Understanding Carbon Sequestration Options in the United States: Capabilities of a Carbon Management Geographic Information System

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Introduction

Addressing the threat posed by climate change represents one of the most pressing challenges facing humanity. It is also a challenge that will ultimately require profound changes in the way we produce and utilize energy. Recent research indicates that advanced carbon capture and sequestration technologies may be vital in helping to smooth the transition between today's energy sector capital stock and the set of advanced energy technologies that will be needed to stabilize atmospheric concentrations of carbon dioxide.[1]

Recent research has also shown that carbon capture technologies could contribute to near-term emissions reductions and that their deployment could significantly lower the cost of achieving these reductions.[2] However, in order to deploy these technologies in the near term we must first understand how they will interact with the existing energy infrastructure. That is, in the development of a sound sequestration strategy for either an individual corporation or for the entire United States, some basic questions must be answered: Where are the main sources of CO_2? Which sinks are currently available? What distribution systems are currently in place? Which sequestration options are available for each given source? And which sequestration options will likely make the most economic sense in a given situation?

Objective

While one can discuss various sequestration options at a national or global level, the actual carbon management approach is highly site specific. In response to the need for a better understanding of carbon management options, Battelle, in collaboration with Mitsubishi Corporation, has developed a state-of-the-art Geographic Information System (GIS) focused on carbon capture and sequestration opportunities in the United States.

The objective of this project was to develop a data management tool for geographically-intensive information such as exists to describe the characteristics of carbon capture and sequestration. A solution was desired that would allow quick screening of sequestration opportunities based on user-defined criteria, and display the results in a readily understandable and widely recognized format, such as on a map.

Approach

Geographic information systems have existed for many years and are now fast emerging as an essential tool in a wide array of fields. A GIS was the logical choice for a system to house the CO_2 source and sink data, as it could visually display spatial relationships and perform queries and screening analyses with ease. It offers a highly flexible, easily updateable database and display tool that facilitates the spatial analyses required to solve complex linking of CO_2 sources with appropriate and cost-effective sinks.

The database is the heart of a GIS. Data reside on tables that are dynamically linked to the maps on which they are displayed. The main sets of data in the CO_2-GIS include fossil-fired power plants, enhanced oil recovery (EOR) projects (both current and planned), enhanced coalbed methane (ECBM) projects, and coal basins with potential for coalbed methane production. In addition, natural geologic domes containing high purity CO_2, anthropogenic sources of CO_2 used for EOR, and major CO_2 distribution pipelines are also included (see Table 1). Further, base map layers consisting of such items as state and county boundaries, major cities, highways, and water bodies are also included to provide spatial reference.

Table 1. CO_2-GIS Datasets

Dataset	General Sources	Description
Power Plants	EIA, EPA, press releases	Fossil-fired power generating units in the U.S. (>100 MW)
EOR – current	Oil & Gas Journal, technical papers, press releases	Current CO_2 EOR projects
EOR – planned	Oil & Gas Journal, technical papers, press releases	Planned CO_2 EOR projects
CO_2 Domes	Information from firms that operate domes, technical articles	Natural underground CO_2 formations
Anthropogenic Sources	Various sources	Anthropogenic CO_2 sources serving EOR projects
Pipelines	Various	Major CO_2 distribution pipelines
ECBM	ARI, technical papers	Current and planned ECBM projects and pilots
Coal Basins	International Coal Seam Gas Report, USGS, AAPG, technical papers	Major coal basins with coalbed methane production potential (and perhaps ECBM potential)

Understanding Anthropogenic CO_2 Sources

Fossil fuel combustion is the largest single source of greenhouse gas emissions in the United States and worldwide.[3] Fossil-fired electric power plants are the most abundant of the large point sources and represent one of the greatest opportunities for the capture and sequestration of significant quantities of carbon dioxide. Compiled from several national power generation and emissions data sources, the CO_2-GIS contains detailed information on 1,337 large fossil-fired electric generating units at 589 locations throughout the United States, representing some 453 gigawatts of generation capacity (about 57% of the total U.S. generating capacity[a]). They include both utility and non-utility plants fueled by coal (60%), natural gas (33%), and oil (7%) and account for nearly 2.3 billion tons of annual CO_2 emissions. In-service dates range from 1941 to 1999, and some units have modern environmental control technology (e.g., flue gas desulfurization systems), while others do not. All of these factors are relevant criteria in attempting to determine whether carbon capture and sequestration is a viable option for any given plant or group of plants. Figure 1 presents an actual generating unit data record from the CO_2-GIS, and Figure 2 displays all of the large generating units across the U.S.

Plant Name	Barry
GenCode	5
County	Mobile
State	AL
Type	Utility
Primary Fuel	Coal
Primemover	Steam Turbine
Nameplate Capacity, MW	789
Summer Capability, MW	768
Capacity Factor	0.642
Vintage	1971
Cogen?	No
SO_2 Controls?	No
NO_x Controls?	Yes
1999 CO_2 Emissions, tons	5,496,151
Utility	Alabama Power Co.
Parent Company	The Southern Company
Latitude	31.0069
Longitude	-88.0103

Figure 1. Generating Unit Data Record for Barry Power Plant Unit 5 (Mobile, AL)

[a] As of 1999, U.S. generating capacity totaled approximately 806 gigawatts.[4,5] The discrepancy between this value and the data in the CO_2-GIS represents the capacity of both non-fossil fired generation technologies (e.g., nuclear, hydro, renewables) as well as fossil-fired units less than 100 MW.

