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Source-Sink Matching and Potential for Carbon Capture and Storage in the Gulf Coast

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ABSTRACT

Current global levels of anthropogenic CO_2 emissions are 25.6 Gigatons yr^{-1}. Approximately 1 Gigaton comes from the Texas, Louisiana, and Mississippi Gulf Coast, representing 16 percent of the U.S. annual CO_2 emissions from fossil fuels. The Gulf Coast region provides an opportunity for addressing the problem. Geologic sequestration results from the capturing of CO_2 from combustion products and injecting the compressed gas as a supercritical fluid into subsurface brine aquifers for long-term storage. The Gulf Coast overlies an unusually thick succession of highly porous and permeable sand aquifers separated by thick shale aquitards.

The Gulf Coast also has a large potential for enhanced oil recovery (EOR), in which CO_2 injected into suitable oil reservoirs could be used first for EOR and then for large-volume, long-term storage of CO_2 in nonproductive formations below the reservoir interval. For example, there are numerous opportunities for locating CO_2 injection wells either in fields for EOR or in stacked brine aquifers near potential FutureGen sites, where a near-zero emission facility would generate primarily hydrogen and CO_2 as by-products. We estimate that in the Gulf Coast, outside of the traditional area of CO_2 EOR in the Permian Basin, an additional 4.5 billion barrels of oil could be produced by using miscible CO_2. At $60 per barrel, this incremental production is estimated to have a wellhead value of $270 billion that could generate more than $40 billion in taxes.

INTRODUCTION

The increasing CO_2 concentration in the atmosphere is of global concern. Current global levels of anthropogenic, or human-produced, CO_2 emissions are 25.6 billion metric tons (Gigatons) of CO_2 yr^{-1} (IEA, 2002). A significant portion of the global total, approximately 1 Gigaton, comes from the Gulf Coast region of Texas, Louisiana, and Mississippi, representing 16 percent of the U.S. annual CO_2 emissions from fossil fuels. A global consensus is emerging that continued burning of fossil fuels is sustainable only if the resultant CO_2 is captured and prevented from entering the atmosphere. There are a number of approaches to remediating CO_2 levels in the atmosphere, including conservation, biomass creation, utilizing alternative or renewable power sources, and geologic sequestration of anthropogenic CO_2. Geologic sequestration enables fossil fuel to be decarbonized by capturing CO_2 from the combustion products and injecting it as a supercritical fluid into subsurface brine aquifers for long-term storage. Although the United States produces one-quarter of the world's CO_2 emissions from combustion of fossil fuel, it has the potential to play a critical role in capturing CO_2 and putting it into long-term storage in deep and thick brine aquifers. The Gulf Coast region, in particular, provides an opportunity for deep brine aquifer storage of CO_2. The Gulf Coast overlies an unusually thick (commonly >20,000-ft [>6,097.6-m]) clastic sequence containing highly porous and permeable sand aquifers, separated by thick shale aquitards (Galloway and others, 2000). This sedimentary wedge provides an amount of potential storage of hundreds of Gigatons of storage. The extensive blankets of low-permeability shales that separate the sand aquifers should assure storage for thousands of years, well past the expected age of fossil fuel dominance. Geologic storage in Gulf Coast brine aquifers, if implemented on a massive scale, could help reduce the rate of increase of CO_2 during a transitional period of a few decades while society effects a change to a hydrogen-based or another alternate energy future.

Additional economic incentive for CO_2 sequestration in the Gulf Coast region is also provided by an abundance of depleted oil fields that have already undergone secondary recovery (waterfloods), where the miscible CO_2 EOR potential could result in the production of and additional 4.5 BSTB (billion stock tank barrels) of oil (Holtz and others, 2005a). Many of these depleted oil fields are near anthropogenic CO_2 sources such as electric power plants, lignite mines and refineries, enabling reduced costs and infrastructure necessary to transport and sequester CO_2 for either EOR or storage.

CO_2 SOURCES IN THE GULF COAST

Anthropogenic or man-made sources of greenhouse gases are principally caused by emissions from fossil fuel combustion processes. In addition to mobile anthropogenic sources, such as automobiles, trains, and aircraft, significant volumes originate from stationary sources, including fossil-fuel-fired power plants, chemical plants, refineries, iron and steel foundries, cement plants, and natural gas processing sites. Moreover, CO_2 is routinely separated and captured as a by-product from industrial processes such as synthetic ammonia, ethylene, and ethylene oxide production, H_2 manufacture, and limestone calcination. Data on anthropogenic sources presented herein are from the International Energy Agency (IEA, 2002).

