Systematic approach to source-sink matching for geological carbon capture and sequestration

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CE 394 K: GIS in Water Resources

Term Project

Introduction

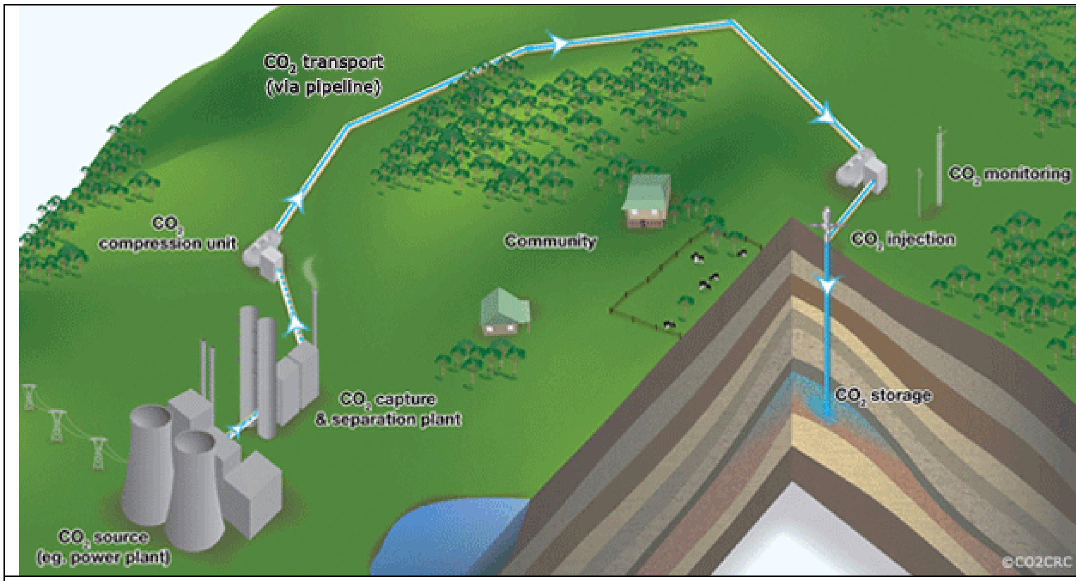

Figure 1. Cartoon illustration of geologic carbon capture and sequestration (CCS). CO_2 emmisions from a large point source such as a power plant are compressed, transported through pipelines and ultimately stored in a geologic reservoir. Source: Global CCS Institute

Geologic carbon capture and sequestration (CCS) is the process of intercepting carbon dioxide emissions from anthropogenic sources, compressing and storing it in underground reservoirs for thousands or millions of years. The goal of CCS is to prevent release ofantrhopogenic CO_2, a greenhouse gas and an agent of global climate change, into the atmosphere. Energy-related CO_2 emissions are the dominant greenhouse gas in the U.S. (EIA, 2011). As such, CCS has become the focus of active research and development to make it an economically and scientifically valid technology. The Intergovernmental Panel on Climate Change (IPCC, 2005) recognized CCS as a "serious [climate change] mitigation option" in their 2001 assessment report, the Department of Energy has established a nationwide CCS research network and dozens of CCS projects are already in effect globally (MIT).

CO_2 emissions are from both mobile and stationary sources. While mobile sources include cars, planes and trains, point sources of CO_2 are localized and include power plants, refineries, chemical plants, and cement plants. CCS technology is designed to reduce emissions from point sources. The National Energy Technology Laboratory estimates that 3,809 million tons per year of CO2 are emitted from about 4,000 point sources in the U.S. alone. About 86% of these point sources are electric-generating plants (NETL, 2007). The predominance of power plants as CO_2 emitters is clear in Figures 2 a and b.

