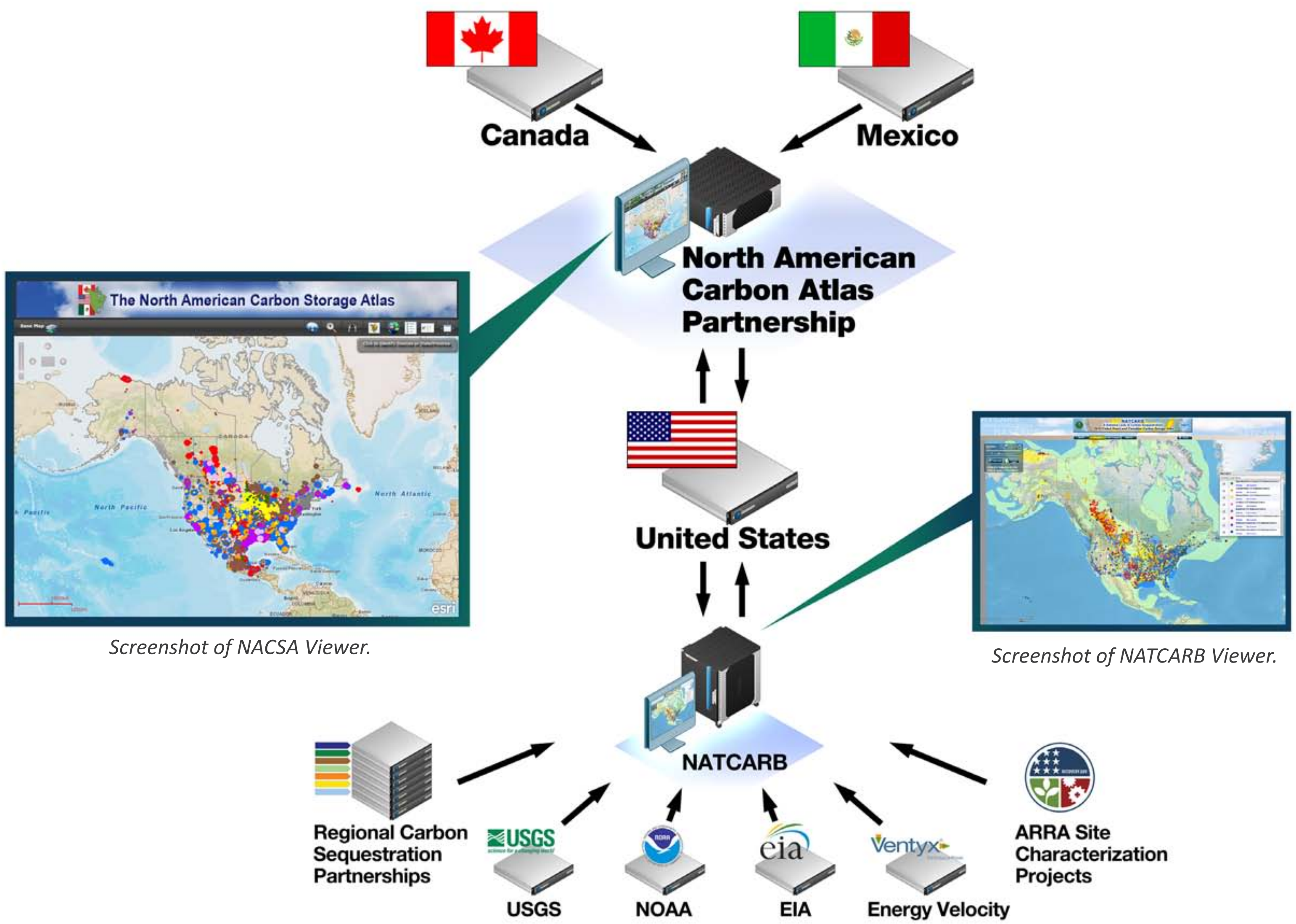
Screenshot of NACSA website (www.nacsap.org).

As part of the NAEWG effort, NACAP has collaborated on the development of this North American Carbon Storage Atlas (NACSA), the NACSA website, and the NACSA Online Viewer, a digital interactive atlas. NACAP's goal is for each country to identify, collect, and distribute data of CO_2 sources and geological storage opportunities in Canada, Mexico, and the United States in order to present these in a comprehensive GIS database for North America.

North American Carbon Storage Atlas Online Viewer

The NACSA Viewer, accessible from the NACSA website, provides web-based access to all NACSA data (CO_2 stationary sources, potential geological CO_2 storage resources, etc.) and analytical tools required for addressing CCS deployment. Distributed computing solutions link the three countries' data and other publicly accessible repositories of geological, geophysical, natural resource, and environmental data.

The NACSA website and NACSA Viewer are hosted by West Virginia University and the U.S. DOE's National Energy Technology Laboratory (NETL), respectively. Canadian and Mexican data are uploaded when new information becomes available. U.S. data are made available in real time from the National Carbon Sequestration Database and Geographic Information System (NATCARB; www.natcarb.org), which in turn receives its data from the seven Regional Carbon Sequestration Partnerships (RCSPs, see page 33) and from specialized data warehouses and public servers.



Screenshot of NACSA Viewer.

Screenshot of NATCARB Viewer.

NACAP distributed database system. Schematic shows data sources and resulting database systems.

Carbon Dioxide Sources in North America

There are two different types of CO_2 sources: natural and anthropogenic (manmade). Natural sources include respiration from animals and plants, volcanic eruptions, forest and grass natural fires, decomposition of biomass material (plants and trees), and naturally occuring sources in geological formations. Anthropogenic sources result from human activity and include the burning of fossil and biomass fuels, cement production and other industrial processes, deforestation, agriculture, and changes in natural land usage. Although CO_2 emissions from natural sources are estimated to be greater than the anthropogenic sources, they are usually in equilibrium with a process known as the global carbon cycle, which involves carbon exchange between the land, ocean, and atmosphere. Increases in anthropogenic emissions throughout the last 200 years have led to an overall increase in the concentration of CO_2 and other GHGs in the atmosphere.

This map shows the location of large stationary sources of CO_2 in North America. The color of a dot indicates the industry sector of the CO_2 emitting facility, whereas the dot size represents the relative quantity of the CO_2 released.

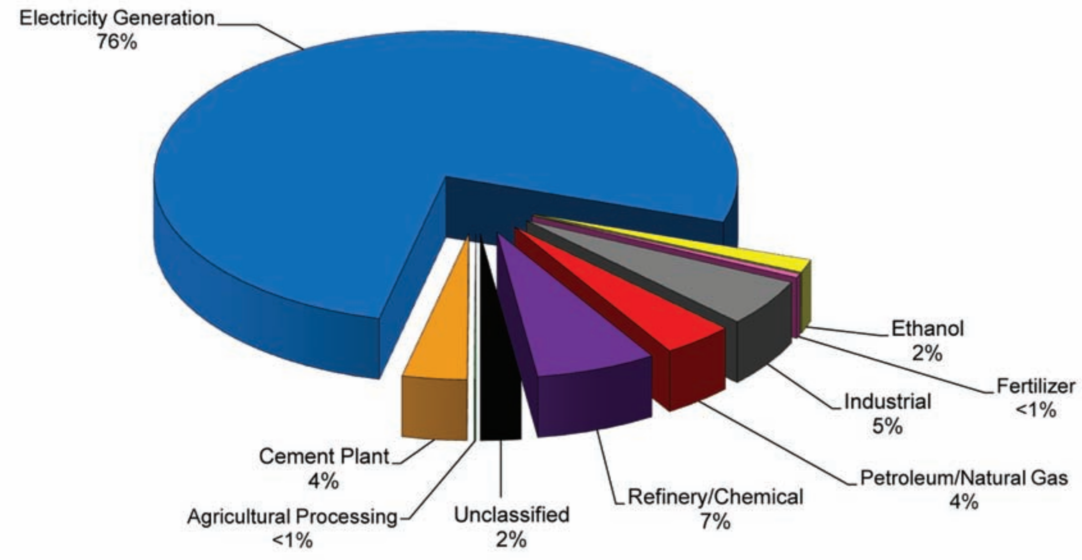
Anthropogenic CO_2 sources can be subdivided into two different types: stationary and non-stationary (e.g., in transportation). For purposes of this Atlas, large stationary sources of CO_2 (greater than 100 kilotonnes per year of CO_2) include power plants, chemical processing facilities, oil refineries, food processing plants, and other manufacturing facilities. Through CCS deployment, CO_2 emitted from these sources can be captured and stored in geological formations.

Different regions of North America vary in the magnitude and density of large stationary CO_2 sources due to the location of energy resources (e.g., coal, oil and gas, carbonate rocks for cement production) and to the amount and nature of various industrial activities. In this Atlas, large stationary sources of CO_2 have been divided into 9 major industry sectors (see figure and table to right). Emissions from petroleum and natural gas processing facilities occur primarily in the western and central regions of Canada and the United States, as well as along the Gulf of Mexico, where oil and gas resources are found. Refineries and chemical production facilities are also found in these locations, although in some cases they are located around harbors to process imported oil. Petroleum and natural gas processing facilities and refineries and chemical production facilities make the capture of CO_2 more economical and efficient because they produce highly concentrated CO_2. Fossil fuel-based power generation sources represent the largest CO_2 emissions by category, but also have the lowest CO_2 concentration in the flue gas; hence, a challenge of CO_2 capture is reducing costs. Most coal-fired power plants are located near coal deposits in western Canada and the United States, and are concentrated in central Canada (Ontario) and the midwest and eastern United States. Most of Mexico's power generating stations are oil-fired and others use coal. Carbon dioxide concentrations from industrial facilities and cement plants, which are spread across North America, range from 15 to 30 percent of total emissions.

For more information on CO_2 sources and the methods each country used to determine its CO_2 emissions, please see Appendix A.

Tonne (t) = 1 metric ton
Kilotonne (kt) = 1,000 metric tons
Megatonne (Mt) = 1,000,000 metric tons
Gigatonne (Gt) = 1,000,000,000 metric tons

Annual CO_2 Emissions from Large Stationary Sources in North America by Industry Sector (Total Emissions 3,438 Mt)†



† Emissions for Mexico and the United States are estimated.

Large Stationary Sources of CO_2 Emissions in North America*

Industry Sector	Canada**		Mexico**		United States**	
	Emissions (Megatonnes/Year)	Number of Sources	Emissions Estimates (Megatonnes/Year)	Number of Sources	Emissions Estimates (Megatonnes/Year)	Number of Sources
Agricultural Processing	<1	1	1	3	2	13
Cement Plant	11	24	26	34	86	103
Electricity Production	100	71	106	64	2,421	1089
Ethanol	1	4			49	155
Fertilizer	5	7			10	13
Industrial	24	51	25	38	131	165
Petroleum/ Natural Gas	50	58	45	38	40	76
Refineries/ Chemical	28	33	2	11	199	136
Unclassified	1	5			76	61
Totals	**219**	**254**	**205**	**188**	**3,014**	**1,811**

* All data from facilities with emissions over 100 kilotonnes/year.
** Canadian sources and emissions data (2009) obtained from the GHGR database; Mexican sources and emissions data (2010) obtained from the RETC database; United States sources and emissions data (2011) obtained from the RCSPs and NATCARB. Additional details appear in Appendix A.

Sedimentary Basins in North America

Data displayed on this map were collected by the governments of Canada, Mexico, and the United States. For more information, please refer to the respective country section found in NACSA.

This map depicts the extent of sedimentary basins in North America. There are three types of sedimentary rocks: (1) clastic (broken fragments derived from pre-existing rocks like sandstone); (2) chemical precipitates (such as carbonates [limestone] and rock salt); and (3) organics (plant or animal constituents that may form coal or limestone). Geological formations being investigated for CO_2 storage are either clastics or fractured carbonates (both precipitates and organic), where CO_2 is stored in the pore spaces between grains or in fractures that are often filled with brine. In this type of CO_2 storage system, impermeable layers are required to form a confining zone that prevents the upward migration of CO_2.

North American Geology Pertaining to CO_2 Storage

At its core, North America is composed of ancient (Precambrian) rocks that formed during the first 3.5 billion years of Earth's history. They are mainly crystalline, igneous, and metamorphic rocks, such as granites and gneiss, which are not suitable for carbon storage. These ancient rocks are exposed in the north-central part of the continent, called the Precambrian Shield. A series of sedimentary basins formed on the Precambrian Shield, such as the Williston, Illinois, and Michigan basins in the United States. These basins are generally the best suited for CO_2 storage because they are tectonically stable and have a suitable succession (usually layer-cake type) of oil and gas reservoirs, deep saline formations, and coal beds with intervening shales and evaporite rocks that constitute caprocks (barriers to the flow of fluids, including CO_2).

Badlands, Drumheller, Alberta Canada.
(Copyright Her Majesty the Queen in Right of Canada. NRCan-1819)

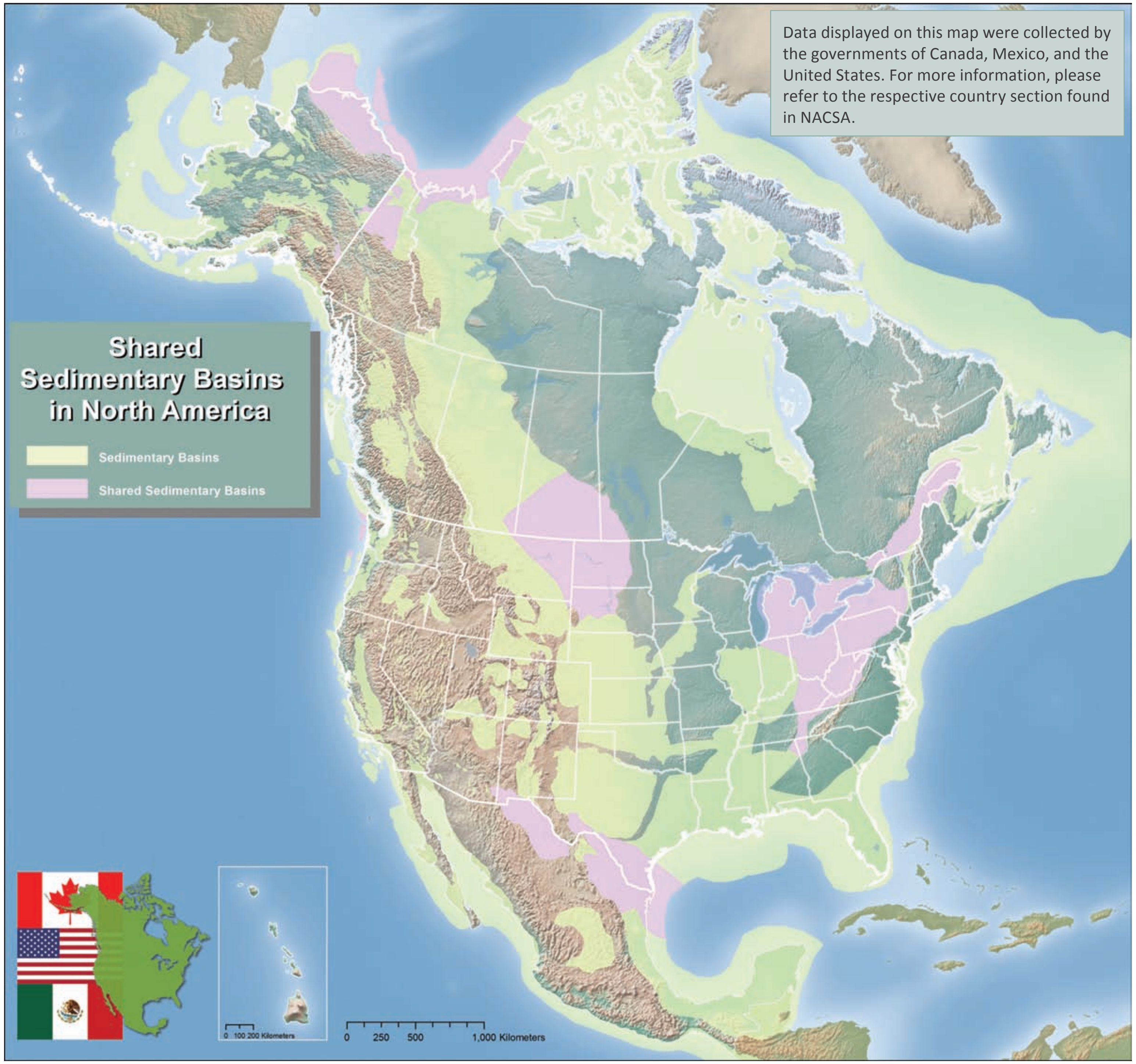
Another significant feature of the North American continent is the collision of the North American tectonic plate with the Juan de Fuca, Pacific, and Cocos plates in the west, and the Caribbean plate in the south. As a result, mountain ranges and volcanic regions are present along the western coast of North America, which may not be suitable for CO_2 storage. Small sedimentary basins are present along the coast and within the mountain ranges. These basins contain oil and gas or coals, such as the Bowser basin in British Columbia, but due to high levels of tectonism, faulting, and fracturing, some of these basins may be unsuitable for CO_2 storage. On the eastern side of the mountain ranges in western North America are basins of various sizes located from the Mackenzie basin in northern Canada to the Veracruz basin in southern Mexico. These include the Alberta basin in Canada; the Denver, Anadarko, and Permian basins in the United States; and the Sabinas and Tampico basins in Mexico. On the eastern side of North America, mainly in the United States, the Appalachian Mountains form a mirror image to the Rocky Mountains, with basins to their west, such as the Black Warrior and Appalachian basins. The mid-continent basins between the eastern side of the Rocky Mountains and the western side of the Appalachian Mountains are separated by the Transcontinental Arch, which trends into Canada across western-central North America and consists of sedimentary rocks overlying the Precambrian basement. The basins are also underlain by Precambrian rocks and contain oil and gas and/or coals. Given their attributes and depth, they are likely suitable for CO_2 storage.

Geological structure in southwestern United States.

The third important geological feature for North America as it relates to geological storage is the spread of the mid-Atlantic ridge and the formation of a series of sedimentary basins along the entire eastern coast of North America to the Gulf of Mexico and Campeche basins in Mexico. These basins usually contain oil and gas and are likely suitable for CO_2 storage, but the challenge is their offshore location. Finally, a series of sedimentary basins, rich in oil, gas, and coal, are present in Alaska and the Canadian Arctic, such as the Alaska North Slope, Beaufort, and Sverdrup basins. They are also suitable for CO_2 storage, but their distance from CO_2 sources and the Arctic environment poses challenges for CO_2 storage.

A majestic geological feature in Mexico.

Shared Sedimentary Basins in North America



Canada–U.S. Border

Canada and the United States share sedimentary basins in the Arctic, on the Pacific coast, along the continental border and possibly on the Atlantic coast.

The Alberta basin, a large basin located mainly in Alberta and extending into northern Montana, is the Canadian basin most suitable for CO_2 storage. It is separated from the Williston basin by the Bow Island (Sweetgrass) Arch, which trends southwest-northeast stretching through northern Montana, southeastern Alberta, and western Saskatchewan.

The Williston basin is a large basin located in eastern Montana, North and South Dakota, southern Saskatchewan, and southwestern Manitoba. It has significant CO_2 storage resource potential in the United States and is the second most important basin for CO_2 storage in Canada. Both the Alberta and Williston basins are well-explored and rich in oil and gas reservoirs, coal and salt beds, and saline formations. They occur in tectonically stable regions, have infrastructure already in place, and are located underneath or near large stationary CO_2 sources. They constitute primary targets for CO_2 storage both in western Canada and in the United States west of the Transcontinental Arch.

The Michigan basin is located in Michigan, eastern Wisconsin, Indiana, Ohio, and under Lake Huron in Ontario. It has good CO_2 storage potential, with most of the resource situated in the United States. The Appalachian basin likely also has good CO_2 storage potential, with most potential located in the United States.

Rocks overlaying the Cincinnati Arch, which trends southwest-northeast from Alabama to Ohio and Ontario, include (in Canada) carbonates where oil and gas has been trapped. However, because of its shallow depth, the storage resource in Canada is likely limited, with more potential possibly under Lakes Huron, Erie, and Ontario.

Small, shared Pacific basins are located offshore along the Pacific coast from southwestern British Columbia to northwestern Washington State. No infrastructure exists and little exploration has been carried out on these basins. Generally, these basins are likely not suitable for CO_2 storage.

Among the Atlantic basins that occur offshore along the Atlantic shelf, the Scotia shelf is within Canada's territorial waters, and the Georges Bank basin is within the U.S. territorial waters, although some sediments may be present between the two. The small Bay of Fundy basin is shared between New Brunswick and Nova Scotia in Canada and Maine in the United States.

Along the Alaska-Yukon border, some small basins are shared. Offshore in the Arctic, the Beaufort basin is shared between the Northwestern Territories and Yukon in Canada and Alaska in the United States. The basin most likely has significant CO_2 storage potential, given the presence of oil and particularly large gas reserves, but the basin is far from major CO_2 sources and the difficult Arctic marine conditions make it an unlikely candidate for CO_2 storage.

To conclude, significant storage potential exists in the shared basins between Canada and the United States.

Domes covering CO_2 injector wellheads at the Weyburn CO_2-EOR project in Saskatchewan, Canada, blend into the landscape. (Courtesy: CCS101)

Mexico–U.S. Border

The United States and Mexico share sedimentary basins along their border, predominantly in the east. The Gulf of Mexico basin is located in the southeastern United States and northeastern Mexico, both onshore and offshore the Gulf of Mexico. Several sub-basins exist within the broader Gulf of Mexico basin, with the Rio Grande embayment and Burgos basin occurring along the border. The Rio Grande embayment is located along the southeastern coast of Texas, while the Burgos basin is located along the northeastern coast of Mexico. The boundary between the two intersects at the international border, where the Burgos basin is considered to be the equivalent or southern limit of the Rio Grande embayment. They are geologically similar and occur both onshore and offshore. Together, they form the westernmost part of the Gulf of Mexico basin. The Burgos basin has a high potential for gas reservoirs with a variety of traps. Considering the many oil and gas reservoirs in the Gulf of Mexico basin, significant CO_2 storage potential exists in this basin.

The South Texas basin extends from Texas into Mexico; within the South Texas basin is the Maverick basin, which straddles the border. There are potential oil and gas reservoirs in the Maverick basin. However, little exploration has taken place in this basin. The Marfa basin, located in west Texas and northeastern Mexico, may have some CO_2 storage potential.