There are numerous sources of anthropogenic CO_2 in the Texas, Louisiana, and Mississippi part of the Gulf Coast. Many of these sources are from power plants that are widely distributed across the region. Most of these plants individually account for approximately 4,000 kiloton (kt) of CO_2 emitted per year, although some coal-fired power plants in east Texas and exceed 12,000 kt per year (Fig. 1). In contrast to pervasively distributed power plants, other CO_2-emitting sources such as refineries, ethylene, and ethylene-oxide plants are concentrated in coastal areas, particularly Houston, New Orleans, Texas City, and Beaumont (Fig. 2). Individual refineries account for as much as 4,000 kt of CO_2 emitted per year, with the greatest emitters located in the Houston-Beaumont-Texas City area. Other refineries are located in central and south Texas. Ethylene-processing plants in the region individually emit from 180 to over 4,000 kt of CO_2 per year, and the greatest emitters are located in southeast Louisiana and coastal part of Texas. Ethylene-oxide procession plants in the Gulf Coast emit lesser volumes of CO_2, with individual plants producing a maximum of approximately 200 kt of CO_2 per year.

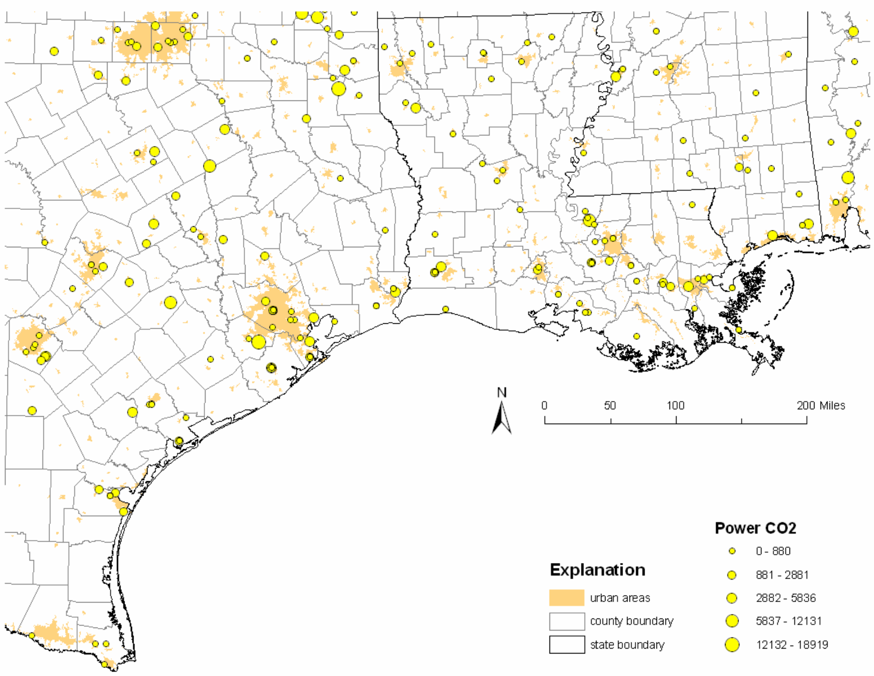

Figure 1. Annual CO_2 emissions in kilotons per year from power plants in the Texas, Louisiana, and Mississippi Gulf Coast area. Data from IEA (2002).

