

Geologic Sequestration of Carbon Dioxide in Kansas

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Introduction

Greenhouse gases, particularly carbon dioxide, are of growing international concern. Increased levels of these gases in the atmosphere have been potentially linked to global climate change. Reducing greenhouse gas emissions, while ensuring the availability of energy resources essential to our economy, is a priority and a challenge.

Worldwide carbon dioxide (CO₂) emissions from human activity have increased from an insignificant level two centuries ago to more than 33 billion tons annually. At the same time, CO₂ concentrations in the atmosphere have increased from 280

to 384 parts per million (IPCC, 2007). To curb these trends, scientists are studying the feasibility of capturing and sequestering, or storing, CO₂ (fig. 1).

One type of sequestration that may be viable, particularly in Kansas, is storing CO₂ in deep underground rock formations, or geologic sequestration. This Public Information Circular provides background about geologic sequestration, the issues it raises, and potential locations in Kansas that might be amenable to carbon capture and sequestration. Terms shown in **bold** are defined in the glossary at the end.

Carbon Dioxide

Carbon dioxide (CO₂), a colorless, odorless gas, is a natural and critical component of the atmosphere. It is given off through various natural and human processes. Among the most common sources of CO₂ from human activity are fossil fuels, such as oil, gas, and coal, which are burned for transportation and power generation. CO₂ is one of several greenhouse gases that are essential to main-

taining life-sustaining temperatures on earth, but too much CO₂ in the atmosphere could have a detrimental impact on the environment. **Greenhouse gases** allow heat from the sun to penetrate the earth's atmosphere but do not allow it to escape back into outer space. Though some scientists disagree about the nature and degree of climate change, there is a general consensus that increased greenhouse gases can contribute

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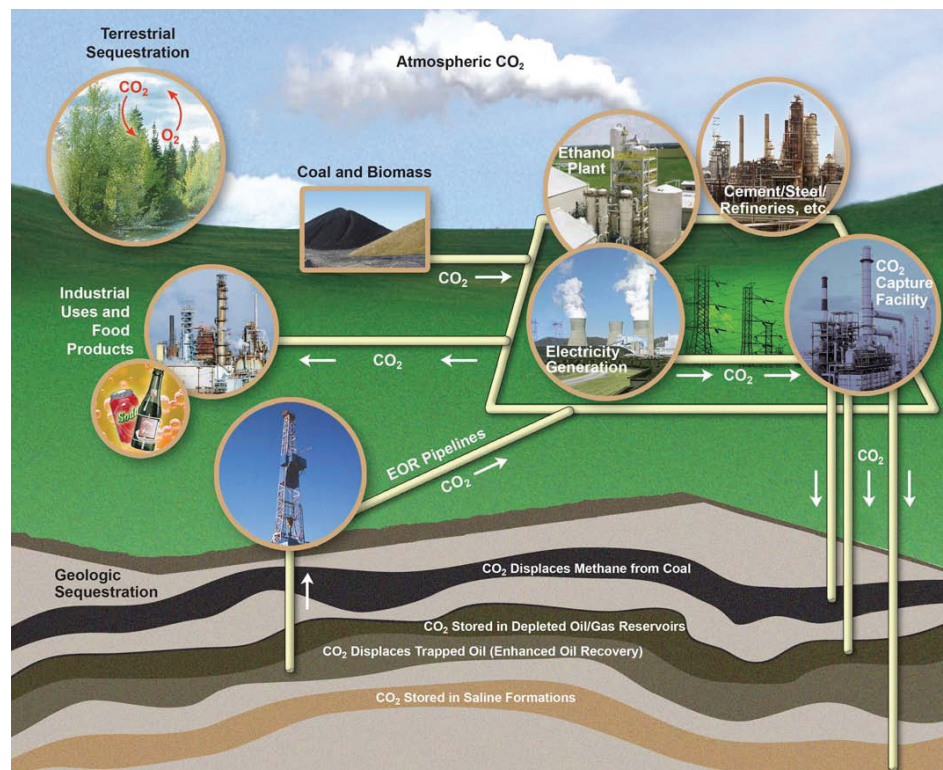


Figure 1—The carbon capture and storage process showing major pathways for geologic and terrestrial storage. Image adapted from U.S. DOE, 2007a.

to increased temperatures and other changes in regional climate patterns. CO₂ is of particular concern because it is increasingly produced through human activities. If current trends continue, the United States will emit 6.8 billion tons of CO₂ by 2030, a 16% increase over 2006; Kansas CO₂ emissions would be 89.5 million tons by 2030 (U.S. DOE, 2008).