The Orogrande basin is located in south-central New Mexico and Mexico and contains oil and gas reservoirs with CO_2 storage potential. The Pedregosa basin starts in the corner of southeastern Arizona and southwestern New Mexico and extends southeastward into north-central Mexico. The Pedregosa basin contains unexplored oil and gas reservoirs that may have CO_2 storage potential like other basins to the north.

To conclude, Mexico and the United States share many basins with CO_2 storage potential, largely concentrated in the Gulf of Mexico basin.

CO_2 Storage Resource Estimates for Oil and Gas Reservoirs in North America (Gigatonnes)			
	Canada	Mexico	United States
Total	16	Data not available	120

Oil and Gas Reservoirs in North America

Oil and gas reservoirs are porous rock formations (usually sandstones or carbonates) containing hydrocarbons (crude oil and/or natural gas) that have been physically trapped. There are two main types of physical traps: (1) stratigraphic traps, created when changes have occured in rock types, and (2) structural traps, in which the rocks have been folded or faulted to create a trapping reservoir. Oil and gas reservoirs are ideal geological storage sites because they have held hydrocarbons for thousands to millions of years and have conditions that allow for CO_2 storage. Furthermore, their architecture and properties are well known as a result of exploration for and production of these hydrocarbons, and infrastructure exists for CO_2 transportation and storage.

Traditionally, oil can be extracted from a reservoir in three different phases. The primary recovery phase uses the natural pressure in a reservoir to push the oil up through wells until the pressure drops to levels that do not allow the oil to flow any more. This process usually accounts for 10 to 15 percent of oil recovery. The secondary recovery phase involves the injection of water to increase the reservoir pressure and displace the oil towards producing wells. This process produces an additional 15 to 25 percent of the original oil. Together, these two phases account for the recovery of 25 to 40 percent of the original oil, but two-thirds of the oil remains in the reservoir. Tertiary recovery, or EOR, methods are used to recover an additional 20 to 60 percent of the original oil. Carbon dioxide can be used for EOR. When CO_2 is injected, it raises the reservoir pressure and increases the mobility of the oil, making it easier for the oil to flow towards producing wells. This method, called CO_2-EOR, is an attractive option for CO_2 storage because it uses pore space that otherwise would remain unavailable and it allows for the recovery and sale of additional oil that would otherwise remain trapped in the reservoir, thus lowering the net cost of CO_2 storage. In North America, CO_2 has been injected into oil reservoirs to increase oil recovery for more than 30 years.

For more information on CO_2 storage resource potential in oil and gas reservoirs and the methodologies each country used to estimate this potential, please see the country chapters and Appendix B.

Coal in North America

Coal that is considered unmineable as determined by geological, technological and economic factors (typically too deep, too thin or lacking internal continuity to be economically mined with today's technologies) may have potential for CO_2 storage. Coal preferentially adsorbs CO_2 over methane, which is naturally found in coal seams, at a ratio of 2 to 13 times. This property (known as adsorption trapping) is the basis for CO_2 storage in coal seams. Methane gas is typically recovered from coal seams by dewatering and depressurization, but this can leave significant amounts of methane trapped in the seam. The process of injecting and storing CO_2 in unmineable coal seams to enhance methane recovery is called enhanced coalbed methane (ECBM) recovery. Enhanced coalbed methane recovery parallels CO_2-EOR because it derives an economic benefit from the recovery and sale of the methane gas that helps to offset the cost of CO_2 storage. However, for CO_2 storage in coals to be possible, the coal must have sufficient permeability, which controls injectivity. Coal permeability depends on the effective stress and usually decreases with increasing depth. Furthermore, studies have shown that CO_2 injection can negatively affect coal permeability and injectivity.

For CO_2 storage in coals or ECBM recovery, the ideal coal seam should have sufficient permeability and be considered unmineable. Carbon dioxide storage in coals can take place at shallower depths (but at least 200 meters deep) than storage in hydrocarbon reservoirs and saline formations (which require at least 800 meters), because the CO_2 should be in the gaseous phase rather than in the supercritical or liquid phase. Research in this area is ongoing to optimize CO_2 storage.

For more information on CO_2 storage resource potential in unmineable coals and the methodologies each country used to estimate this potential, please see the country chapters and Appendix B.

CO_2 Storage Resources Estimates for Unmineable Coal in North America (Gigatonnes)					
	Canada		Mexico	United States	
	Low Estimate	High Estimate	Low Estimate	Low Estimate	High Estimate
Total	4	8	0	61	119

CO_2 Storage Resources Estimates for Saline Formations in North America (Gigatonnes)					
	Canada		Mexico	United States	
	Low Estimate	High Estimate	Low Estimate	Low Estimate	High Estimate
Total	28	296	100	1,610	20,155

Saline Formations in North America

Saline formations are layers of sedimentary porous and permeable rocks saturated with salty water called brine (water with a total dissolved solid count exceeding 10,000 parts per million). These formations are fairly widespread throughout North America, occurring in both onshore and offshore sedimentary basins, and have potential for CO_2 storage. For storage in saline formations, CO_2 is pressurized and injected at depths greater than 800 meters, where, under high pressure, it maintains a supercritical state (liquid-like density, but gas-like viscosity). Under these conditions, it fills the pore space by displacing already present brine.

It is important that a regionally extensive confining zone (often referred to as caprock) overlies the porous rock layer and that no major faults exist. Also, the storage capacity and injectivity of the formation needs to be known in order to determine whether CO_2 injection is economical. Another important factor is the ability of the porous rock reservoir layer to permanently trap the CO_2, because the CO_2 can dissolve in the brine (solubility trapping), react chemically with the minerals and fluid to form solid carbonates (mineral trapping), or become trapped in the pore space (volumetric trapping).

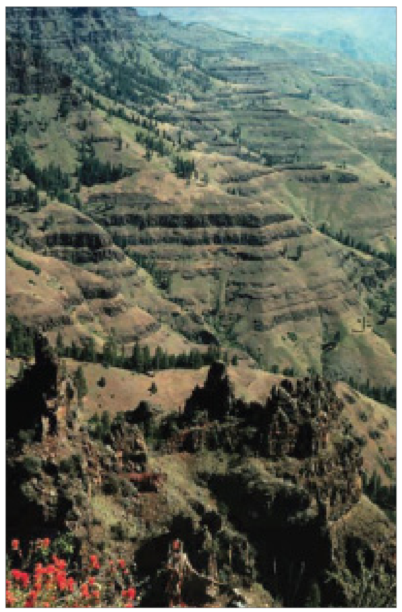
Saline formations are estimated to have much larger storage potential for CO_2 than oil and gas reservoirs and unmineable coals because they are more extensive and widespread, but their properties are less known. However, some knowledge about saline formations exists from the exploration for oil and gas and prior experience exists from the oil industry. Although saline formations have a greater amount of uncertainty than oil and gas reservoirs, they represent an enormous potential for CO_2 storage, and recent project results suggest that they can be used as reliable, long-term storage sites.

For more information on CO_2 storage resource potential in saline formations and the methodologies each country used to estimate this potential, please see the country chapters and Appendix B.

Future Geological Storage Options: Basalt Formations and Organic Shale Formations in North America

Two additional geological environments being investigated for CO_2 storage are basalt formations and organic shale formations. The relatively large amount of potential storage resource and favorable geographic distribution make basalt formations an important formation type for possible CO_2 storage, particularly in the Pacific Northwest and the southeastern United States. Basalt formations are geological formations of solidified lava. These formations have a unique chemical makeup that could potentially convert injected CO_2 into a solid mineral form, thus isolating it from the atmosphere permanently. Some key factors affecting the capacity and injectivity of CO_2 into basalt formations are effective porosity and interconnectivity. Current efforts are focused on enhancing and utilizing the mineralization reactions and increasing CO_2 flow within basalt formations.

Organic-rich shales are another geological storage option. Shales are formed from silicate minerals, which are degraded into clay particles that accumulate over millions of years. The plate-like structure of these clay particles causes them to accumulate in a flat manner, resulting in rock layers with extremely low permeability in a vertical direction. Therefore, shales are most often used in geological storage as a confining zone or caprock. Ongoing efforts are focused on using CO_2 for enhanced gas recovery (EGR).



Columbia River Basalt.

While the location of some basalt formations and organic-rich shale basins has been identified, a number of questions relating to the basic geology, the CO_2 trapping mechanisms and their kinetics, and monitoring and modeling tools need to be addressed before they can be considered viable storage targets. As such, no CO_2 storage resource estimates for basalt formations or organic-rich shale basins are currently available. Shale basins in North America of potential future interest for storage are indicated on the map.

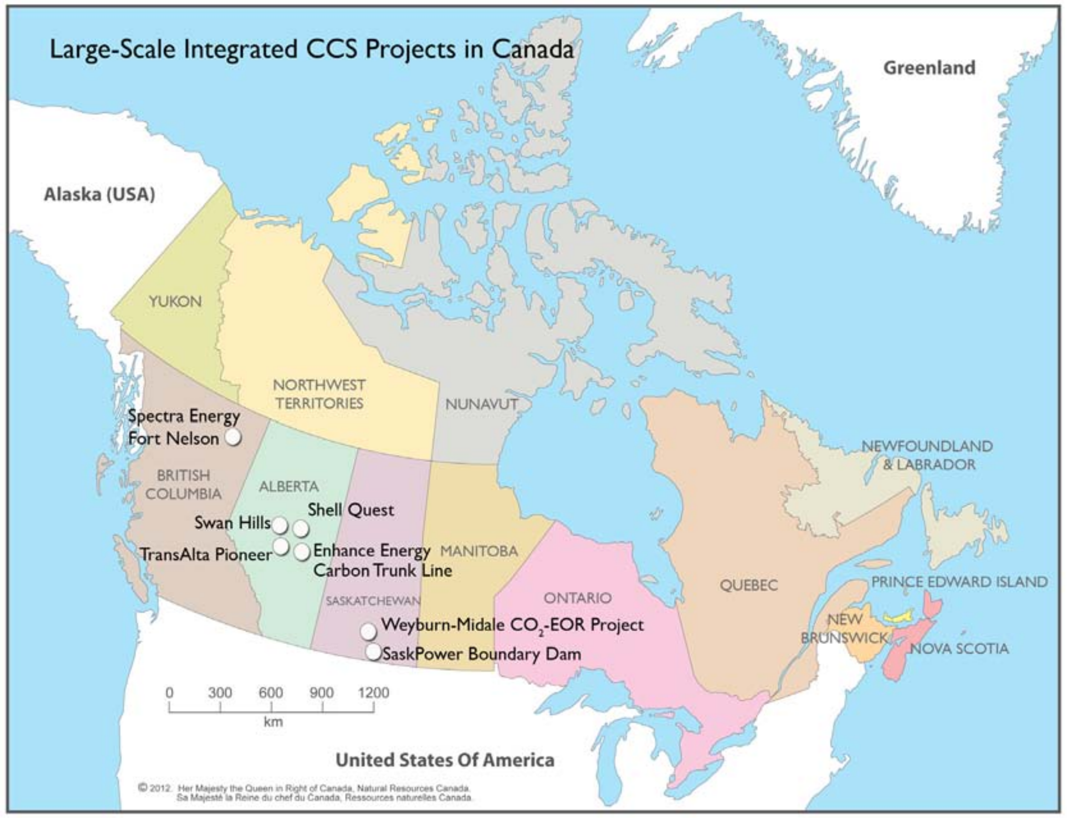
This map displays organic-rich shale basin data that were obtained by the U.S. DOE and other sources and compiled by NATCARB. Carbon dioxide geological storage information in NACSA was developed to provide a high-level overview of CO_2 geological storage potential across North America. Areal extents of geological formations presented are intended to be used as an initial assessment of potential geological storage. This information provides CCS project developers a starting point for further investigation. Furthermore, this information is required to indicate the extent to which CCS technologies can contribute to the reduction of CO_2 emissions and is not intended to serve as a substitute for site-specific assessment and testing.

Carbon Capture and Storage in Canada

Canada is committed to exploring carbon capture and storage as a leading technology to reduce GHG emissions in key sectors of the economy. With world-class geological storage potential, innovative companies, and a supportive policy and regulatory environment, Canada is making a significant global contribution to demonstrate CCS technology.

Canada's National Round Table on the Environment and Economy—an independent national advisory body on the environment and economy—reported in 2009 that, of all GHG reduction strategies needed to meet Canada's emissions reduction commitments, CCS technology has the potential to offer the single largest reduction in CO_2 emissions (up to 40 percent by 2050).

A Canada-Alberta ecoENERGY Carbon Capture and Storage Task Force confirmed in a 2008 report the strong case for rapid and widespread deployment of CCS in Canada, estimating that Canada has the potential to store as much as 600 megatonnes of CO_2 per year. Following that report, Alberta launched the Alberta CCS Development Council, which in 2009 produced a roadmap for the implementation of CCS in Alberta. In response to these task forces, the federal government and provincial governments have committed more than $3 billion to CCS initiatives through a number of federal and provincial programs.



As a result of these incentives, six first-of-a-kind, large-scale integrated CCS demonstration projects, which are to capture and store more than 1 megatonne of CO_2 annually each, are currently being advanced in Canada. Two are proceeding with construction; these include the SaskPower Boundary Dam project (a coal-fired electricity generation project) in Saskatchewan, and Enhance Energy's Alberta Carbon Trunk Line (a CO_2 pipeline project) in central Alberta.

Four other projects are at various stages of planning and engineering. They include the Quest project at Shell's Scotford oil sands upgrading facility in Alberta, the TransAlta Pioneer project (also a coal-fired electricity generation project) and the Swan Hills project (underground coal gasification and syngas-based electricity generation) in Alberta, and Spectra Energy's Fort Nelson shale gas processing project in northeast British Columbia. In almost all of these projects the captured CO_2 is either used for CO_2-EOR or stored in saline formations.

A seventh project, in operation since 2000, is the commercial CO_2-EOR project at Weyburn, Saskatchewan—one of the first large-scale CO_2 storage projects in the world. This project, operated by Cenovus Energy, together with a similar CO_2-EOR project operated by Apache Canada at its adjacent Midale oilfield, injects nearly 3 megatonnes of CO_2 per year to boost oil production. The CO_2 is captured at a coal gasification facility in North Dakota, transported across the Canada-U.S. border, and delivered to the EOR operations at Weyburn. To date, more than 21 megatonnes of CO_2 have been injected and safely and securely stored.

The Weyburn-Midale site also serves as the location of the International Energy Agency Greenhouse Gas R&D Program (IEAGHG) Weyburn-Midale CO_2 Monitoring and Storage Project. Canada is a founding member of this research initiative, which constitutes the world's largest international CO_2 measuring, monitoring and verification project, involving a consortium of several governments and many energy companies and research organizations.

Legal and regulatory frameworks are being aligned to facilitate CCS deployment. In order for Alberta to proceed with its large-scale CCS projects, the government of Alberta passed the Carbon Capture and Storage Statutes Amendment Act in 2010 to address uncertainty related to geological pore space ownership and the management of long-term liability of stored CO_2. Alberta also launched a Regulatory Framework Assessment to examine the existing environmental, safety, and assurance processes and determine what, if any, new regulatory processes need to be implemented. A final report is expected by the end of 2012. In Saskatchewan, amendments to the Oil and Gas Conservation Act to clarify and expand regulatory authority around CCS were passed in 2011. And in British Columbia a CCS policy and regulatory framework is currently being developed.

At the international level, Canada is working with the United States, through the U.S.-Canada Clean Energy Dialogue, to collaborate on CCS research and development projects, share knowledge gained from CCS projects, and enhance public engagement in CCS. Canada is also actively engaged in other international fora on CCS. It is a member of the Global CCS Institute; the Carbon Sequestration Leadership Forum; the Clean Energy Ministerial's Carbon Capture, Utilization, and Storage Action Group; the International Energy Agency; G-8; G20; and the Asia-Pacific Economic Cooperation.

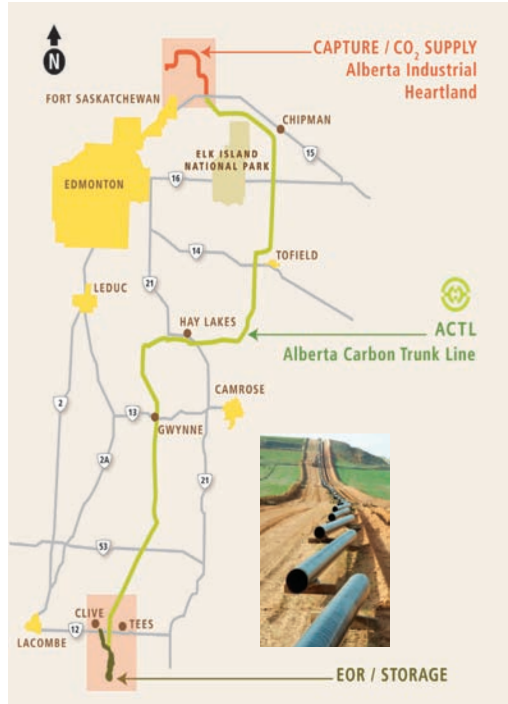
General view of the 1 megatonne/year CO_2 capture plant under construction at the SaskPower Boundary Dam Generating Station near Estevan, Saskatchewan, Canada. (Courtesy: SaskPower)

Tonne (t) = 1 metric ton Kilotonne (kt) = 1,000 metric tons Megatonne (Mt) = 1,000,000 metric tons Gigatonne (Gt) = 1,000,000,000 metric tons

Overall, Canada is committed to working both domestically and internationally to disseminate the knowledge gained from publicly-funded research and demonstration projects in order to accelerate the global deployment of CCS. This commitment includes the development of strategies and best practices for ensuring and communicating the safety and overall integrity of CO_2 storage.

The following pages describe the location, size, and type of Canada's large stationary CO_2 emission sources and the location and estimated size of the CO_2 storage resources assessed in this Atlas. These resources comprise oil and gas reservoirs, unmineable coal, and saline formations.

Based on these assessments, Canada's CO_2 storage resources are large. The summary table below shows for each province and territory the estimated mid-range CO_2 storage resources and provides an indication of how many years that province or territory could theoretically store the CO_2 emissions from its large stationary CO_2 sources. While emissions from western Canada are the highest in the country, the region also has the largest storage resources, which will last for hundreds of years. On the other hand, Ontario, the second largest emitting province in Canada, has limited storage potential compared to its emissions.



The Alberta Carbon Trunk Line , which will carry CO_2 captured at Alberta's industrial heartland to CO_2-EOR and storage sites in central Alberta. (Courtesy: Enhance Energy)

A technician monitors the CO_2-EOR operations of the Cenovus Weyburn oilfield in Saskatchewan, Canada. (Courtesy: Cenovus)

Summary of Canada's CO_2 Emissions from Large Stationary Sources, Storage Resource Estimates and Theoretical Storage Duration by Province/Territory

Province / Territory	CO_2 Emissions* (Megatonnes/ Year)	Oil and Gas Reservoirs		Unmineable Coal		Saline Formations		Total Provincial/ Territorial Storage Resources (Gigatonnes)	Total Provincial/ Territorial Storage Duration (Year)
		Storage Resources (Gigatonnes)	Storage Duration*** (Year)	Storage Resources** (Gigatonnes)	Storage Duration*** (Year)	Storage Resources** (Gigatonnes)	Storage Duration*** (Year)		
Alberta	107	12	110	6	55	28	270	46	430
British Columbia	8	3	350	<1	20	<1	30	3	400
Manitoba	1	<<1	10	0	0	1	1,000	1	1,000
Northwest Territories	<1	0	0	0	0	<<1	130	<<1	130
Ontario	41	<1	5	0	0	1	25	1	30
Quebec	16	0	0	0	0	4	210	4	210
Saskatchewan	20	1	40	<1	15	75	3,800	76	3,900
Other Provinces / Territories	24	N/A		N/A		N/A		N/A	
Canada	**219**	**16**	**70**	**6**	**30**	**110**	**500**	**132**	**600**

* Based on 2009 emissions from stationary sources emitting over 100 kilotonnes/year.

** Storage resources shown for unmineable coal and saline formations are mid-estimates.

*** Storage duration is provided as an indication of the amount of CO_2 storage resources available in a jurisdiction relative to its CO_2 emissions. Storage duration is calculated by dividing the amount of a CO_2 storage resource in a jurisdiction by the magnitude of the annual CO_2 emissions of that jurisdiction. All emission, storage resource, and storage duration figures are rounded. N/A – Not assessed. <<1 – much smaller than 1.

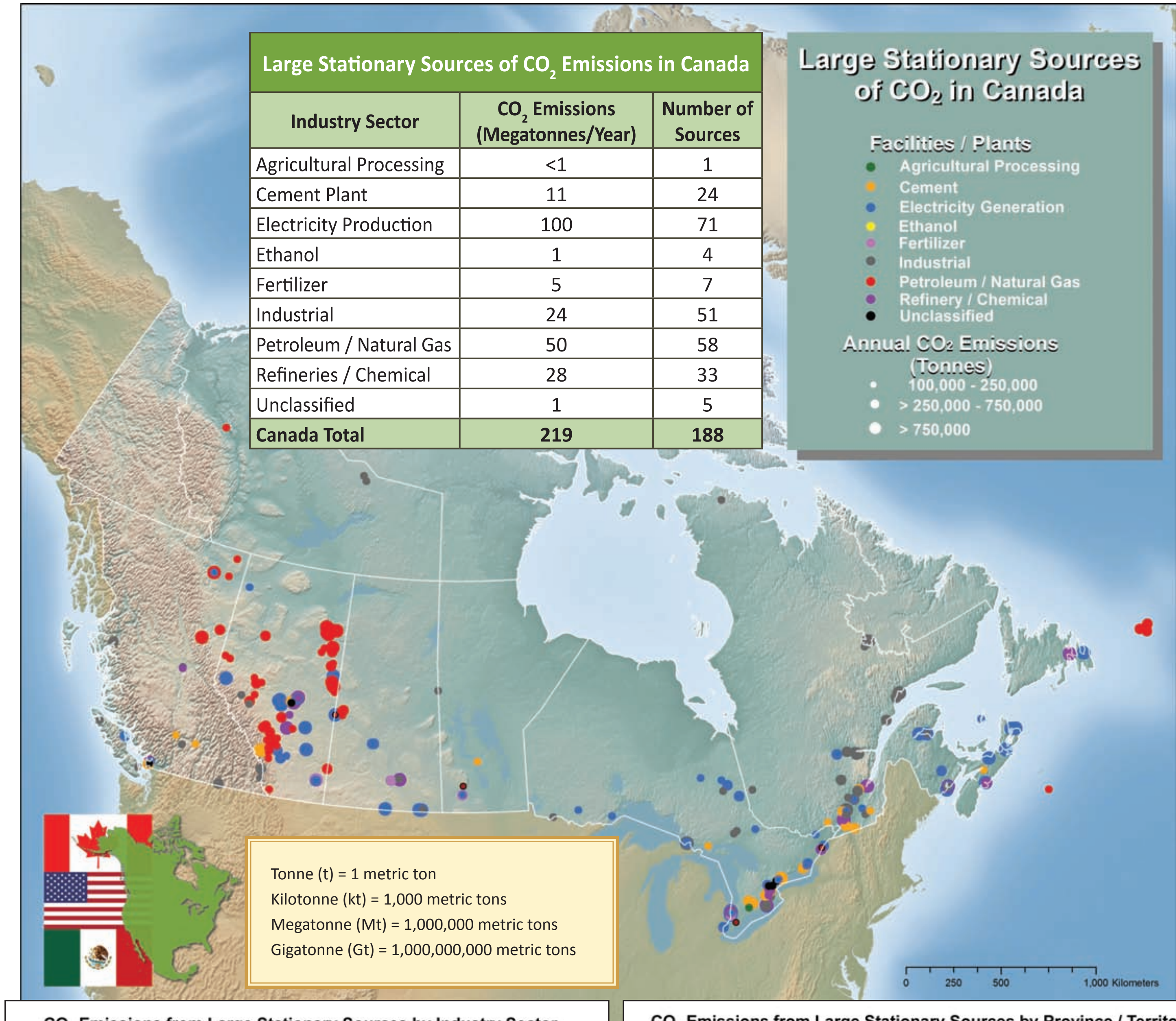
Large Stationary Sources of CO_2 in Canada

In 2009, Canada's total anthropogenic GHG emissions were estimated to be 690 megatonnes of CO_2 eq., of which 545 megatonnes (79 percent) was CO_2, which in turn represented 1.8 percent of the world's CO_2 emissions. Close to one-third of the GHG emissions (219 megatonnes CO_2 eq.) originates from large stationary CO_2 sources with emissions greater than 100 kilotonnes per year. These emissions consisted primarily of CO_2 (93.7 percent).