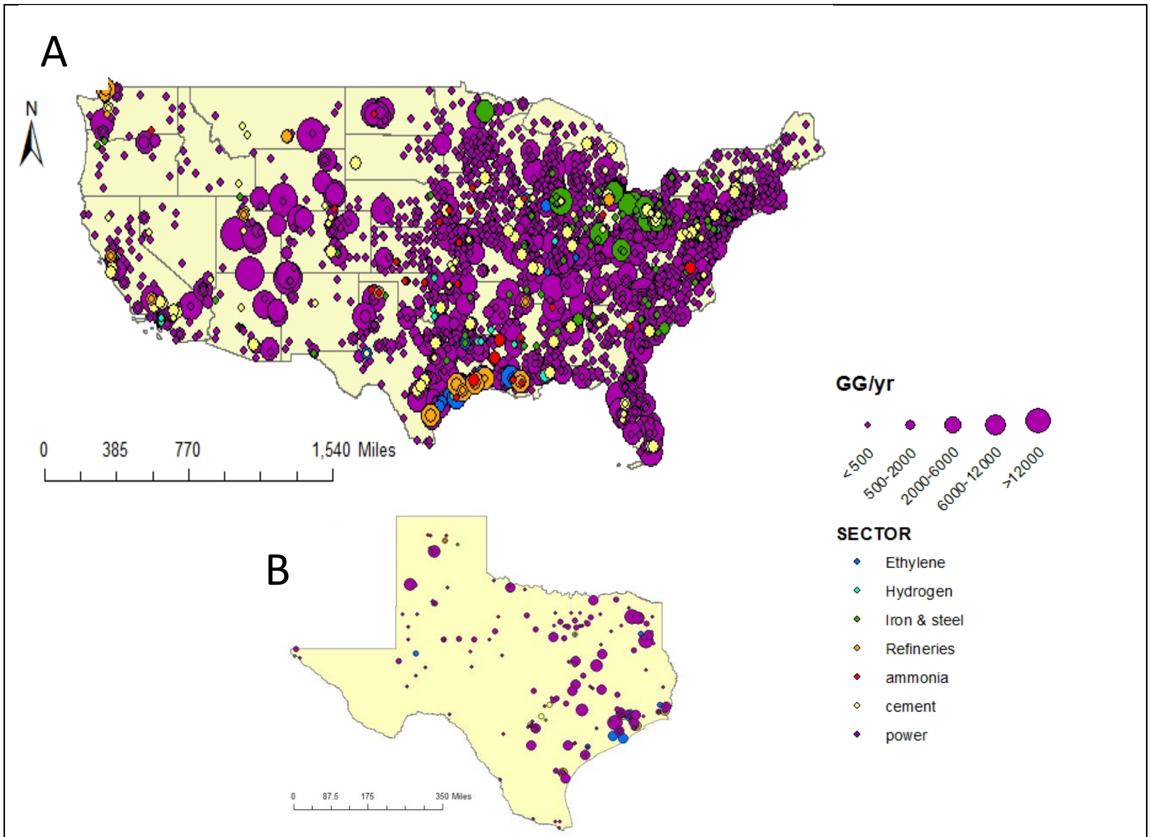

Figure 2. Major CO_2 producers in the U.S. (A) and in TX (B). Dot size represents size of producer. Dot color represents sector.

CO_2 sinks are geologic reservoirs such as depleted oil and gas field reservoirs or deep brine-bearing formations where existing pore fluids can be replaced with supercritical CO_2. CO_2 sinks must have several key properties: (1) sufficient storage capacity, (2)sufficient infectivity and (3) a sealing and trapping system or "lid" to sequester CO_2 over a long period of time (WRI, 2008). Though the potential for storage in brine bearing formations is vast, this report focuses on depleted oil and gas field reservoirs where there exists ample data on the physical, chemical and structural characteristics of reservoirs. Notably, CO_2 sequestration technologies are currently