In Kansas, coal-fired electrical power plants, refineries, cement plants, and ethanol plants are the most common stationary sources of CO₂ (fig. 2). Unlike emissions from non-stationary sources such as vehicle exhaust, CO₂ from stationary sources can

be captured for various uses, such as in food products and as dry ice. CO₂ produced from many Kansas stationary sources, however, is impure—mixed with other gases—making it harder to use. The technology to isolate and capture CO₂ from these sources is expensive, energy intensive, and undeveloped for large-scale applications. Currently, CO₂ is only captured in Kansas at a few facilities that produce high-purity CO₂. However, work is underway to reduce costs and energy requirements to make the isolation of CO₂ from impure sources feasible on a commercial scale.

Managing Carbon Dioxide

Using energy more efficiently to reduce our reliance on fossil fuel combustion is one way to manage CO₂. Promoting low-carbon and carbon-free fuels and technologies, such as geothermal power, hydropower, nuclear power, solar energy, wind power, and biomass fuels, is another. A third strategy is to manage CO₂ through carbon storage sites sometimes referred to as “sinks.” Some **carbon dioxide sinks**, such as oceans, plants, trees, and other photosynthetic organisms, are a natural part of the earth’s carbon cycle.

Sequestration, the deliberate removal of CO₂ from the atmosphere so that it can be safely contained, involves artificially storing the CO₂ in such sources as water, vegetation, or geologic reservoirs in underground rocks (fig. 1). The entire process of capturing and sequestering CO₂ is sometimes referred to as

carbon capture and storage, or CCS. Several types of sequestration are being studied. One method under consideration is the injection of liquid-like CO₂ deep into ocean water at depths greater than 3,300 ft (1,000 m). However, this might cause ocean acidification and long-term contamination. Another possibility is terrestrial sequestration. Trees, grasses, and other types of vegetation would be planted to remove CO₂ from the air through photosynthesis. Carbon extracted from the CO₂ would be incorporated into the plant biomass or stored in the soil. Terrestrial sequestration, however, has volume limitations. An estimated 220,000 acres of plants could be required to offset emissions from one average-sized power plant (Newell and Stavins, 2000). Geologic sequestration, described below, is a third option.

Geologic Sequestration of CO₂

Geologic sequestration, injecting CO₂ into underground rocks for secure containment, is efficient at depths greater than 2,400 ft (about 800 m). CO₂ increases in density and becomes a **supercritical fluid** under the great pressures that naturally exist at those depths. Supercritical fluids take up less space and diffuse more easily through the pore spaces in rock formations than either gases or ordinary liquids. Five types of geologic formations considered the most likely candidates for geologic sequestration are

- deep saline **aquifers**, underground rock formations whose pore space is saturated with saltwater,
- coal seams, including those that are deep and unmineable and shallower coal beds too thin to be mined economically,
- oil and natural gas **reservoirs**, underground rocks with pore space that holds oil or natural gas,
- oil- and gas-rich organic shales, and
- basalt, a volcanic rock with a chemical makeup that converts the CO₂ to a solid mineral form, thus isolating it from the atmosphere.