Emissions from power generation from fossil fuels, mainly coal, represent approximately half of Canada's CO_2 emissions from large stationary sources (see pie chart), with power plants concentrated in Alberta and Saskatchewan, where coal is mined locally, and in Ontario, New Brunswick, and Nova Scotia whose power plants import coal (see map). The next sectors that emit significant amounts of CO_2 are the energy sector (petroleum and natural gas) and refineries, petrochemical and chemical plants. The distribution of these large CO_2 sources reflects the location of the energy industry in western Canada and also the location of oil importing ports and processing facilities on the east coast and in central Canada. The industrial sector is responsible for approximately one-tenth of the CO_2 emissions from large stationary sources and is concentrated in Ontario and Quebec, the industrial heartland of Canada. Carbon dioxide emissions from cement plants, fertilizer plants, and other sectors (agricultural processing, ethanol production, and other unclassified) are cumulatively less than one-tenth of Canada's emissions from large stationary sources.

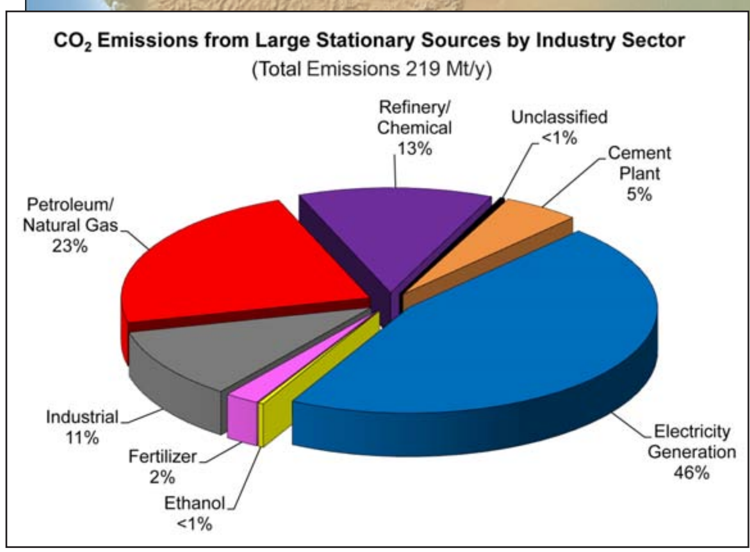
Given the nature of power generation, energy production, and the industrial base in the country, approximately half of the CO_2 emissions from large stationary sources originates in Alberta (see pie chart), as a result of its fossil fuel-based power generation and economy. Large sources in Ontario emit approximately one-fifth of the emissions from large stationary sources, while large sources in Saskatchewan represent approximately one-tenth of Canada's emissions from such sources. All other provinces and territories emit cumulatively approximately one-fifth of emissions from large sources. A full breakdown of the CO_2 emissions from large stationary sources by industry sector and province/territory is provided in Appendix C.

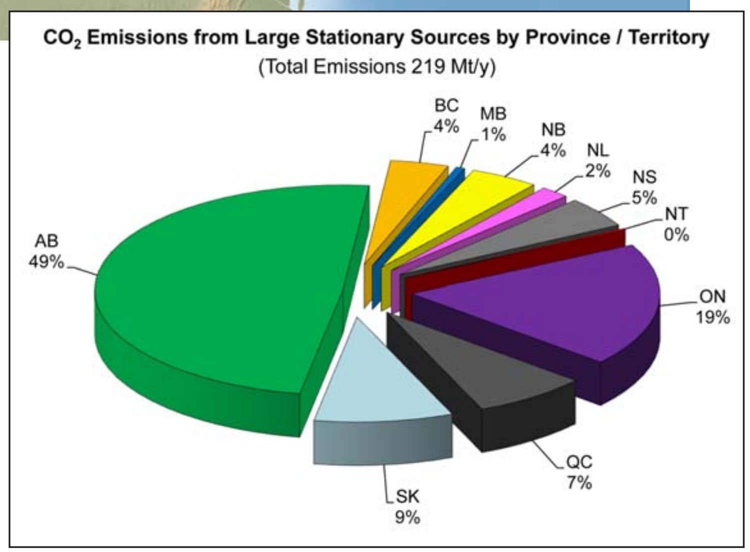
To conclude, the profile of the CO_2 emissions from large stationary sources in Canada reflects the energy and industrial base of the country, with power generation and the energy industry concentrated in the Prairie provinces (Alberta and Saskatchewan) and the Maritimes (mainly Nova Scotia), and the industrial base concentrated in central Canada (Ontario and Quebec).



Large Stationary Sources of CO_2 Emissions in Canada

Industry Sector	CO_2 Emissions (Megatonnes/Year)	Number of Sources
Agricultural Processing	<1	1
Cement Plant	11	24
Electricity Production	100	71
Ethanol	1	4
Fertilizer	5	7
Industrial	24	51
Petroleum / Natural Gas	50	58
Refineries / Chemical	28	33
Unclassified	1	5
Canada Total	**219**	**188**



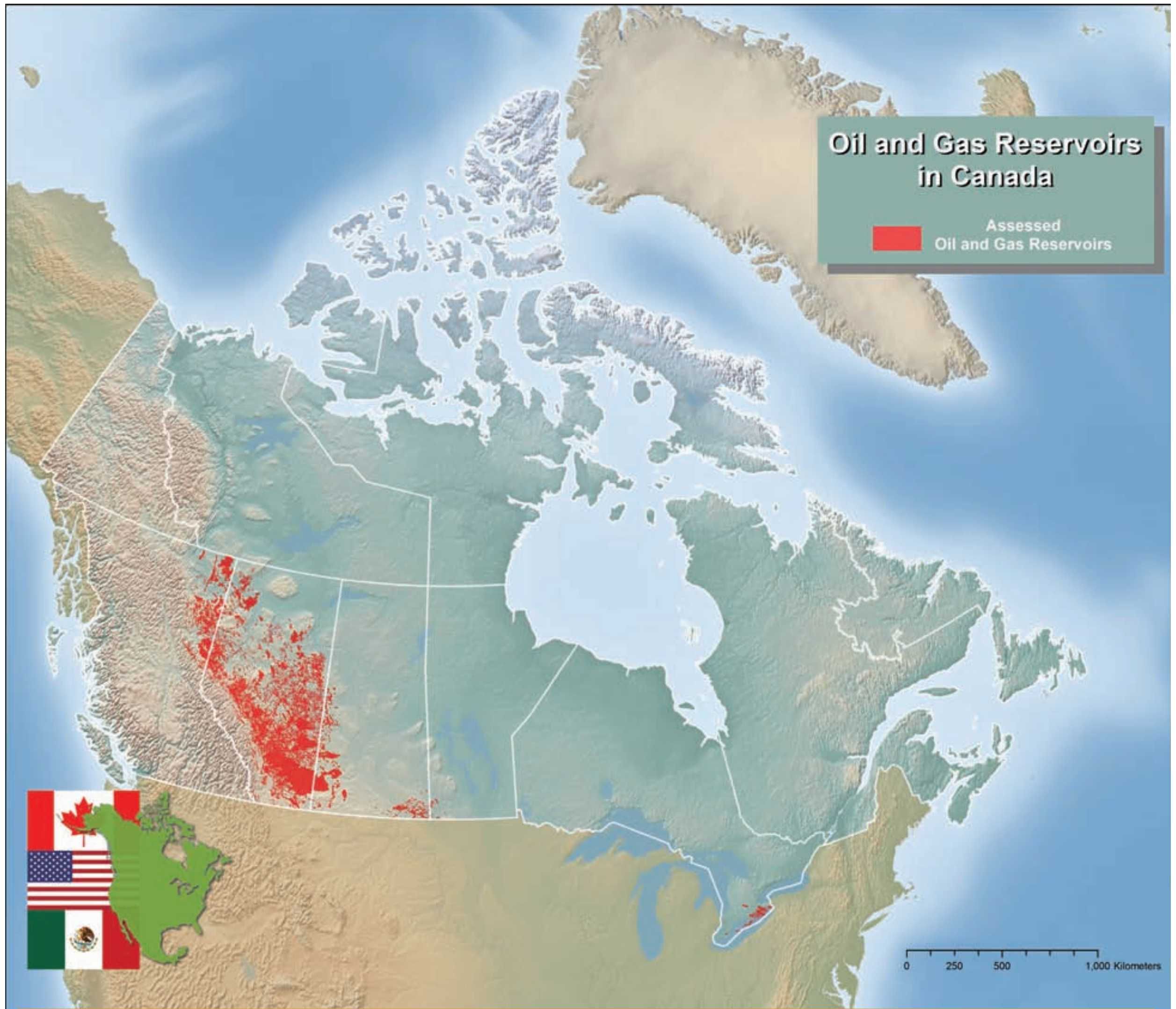


Oil and Gas Reservoirs in Canada

More than 50,000 distinct oil and gas reservoirs and oil reservoirs with a gas cap are found in northeastern British Columbia, Alberta, western and southeastern Saskatchewan, and southwestern Manitoba. A few gas reservoirs and oil reservoirs with a gas cap are also found in southern Ontario, most of them offshore beneath Lake Erie. Oil and gas reservoirs are also found offshore Nova Scotia and Newfoundland and in the Northwest Territories. Only reservoirs in British Columbia, Alberta, Saskatchewan, Manitoba, and Ontario have been assessed (see map), because reservoirs in other places are too far from CO_2 sources. Several hundred large oil reservoirs in secondary and tertiary recovery (see page 16) were not considered because there is little CO_2 storage resource left after flooding them with water and solvent or natural gas. Heavy oil and bitumen reservoirs, which are produced using thermal processes, were also not considered because of the geomechanical effects on the reservoir and caprock caused by the significant temperature variations during oil production. Hundreds of commingled oil or gas reservoirs were not evaluated in terms of CO_2 storage resource because of the challenge in assessing the recovery and in-situ conditions of the individual reservoirs whose production is commingled. Finally, the additional CO_2 storage resource that would be created by using CO_2-EOR was not evaluated because CO_2-EOR requires detailed evaluations based on numerical simulations of incremental oil recovery and CO_2 storage. Such evaluations were beyond the scope of this Atlas.

In calculating the storage potential of a given reservoir, it was assumed that, in conformance with current regulatory practices, CO_2 injection will raise the reservoir pressure to the initial reservoir pressure. Thus, the current evaluation of the CO_2 storage resource in oil and gas reservoirs covers only oil, gas, and oil & gas reservoirs that are, or have been, in primary production in the above-mentioned provinces. The majority of oil and gas reservoirs have small CO_2 storage resource, in the order of kilotonnes. Only reservoirs with a CO_2 storage resource at depletion greater than 1 megatonne were considered as a CO_2 storage resource to be inventoried. This resulted in only approximately 1,000 oil and gas reservoirs with sufficient individual storage potential being evaluated; their cumulative storage resource is reported by province and type of reservoir in the adjacent table. Gas reservoirs have 24 times more CO_2 storage capacity than oil reservoirs due to their larger number, larger size, and much higher recovery factor. Oil reservoirs with gas cap also have significant capacity at approximately 3 gigatonnes, and this is due mainly to the gas cap.

Provincially, the largest CO_2 storage resource is in Alberta, at close to 12 gigatonnes, followed by British Columbia with close to 3 gigatonnes. The CO_2 storage resource in Saskatchewan is much smaller compared with these two provinces, while the CO_2 storage resource in oil and gas reservoirs in Manitoba is negligible. The CO_2 storage resource in oil and gas reservoirs in Ontario is small compared with the western provinces and also compared with Ontario's CO_2 emissions from large stationary sources.



Location of the assessed CO_2 storage resource in oil and gas reservoirs in Canada. Offshore reservoirs, reservoirs too far from CO_2 sources, or reservoirs shallower than 800 meters were not considered in this evaluation. Also, heavy oil reservoirs, bitumen reservoirs, and oil reservoirs in secondary or tertiary recovery were not considered either. Only reservoirs with storage potential greater than 1 megatonne were considered in the final analysis.

CO_2 Storage Resource Estimates for Oil and Gas Reservoirs in Canada (Gigatonnes)

Province	Oil	Gas	Oil & Gas (oil reservoirs with gas cap)	Total
Alberta	<1	9	3	12
British Columbia	<<1	3	<1	3
Manitoba	0	0	<<1	<<1
Ontario	0	<1	0	<1
Saskatchewan	<1	1	<1	1
Canada Total	**<1**	**12**	**3**	**16**

Location of CO_2 storage resources in coal in Canada. Coals in small intra-montane basins in British Columbia, Yukon, on Vancouver Island, in the Northwest Territories and in the Arctic were not considered because they are located too far from CO_2 sources. Coals in southern Saskatchewan, New Brunswick, Nova Scotia and Newfoundland were not considered because they are too shallow. Only coals in the Alberta basin in the depth range 800 to 1200 meters were considered in the assessment.

CO_2 Storage Resource Estimates for Unmineable Coal in Canada (Gigatonnes)

Province	Low Estimate	Mid Estimate	High Estimate
Alberta	3	6	8
British Columbia	<1	<1	<1
Saskatchewan	<1	<1	<1
Canada Total	**4**	**6**	**8**

Coal in Canada

Canada has significant coal resources of variable rank (from lignite to anthracite) in British Columbia, Alberta, Saskatchewan, Nova Scotia, Yukon and Northwest Territories, and in the Arctic. Except for metallurgical or coking coal, which is exported, lower rank coal (thermal coal) is mined in Alberta and Saskatchewan for power generation. In terms of the CO_2 storage resource in coal, coals that are too far from CO_2 sources, shallower than 800 meters, or deeper than 1200 meters were not considered in Canada's evaluation, thus ensuring that they are deeper than protected groundwater resources and also taking into account the decrease in coal permeability, hence injectivity, with depth as a result of increasing effective stress. Only coals in the Alberta basin (northeastern British Columbia, Alberta, and western Saskatchewan) were considered in this inventory of the CO_2 storage resource in coal in Canada (see map).

Several coal zones in the Alberta basin were mapped: the Upper Cretaceous Ardley, Edmonton and Belly River, and the Lower Cretaceous Mannville. Except for the latter, all other coals crop out at the ground surface where they are mined for power generation. Given the structure of the Alberta basin, these coal zones form distinct arcuate bands parallel with the Rocky Mountains. Coal CO_2 adsorption isotherms and moisture and ash content were used in calculating the CO_2 storage resource. The distribution of the CO_2 storage resources in coal in the three westernmost Canadian provinces is shown in the table for low, mid, and high estimates (see also Appendix B for the methodology used). The discussion below is based on the mid estimates.

Again, as in the case of oil and gas reservoirs, it can be seen that Alberta has by far the largest CO_2 storage resource in coals in the country at 6 gigatonnes of CO_2. Saskatchewan's CO_2 storage resource is much smaller (300 megatonnes of CO_2) and is located in western Saskatchewan, while Saskatchewan's emissions from large sources are located in central, southern, and southeastern Saskatchewan. Therefore, utilization of this resource would require the construction of long pipelines. The CO_2 storage resource in coals in northeastern British Columbia is the smallest at 170 megatonnes and is dwarfed by the CO_2 storage resource in oil and gas reservoirs in the region.

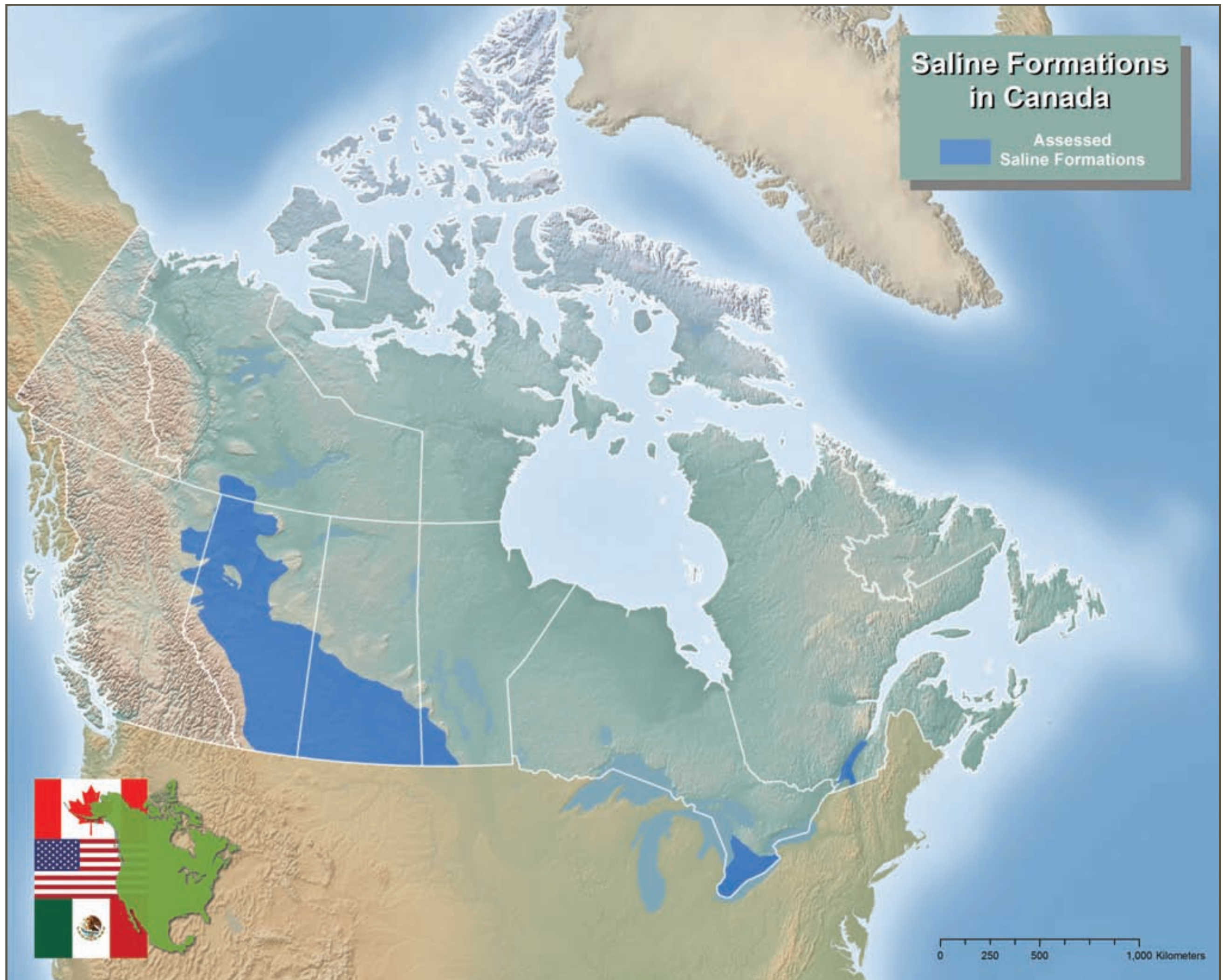
Given the size of the CO_2 storage resource in coals in the three provinces compared with the size of the storage resource in oil and gas reservoirs and in saline formations (see next section) and considering the immaturity of this storage technology compared with storage in the other two geological formations, it is unlikely that the coal storage resource will be utilized in the near future.

Saline Formations in Canada

The CO_2 storage resource in saline formations was estimated for the Alberta, Williston, Michigan, and Appalachian basins in Canada, corresponding to northeastern British Columbia, Alberta, Saskatchewan, southwestern Manitoba, southern Ontario, and southern Quebec. Only saline formations deeper than 800 meters were considered to ensure that CO_2 is in dense phase (liquid or supercritical, depending on temperature). Similarly, only regions of these saline formations with porosity greater than 4 percent were considered on the assumption that regions with porosity of less than 4 percent lack local capacity and injectivity to make them suitable for CO_2 storage. The CO_2 storage resource was estimated based on existing geothermal gradients and on the assumption of an overall average pressure increase of 10 percent above the initial formation pressure as a result of CO_2 injection.

Because the sedimentary succession in the Michigan and Appalachian basins in Canada is relatively thin, being located at the edge of these basins whose depo-centers are located in the United States, the CO_2 storage resource was estimated for all saline formations occuring in these basins. The situation is quite different in western Canada (Alberta and Williston basins), where there are close to 30 saline formations of various areal extent and thickness in the sedimentary succession. It was not possible to estimate the CO_2 storage resource in all these formations within the scope of this Atlas, so the CO_2 storage resource was estimated for only the six deepest saline formations in the sedimentary succession. They are, listed in ascending order: Basal Aquifer (overlying the Precambrian crystalline basement), Winnipegosis, Slave Point, Cooking Lake, Nisku, and Charles-Rundle. These saline formations were selected based on several criteria, including areal extent, depth, thickness, porosity, permeability, pressure, temperature, water salinity, and seal integrity. The CO_2 storage resources for British Columbia, Alberta, Saskatchewan, and Manitoba, provided in the table to the right, are based on CO_2 storage resource estimates for these six saline formations only. This means that considerable CO_2 storage resource in saline formations in the Alberta and Williston basins has not yet been assessed, and that the values provided in the table represent a lower limit of the CO_2 storage resource in saline formations in the four western Canadian provinces. As shown in the table, for each of the assessed saline formations, low, mid, and high estimates for the CO_2 storage resource were obtained using the methodology described in Appendix B.