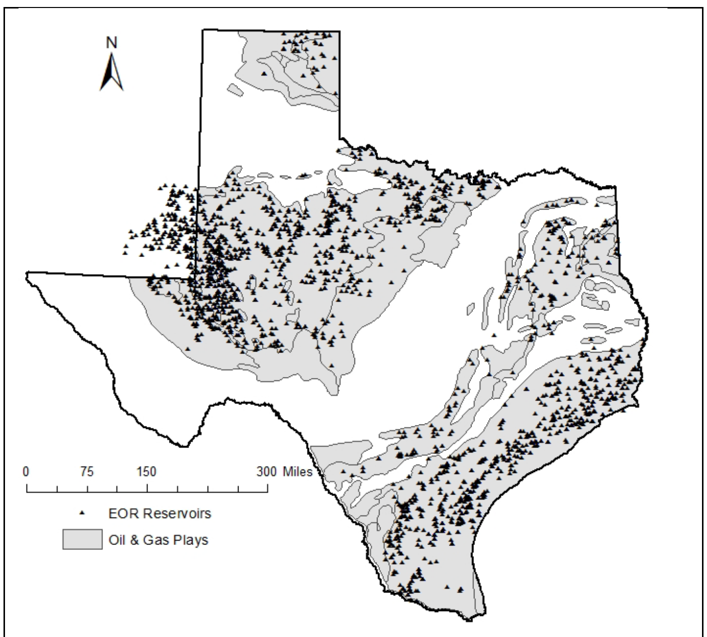

Figure 3. Relationship between potential CCS reservoirs and major oil and gas plays in TX

implemented as a method of “enhanced oil recovery” (EOR), a term for a suite of technologies that increase the amount of oil extracted from an oil field. Hence, many of the graphs in this report identify potential CO_2 sinks as “EOR reservoirs.” Figure 3 is a graph of all major potential enhanced oil recovery fields in Texas superimposed with major oil and gas plays in Texas. Geology controls both the location of major reservoirs and the potential location for CCS activities. Reservoirs primarily occur on trends along the Texas Gulf Coast and West Texas. Notably, all current TX CCS projects are occurring either on the Gulf Coast or in West TX near the panhandle (MIT).

Success of CCS is dependent on many factors. In this paper, I will focus on the importance of appropriate pairings of CO_2 sources and sinks. CO_2 source-sink pairing means matching a CO_2 emitter such as a power plant with a potential reservoir, taking into consideration factors like health, environment, economy and safety. Factors to consider for appropriate pairing include distance from source to sink, availability of existing CO_2 pipelines to transport supercritical CO_2, depth and geologic attributes of the sink, population distribution near proposed projects, nearness to parks and vulnerability of overlying environment. Ambrose et al (2009)[*] documented geographic distribution of point and geologic sources of CO_2, brine aquifers, CO_2 pipelines and geologic sinks for CCS in the continental United States, focusing on The Texas Gulf Coast and Permian Basin. This project aims to expand upon this work and incorporate protected areas and population distribution into matching decisions, focusing on Texas.

For the purposes of this term project, I will focus on several key aspects of source sink matching:

1. Location of freshwater resources and other environmentally vulnerable areas
2. Location of existing CO_2 pipelines
3. Population distribution

For each of these factors, I utilize ArcMap 10 to make spatial linkages between sources/sinks and my three key factors. I use simple selection tools to do a first-order criterion matching on sources and sinks. I then draw some conclusions about the best areas for CCS in Texas. A list of sources for data is provided at the end of the paper.

1. **Location of freshwater resources and other environmentally sensitive areas**.

Although it may seem simple to maximize the distance between CCS projects and freshwater resources, Figure 4 a makes it clear that the coincidence of Texas aquifers and CCS reservoirs is unavoidable. One logical next step might be to choose the reservoirs that are the greatest vertical distance from the freshwater resource. However, this data must be gleaned from individual wells and is

[*] Ambrose, W.A., Breton, C., Holtz, M.H., Nunez-Lopez, V., Hovorka, S.D., Duncan, I.J. 2009. CO_2 source-sink matching in the lower 48 Unite States, with examples from the Texas Gulf Coast and Permian Basin.

not within the scope of a term project. Instead, I decided to focus on what the Texas Center for Environmental Quality (TCEQ) has already deemed "Priority Groundwater Management Area." I also decided to pull data on the national and state parks in TX, which will be lumped into the CCS "no fly zone."