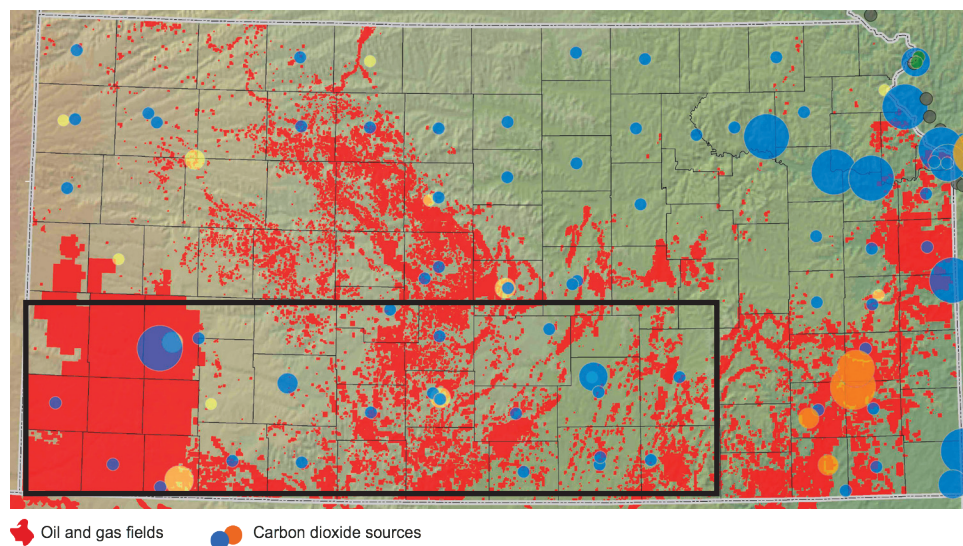


Figure 2—Documented stationary sources of CO₂ and evaluated potential geological storage sites. Stationary sources include power-generation facilities, refineries, cement kilns, and ethanol plants. Black box outlines the area that the KGS and partners are studying for potential storage of CO₂. Map created from NatCarb (2008) database.

Geologic storage of CO₂ has been underway for more than a decade with projects in Norway and Algeria and a joint U.S.–Canadian effort at the Dakota Gasification facility in North Dakota and the Weyburn field in Saskatchewan. These enterprises have provided significant data and experience with a variety of natural reservoirs. Numerous field projects in the U.S. and Canada are being developed in saline aquifers, oil reservoirs, and coal seams through the U.S. Department of Energy’s Regional Carbon Sequestration Partnerships (U.S. DOE, 2007b), regional partnerships between private companies, universities, and governmental agencies. Thus far, no evidence suggests significant volumes of CO₂ have migrated out of the confining reservoirs, indicating that long-term storage is feasible.

Geologic Sequestration of CO₂ in Kansas

In Kansas, geologic sequestration of CO₂ may be possible in all five of the geologic formations: deep saline aquifers, coal seams, oil and natural gas reservoirs, oil- and gas-rich organic shales, and basalt (the most problematic because no one knows how much CO₂ the ancient rock—deeply buried in parts of Kansas—can hold). Altogether, researchers estimate Kansas has at least 2.7 to 5.4 billion tons of potential geologic sequestration space, enough to hold almost 70 years worth of the state's stationary CO₂ production.

Saline aquifers could potentially store large amounts of CO₂ in Kansas. The highly saline water is not usable for other purposes and would dissolve the CO₂. The Arbuckle Group, a series of rock layers found only in the subsurface in Kansas, is a prospective environment for CO₂ sequestration. Consisting mainly of dolomite, the sedimentary strata of the Arbuckle Group were deposited about 480 million years ago during the Cambrian and Ordovician periods of geologic history. They are found at depths ranging from less than 250 ft (75 m) in southeast Kansas to 8,000 ft (2,500 m) in southwest Kansas. In parts of the state, large amounts of oil have been produced from rocks in the Arbuckle Group. Brine from thousands of oil wells has already been successfully placed in the Arbuckle and other aquifers, indicating the aquifers might safely contain CO₂ as well (Carr et al., 2005).

Sequestering CO₂ in unmineable coal beds would remove it from the atmosphere and might also aid in the recovery of natural gas from Kansas coal beds, an important source of the gas (Sawin and Brady, 2001). In 2009 Kansas produced 43 billion cubic feet of coal-related gas, much of it from the Cherokee basin in the southeast. Although this gas is sometimes referred to as **coalbed methane**, it includes constituents other than methane.