An examination of the maps in this section and in the section on CO_2 sources shows that saline formations underlie most of the large stationary CO_2 sources in Canada from northeastern British Columbia to southwestern Manitoba (the Alberta and Williston basins), where power generation, energy, and petrochemical industries are located, and in southern Ontario and southern Quebec, where power generation, manufacturing, refineries/petrochemical, and mining/smelting industries are located. Saskatchewan has the largest CO_2 storage resource in saline formations, due to the large storage resource in the Basal Formation, followed by Alberta.



Map shows location of saline formations in Canada assessed in NACSA. Saline formations too far from large CO_2 sources, located in an area of high tectonic activity, located in small intra-montane basins in the Rocky Mountains and in the Atlantic provinces were not evaluated at this time on the basis of a screening process adapted after Bachu (2003). Only the saline formations underlying or close to large stationary sources in Alberta and Saskatchewan in the west (in the Alberta basin and the Canadian portion of the Williston basin) and in central Canada (in the Michigan and Appalachian basins) were evaluated, and the results are presented in the table below.

CO_2 Storage Resource Estimates for Saline Formations in Canada (Gigatonnes)

Province	Low Estimate	Mid Estimate	High Estimate
Alberta	7	28	76
British Columbia	<<1	<1	<1
Manitoba	<1	1	4
Northwest Territories	<<1	<<1	<1
Ontario	<1	1	3
Quebec	1	4	9
Saskatchewan	19	75	203
Canada Total	**28**	**110**	**296**

Carbon Capture and Storage in Mexico

Developing an understanding of CCS in Mexico's energy sector has followed two parallel paths. The first path evaluates research for EOR technologies, which started at the beginning of the last decade. The second path includes the Federal government´s role in mitigating climate change. Carbon capture and storage was first introduced as a suitable technology to be developed and deployed in Mexico in the National Climate Change Strategy presented in 2007. The role of CCS was further explored in the Special Climate Change Program, which included commitments for the period 2009-2012:

- Develop a study on the state of the art of CO_2 capture and geological storage technologies, and their viability in Mexico (completed and published).
- Prepare an analysis of a thermal power plant or a combined-cycle plant and its synergies with projects that can use CO_2 emissions to accelerate photosynthesis processes and produce materials or alternative fuels.

The inclusion of these specific objectives, as well as the federal government's positive attitude towards technology development under international cooperation arrangements, led the energy sector to work on a set of CCS activities. NACSA is a tool to broaden technical cooperation and enhance public awareness of the development of CCS technology and its potential economic and environmental benefits.

Mexico has embraced other parallel international initiatives, placing Mexico at the forefront of developing countries. Mexico is a founding member of the Global Carbon Capture and Storage Institute; an active participant in the Carbon Sequestration Leadership Forum; and the Carbon Capture, Use, and Storage Action Group of the Clean Energy Ministerial.

In 2012, the federal government included Carbon Capture, Use, and Storage as a topic in the National Energy Strategy 2012-2026, with specific tasks and goals for the next 5 years, which comprise the development of a national atlas, a GIS on CCS, and a national strategy to be developed by the end of 2012. Likewise, other goals have been established for pilot and demonstration projects on CCS-EOR and the acceleration of photosynthesis processes.

Pipe conveyor oil, Mexico.

Cargo ship, Mexican Sea.

Electric tower, Mexico.

Thermoelectric Central Petacalco, Michoacan.

The information presented in this Atlas includes geological analyses and estimations of the CO_2 storage potential on country and basin scales. The work was completed using theoretical methods, and no fieldwork was performed. However, it is expected that future research will include fieldwork, well drilling, and laboratory tests as part of regional, local, and site-specific assessments.

Within the inclusion zone recommended for CO_2 storage, nine out of eleven defined sedimentary provinces or basins were assessed to determine their theoretical storage potential in saline formations. Based on the analysis of 111 sectors, the theoretical CO_2 storage resource was approximately 100 gigatonnes.

Large Stationary Sources of CO_2 in Mexico

The most recent update of Mexico's National Inventory of Greenhouse Gases was completed and submitted in 2010 under the Fourth National Communication to the United Nations Framework Convention on Climate Change with data from 2006. The Inventory shows total annual GHG emissions in Mexico to be above 709 megatonnes of CO_2 eq. Of this total, CO_2 emissions amount to 492 megatonnes or 69.5 percent, which includes both stationary and non-stationary sources. If only large stationary sources are considered, annual CO_2 emissions are estimated at 285 megatonnes or 40 percent.

According to 2010 data from the Mexican Pollutants Release and Transfer Registry (RETC), there are 188 large stationary CO_2 sources with emissions totaling more than 100 kilotonnes per year. Their total emissions amount to approximately 205 megatonnes per year of CO_2. Power generation contributes the most to CO_2 emissions from stationary sources, with emissions of 106 megatonnes per year or roughly 52 percent of the total. This figure includes emissions from Comisión Federal de Electricidad (CFE), as well as private power producers. The oil and petrochemical sector accounts for another 22 percent. Therefore, with emissions of 151 megatonnes per year, the energy sector as a whole is responsible for 74 percent of CO_2 emissions from stationary sources in Mexico.

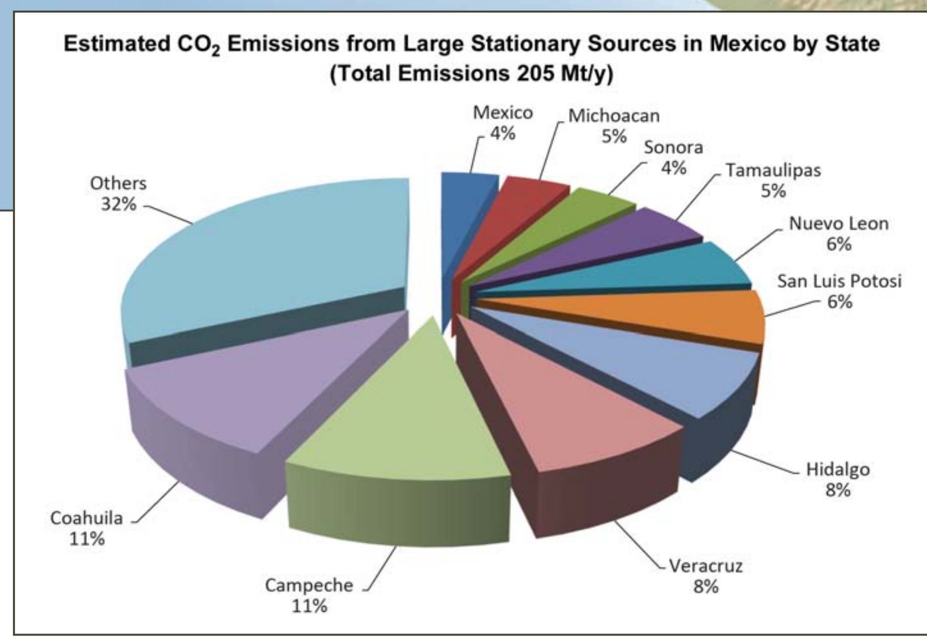
Power generation produces a large volume of CO_2 emissions from a small number of sources. Therefore, there is opportunity to use CO_2 capture techniques in power plants.

Estimated CO_2 Emissions from Large Stationary Sources in Mexico*

Industry Sector	CO_2 Emissions (Megatonnes/Year)	Number of Sources
Agricultural Processing	1	3
Cement Plant	26	34
Electricity Generation	106	64
Industrial	25	38
Petroleum / Natural Gas	45	38
Refineries / Chemical	2	11
Mexico Total	**205**	**188**

* Only includes facilities with emissions greater than 100 kilotonnes/year, as reported via Annual Certificate of Operation (COA) to RETC, managed by SEMARNAT.

Tonne (t) = 1 metric ton
Kilotonne (kt) = 1,000 metric tons
Megatonne (Mt) = 1,000,000 metric tons
Gigatonne (Gt) = 1,000,000,000 metric tons



Selected Geological Provinces in Mexico

Mexico is subdivided into two general zones: an exclusion zone and an inclusion zone. The exclusion zone is characterized by extensive volcanic igneous rocks and frequent seismic, tectonic, and volcanic activities. This zone is not recommended for CO_2 storage until further geological studies have been conducted.

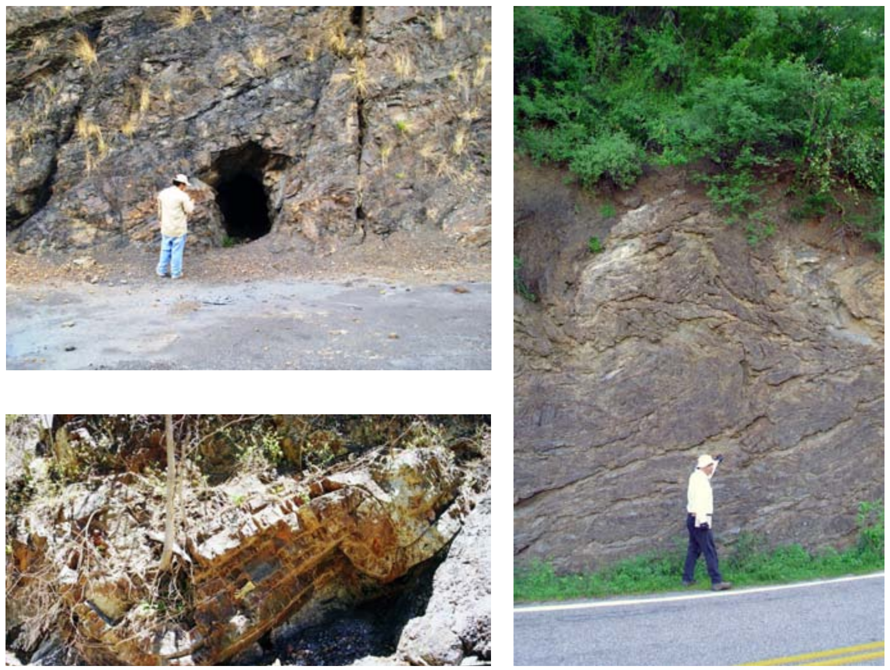
The inclusion zone is represented by geologically stable areas, involving terrigenous, carbonate and evaporitic sedimentary rock sequences of different ages and depositional environments. The inclusion zone is the country´s best potential target for CO_2 storage, although specific geological studies are still required. The inclusion zone comprises mainly the north-central and eastern portions of Mexico.

Within the inclusion zone, 11 geological provinces were identified as having potential for CO_2 storage in saline formations deeper than 800 meters. Nine of these provinces were assessed and an estimate was generated for their CO_2 storage resource potential. These provinces include Chihuahua, Coahuila, Central, Burgos, Tampico-Misantla, Veracruz, Southeastern, Yucatan, and Chiapas.

In terms of CO_2 storage in depleted and mature oilfields, Petróleos Mexicanos (PEMEX) is at present conducting several studies that would facilitate a nation-wide evaluation of these storage resources. The results of such studies would be available for future editions of this Atlas.

Coal in Mexico

The most important coal basins in Mexico are not suitable for CO_2 storage. The Sabinas and Río Escondido coal basins in Coahuila state are still in production. They produce 10 megatonnes of coal each year to fire two of Mexico's three coal-fired power plants. The Sabinas coal basin is also the current source of coal for the iron and steel industry in northeast Mexico, the most important in the country. As long as this situation continues, which according to evaluations could be more than 50 years, the northeast coal region cannot be used for CO_2 storage purposes. As for the other two well-known Mexican coal basins, Sonora and Oaxaca, they both are of such structural complexity that CO_2 storage would be difficult. The coal basins in the central and northern part of Sonora State are of Triassic and Cretaceous age, respectively, and have been subjected to a series of tectonic phenomena that have resulted in fractured, folded, faulted, and dislocated blocky formations, which makes it difficult to pursue and trail a coal bed. This situation limits the coal industry in Sonora to low-scale craft well-mining with production rates too low to develop industrial facilities. The Cretaceous coal basin in Oaxaca State is of a similar structure and complexity as Sonora. The pictures below illustrate the condition of the beds in the coal basins of Sonora and Oaxaca.



Different coal outcrops in the Santa Clara Formation in Central Sonora. Note the fractures, faults, and folds over very short intervals. (Courtesy: CFE Geology Department, 2010)

Saline Formations in Mexico

Saline formations in Mexico are located in continental areas as well as offshore along the marine shelf platform of the Gulf of Mexico. These saline formations occur within sedimentary rock sequences in geological basins or provinces, and they are envisaged as some of the most favorable CO_2 storage resources in Mexico. Therefore, for the purposes of this Atlas, Mexican analyses only consider deep saline formations.

Biosphere Reserve Centla Swamps, Tabasco.

Detailed Analysis of Saline Formations in Mexico

The theoretical CO_2 storage resource estimate for saline formations in 111 assessed sectors currently stands at 100 gigatonnes, distributed in different regions.

The analysis of stratigraphical and structural data in the Chihuahua geological province yields five sectors with a CO_2 storage resource estimate of approximately 0.42 gigatonnes in carbonate sedimentary rock sequences.

Within the Coahuila geological province, 12 sectors are proposed that show a CO_2 storage resource of 13 gigatonnes. Six gigatonnes were found in carbonate sedimentary sequences, and 7 gigatonnes in terrigenous sedimentary sequences.

The estimated total CO_2 storage resource in the Central geological province is approximately 0.01 gigatonnes; this considers only one carbonate sector.

In the Burgos geological province, geological and stratigraphical analyses indentified 31 potential sectors within terrigenous sedimentary sequences. A total of 17 gigatonnes of CO_2 storage resource was estimated.

The analysis of stratigraphical and structural data in the Tampico-Misantla geological province yields 12 sectors with a total CO_2 storage resource estimate of 10 gigatonnes. Four sectors correspond to carbonate sedimentary sequences and eight to terrigenous sedimentary sequences.

The Veracruz geological province shows 21 sectors with CO_2 storage potential. Five sectors are included within carbonate sedimentary sequences while 16 correspond to terrigenous sedimentary sequences. The total CO_2 storage resource estimation is 15 gigatonnes.

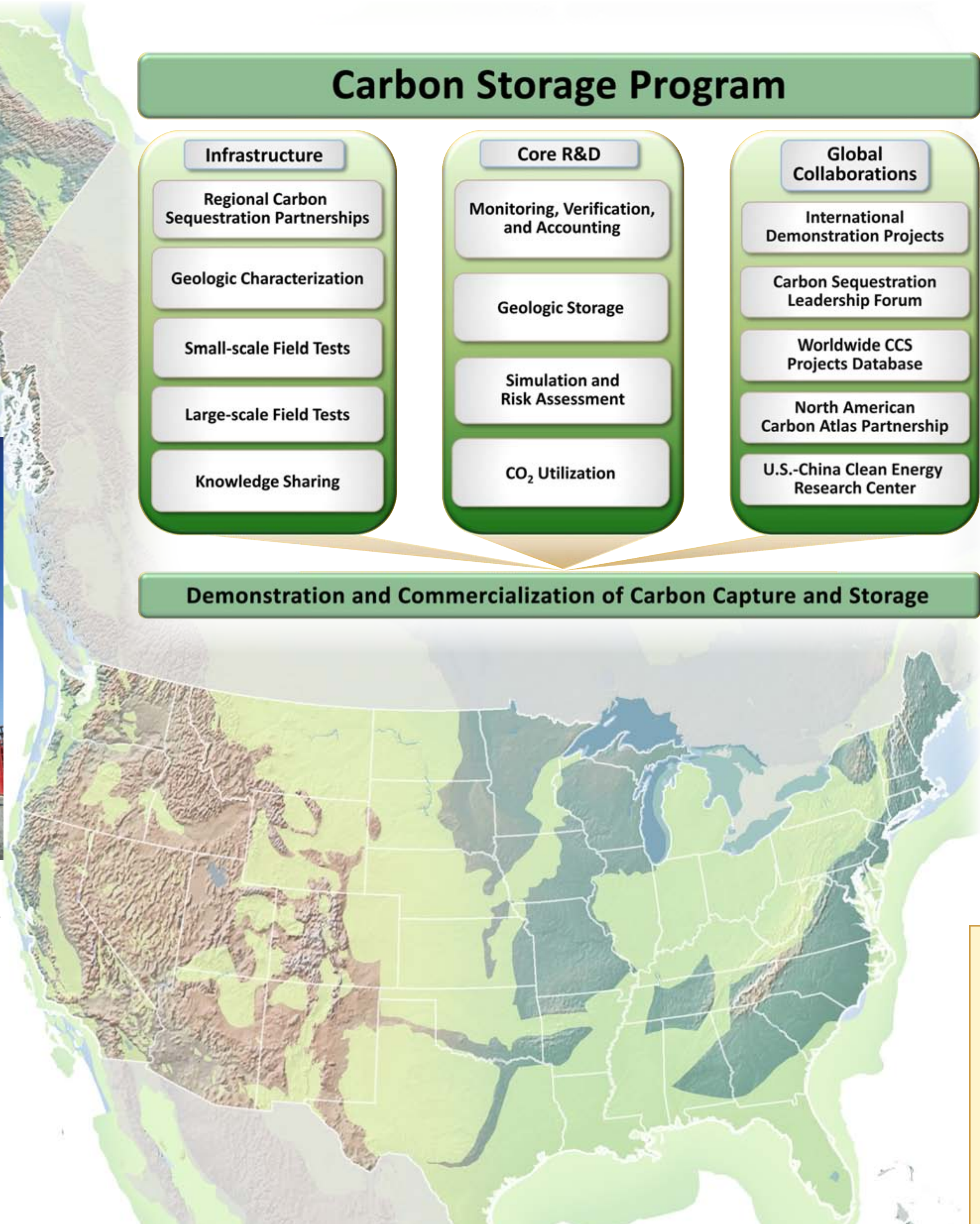
Within the Southeastern geological province, 17 sectors are capable of CO_2 storage in terrigenous sedimentary rock sequences with a theoretical storage potential of 24 gigatonnes.

After geological and stratigraphical analyses were carried out in the Yucatan geological province, 7 sectors were found with an estimated theoretical CO_2 storage resource of 14 gigatonnes. Ten gigatonnes are in terrigenous rock sequences while four are in carbonate sequences.

The CO_2 storage resource estimated for the Chiapas geological province is 6 gigatonnes, located in five sectors composed of carbonate sedimentary sequences.

CO_2 Storage Resource Estimates for Saline Formations in Assessed Geological Provinces / Sectors in Mexico

Geological Province	Sedimentary Sequence	Theoretical Storage Potential (Gigatonnes)	Sectors Assessed
Chihuahua	Carbonate	<1	5
Coahuila	Carbonate	6	10
	Terrigenous	7	2
Central	Carbonate	<1	1
Burgos	Terrigenous	17	31
Tampico-Misantla	Carbonate	3	4
	Terrigenous	7	8
Veracruz	Carbonate	1	5
	Terrigenous	14	16
Southeastern	Terrigenous	24	17
Yucatan	Carbonate	4	2
	Terrigenous	10	5
Chiapas	Carbonate	6	5
Mexico Total	—	**100**	**111**



BSCSP Validation Phase geological pilot site near Wallula, Washington. (Courtesy: Sarah Koenigsberg)

An estimated 600 to 6,700 years of CO_2 storage resource is available in the United States based on 2011 emission rates.

Carbon Capture and Storage in the United States

The U.S. DOE's Carbon Storage and Carbon Capture Programs are helping to develop technologies to capture, separate, and store CO_2 in order to reduce GHG emissions without adversely influencing energy use or hindering economic growth. These technologies encompass the entire life-cycle process for controlling CO_2 emissions from large stationary sources, such as coal-based power plants. By cost-effectively capturing CO_2 before it is emitted to the atmosphere and then permanently storing it, coal can continue to be used while promoting economic growth and reducing CO_2 emissions. Integrated, cost-effective, and efficient CCS technologies must be developed and demonstrated at full-scale prior to their availability for widespread commercial deployment.

The U.S. DOE's Carbon Storage Program is comprised of three key elements for CCS technology development and research: (1) Infrastructure; (2) Core R&D; and (3) Global Collaborations. The primary component of the Infrastructure element is the Regional Carbon Sequestration Partnerships (RCSPs), a government/academic/industry cooperative effort tasked with characterizing, testing, and developing guidelines for

U.S. DOE's Carbon Storage Program Field Projects

Regional Carbon Sequestration Partnership Field Projects:

- 8 large-scale field tests planned (approximately 1 megatonne)
- 18 small-scale field tests complete (more than 1.23 megatonnes injected)
- 11 terrestrial CO_2 storage tests complete

Non-Regional Carbon Sequestration Partnership Field Projects:

- 3 small-scale field tests (injection of less than 0.5 megatonnes of CO_2 per year) in unconventional reservoirs the most suitable technologies, and infrastructure for CCS in different regions of the United States and several provinces in Canada. The Core R&D element is comprised of four focal areas for CCS technology development: (1) Monitoring, Verification, and Accounting; (2) Geologic Storage; (3) Simulation and Risk Assessment; and (4) CO_2 Utilization. The Core R&D element is driven by technology needs and is accomplished through applied laboratory and pilot-scale research aimed at developing new technologies for GHG mitigation. The Core R&D and Infrastructure elements provide technology solutions that support the Global Collaborations element. The U.S. DOE participates and transfers technology solutions to international efforts that promote CCS, such as the Carbon Sequestration Leadership Forum, NAEWG, and several international demonstration projects.

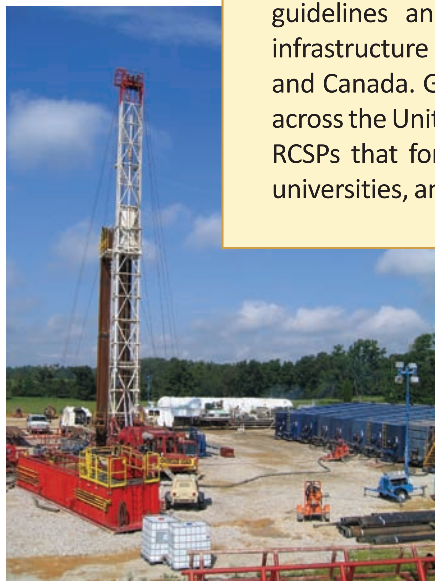
To accomplish widespread deployment, four Carbon Storage Program goals have been established: (1) develop technologies that will support industries' ability to predict CO_2 storage capacity in geological formations; (2) develop technologies to demonstrate that 99 percent of injected CO_2 remains in the injection zones; (3) improve efficiency of storage operations; and (4) complete a series of Best Practices Manuals that serve as the basis for the design and implementation of commercial CCS projects.