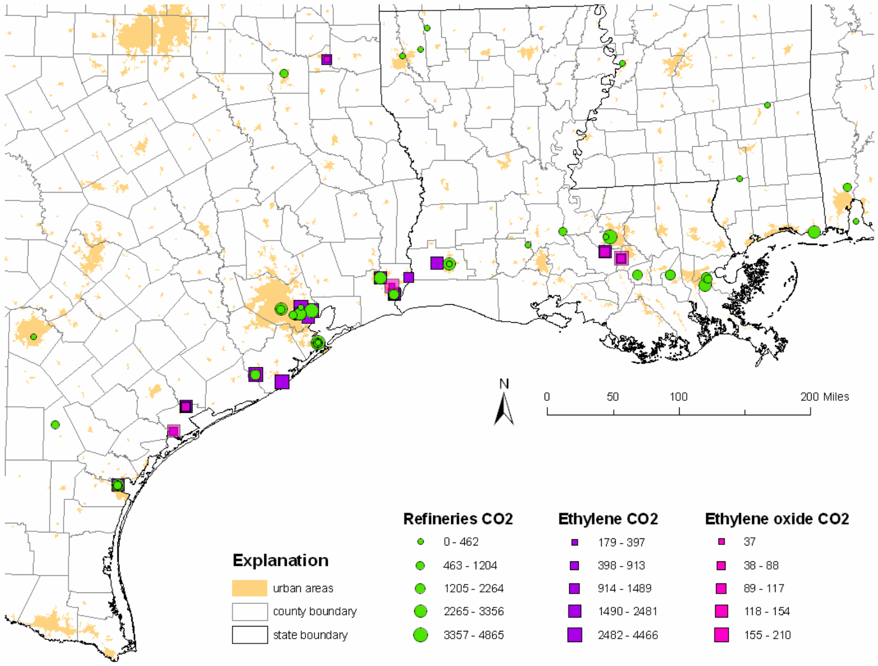

Figure 2. Annual CO_2 emissions in kilotons per year from refineries, ethylene plants, and ethylene-oxide plants in the Texas, Louisiana, and Mississippi Gulf Coast area. Data from IEA (2002).

CO_2 SINKS IN THE GULF COAST

Deep Brine-Bearing Formations

The Gulf Coast region, particularly Texas, contains abundant thick accumulations of brine-bearing formations for potential storage of CO_2. These formations could potentially store hundreds of Gigatons of CO_2, even with the injected CO_2 occupying only a small percent of the available pore volume. The Gulf Coast is an attractive target for CO_2 sequestration because potential sources of CO_2 (industrial and power-generation facilities) coincide spatially with potential sinks in thick Tertiary successions, which contain many high-permeability sandstones separated by regionally extensive, low-permeability shale beds that serve as seals. These shale beds (for example, the Anahuac Shale above the Oligocene Frio Formation) (Galloway and others, 1982) are known to provide excellent seals over hydrocarbon reservoirs (both oil and gas) and are thus inferred to provide excellent seals for injected CO_2.

Although fresh water extends to depths of 1,000 to 3,000 ft (304.9 to 914.6 m) below surface, candidate sandstones containing brine retain their ability to accept injected fluids to depths of 14,000 ft (4,268.3 m) in many areas. The capacity of these formations to accept large volumes of injected fluids is unequaled in any other large area of the United States. For example, Gulf Coast sandstones such as those in the Frio Formation have been extensively used for underground injection of chemical and other wastes (Kreitler and others, 1988).

Other areas and basins in Texas also possess thick deposits of brine-bearing formations, including the East Texas, Fort Worth, and Permian Basins. However, sandstones in these basins are older geologically than those in the Gulf Coast Tertiary section, have undergone relatively more compaction, and may therefore not be as transmissive for CO_2 injection (Galloway and others, 1983). Nevertheless, these basins are also deemed to be suitable for CO_2 storage because of the proven existence of seals and extensive documentation as a result of oil and gas exploration and production.

CO_2 EOR Oil Fields

Texas and seven nearby states contain several oil plays comprising numerous reservoirs having potential for enhanced oil recovery (EOR) from injection and miscible displacement of CO_2 (Fig. 3). The database of possible CO_2 EOR miscible flood candidates includes major oil reservoirs in Texas, Louisiana, Alabama and Mississippi. Other oil reservoirs in New Mexico, Oklahoma, and Arkansas are included in the database but data are too scarce for these reservoirs to be screened for EOR potential. An unpublished Bureau of Economic Geology Texas oil reservoir database was combined with data from the Tertiary Oil Recovery Information System (TORIS) database, as well as reservoir data from the Alabama Geologic Survey. The Louisiana Geological Survey (LGS) provided field outlines and field names for Louisiana. Data for Texas reservoirs are derived from engineering information from numerous sources, including the *Atlas of Major Texas Oil Reservoirs* (Galloway and others, 1983), *Atlas of Major Texas Gas Reservoirs* (Kosters and others, 1989) and hearings reports from the Railroad Commission of Texas. The database also includes petrophysical data, fluid characteristics, and geological information, along with production information and location data. Reservoirs having similar geological and production characteristics are grouped into plays.