Scientists at the Kansas Geological Survey (KGS) have studied ways to use gas high in CO₂ emitted from cement plants and commercial landfills to enhance natural gas production from coal. They are investigating the practicality of injecting CO₂ into subsurface coal beds to displace coalbed methane, which could then be processed and used. Such studies are preliminary, and the feasibility of using CO₂ to produce natural gas from coal will be determined only after taking many geologic and economic factors into account. Whether or not CO₂ sequestration in coal seams could be used to successfully produce more natural gas, the coal could still be used to sequester CO₂.

Another way to manage CO₂, at least in the near term, would be to use it in the production of hard-to-recover oil from older fields. In the process known as **enhanced oil recovery (EOR)**, CO₂ could be injected to force out additional oil, a procedure that would also sequester much of the CO₂. Even in Kansas fields that are declining after decades of production, significant amounts of oil remain trapped in the pore space of underground rocks. CO₂ pumped into these reservoirs would dissolve into the oil and reduce the oil's viscosity, making it easier to recover (fig. 3). Small amounts of CO₂ coming back to the surface with the oil

could be captured and reinjected to help produce more oil. Much of the CO₂, however, would remain trapped below ground. CO₂ is already being used commercially and experimentally to enhance oil recovery in a number of locations in the country, most notably in west Texas.

To better understand the use of CO₂ in enhanced oil recovery, a mature oil field in Russell County, Kansas, was flooded with CO₂ starting in 2003. The KGS monitored the movement of the CO₂ underground using a geophysical technique called seismic reflection. Oil production increased as a result, though the complexity of the subsurface formations made it difficult to predict the exact movement of the CO₂ flood.

In addition, the KGS has received major funding from the U.S. Department of Energy to characterize the underground geology of large parts of south-central and southwestern Kansas (see fig. 2). This research is particularly focused on analyzing subsurface rocks and fluids, looking at their ability to store CO₂. None of these projects involves actual injection of CO₂ into the subsurface, but they are designed to provide data that could be used for potential CO₂ sequestration projects, both in terms of enhanced oil recovery and deeper sequestration in the Arbuckle.

In Kansas, the suitability of CO₂ for enhanced recovery will depend on oil prices, the nature of the state's oil and gas reservoirs, and the ready availability of CO₂. Because the state has had a long history of oil production, a great deal is known about its subsurface geology and incredible amounts of geologic data are available. Many known oil reservoirs appear to be candidates for CO₂ flooding. KGS scientists estimate that oil reservoirs in Kansas could produce between 400 and 900 million additional barrels of oil with the use of CO₂ flooding (Byrnes, 2000). At the same time, the process would sequester significant quantities of CO₂. However, concerns have been raised in the state about regulating CO₂ enhanced oil recovery and whether the CO₂ would be trapped in these reservoirs or move back to the surface over time. Because Kansas has long been drilled for oil and gas and some areas have been very densely drilled, concerns also exist that CO₂ could move back to the surface through poorly plugged or long-forgotten wells.

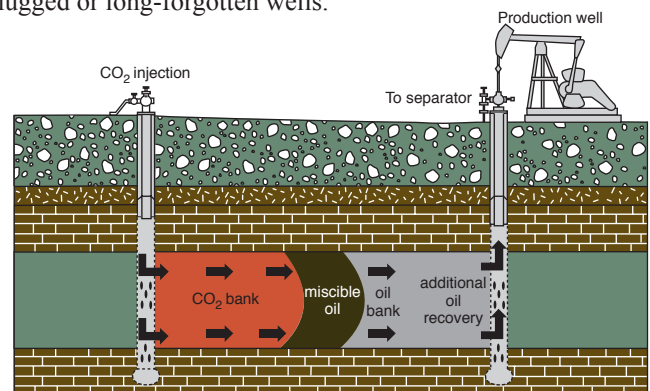


Figure 3—Carbon dioxide flooding.