Carbon capture and storage and other clean coal technologies being developed by U.S. DOE can play a critical role in mitigating CO_2 emissions while supporting energy security in the United States. The U.S. DOE's Carbon Storage Program is working to ensure that enabling technologies will be available to affect broad CCS deployment in the United States. Continued U.S. leadership in technology development and future deployment is important to the cultivation of economic rewards and new business opportunities both domestically and abroad.

Regional Carbon Sequestration Partnership (RCSP)	Acronym/Abbreviated Name
Big Sky Carbon Sequestration Partnership	BSCSP
Midwest Geological Sequestration Consortium	MGSC
Midwest Regional Carbon Sequestration Partnership	MRCSP
Plains CO_2 Reduction Partnership	PCOR
Southeast Regional Carbon Sequestration Partnership	SECARB
Southwest Regional Partnership on Carbon Sequestration	SWP
West Coast Regional Carbon Sequestration Partnership	WESTCARB

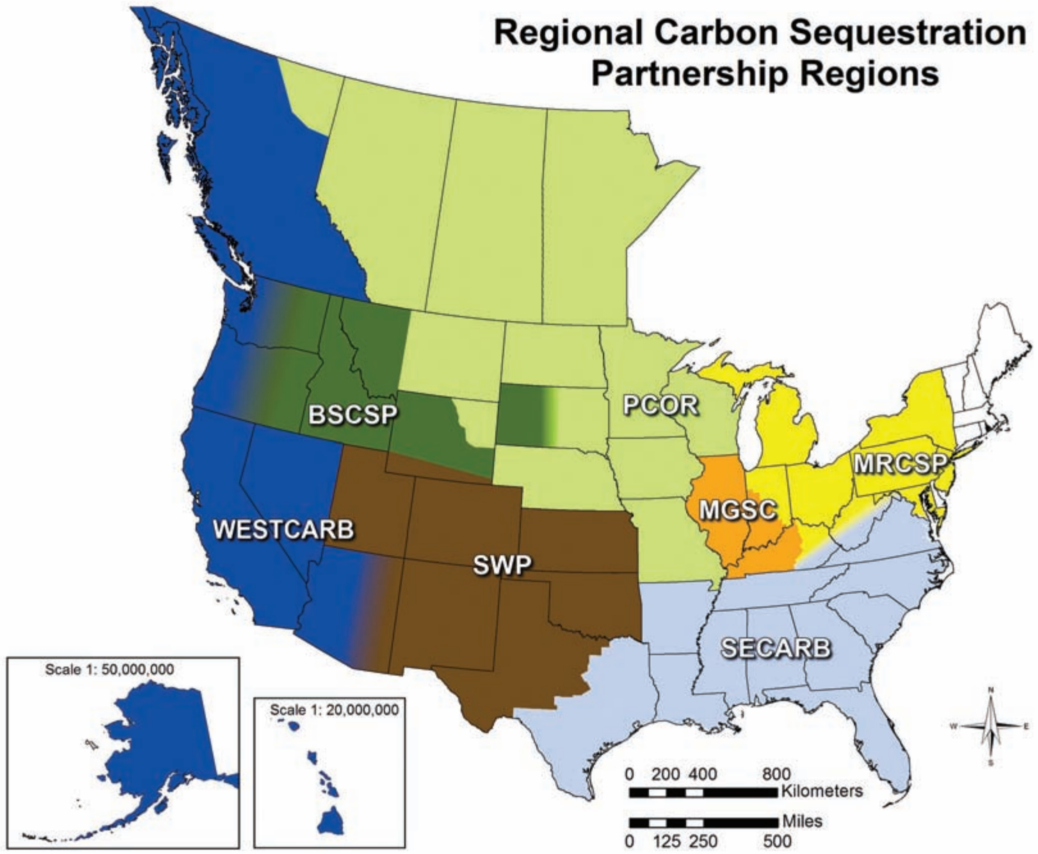
Regional Carbon Sequestration Partnership Initiative

Initiated by U.S. DOE Fossil Energy, the Regional Carbon Sequestration Partnerships (see map at bottom) are a public/private partnership tasked with developing guidelines and testing for the most suitable technologies, regulation, and infrastructure needs for CCS within seven different regions of the United States and Canada. Geographical differences in fossil fuel use and CO_2 storage potential across the United States and Canada dictate regional approaches to CCS. The seven RCSPs that form this network currently include more than 400 state agencies, universities, and private companies, spanning 43 states, and 4 Canadian provinces.

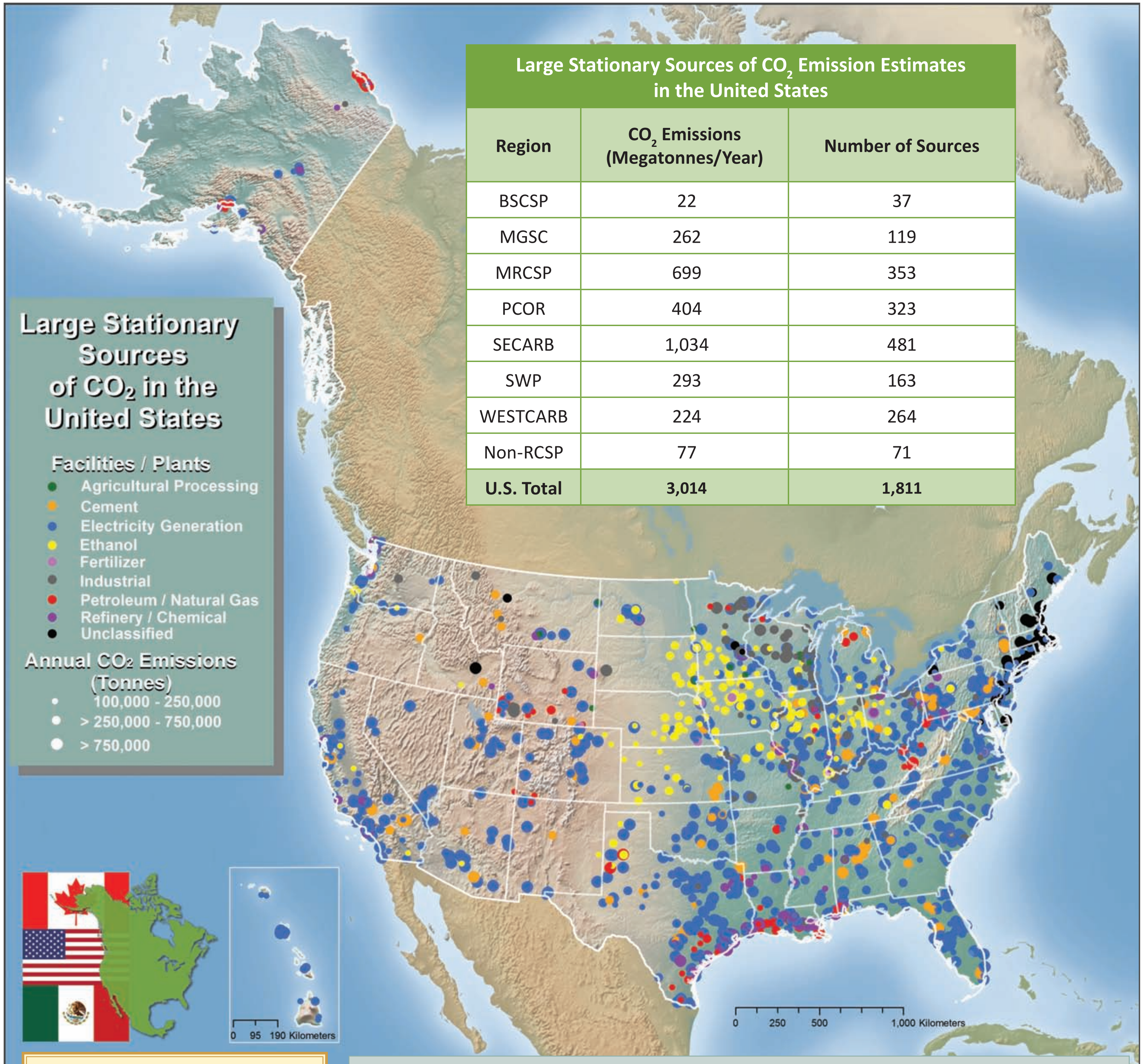


MGSC's CO_2 injection testing in the Blan No. 1 well, Hancock County, Kentucky.

Preparation of the injection well for the PCOR Partnership's huff 'n' puff test.



SECARB's Development Phase Early Test detailed area of study.



Large Stationary Sources of CO_2 Emission Estimates in the United States

Region	CO_2 Emissions (Megatonnes/Year)	Number of Sources
BSCSP	22	37
MGSC	262	119
MRCSP	699	353
PCOR	404	323
SECARB	1,034	481
SWP	293	163
WESTCARB	224	264
Non-RCSP	77	71
U.S. Total	**3,014**	**1,811**

Tonne (t) = 1 metric ton
Kilotonne (kt) = 1,000 metric tons
Megatonne (Mt) = 1,000,000 metric tons
Gigatonne (Gt) = 1,000,000,000 metric tons

This map displays CO_2 stationary source data that were obtained from the RCSPs and other external sources and compiled by NATCARB. Each colored dot represents a different type of CO_2 stationary source with the dot size representing the relative magnitude of the CO_2 emissions (see map legend).

Large Stationary Sources of CO_2 in the United States

In the United States, U.S. DOE's RCSPs have documented the location of 1,811 stationary CO_2 sources (each emitting more than 100 kilotonnes per year) with total annual emissions of approximately 3,014 megatonnes of CO_2.

The U.S. Environmental Protection Agency estimates total U.S. GHG emissions at approximately 6,800 megatonnes CO_2 equivalent in 2010. This estimate includes CO_2 emissions, as well as other GHGs, such as methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

The states with the largest CO_2 stationary source emissions are Texas, Indiana, Ohio, Florida, Pennsylvania, Illinois, Louisiana, West Virginia, Missouri, and Kentucky. The 210 stationary sources identified in Texas are estimated to emit 368 megatonnes per year of CO_2. The 62 stationary sources identified in Indiana are estimated to emit 154 megatonnes per year of CO_2. The 51 stationary sources identified in Ohio are estimated to emit 149 megatonnes per year of CO_2. For details on large stationary sources of CO_2 by state, see Appendix C.

Additional details can be obtained from the NATCARB website (http://www.netl.doe.gov/technologies/carbon_seq/natcarb/index.html).

The number of sources and emissions reported in this Atlas was based on information gathered by the RCSPs and NATCARB as of April 2011.

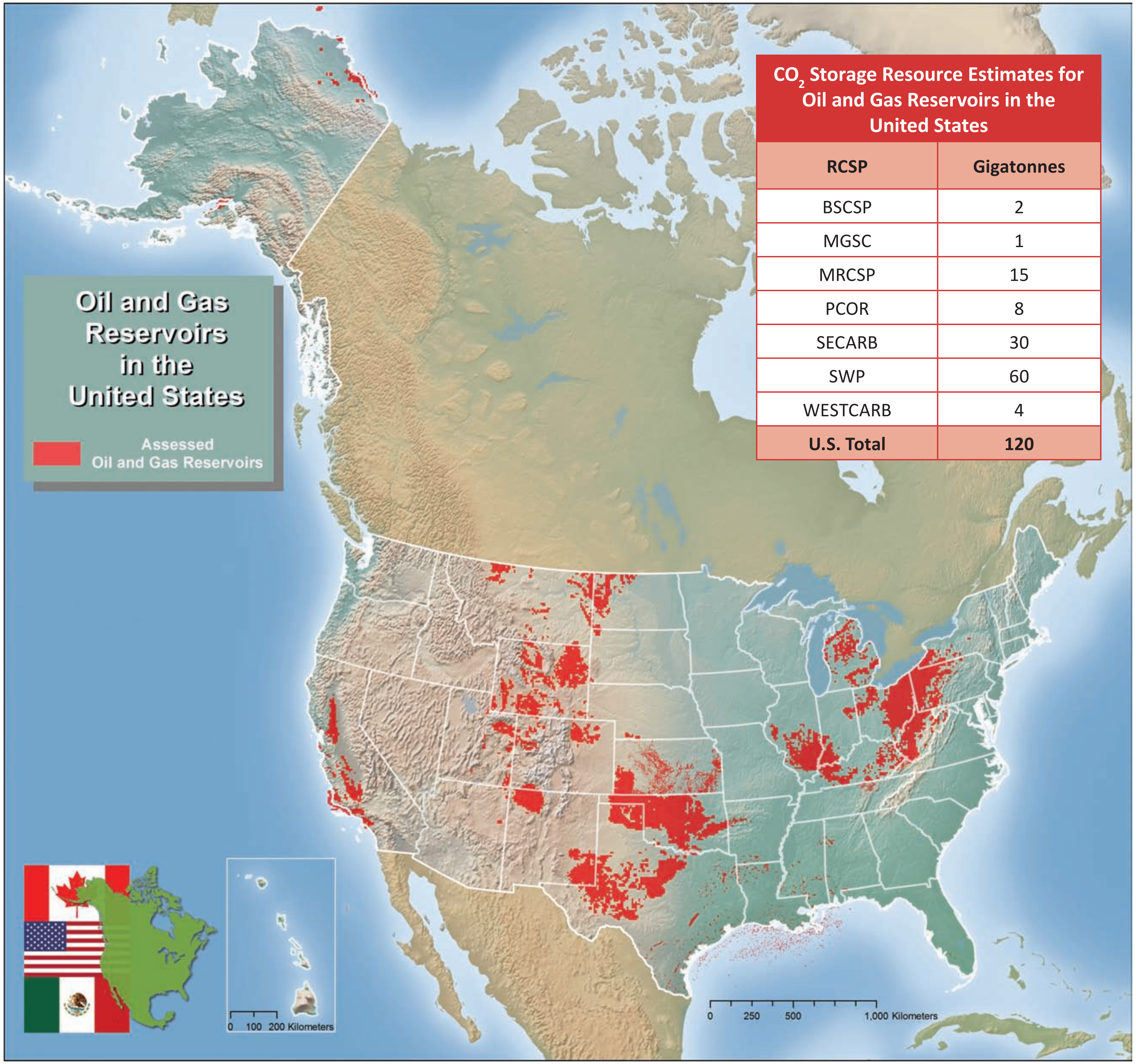
Oil and Gas Reservoirs in the United States

Mature oil and gas reservoirs have held crude oil and natural gas for millions of years. These reservoirs consist of a layer of permeable rock (usually sandstone, but sometimes carbonates) with a layer of nonpermeable rock, also called caprock (usually shale) above that forms a seal holding the hydrocarbons in place. These same characteristics make oil and gas reservoirs excellent target locations for geological storage of CO_2. An added advantage is that they have been extensively explored, which generally results in a wealth of data available to plan and manage proposed CCS efforts.

While not all potential mature oil and gas reservoirs in the United States have been examined, U.S. DOE's RCSPs have documented the location of approximately 120 gigatonnes of CO_2 storage resource. Areas with the largest oil and gas reservoir CO_2 storage resource potential are Texas, federal offshore, Ohio, Louisiana, Oklahoma, New Mexico, North Dakota, California, Pennsylvania, and Montana. These CO_2 storage resources are significant, with an estimated 120 years of storage available in Texas oil and gas reservoirs at Texas's current emission rate. Louisiana's oil and gas reservoirs are estimated to have CO_2 storage resource for more than 95 years of emissions from the state. For details on oil and gas reservoir CO_2 storage resource by state, see Appendix C.

Additional details can be obtained from the NATCARB website (http://www.netl.doe.gov/technologies/carbon_seq/natcarb/index.html).

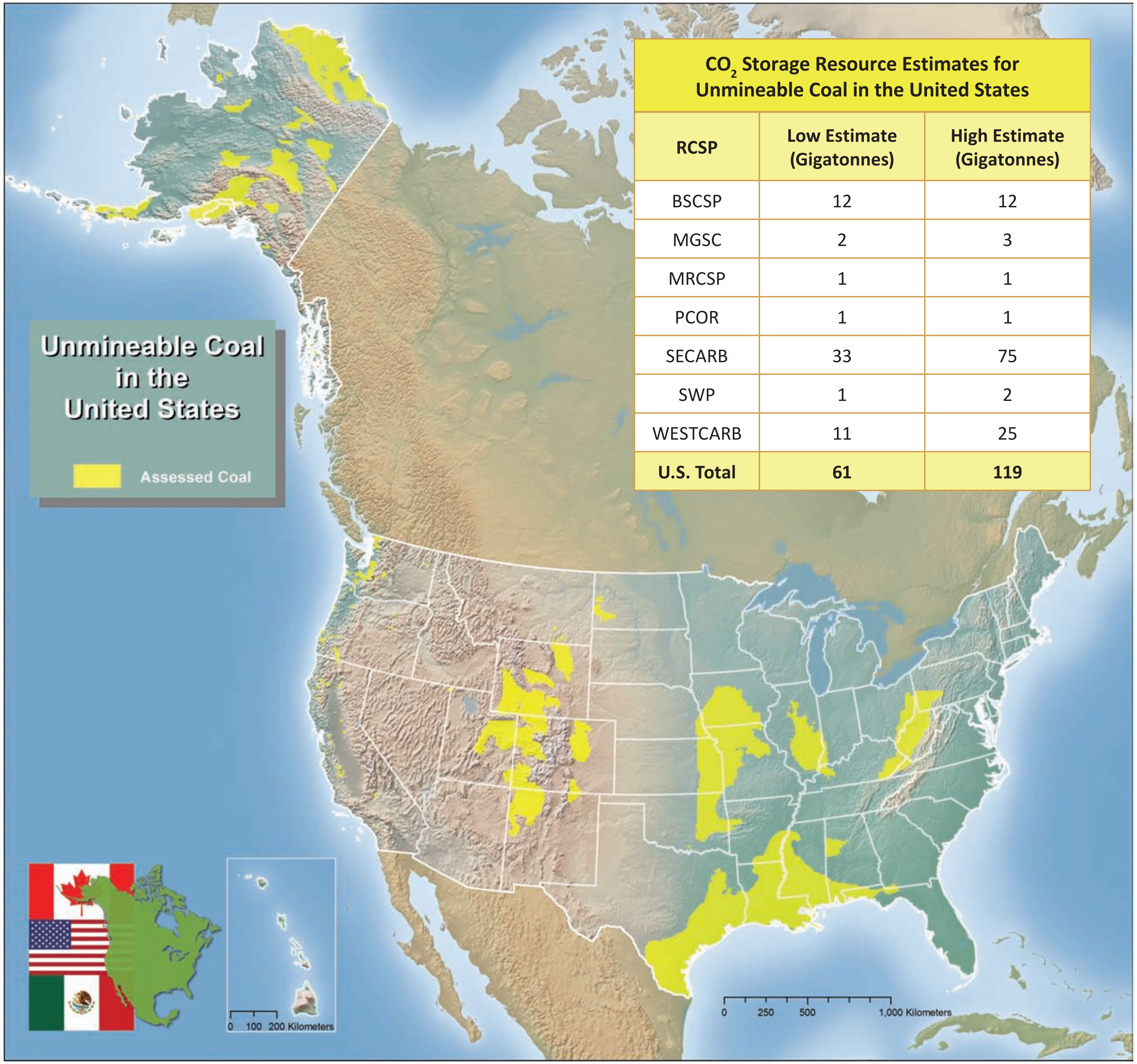
CO_2-EOR production wellhead at a SECARB test site.
(Courtesy: Bureau of Economic Geology, University of Texas–Austin)



CO_2 Storage Resource Estimates for Oil and Gas Reservoirs in the United States

RCSP	Gigatonnes
BSCSP	2
MGSC	1
MRCSP	15
PCOR	8
SECARB	30
SWP	60
WESTCARB	4
U.S. Total	**120**

The map above displays CO_2 storage resource data that were obtained by the RCSPs and other sources and compiled by the NATCARB team. Carbon dioxide geological storage information presented on this map was developed to provide a high-level overview of CO_2 geological storage potential across the United States. Areal extents of geological formations and CO_2 resource estimates presented are intended to be used as an initial assessment of potential geological storage. This information provides CCS project developers a starting point for further investigation. Furthermore, this information is required to indicate the extent to which CCS technologies can contribute to the reduction of CO_2 emissions and is not intended to serve as a substitute for site-specific assessment and testing. Please note that data resulting in a straight edge in the map above is indicative of an area lacking sufficient data and is subject to future investigation.



CO_2 Storage Resource Estimates for Unmineable Coal in the United States

RCSP	Low Estimate (Gigatonnes)	High Estimate (Gigatonnes)
BSCSP	12	12
MGSC	2	3
MRCSP	1	1
PCOR	1	1
SECARB	33	75
SWP	1	2
WESTCARB	11	25
U.S. Total	**61**	**119**

The map above displays CO_2 storage resource data that were obtained by the RCSPs and other sources and compiled by the NATCARB team. Carbon dioxide geological storage information presented on this map was developed to provide a high-level overview of CO_2 geological storage potential across the United States. Areal extents of geological formations and CO_2 resource estimates presented are intended to be used as an initial assessment of potential geological storage. This information provides CCS project developers a starting point for further investigation. Furthermore, this information is required to indicate the extent to which CCS technologies can contribute to the reduction of CO_2 emissions and is not intended to serve as a substitute for site-specific assessment and testing. Please note that data resulting in a straight edge in the map above is indicative of an area lacking sufficient data and is subject to future investigation.

Coal in the United States

In the United States, unmineable coals that are too deep or too thin to be economically mined are potentially viable for CO_2 storage.

While not all unmineable coal has been examined, U.S. DOE's RCSPs have documented the location of approximately 61 to 119 gigatonnes of potential CO_2 storage resource in unmineable coal. Areas with the largest unmineable coal CO_2 storage resource potential are Texas, Alaska, Louisiana, Mississippi, Wyoming, Alabama, Arkansas, Florida, Illinois, and Washington. An estimated 35 to 85 years of CO_2 storage resource is available in Texas unmineable coals for Texas's current emission rate. Alaska's unmineable coal are estimated to have CO_2 storage resource for 520 to 1,200 years worth of emissions from the state. For details on unmineable CO_2 storage resource by state, see Appendix C.