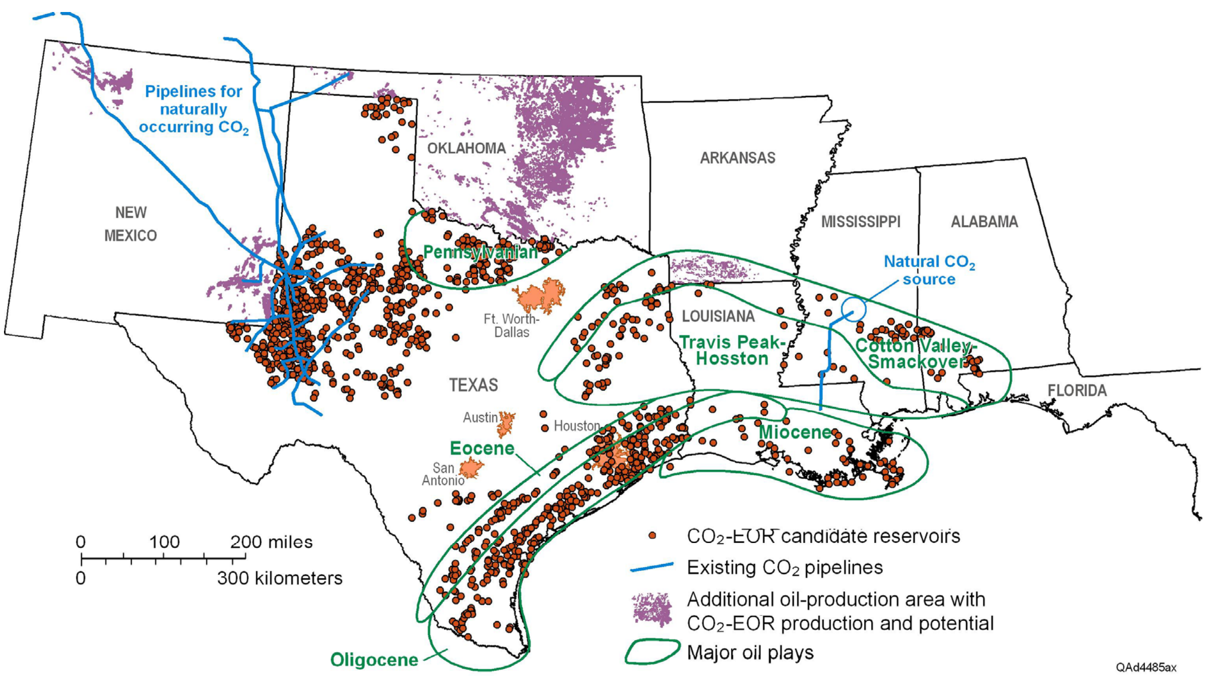

Figure 3. Map of candidate oil reservoirs for EOR from CO_2 miscible displacement in Texas and adjacent areas. From Holtz and others (2005a).

A variety of factors, described in Holtz and others (2001), were used in screening candidate oil reservoirs for EOR CO_2 potential. The primary factors were cumulative oil production and minimum miscibility pressure (MMP), a function of oil properties such as oil viscosity as well as reservoir temperature and pressure. Other factors include reservoir drive mechanism and the current stage of development. No reservoirs were included as candidates for CO_2 EOR unless the MMP was less than the initial reservoir pressure. Cumulative production was used as a screening criterion instead of remaining recoverable oil because cumulative production data were commonly available and because of uncertainties inherent in estimating recoverable oil volumes using variable data sets.

The estimated current volume of storage in the EOR candidates is more than 2,500 million metric tons (MMT) of CO_2 (Holtz and others, 2005a). The largest sequestration capacity in these economic EOR reservoirs is in Texas, which has more than 1,300 MMT of sequestration capacity. Louisiana also contains a large capacity exceeding 1,100 MMT. Mississippi and Alabama account for smaller but significant volumes of sequestration capacity. These results indicate that Oligocene and Miocene oil reservoirs contain a large target for sequestering CO_2. At the end of CO_2 EOR operations this sequestration potential could increase by another 15 percent, based on tertiary recovery efficiencies observed in other Gulf Coast oil reservoirs (Holtz and others, 2005b).

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CONCLUSIONS

A significant portion of the global total of 25.6 billion metric tons (Gigatons) of anthropogenic CO_2 yr^{-1} (approximately 1 Gigaton), originates in the Gulf Coast region of Texas, Louisiana, and Mississippi. Of the variety of approaches to remediating CO_2 levels in the atmosphere, geologic sequestration of anthropogenic CO_2 in the Gulf Coast offers a solution via injecting the compressed gas as a super-critical fluid into subsurface brine aquifers for long-term storage. The Gulf Coast overlies an unusually thick (commonly >20,000-ft [>6,097.6-m]) clastic sequence containing highly porous and permeable sand aquifers, separated by thick shale aquitards. This sedimentary wedge provides an amount of potential storage of hundreds of Gigatons of storage.

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