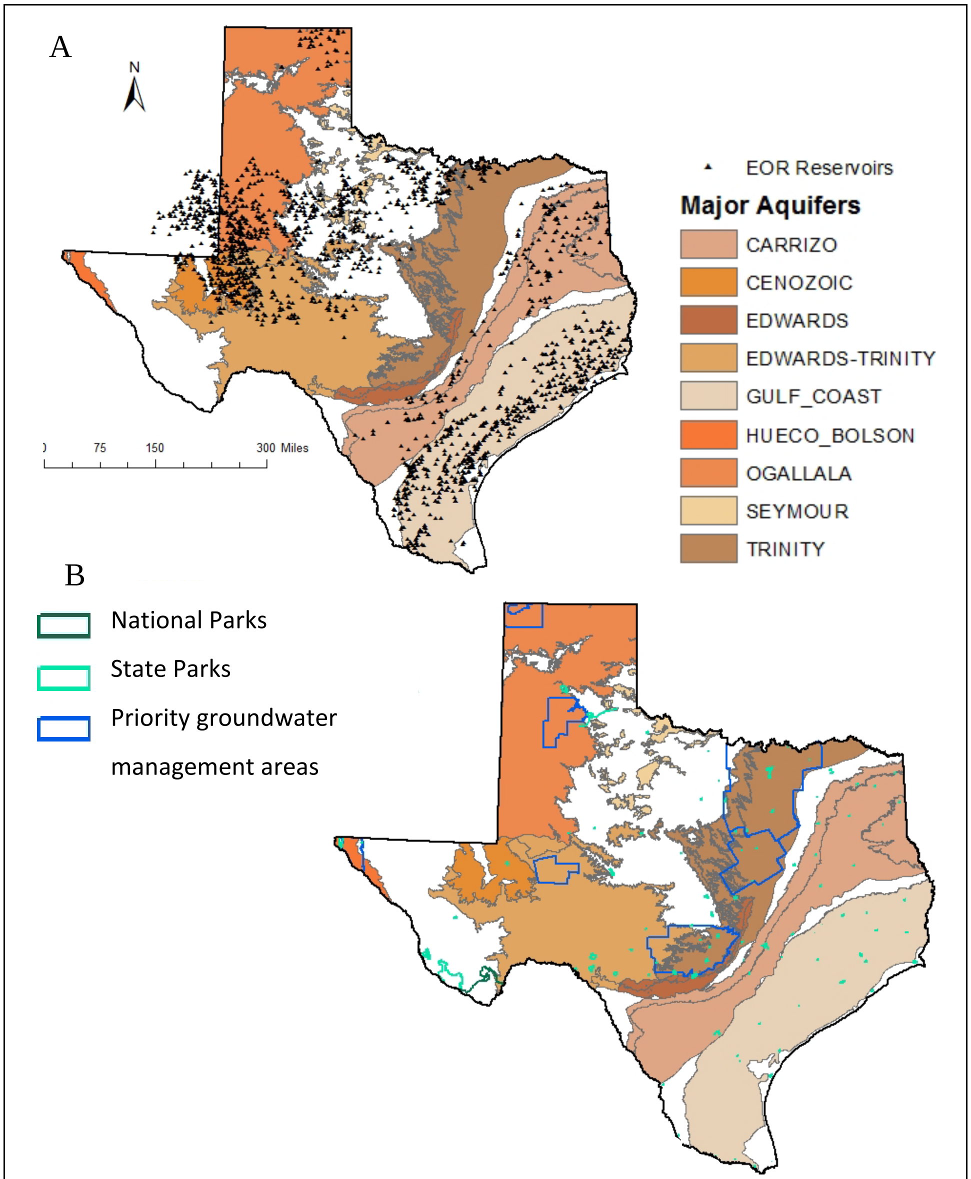

Figure 4. Relationship between potential CCS sites (EOR reservoirs) and major TX aquifers. It is clear that CCS activities will be coincident with freshwater resources. (A) shows the coincidence of EOR reservoirs and aquifers. (B) shows the aquifers overlain by environmentally sensitive areas.