Additional details can be obtained from the NATCARB website (http://www.netl.doe.gov/technologies/carbon_seq/natcarb/index.html).

Surface coal mine near Gillete, Wyoming. (Courtesy: Greg Goebel)

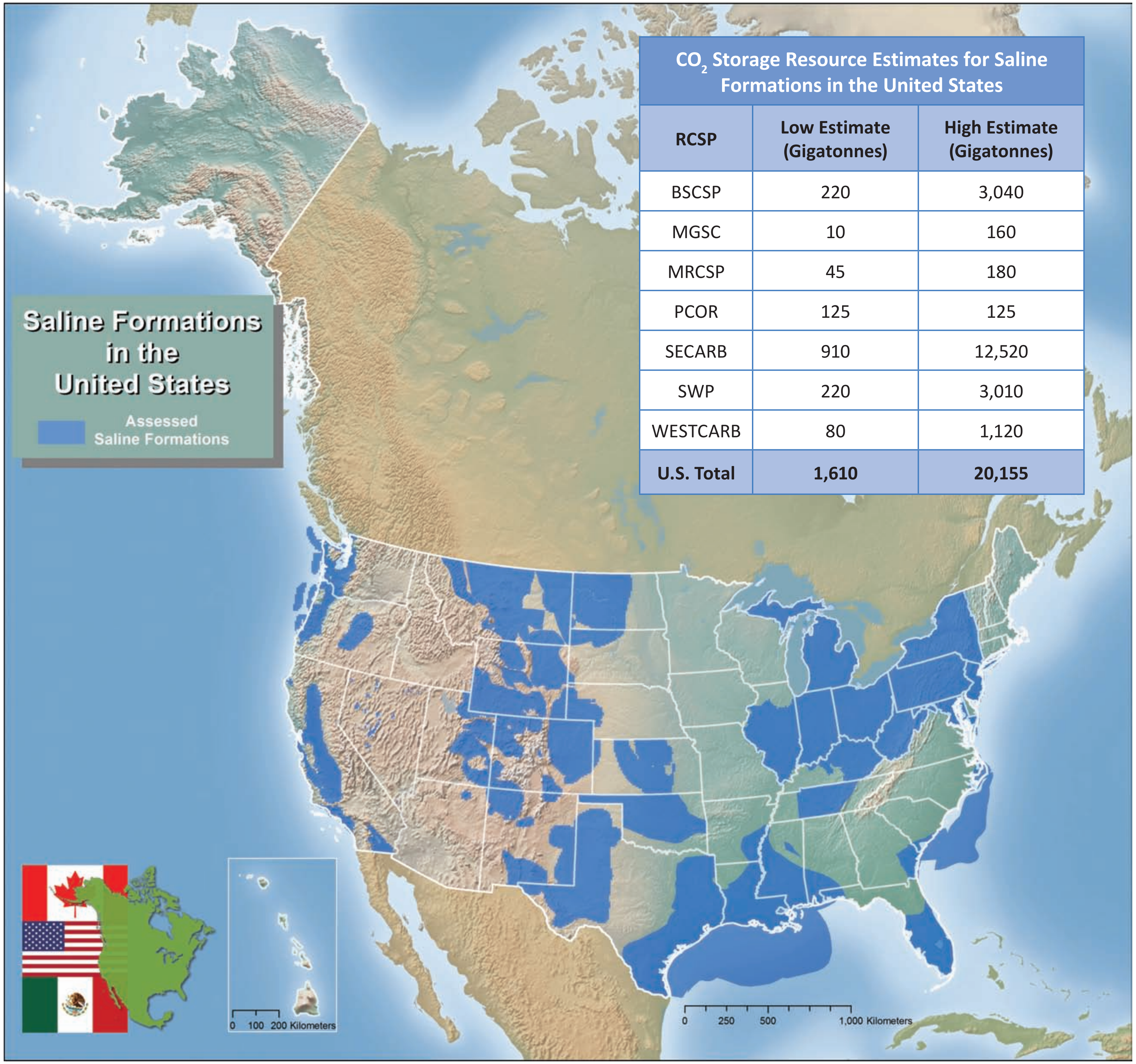
Saline Formations in the United States

In the United States, saline formations, layers of porous rock saturated with brine, are much more extensive than coal or oil- and gas-bearing rock and hold enormous potential for CO_2 geological storage. However, less is known about saline formations because they have not been characterized extensively compared to oil and gas reservoirs and coal.

While not all saline formations in the United States have been examined, U.S. DOE's RCSPs have documented an estimated CO_2 storage resource ranging from approximately 1,610 gigatonnes to more than 20,155 gigatonnes of CO_2. Areas with the largest saline formation CO_2 storage resource potential are federal offshore, Texas, Louisiana, Montana, Wyoming, Mississippi, Washington, New Mexico, Colorado, and California. At Texas's current emission rate, there is an estimated 935 to 12,800 years of CO_2 storage resource available in Texas saline formations. For details on saline formation CO_2 storage resource by state, see Appendix C.

Additional details can be obtained from the NATCARB website (http://www.netl.doe.gov/technologies/carbon_seq/natcarb/index.html).

MRCSP CO_2 injection testing in the Mt. Simon Sandstone deep saline formation.



CO_2 Storage Resource Estimates for Saline Formations in the United States

RCSP	Low Estimate (Gigatonnes)	High Estimate (Gigatonnes)
BSCSP	220	3,040
MGSC	10	160
MRCSP	45	180
PCOR	125	125
SECARB	910	12,520
SWP	220	3,010
WESTCARB	80	1,120
U.S. Total	**1,610**	**20,155**

The map above displays CO_2 storage resource data that were obtained by the RCSPs and other sources and compiled by the NATCARB team. Carbon dioxide geological storage information presented on this map was developed to provide a high-level overview of CO_2 geological storage potential across the United States. Areal extents of geological formations and CO_2 resource estimates presented are intended to be used as an initial assessment of potential geological storage. This information provides CCS project developers a starting point for further investigation. Furthermore, this information is required to indicate the extent to which CCS technologies can contribute to the reduction of CO_2 emissions and is not intended to serve as a substitute for site-specific assessment and testing. Please note that data resulting in a straight edge in the map above is indicative of an area lacking sufficient data and is subject to future investigation.

Further Reading

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Summary of Methodologies for Determining Stationary CO_2 Source Emissions

Canada

All facilities in Canada that emit the equivalent of 50 kilotonnes or more of greenhouse gas emissions (in CO_2 eq.) per year are required to submit a report on their emissions under the Greenhouse Gas Emissions Reporting Program (GHGRP) administered by Environment Canada. The GHGRP database is public and searchable (http://www.ec.gc.ca/pdb/ghg/onlineData/dataSearch_e.cfm).

The 2009 GHGRP database was used to identify large stationary sources of CO_2 in Canada. For the purposes of this Atlas, only facilities with annual CO_2 emissions equal to or greater than 100 kilotonnes were retained. Facilities reporting combined CO_2 emissions from multiple small emission sources spread out over large areas—typically pipelines and compressor stations—were removed from the data.

All facilities selected were categorized according to nine industry sectors established by NACAP. This process was facilitated by the North American Industry Classification System codes, which were provided for each facility through the GHGRP database. The geographic location of each facility was validated by cross-referencing its GIS coordinates, also obtained from the GHGRP database, with those from other databases (e.g., National Pollutant Release Inventory). Other spatial location tools, such as Google Earth™, Google Maps™, and Google Street View™, were also used to verify actual facility locations and obtain GIS coordinates.

Mexico

Mexican law requires that facilities with emissions totaling more than 100 tonnes per year of CO_2 submit an emissions report to the Mexican Pollutant Release and Transfer Register Database (RETC in Spanish). This database is administered by the Ministry of Environment and Natural Resources and currently contains emission information from hundreds of facilities classified as stationary sources in federal jurisdiction according to Mexican environmental law.

Through the RETC, it is possible to compile, integrate, and disseminate information concerning the release and transfer of toxic substances, which are generated during the production processes at industrial facilities and which may represent significant impacts to the ecosystem, natural resources (water, air, and soil) and human health.

To calculate CO_2 emissions, the Secretariat of Environment and Natural Resources recommends the *Air Clearinghouse for Inventories & Emissions Factors AP-42* ("Air CHIEF" AP-42) document, published by the U.S. Environmental Protection Agency.

The RETC database is available at: http://app1.semarnat.gob.mx/retc/.

Using the RETC database, 1,860 industrial facilities were identified as stationary sources of CO_2 emissions. For the purposes of this Atlas, further information was obtained on 188 sources whose emissions were more than 100 kilotonnes per year. The geographic location of each facility was validated using Google Earth to obtain its GIS coordinates.

When information was not available from the RETC database, CO_2 stationary source fuel usage and CO_2 emissions factors were used to estimate annual CO_2 emissions.

Fuel	Emission Factor ($t\ CO_2$ / m^3 fuel)	Emission Factor ($t\ CO_2$ / t fuel)
Light Fuel Oil	3.2197	3.2938
Heavy Fuel Oil	3.1593	3.2172
Diesel	3.0476	3.5232
LP Gas	1.6800	3.0000
Natural Gas	0.0019	2.9068
Diesel Fuel / Gasoil	2.8345	3.1530
Coal	—	2.1771
Fuel Oil (Light and Heavy)	3.04	3.1100
Wood	0.5167	0.8612
Bagasse	—	0.7091
Petroleum Coke	—	3.1258
Other Fuel	1.0	1.0000

This table presents a list of emission factors that can be applied by fuel consumption values for mass or volume as appropriate, these factors are related through the density of fuels.

United States

The U.S. DOE's RCSPs have identified 3,959 CO_2 stationary sources with total annual emissions of more than 3,050 megatonnes of CO_2 in the United States. These sources include electricity generating plants, ethanol plants, petroleum and natural gas processing facilities, cement plants, agricultural processing facilities, industrial facilities, refineries and chemical plants, and fertilizer producing facilities. Estimates were derived using databases and emissions factors, as listed in tables in the methodology.

The NACSA website (www.nacsap.org) houses the documents used to identify each CO_2 stationary source, as well as the practical quantitative method (i.e., emission factors, continuous emissions-monitoring results, emission estimate equations, etc.) used to estimate CO_2 emissions from that source. In addition, the data sources used to determine specific plant capacities, production outputs, or fuel usage data are listed by RCSP.

These methodologies were determined by identifying CO_2 stationary sources within each RCSP region, and then assessing the availability of CO_2 emission data or applying an estimate of the CO_2 emissions based upon sound scientific and engineering principles. In each RCSP, emissions were grouped by source and a methodology was established for each emission source industry sector; then the methodology was utilized to estimate the CO_2 emissions from each emission source industry sector. Nine tables containing CO_2 emission estimation methodologies and equations for the major CO_2 stationary source industries summarize these efforts. During the RCSPs' Characterization Phase, each RCSP developed GHG emission inventories and stationary source surveys within their respective boundary area.

Carbon dioxide stationary sources fall under one of eight industry sectors. The table identifies the stationary sources included in various industry sectors.

The RCSPs employed CO_2 emissions estimate methodologies based on the most readily available representative data for each particular industry sector within the respective RCSP area. CO_2 emissions data from databases (for example, eGRID, or ECOFYS) were the first choice for all of the RCSPs, both for identifying major CO_2 stationary sources and for providing reliable emissions estimations. Databases contain reliable and accurate data obtained from direct emissions measurements via continuous emissions monitoring systems. When databases were not available, CO_2 stationary source facility production or fuel usage data were coupled with CO_2 emissions. Emissions factors, fuel usage data, and facility production data were obtained from various databases, websites, and publications. Carbon dioxide stationary source spatial location data (latitude and longitude) were determined from a variety of sources. Some databases (eGRID) contain latitude and longitude information for each CO_2 stationary source. Where spatial location information was not available through an emissions database, other spatial location methods were utilized. These include the use of mapping tools (Google Earth™, TerraServer, and USGS Digital Orthophoto Imagery) equipped with geospatially defined data, along with web-based databases (Travelpost) containing latitude and longitude information for various U.S. locations.

CO_2 Stationary Sources by Industry Sector

Industry Sector	CO_2 Stationary Sources Include
Agricultural Processing	Sugar Production
Cement Plant	Lime Production Facilities
	Cement Plants
Electricity Generation	Coal-, Oil-, and Natural Gas-Fired Power Plants
Ethanol Plant	Ethanol Plants, Any Feedstock Type
Fertilizer Plant	Ammonia Production
Industrial	Aluminum Production Facilities
	Soda Ash Production Facilities
	Glass Manufacturing Facilities
	Automobile Manufacturing Facilities
	Compressor Stations
	Iron Ore Processing Facilities
	Paper and Pulp Mills
Petroleum/Natural Gas	Natural Gas & Petroleum Extracting Facilities
Refinery/Chemical Plant	Petroleum Refinery Processing
	Ethylene Production Facilities
	Ethylene Oxide Production
	Hydrogen Production Facilities

Summary of Methodologies Used To Estimate CO_2 Storage Resource

To produce readily comparable CO_2 storage resource estimates between Canada, Mexico, and the United States, a default calculation approach was agreed upon. The NAEWG members have agreed to use the CO_2 storage resource estimation methodologies described in the third edition of U.S. DOE's *Carbon Sequestration Atlas of the United States and Canada (Atlas III)*, or, where appropriate, the methodology developed by the Carbon Sequestration Leadership Forum. It has been shown that the two methodologies are equivalent and can be used as appropriate depending on data availability. These methodologies were developed to be consistent across North America for a wide range of available data. Adopting these methodologies will allow for the integration of data compiled by Canada, Mexico, and the United States for the three types of geological formations under consideration for CO_2 storage: saline formations, unmineable coal, and oil and gas reservoirs.

The methodologies derived for estimating geological storage potential for CO_2 consist of widely accepted assumptions about in-situ fluid distributions in porous formations and fluid displacement processes commonly applied in the petroleum and groundwater science fields. The volumetric approach is the basis for CO_2 resource calculations for all three geological storage formations. At a basic level, the methods require the area of the target formation or horizon along with an understanding of the formation's thickness and porosity. There are other specific parameters unique to oil & gas fields and coal seams that are needed to compute the estimated CO_2 storage resource. Because not all of the pore space within any given geological formation will be available or amenable to CO_2, a storage coefficient (referred to as the efficiency- or E-factor) is applied to the theoretical maximum volume in an effort to determine what fraction of the pore space can effectively store CO_2.

Efficiency is the multiplicative combination of volumetric parameters that reflect the portion of a basin's or region's total pore volume that CO_2 is expected to actually contact. For example, the CO_2 storage efficiency factor for saline formations has several components that reflect different physical barriers that inhibit CO_2 from contacting 100 percent of the pore volume of a given basin or region. Depending on the definitions of area, thickness, and porosity, the CO_2 storage efficiency factor may also reflect the difference between bulk volume, total pore volume, and effective pore volume. These terms can be grouped into a single term that defines the entire basin's or region's pore volume and terms that reflect local formation effects in the injection area of a specific injection well. Assuming that CO_2 injection wells can be placed regularly throughout the basin or region to maximize storage, this group of terms is applied to the entire basin or region. Given this assumption, the CO_2 storage resource estimate is the maximum storage available because there is no restriction on the number of wells that could be used for the entire area of the basin or region.

Ranges of values for the E-factor have been calculated for deep saline formations from statistical approaches that consider the variation in geological properties encountered in subsurface target formations. For coal seams and oil and gas reservoirs, the values used for the E-factor are those developed by U.S. DOE for *Atlas III*. The E-factor values for a particular injection horizon can be modified if more specific information about the formation is known, resulting in more precise resource estimations. In situations where this approach is taken, additional metadata will be compiled to explain why the default numbers were not employed.

Carbon Dioxide Storage Resource Estimate Calculation

A CO_2 resource estimate is defined as the volume of porous and permeable sedimentary rocks available for CO_2 storage and accessible to injected CO_2 via drilled and completed wellbores. Carbon dioxide resource assessments do not include economic or regulatory constraints; only physical constraints to define the accessible part of the subsurface are applied. In the following relationships, the symbol G_{CO2} refers to the mass of CO_2 that would be stored in the respective geological medium, A refers to area, and h refers to thickness. The following are brief descriptions of the formulas used in calculating CO_2 resource estimations.

<u>Computing CO_2 Resource Estimate – Oil and Gas Reservoirs</u>. The general form of the volumetric equation being used for oil and gas reservoirs in this assessment is as follows:

$$G_{CO2} = A\, h_n\, f_e\, (1\text{-}S_w) B\, \rho\, E_{oil/gas} \qquad \text{[Eq. 1]}$$

The reservoir area (A), its net thickness (h_n), and its average effective porosity (f_e) terms account for the total volume of pore space. The oil and gas saturation (1-water saturation as a fraction [S_w]) and formation volume factor (B) terms account for the pore volume available for CO_2 storage, and CO_2 density (ρ) transforms the pore volume into mass at the reservoir in-situ conditions of temperature and pressure. For the oil and gas reservoirs in Canada, the Carbon Sequestration Leadership Forum (CSLF) methodology based on original oil or gas in place and recovery factor was used because these data are readily available in provincial oil and gas reserves databases. The CO_2 storage efficiency factor ($E_{oil/gas}$) reflects the fraction of the total pore volume of the oil or gas reservoir that can be filled by CO_2. An efficiency factor is derived from local experience or reservoir simulations.

<u>Computing CO_2 Resource Estimate – Saline Formations</u>. The volumetric equation for CO_2 storage resource estimate potential in saline formations is as follows:

$$G_{CO2} = A_t\, h_g\, f_{tot}\, \rho E_{saline} \qquad \text{[Eq. 2]}$$

The total area (A_t), gross formation thickness (h_g), and total porosity (f_{tot}) terms account for the total volume of pore space available. The CO_2 density (ρ) term transforms pore volume into the CO_2 mass that can fit into the formation volume at in-situ conditions of temperature and pressure. The storage efficiency factor (E_{saline}) reflects the fraction of the total pore volume of the saline formation that will be occupied by the injected CO_2. E_{saline} factors for the P_{10}, P_{50}, and P_{90} percent confidence intervals are 0.51 percent, 2.0 percent, and 5.5 percent, respectively.

Computing CO_2 Resource Estimate – Unmineable Coal. The volumetric equation for CO_2 storage resource estimate potential in unmineable coal seams is as follows:

$$G_{CO2} = A\ h_g\ C_s\ r_{s,max}\ E_{coal} \qquad \text{[Eq. 3]}$$

The total area (A) and gross seam thickness (h_g) terms account for the total volume of coal available. The fraction of adsorbed CO_2 (C_s) and CO_2 density ($r_{s,max}$) terms account for the mass of CO_2 that would be stored by adsorption in the respective volume of coal at maximum CO_2 saturation. The term C_s must consider coal density, CO_2 adsorption capacity (volume of CO_2 adsorbed per unit of coal mass) and coal moisture and ash content. The density of CO_2 in Eq. 3 is that at standard conditions of temperature and pressure ($\rho_{s,max}$=1.87 kg/m^3). The storage efficiency factor (E_{coal}) reflects the fraction of the total pore volume that will be occupied by the injected CO_2. E_{coal} factors for the P_{10}, P_{50}, and P_{90} percent confidence intervals are 21 percent, 37 percent, and 48 percent, respectively.

The assessments presented are intended to identify the geographical distribution of CO_2 resource for use in energy-related government policy and business decisions. They are not intended to provide site-specific information for a company to select a site to build a new power plant or to drill a well. Similar to a natural resource assessment such as petroleum accumulations, this resource estimation is volumetrically based on physically accessible CO_2 storage in specific formations in sedimentary basins without consideration of injection rates, regulations, economics, or surface land usage.

Further Details on Mexico's Assessment Methodology

Mexico was subdivided into two zones in order to determine carbon storage options, the exclusion and inclusion zones. The exclusion zone is not recommended for geological storage due to high seismic, geothermic, and active volcanic hazards. The inclusion zone, which yields the best CO_2 storage potential, was outlined by gathering lithological parameters from outcrops, identifying large geological subsurface structures, and quantifying recent volcanic and tectonic activity in a country-scale assessment.

This analysis represents the first coordinated assessment of carbon storage potential across Mexico. It considered deep saline formations and the location of stationary CO_2 sources currently available for the whole nation. This methodology was based on data accessible to the public domain as well as current geological knowledge. It does not incorporate geological constraints in its theoretical capacity estimations, nor does it incorporate risk factors, environmental hazards, solubility and mineral trapping of CO_2, or quantification of injectivity for potential storage rock sequences.

Subsurface layers of porous rocks, generally saturated with brine, were identified as the most favorable CO_2 storage option for Mexico. Such deep saline formations are characterized by high concentrations of dissolved salts and are unsuitable for agriculture or human use. Oil and gas reservoirs would also be a favorable option, particularly EOR in depleted oil fields; however, oil databases and information are unavailable.