Sequestration Concerns and Information Resources

A number of issues must be resolved before geologic sequestration can play a major role in CO₂ management. The capture of CO₂ from waste streams, such as smokestacks, requires considerable cost and energy and has only been tested on a small scale. Even if it could be efficiently captured, much CO₂ would have to

be transported to storage locations. This would likely require construction of an extensive pipeline network. To be pumped underground, the gas would have to be compressed and perhaps turned into liquid CO₂. This would require additional energy, although it would also significantly reduce the volume of the gas, which



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The mission of the Kansas Geological Survey, operated by the University of Kansas in connection with its research and service program, is to conduct geological studies and research and to collect, correlate, preserve, and disseminate information leading to a better understanding of the geology of Kansas, with special emphasis on natural resources of economic value, water quality and quantity, and geologic hazards.

The Geology Extension program furthers the mission of the KGS by developing materials, projects, and services that communicate information about the geology of Kansas, the state's earth resources, and the products of the Kansas Geological Survey to the people of the state.

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would make less storage space necessary. Finally, a regulatory environment would have to be created to protect health, safety, and the environment for long periods. Storage locations, for example, would need to be regularly monitored for leaks.

In Kansas, sequestration needs to be studied in more detail to determine if oil and natural gas reservoirs and coal beds have the capacity to take and hold CO₂. This is especially true in locations with long histories of oil and gas exploration where older, poorly plugged wells could provide avenues for CO₂ to return to the surface. In addition, a variety of legal issues, such as ownership of the underground pore space used for sequestration, would need to be resolved, and a workforce would have to be developed. Ultimately, regulatory decisions, economics, and a well-defined environment for greenhouse gas management will highly influence any decisions concerning the feasibility of geologic sequestration. Determining its future will require much data collecting and analysis.

The success of geologic sequestration depends on the availability of information about the location of CO₂ sources, such as power plants, cement plants, refineries, and fertilizer plants, and the amount of CO₂ they produce. Information about potential sequestration sites and transportation needs, such as pipelines, also is necessary. With funding from the U.S. Department of Energy, the KGS worked with geologic institutions in other states across the U.S. and Canada to develop a database of available information (<http://www.natcarb.org>) (Natcarb, 2008). A Carbon Sequestration Atlas of the United States and Canada was produced as a result of that project (U.S. DOE, 2010) and allows users to most efficiently match the sources, transportation methods, and potential sequestration locations for CO₂.

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Glossary

- Aquifer:** Rock formation capable of holding and yielding large amounts of ground water, usually held in pore spaces between rock particles. Aquifers of saline water are potential locations for sequestering CO₂.
- Carbon capture and storage (CCS):** Process of capturing CO₂ from large stationary sources such as power plants and isolating it from the atmosphere.
- Carbon dioxide (CO₂):** Compound composed of one atom of carbon bonded with two atoms of oxygen that is a gas at standard temperatures and pressures.
- Carbon dioxide sink:** A reservoir that takes CO₂ in, as opposed to a source, which produces CO₂. Natural sinks are oceans, plants, and other organisms. Artificial sinks include geologic reservoirs.
- Coalbed methane (CBM):** Methane produced from coal layers. Because gas from the coal contains other components besides methane, the more general term is coalbed natural gas.
- Enhanced oil recovery (EOR):** Methods of producing oil after primary and secondary methods of production have been used. Primary production involves using natural underground pressures or pumping; in Kansas, secondary production generally refers to flooding underground oil reservoirs with water to produce more oil. Flooding with CO₂ is a form of EOR.
- Greenhouse gases:** Gases that trap heat in the atmosphere and thus are often blamed for higher temperatures. The most abundant are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.
- Reservoir:** As used herein, a natural underground formation that holds a liquid, such as oil or water. In Kansas, reservoirs generally hold oil or water in the pore space between rock particles.
- Supercritical fluids:** Highly compressed gases that take on many of the properties of both gases and liquids.

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