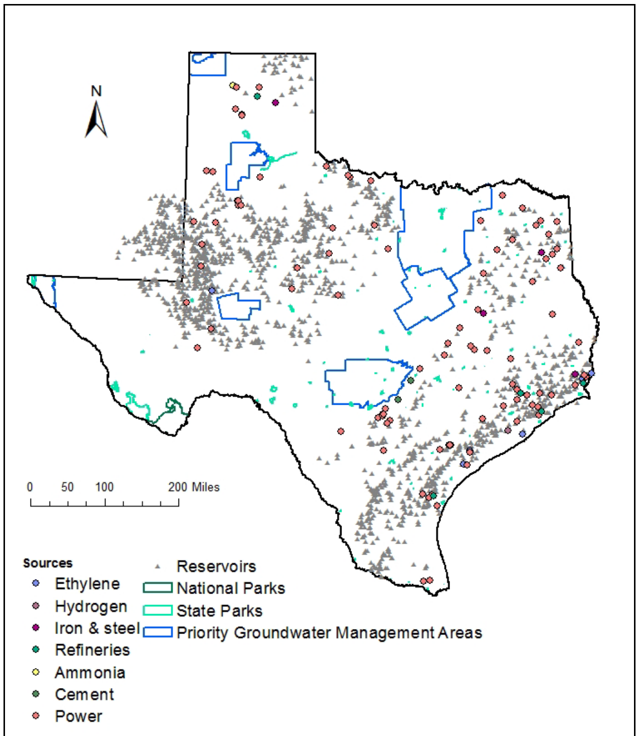

Figure 5. TX potential CCS reservoirs and sinks, selected for those not within 25 km of a state park, national park or priority groundwater management area.

Figure 4 B shows the areas which are deemed unsuitable for CCS due to environmental concerns. I removed all sources and sinks within 25 km of an environmentally sensitive area from the map. The result is shown in Figure 5. This process did not eliminate a large number of sources and sinks. Sinks were reduced from 3207 to 2973. Sources were reduced from 296 to 227. This is not a drastic reduction in source-sink choices but does represent an important consideration for source-sink pairing and maintaining environmental safety.

2. **Location of existing CO_2 pipelines**

For economic and safety reasons, it would be beneficial to a CCS project to utilize an existing CO_2 pipeline rather than having to permit and build a new one. This is particularly true when the CCS reservoir is not to be located directly next to or near to the emitting plant. The CO_2 pipeline network in Texas is not evenly distributed. Major CO_2 pipelines are focused in in West Texas. For this region, west Texas source sink matches are more favorable in terms of economic potential. Although in reality, CO_2 pipelines will be built either separately from existing networks or in order to link sources and sinks to the existing network, I found that only 705 reservoirs and 10 CO_2 producers are located within 25 km of a major CO_2 pipeline.