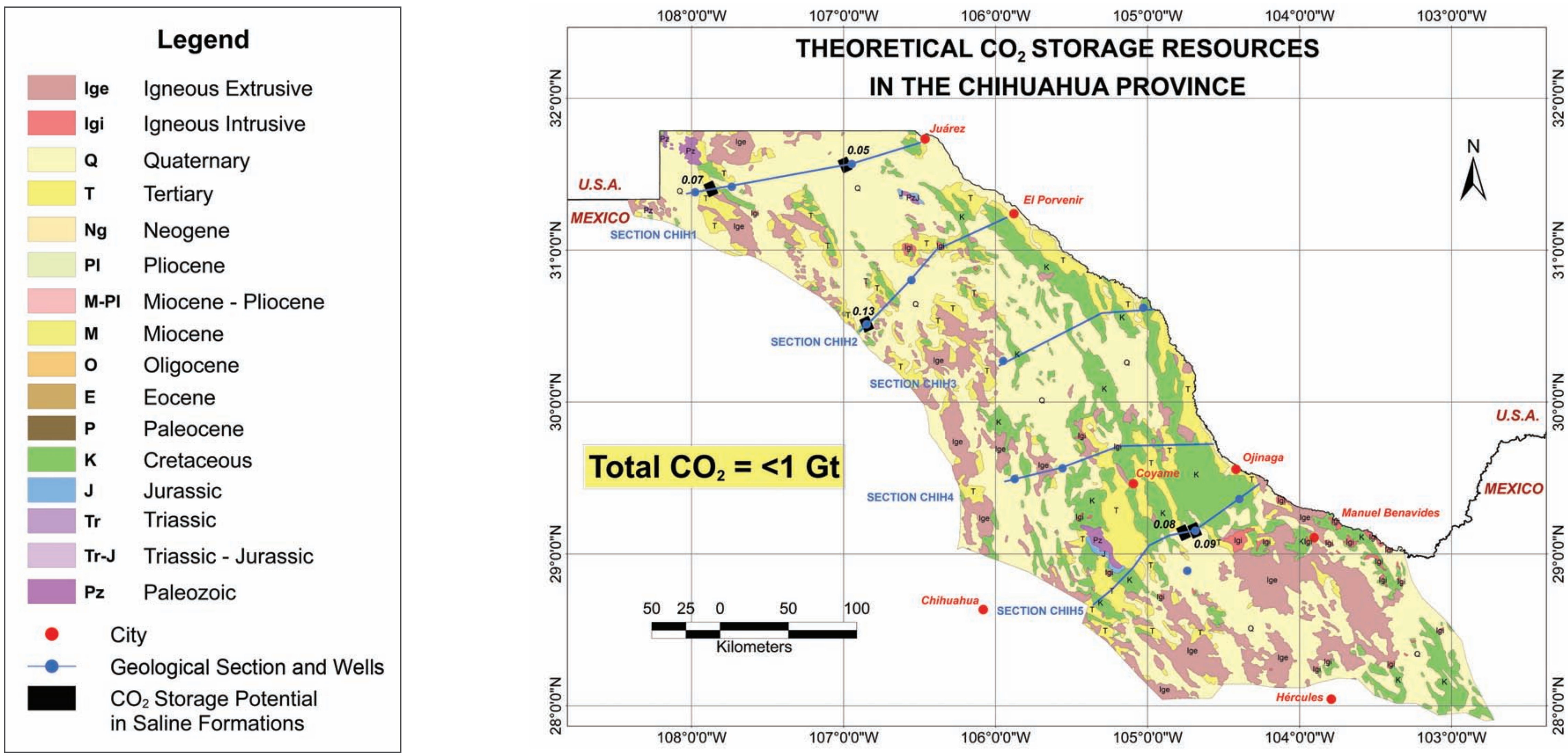
Analysis of Mexico's storage potential was undertaken in two phases. Phase 1 analyzed geological provinces that have the most favorable conditions for underground CO_2 storage in sedimentary rock successions of the Mesozoic and Tertiary ages. Candidate storage geological provinces were selected according to basin-scale exploration, which required more local data categories and a higher level of detail than at country scale. Through screening available geological data, nine geological provinces were identified for further study to estimate storage potential. These provinces are located in the continental and marine platform areas in northern, northeastern, southern, and southeastern parts of Mexico. They are Chihuahua, Coahuila, Central, Burgos, Tampico Misantla, Veracruz, Southeastern, Yucatan, and Chiapas geological provinces. Three main groups of sedimentary formations were observed in all nine provinces: carbonate, evaporate, and terrigenous sequences, depending upon the main, respectively, carbonated, evaporitic, and clastic content of their rock units.

Phase 2 estimated theoretical storage resource in potential saline formation sectors for each geological province. For this estimation, storage resource refers to the volume of CO_2 that can be retained in the available porous space of the storage formation at depths ranging from 800 to 2,500 meters at supercritical conditions. Parameterization was used, which relies on observations, deductions, and calculations derived from physical parameters obtained from geological maps, regional stratigraphic and structural cross-sections, and well data from the public petroleum industry. Critical features were reservoir depth (more than 800 meters and less than 2,500 meters), thickness, porosity, lithological composition (predominately carbonates and clastic deposits), and the relationship between net thickness versus total thickness. When a sector was valued as an attractive target, then its potential to store CO_2 was quantified. Critical parameters were substituted in the CSLF saline equation, shown below:

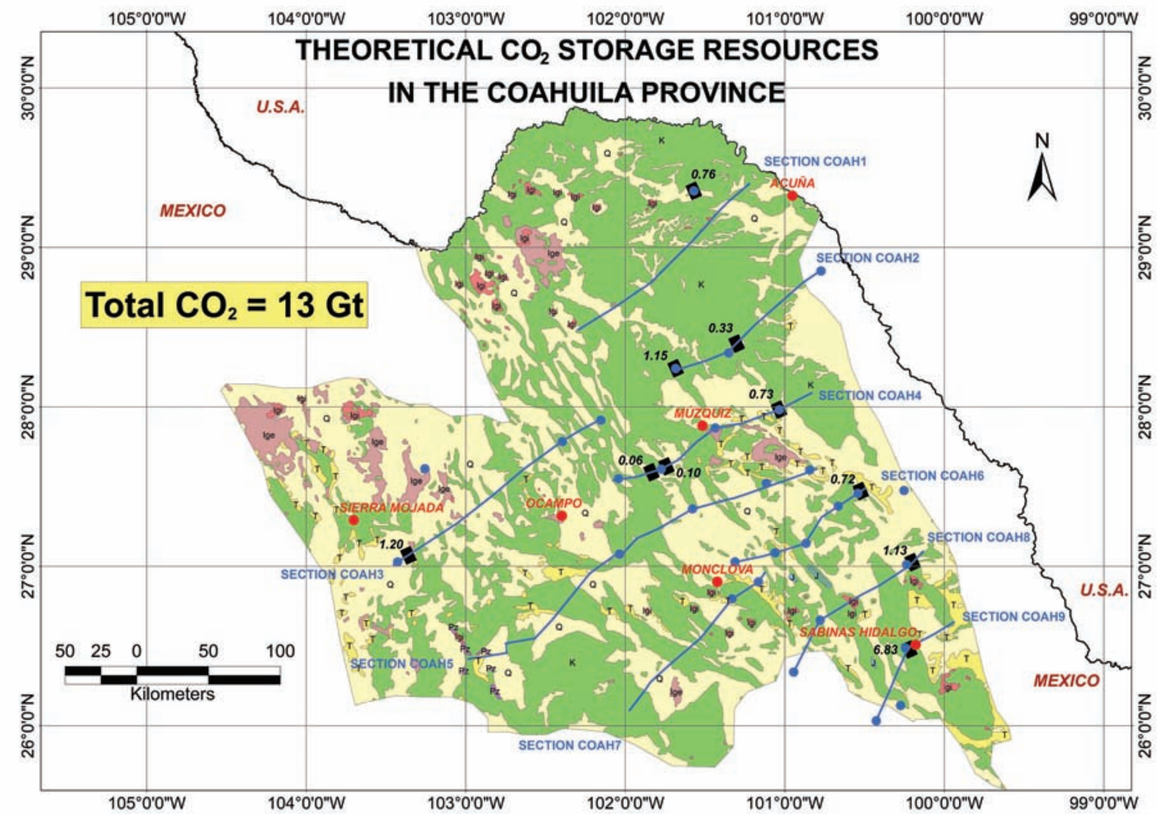
$$V_{CO2}t = V\phi\ (1-S_{wirr}) \equiv Ah\phi\ (1-S_{wirr}) \qquad \text{[Eq. 4]}$$

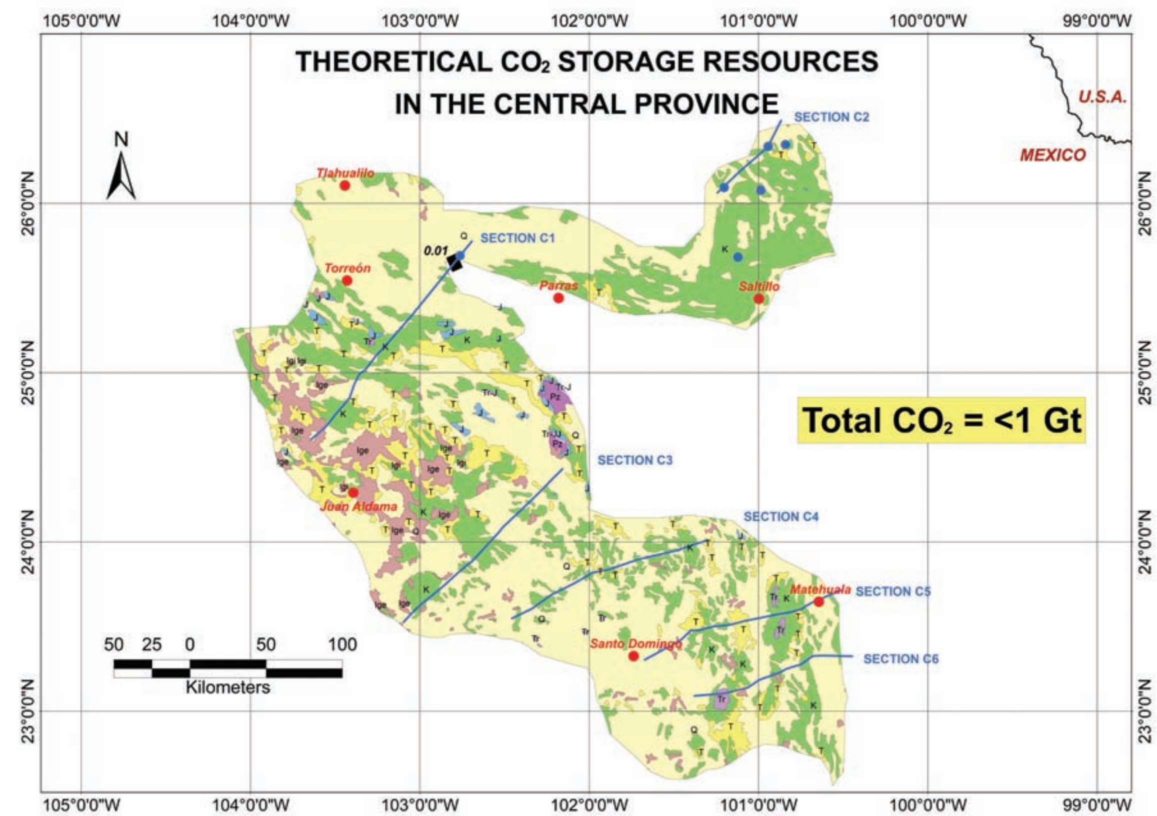
Where A is the trap area, h is the average thickness, $V_{CO2}t$ is the theoretical volume available, ϕ is effective porosity, and S_{wirr} is the irreducible water saturation. Solving the equation yielded the sector's theoretical storage resource volume.

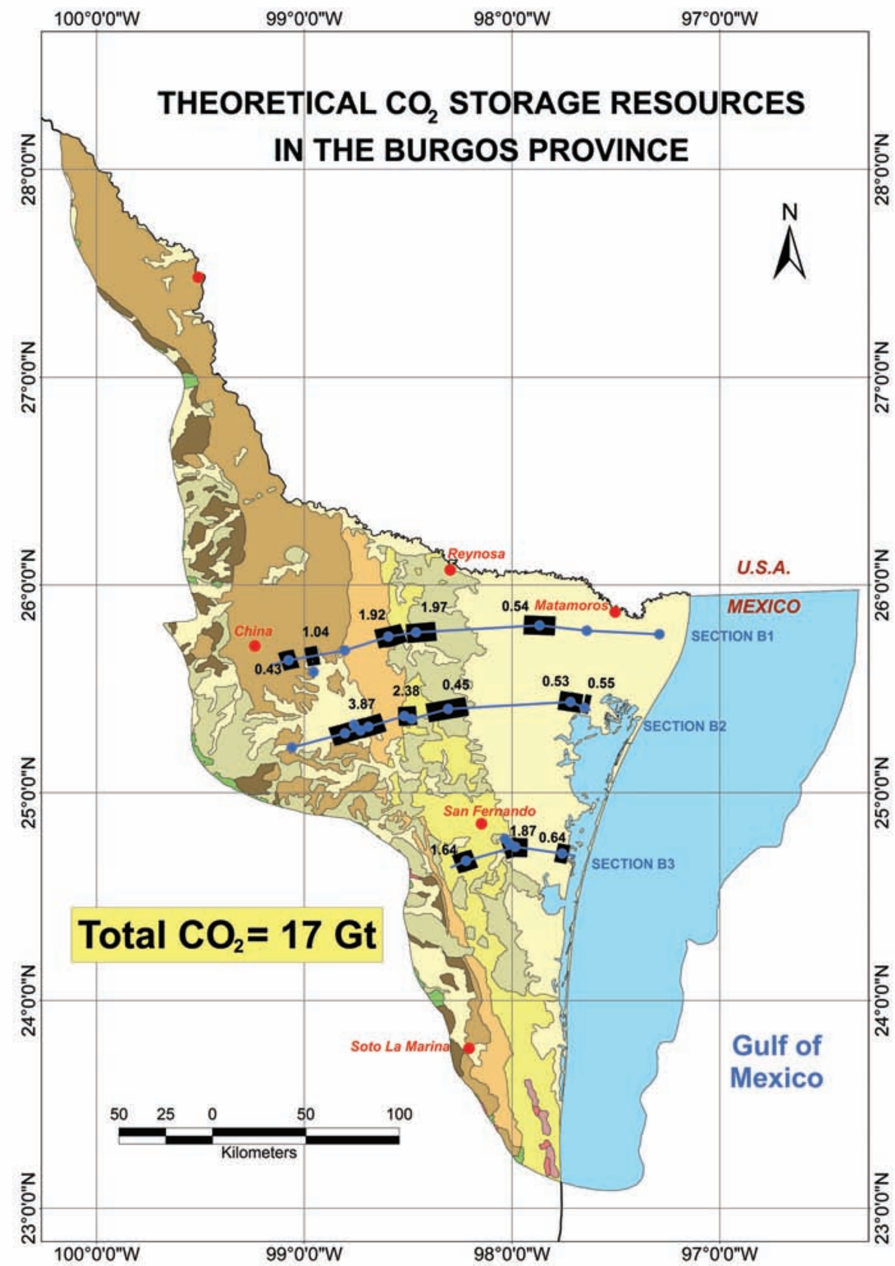
The following geological provinces were assessed for their potential CO_2 storage resources:



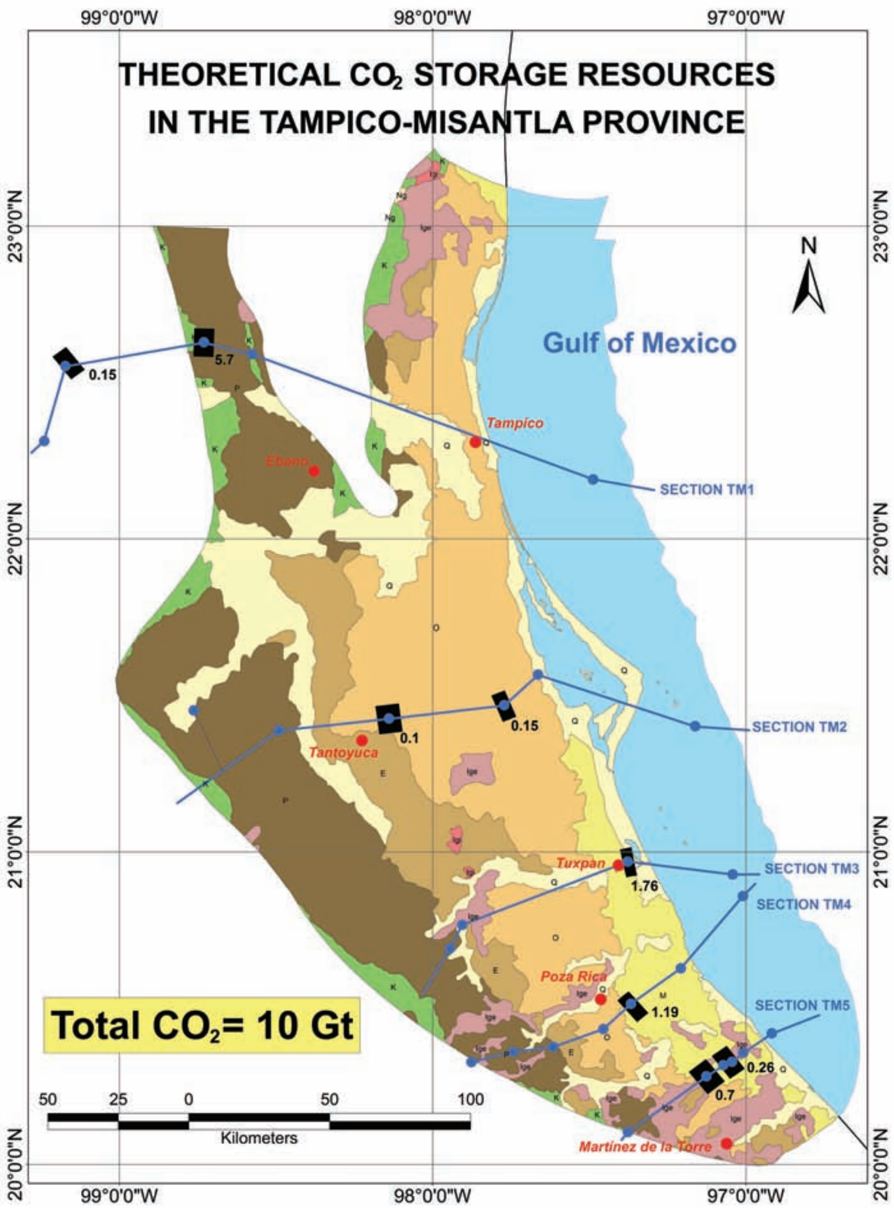
Sectors or prospective regions (shown in black) with CO_2 storage potential in saline formations.