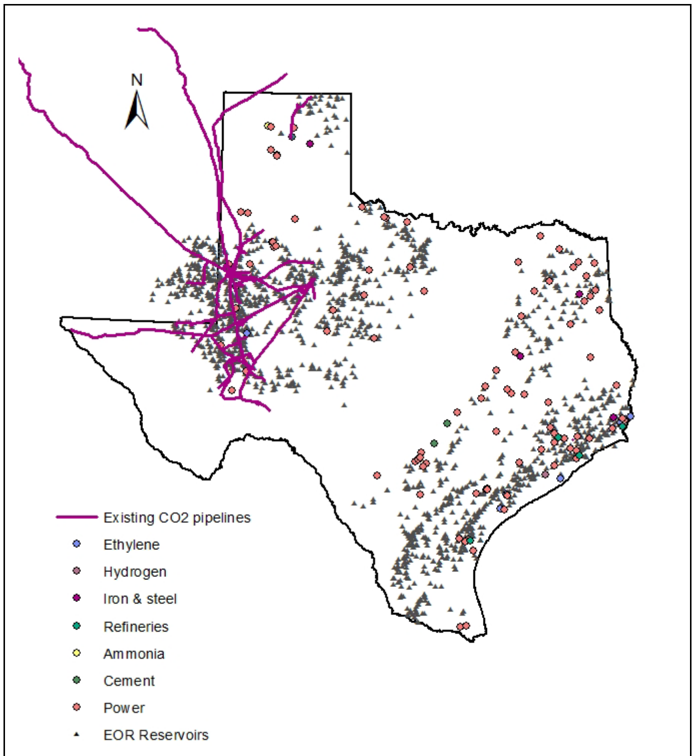

Figure 6. Location of existing CO_2 pipelines, which are concentrated in west Texas

3. **Population Distribution**

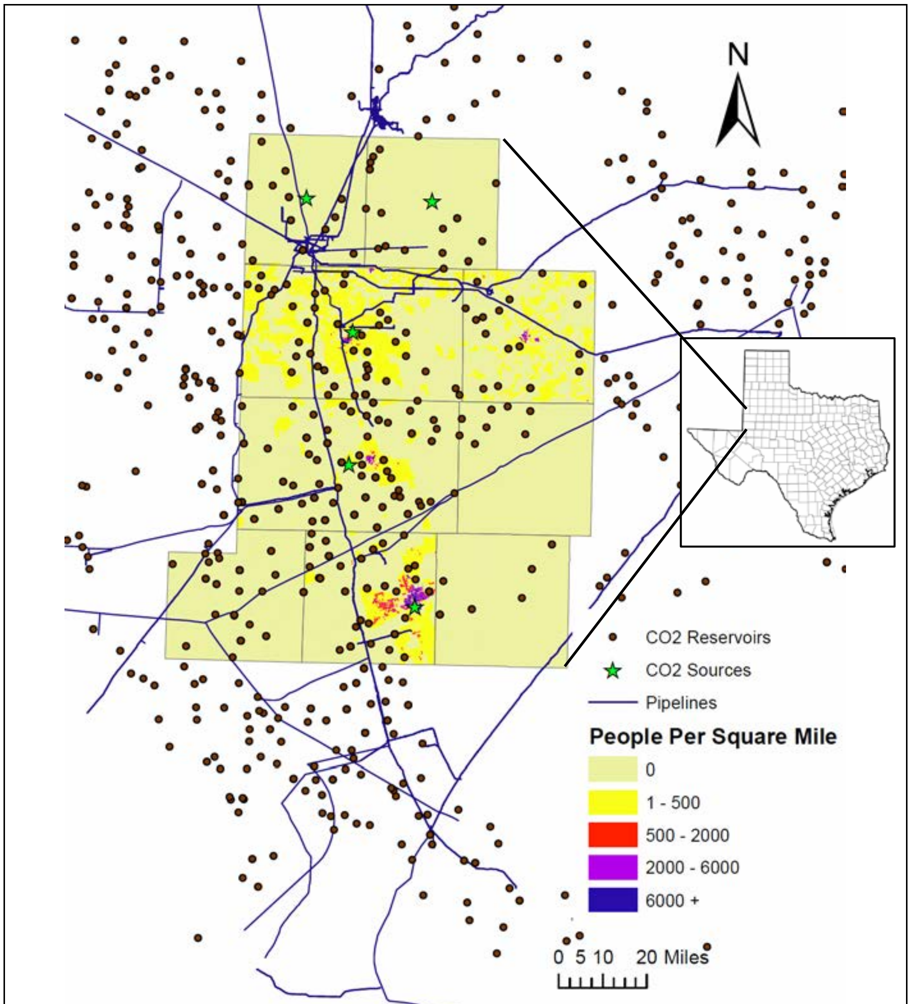

Figure 7 Population density for selected counties in west Texas along with CO2 reservoirs (black dots), CO2 sources (green stars), pipelines (purple lines.)

CCS should ideally take place far from high density population centers, primarily due to issues of public opinion and permitting. However, the population data proved to be the most confounding to work with; due to the sheer amount of data in Texas alone, population files are huge and difficult to work with. It was also the trickiest to project correctly and calculate areas of census regions. In order to avoid computer crashes and slow processing times, I opted to cut the data down to a few counties in west Texas. I chose to work with the west Texas data because the presence of pipelines in the area makes it particularly convenient for CCS.

I used the NAD 1983 UTM Zone 13 projected coordinate system. I attempted to use an Albers equal area conic but was unable to calculate polygon areas with this projection. After trying several other projected systems, I decided the UTM system was the best choice.

Once the file was clipped to a more manageable size and projected correctly, I simply calculated areas of each polygon using the Geometry Calculator function in the attribute table and then calculated population densities.

The result of the population data is interesting. CCS reservoirs are nearly ubiquitous in west Texas and population is sparse making it a good candidate for CCS activities. Many of the areas had no population according to the Census Bureau. While there are still areas of high population density, it would be relatively easy to pick a candidate reservoir many tens of miles from the nearest population center.

Conclusions

There is high potential for CCS in Texas but appropriate matching of CO_2 sources and sinks in is an important first step to ensure CCS success. In this study I have established first-order criteria for source-sink matching with environmental and economic concerns in mind. There is variation across Texas in terms of availability of good CO_2 reservoirs as well as good access to easy transportation of CO_2 and, overall, west Texas appears to be a good area to focus CCS research based on these criteria. West Texas has access to a network of existing CO_2 pipelines, ample EOR reservoirs and large CO_2 producers and very sparse population. Further studies would also take into account the geology of EOR reservoirs, the potential for storage in brine and storage in coal seams.

Data Sources

Data Type	Source
Priority groundwater management areas	TCEQ
National Parks	National Park Service
Aquifers	TNRIS
State Parks	Texas Natural Resources Informatio System
Population	U.S. Census Bureau
Potential EOR/CCS Reservoirs	c/o Carie Breton: USGS, International Energy Agency (IEA) , Bureau of Economic Geology (BEG), Texas Railroad Commission (RRC)
CO2 emitters	c/o Carie Breton: International Energy Agency
CO2 pipelines	c/o Carie Breton: USGS, IEA, BEG, RRC
Major oil and gas plays	c/o Carie Breton: BEG

References

Ambrose, W.A., Breton, C., Holtz, M.H., Nunez-Lopez, V., Hovorka, S.D., Duncan, I.J. 2009. CO2 source-sink matching in the lower 48 United States with examples from the Texas Gulf Coast and Permian Basin. Environ Geol. vol 57, pp 1537-1551.

EIA, 2011. Emissions of Greenhouse Gases in the United States 2009. U.S. Department of Energy Independent Statistics & Analysis. Washington, DC. . DOE/EIA-0573(2008). <http://www.eia.gov/environment/emissions/ghg_report/ghg_overview.cfm>

IPCC Special Report: Carbon Dioxide Capture and Storage 2005. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. New York, NY: Cambridge University Press. <http://www.mnp.nl/ipcc/pages_media/SRCCS-final/SRCCS_WholeReport.pdf>

MIT Carbon Capture & Sequestration Technologies website. <http://sequestration.mit.edu/tools/projects/index.html>

NETL, 2007. CO2 Point Source Emission Estimation Methodologies Summary. 2007 Conference Proceedings Presentation. <http://www.netl.doe.gov/>

WRI, 2008. Guidelines for Carbon Dioxide Capture, Transport, and Storage. Washington, D.C: World Resources Institute. < http://pdf.wri.org/ccs_guidelines.pdf>