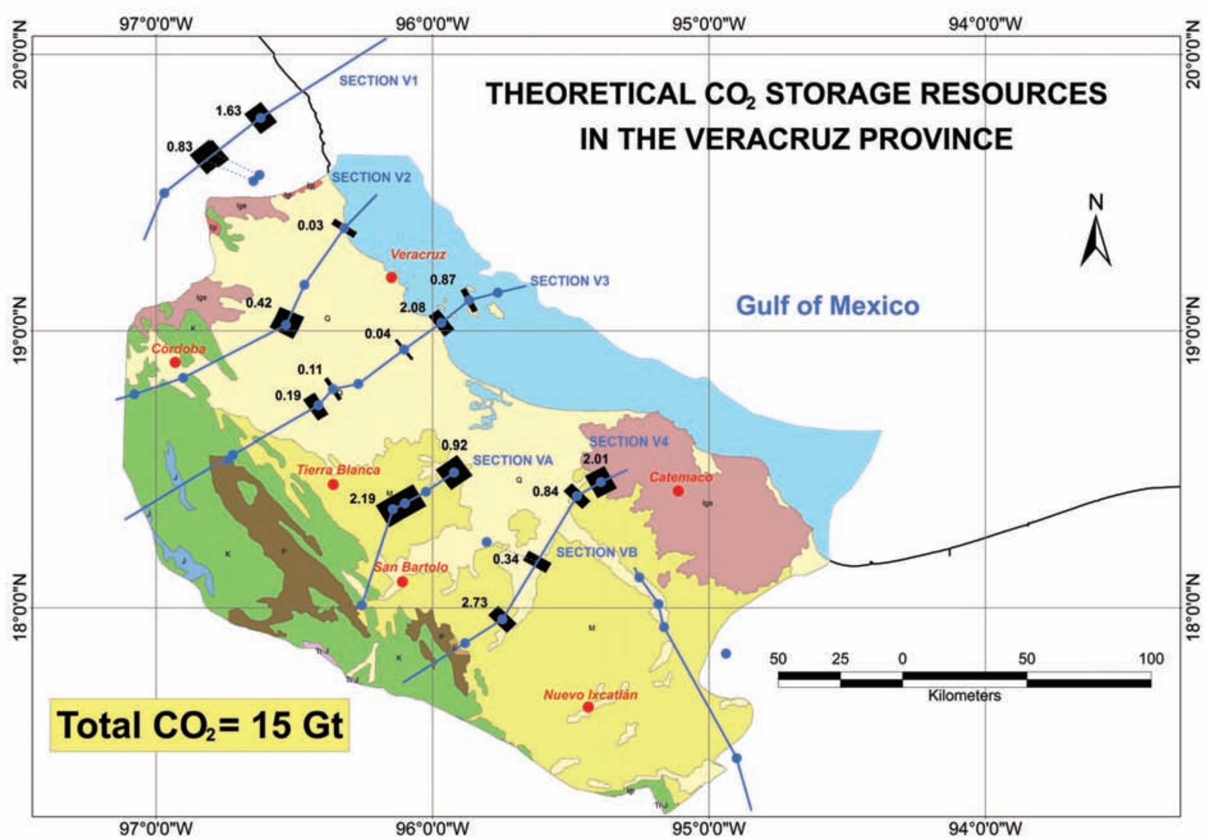


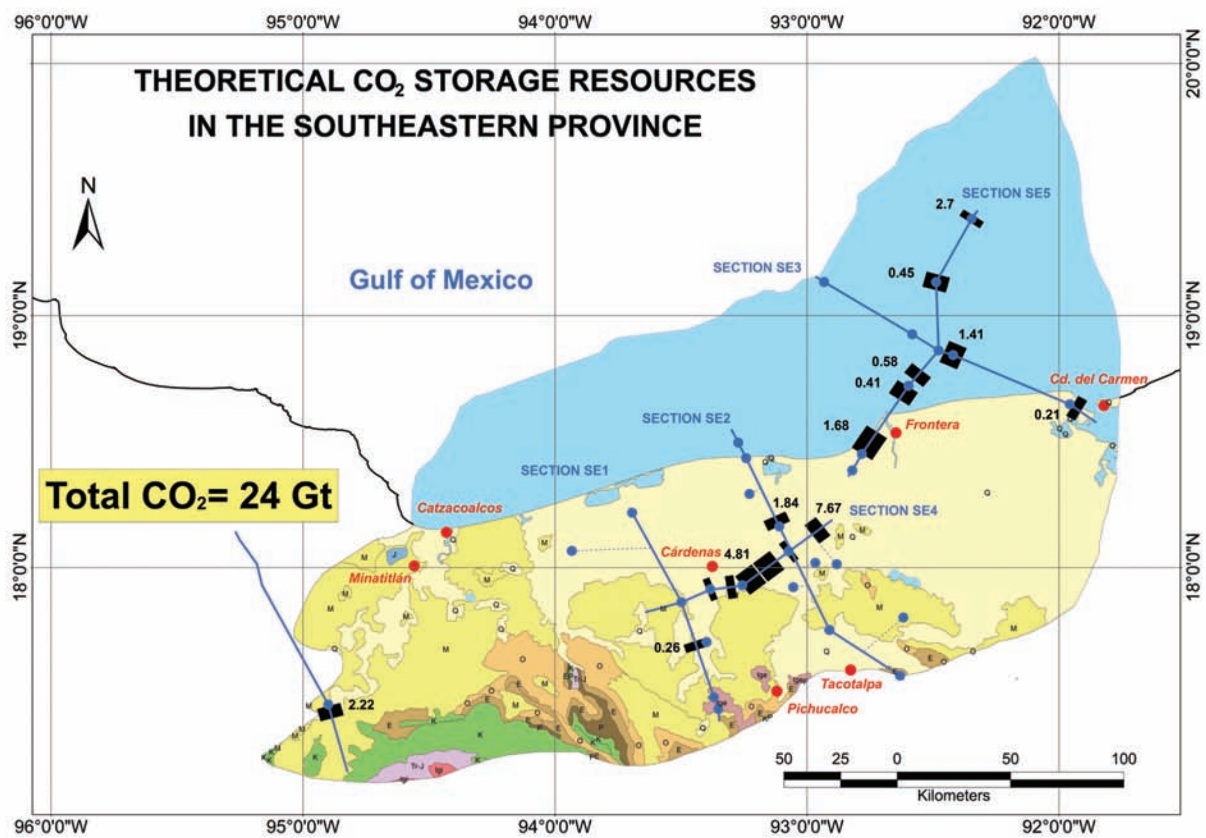


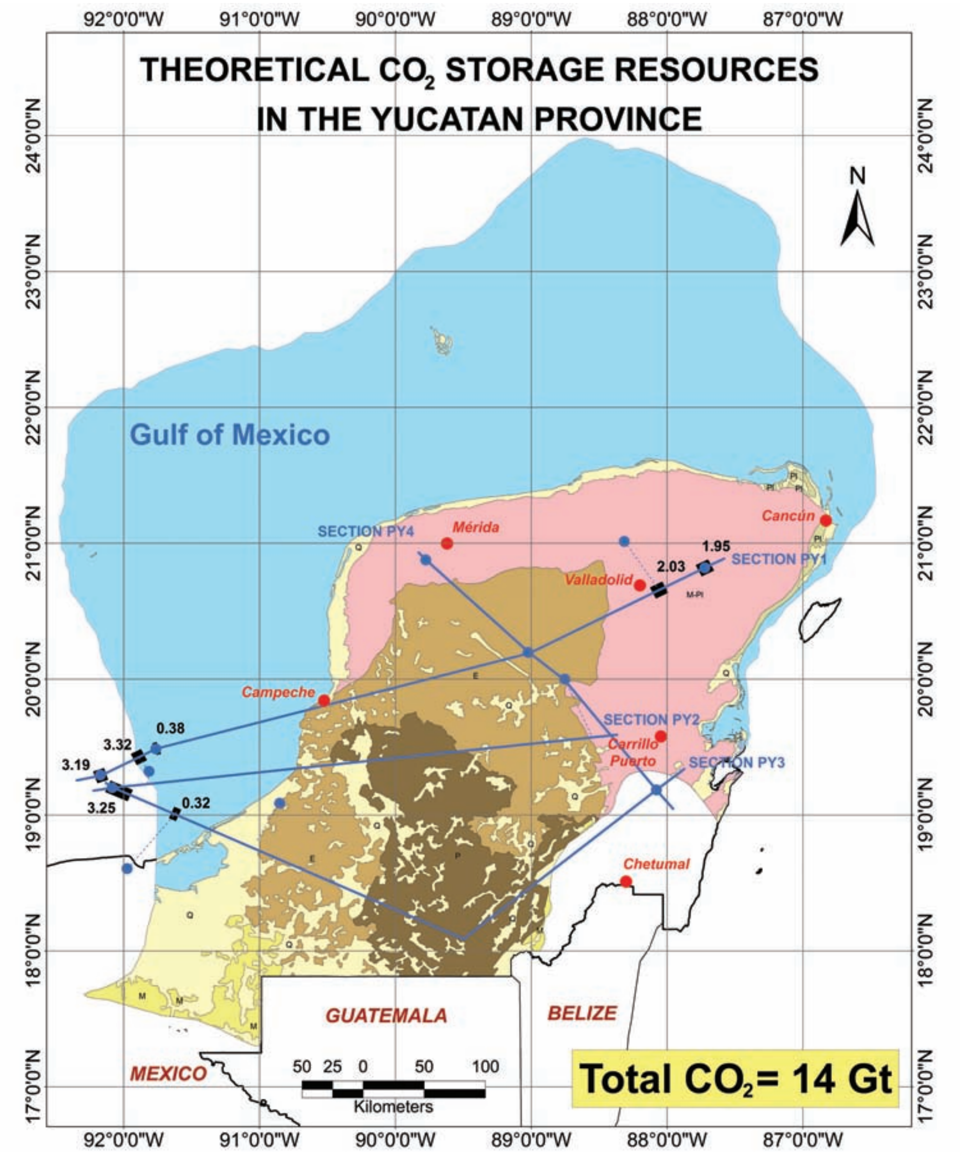
Sectors or prospective regions (shown in black) with CO_2 storage potential in saline formations. The marine zone was not quantified.

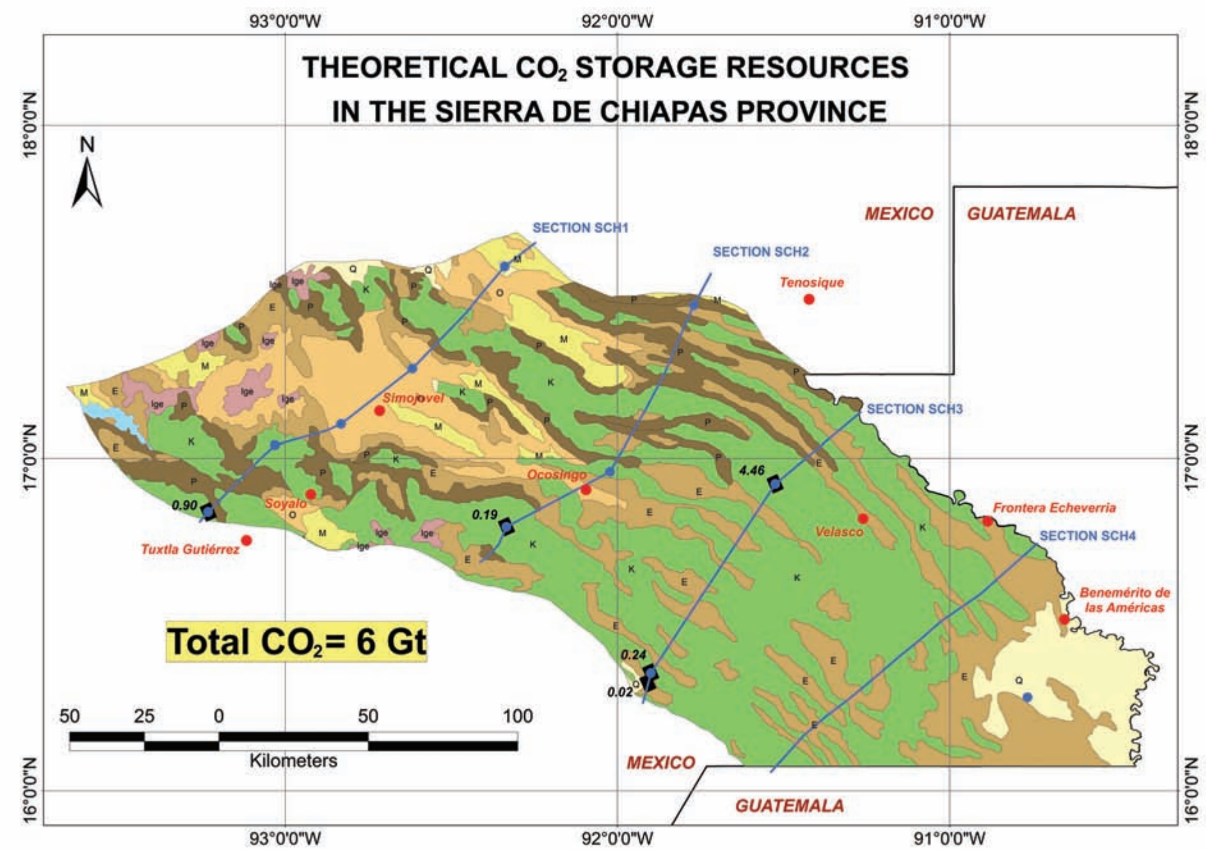


Sectors or prospective regions (shown in black) with CO_2 storage potential in saline formations. The marine zone was not quantified completely.









Sectors or prospective regions (shown in black) with CO_2 storage potential in saline formations. The marine zone was not quantified completely.

Carbon Dioxide Stationary Sources and Estimated Storage Resources by Country

Tonne (t) = 1 metric ton
Kilotonne (kt) = 1,000 metric tons
Megatonne (Mt) = 1,000,000 metric tons
Gigatonne (Gt) = 1,000,000,000 metric tons

Canada

Canada - CO_2 Emissions from Large Stationary Sources by Industry Sector and Province / Territory

Industry Sector	CO_2 Emissions from Large Stationary Sources (t/y)										
	AB	BC	MB	NB	NL	NS	NT	ON	QC	SK	CANADA
Agricultural Processing								118,841			118,841
Cement Plant	1,587,413	1,300,741	136,548			235,790		4,987,450	2,745,149		10,993,091
Electricity Generation	48,098,971	1,428,843	167,265	6,438,451	769,324	9,263,236		17,719,517	876,710	15,294,996	100,057,313
Ethanol			183,920					475,334		116,307	775,561
Fertilizer	3,346,984		597,803					450,482		500,405	4,895,674
Industrial	592,461	2,068,642	164,569	436,342	792,711		334,546	10,211,724	8,518,574	706,839	23,826,408
Petroleum/ Natural Gas	43,563,517	2,829,146			1,494,763	105,903	112,178	153,289		1,618,513	49,877,309
Refineries/ Chemical	9,691,345	592,231		2,930,288	1,083,460	731,841		6,904,647	4,204,722	1,538,341	27,676,875
Unclassified	195,057	108,725						340,138			643,920
Provincial Totals	107,075,748	8,328,328	1,250,105	9,805,081	4,140,258	10,336,770	446,724	41,361,422	16,345,155	19,775,401	218,864,992

Canada - CO_2 Emissions from Large Stationary Sources and CO_2 Storage Resource Estimates by Province / Territory

	CO_2 Emissions		Oil and Gas Storage Resource	Unmineable Coal Storage Resource			Saline Formation Storage Resource			Total Storage Resource		
				Megatonnes			Megatonnes			Megatonnes		
Province / Territory	Megatonnes/ Year	No. Sources	Megatonnes	Low Estimate	Mid Estimate	High Estimate	Low Estimate	Mid Estimate	High Estimate	Low Estimate	Mid Estimate	High Estimate
Alberta	107	82	11,790	3,320	5,850	7,590	7,450	28,420	76,130	22,560	46,060	95,510
British Columbia	8	25	2,880	100	170	230	70	250	690	3,050	3,300	3,800
Manitoba	1	5	10				330	1,300	3,500	340	1,310	3,510
New Brunswick	10	9										
Newfoundland & Labrador	4	6										
Northwest Territories		3					20	60	160	20	60	160
Nova Scotia	10	8										
Nunavut												
Ontario	41	64	210				250	1,000	2,690	460	1,210	2,900
Prince Edward Island												
Quebec	16	36	0				890	3,500	9,460	890	3,500	9,460
Saskatchewan	20	16	750	170	300	390	19,310	75,410	203,250	20,230	76,460	204,390
Yukon												
Canada Total	219	254	15,640	3,590	6,320	8,210	28,320	109,940	295,880	47,550	131,900	319,730

Mexico

Mexico - Estimates of CO_2 Emissions from Large Stationary Sources and CO_2 Storage Resources by State

	CO_2 Emissions		Saline Formation Storage Resources
			Megatonnes
State	Megatonnes/ Year	No. Sources	Low Estimate
Coahuila	23	6	4,760
Campeche	22	15	15,230
Veracruz	17	16	21,610
Hidalgo	16	8	
San Luis Potosi	13	10	
Nuevo Leon	12	13	13,820
Tamaulipas	11	13	17,820
Michoacan	9	7	
Sonora	9	10	
Chihuahua	8	9	420
Mexico	8	12	
Colima	7	3	
Guerrero	7	2	
Guanajuato	6	5	
Baja California	5	7	
Tabasco	5	10	17,350
Oaxaca	4	3	
Puebla	4	6	
Yucatan	4	5	3,980
Durango	3	4	
Jalisco	3	8	
Queretaro	3	4	
Sinaloa	3	2	
Morelos	2	1	
Baja California Sur	< 1	3	
Aguascalientes	< 1	1	
Chiapas	< 1	3	5,810
Distrito Federal	< 1	2	
Mexico Total	205	188	100,800

United States

United States - Estimates of CO_2 Emissions from Large Stationary Sources and CO_2 Storage Resources by State

State	CO_2 Emissions		Oil and Gas Reservoir Storage Resource	Unmineable Coal Storage Resource		Saline Formation Storage Resource		Total Storage Resource	
			Megatonnes	Megatonnes		Megatonnes		Megatonnes	
	Megatonnes/ Year	No. Sources		Low Estimate	High Estimate	Low Estimate	High Estimate	Low Estimate	High Estimate
Alabama	79	33	340	1,930	4,380	11,520	158,380	13,790	163,100
Alaska	20	35		10,340	23,630			10,340	23,630
Arizona	55	23	10	0	0	90	1,290	100	1,300
Arkansas	34	12	220	1,580	3,620	4,340	59,650	6,140	63,490
California	82	148	3,540			30,350	417,370	33,890	420,910
Colorado	46	30	1,590	490	860	30,880	424,650	32,960	427,100
Connecticut	9	11				0	0	0	0
Delaware	6	4				10	50	10	50
District of Columbia	0	1				0	0	0	0
Florida	142	65	110	1,270	2,870	16,520	227,290	17,900	230,270
Georgia	89	23		0	0	500	23,680	500	23,680
Hawaii	9	16							
Idaho	2	5				30	430	30	430
Illinois	119	75	110	1,450	2,860	8,460	115,490	10,020	118,460
Indiana	154	62	20	10	170	14,500	85,870	14,530	86,060
Iowa	54	50		0	10	0	40	0	50
Kansas	43	29	1,680	0	10	1,220	16,830	2,900	18,520
Kentucky	93	31	60	130	220	1,350	9,370	1,540	9,650
Louisiana	100	67	9,950	8,310	18,920	150,630	2,071,200	168,890	2,100,070
Maine	5	7							
Maryland	37	18	0			720	2,960	720	2,960
Massachusetts	24	19				0	0	0	0
Michigan	90	48	780			15,180	60,710	15,960	61,490
Minnesota	57	62							
Mississippi	33	21	560	5,430	12,420	45,830	630,110	51,820	643,090
Missouri	94	50	0	0	10	10	180	10	190
Montana	27	17	2,660	320	320	123,180	1,687,690	126,160	1,690,670
Nebraska	31	30	30	0	0	22,860	76,910	22,890	76,940
Nevada	27	12				0	0	0	0
New Hampshire	8	5							
New Jersey	31	38				0	0	0	0
New Mexico	31	12	7,360	80	300	31,620	434,780	39,060	442,440
New York	68	67	970			1,730	6,940	2,700	7,910
North Carolina	76	24				1,340	18,370	1,340	18,370
North Dakota	41	13	4,420	600	600	102,560	102,720	107,580	107,740
Offshore	0	0	17,180	0	0	467,040	6,440,440	484,220	6,457,620
Ohio	149	51	10,080	110	150	3,990	15,970	14,180	26,200
Oklahoma	51	27	8,060	0	10	0	0	8,060	8,070
Oregon	11	14				6,790	93,410	6,790	93,410
Pennsylvania	142	76	3,070	230	330	6,920	27,670	10,220	31,070
Rhode Island	2	3				0	0	0	0
South Carolina	40	23				200	9,560	200	9,560
South Dakota	18	19	170			17,870	162,330	18,040	162,500
Tennessee	65	13	0	0	0	500	6,780	500	6,780
Texas	369	210	46,090	14,010	32,020	345,130	4,745,550	405,230	4,823,660
Utah	39	15	1,170	30	120	21,030	289,110	22,230	290,400
Vermont	0	1				0	0	0	0
Virginia	46	29	50	210	870			260	920
Washington	24	25		590	1,350	36,020	495,320	36,610	496,670
West Virginia	99	26	1,840	310	450	4,490	17,940	6,640	20,230
Wisconsin	80	86				0	0	0	0
Wyoming	60	30	2,300	11,870	12,150	87,390	1,201,650	101,560	1,216,100
U.S. Total	3,014	1,811	124,420	59,300	118,650	1,612,800	20,138,690	1,796,520	20,381,760

This table is a compilation of all data for the United States. States with the "zero" represent estimates of minimal CO_2 storage resource while states with a blank represent areas that have not yet been assessed by the RCSPs.

Please note CO_2 geological storage information in this atlas was developed to provide a high-level overview of CO_2 geological storage potential across the United States. Carbon dioxide resource estimates presented are intended to be used as an initial assessment of potential geological storage. This information provides CCS project developers a starting point for further investigation of the extent to which geological CO_2 storage is feasible. This information is not intended as a substitute for site-specific characterization, assessment, and testing.

Nomenclature

Anthropogenic CO_2: The portion of CO_2 released into the atmosphere that is produced directly by human activities, such as the burning of fossil fuels, as opposed to natural processes such as plant respiration/decay and sea-surface gas exchange.

Basin: A geological region with strata dipping towards a common axis or center.

Caprock: Rock of low permeability that acts as an upper seal to prevent fluid flow out of a reservoir.

Capacity: Estimate of the pore volume that is expected to be available to CO_2 over the project lifetime. Resource estimates should be specific to the target injection zone at the proposed project site.

Carbon Capture and Storage (CCS): The capture of CO_2 from large stationary sources, such as power plants, chemical processing facilities, oil refineries, and other industrial facilities, followed by the transportation and injection of CO_2 into geological formations for safe, permanent storage. Examples of storage sites include depleted oil and gas reservoirs, unmineable coal, and deep saline formations.

Carbon Dioxide (CO_2): A colorless, odorless, gas that is a normal constituent of the Earth's many systems including the atmosphere, biosphere, and oceans.

Carbon Dioxide-Enhanced Oil Recovery (CO_2-EOR):. The use of CO_2 to raise the reservoir pressure of an oilfield and increases the mobility of the oil, thus making it easier for the oil to flow towards producing wells.

Carbon Dioxide Equivalent (CO_2 eq.):. A unit of measurement that allows the climate change potential of different GHGs to be compared using CO_2 as a standard unit for reference.

Centro Mario Molina (CMM): An independent, non-profit organization in Mexico working for strategic studies on energy and environment.

Comisión Federal de Electricidad (CFE): Mexico´s National Electricity Company.

Dense Phase: The physical state of a gas close to or above its critical pressure, where many of its properties are similar to that of a liquid (see also supercritical).

Enhanced Coalbed Methane (Recovery) (ECBM): The use of CO_2 to enhance the recovery of the methane present in coal beds through the preferential adsorption of CO_2 to coal.

Enhanced Oil Recovery (EOR): Generic term for techniques for increasing the amount of oil that can be extracted from an oilfield additional to that produced using primary and secondary recovery.

Exclusion Zone (Mexico): Area not recommended for CO_2 storage until further geological studies have been completed.

Exajoule (EJ): $1x10^{18}$ Joule (0.95 quadrillion British thermal units [BTU]).

Fault: In geology, a surface at which strata are no longer continuous, but displaced.

Formation: A body of rock of considerable extent with distinctive characteristics that allow geologists to map, describe, and name it.

Fracture: A crack within a rock along which there has been no movement. Fractures can enhance the permeability of rocks by connecting pores together.

Geographic Information System (GIS): a system of hardware and software used for the storage, retrieval, mapping, and analysis of geographical information.

Geological Storage: Also called geological sequestration, refers to the indefinite isolation of CO_2 in subsurface formations. Injected CO_2 is trapped within the pore space, dissolved in formation fluids, and (over long time periods) mineralized.

Gigatonne (Gt): One billion tonnes (1 billion metric tons).

Inclusion Zone (Mexico): Area that yields the best potential for CO_2 storage based on current geological knowledge.

Injectivity: A measure of the rate at which a quantity of fluid can be injected into a well.

Instituto Nacional de Ecología (INE): Mexican National Institute of Ecology.

Instituto Nacional de Estadística Geografía e Informática (INEGI): National Institute of Statistics, Geography, and Information Technology.

Kilotonne (kt): One thousand tonnes (one thousand metric tons).

Megatonne (Mt): One million tonnes (one million metric tons).

Monitoring, Measurement, and Verification (MMV) or Monitoring, Verification, Accounting, and Assessment (MVAA): A series of measures designed to confirm that injected CO_2 will remain safely and permanently stored within the injection formation through observing the subsurface behavior of the CO_2 plume, monitoring the site for releases or other deterioration of storage integrity over time, and accounting for the quantity and injection of CO_2 that has been stored underground.

NACAP: North American Carbon Atlas Partnership.

NACSA: North American Carbon Storage Atlas.

North American Energy Working Group (NAEWG): Established in 2001 by the Minister of Natural Resources Canada, the Secretary of Energy of Mexico, and the Secretary of Energy of the United States of America.

The National Carbon Sequestration Database and Geographic Information System (NATCARB): A GIS-based tool developed to provide a view of the CCS potential in the regions assesses by the RCSPs.

Natural Resources Canada (NRCan): Canadian Federal Ministry of Natural Resources.

National Energy Technology Laboratory (NETL): Owned and operated by U.S. Department of Energy.

Permeability: Ability to flow or transmit fluids through a porous solid such as rock.

Petróleos Mexicanos (PEMEX): Mexico´s National Oil Company.

Pore Space: Space between rock or sediment grains that can contain fluids.

Porosity: Measure of the amount of pore space in a rock.

Registro de Emisiones y Transferencia de Contaminantes (RETC): Mexican Pollutant Release and Transfer Register.

Regional Carbon Sequestration Partnerships (RCSP): Network of seven partnerships created in 2003 by U.S. DOE to help develop the technology and infrastructure to implement large-scale CCS in different regions and geological formations within the United States.

Saline Formation: Sediment or rock body containing brackish water or brine.

Seal: An impermeable rock that forms a barrier above and around a reservoir such that fluids are held in the reservoir.

Sedimentary Basin: Natural large-scale depression in the Earth's surface that is filled with sediments.

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT): Mexican Ministry of the Environment and Natural Resources.

Secretaría de Energía (SENER): Mexican Ministry of Energy.

Supercritical: The physical state of a substance above its critical point where distinct liquid and gas phases do not exist.

Terrigenous: Sediments derived from the erosion of rocks.

U.S. DOE: United States Department of Energy.

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