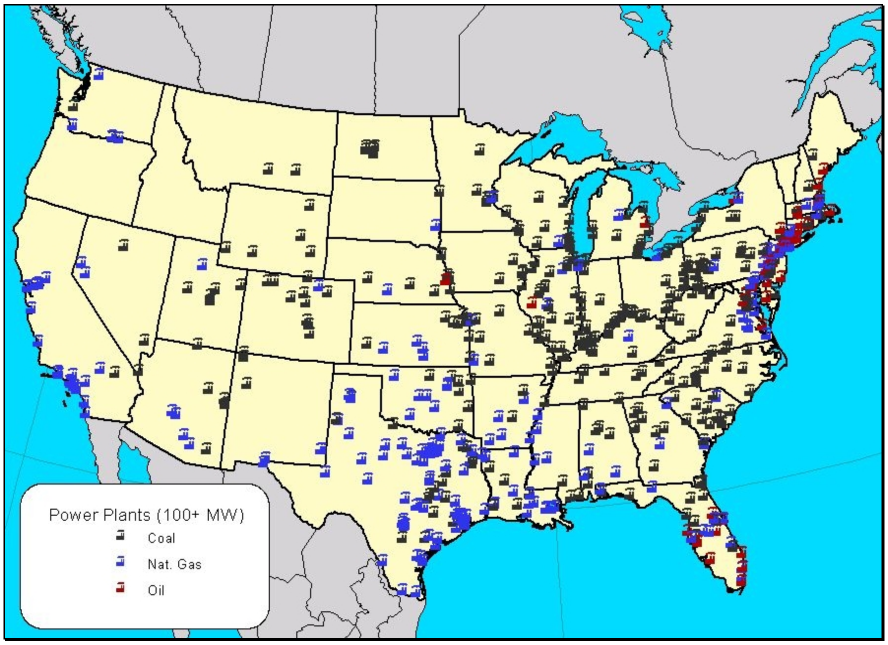

Figure 2. Map of Fossil-Fired Generating Capacity by Fuel Type for the United States

Understanding Sequestration Pathways

The CO_2-GIS also contains detailed information on all active EOR and ECBM projects using CO_2 injection, as well as available data on all proposed EOR and ECBM sites. As this paper goes to publication, we are actively collecting data on deep saline aquifers that appear to be candidates for carbon sequestration, which we will then add to the system. Even without these aquifer data there are over 100 potential sites covering areas of 27 states that appear at the broadest level to be candidates for geologic sequestration. The quality of these data as they relate to CO_2 sequestration varies greatly from very robust data on EOR projects like the Wasson Denver unit in the Permian Basin that has been in operation for 18 years (Figure 3), to less robust data on enhanced coalbed methane prospects. Given that ECBM is an emerging, but still immature technology that has not been widely deployed, the existing project sites do not give a true indication of its potential for sequestering CO_2. Therefore, data were collected and integrated on conventional coalbed methane reserves and production for each of the major coal basins, and were mapped as an upper bound of future ECBM production and carbon sequestration potential, as shown in Figure 4.

Field	Wasson (Denver)
Flood Type	CO2 miscible
Operator	Altura (Oxy)
State	Texas
County	Yoakum & Gaines
Start Date	4/1/83
Area, acres	27,848
# Production Wells	735
# Injection Wells	365
Pay Zone	San Andres
Formation	Dolomite
Porosity, %	12
Permeability, md	8
Depth, ft.	5,200
API Gravity	33
Viscosity, cp	1.2
Temp., F	105
Previous Production	Waterflood
Saturation, % start	51
Saturation, % end	30.5
Project Maturity	Half Finished
Total Production, b/d	38,000
Enhanced Production, b/d	29,000
Project Evaluation	Successful
Profit?	Yes
Project Scope	Field Wide
CO2 Type	Natural
CO2 Source	McElmo Dome

Figure 3. The complete data record for the Wasson (Denver) EOR unit

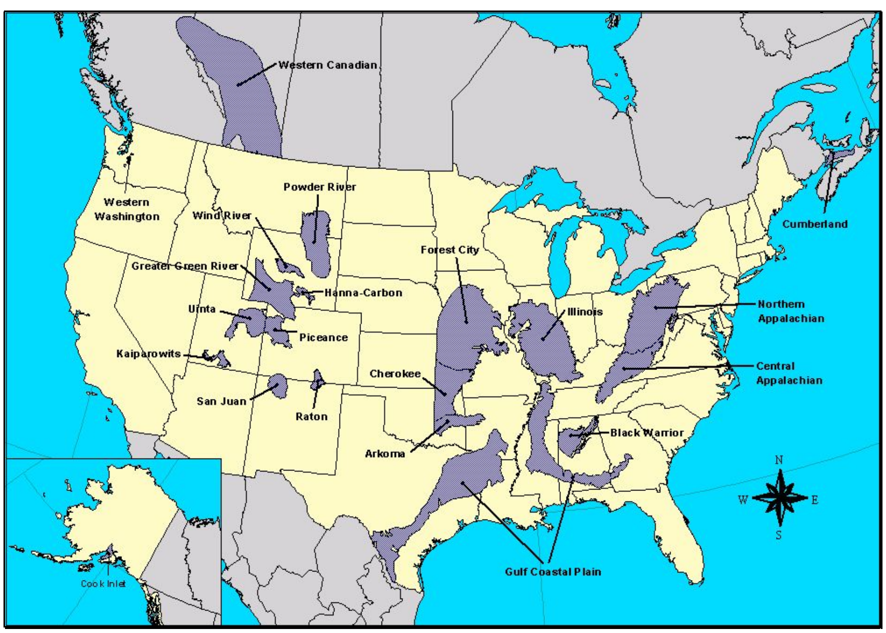

Figure 4. Map illustrating the extent of possible ECBM plays (major coal basins) across the U.S.

Understanding Existing CO_2 Supply Infrastructure for EOR

In addition to identifying potential sources of captured CO_2, it is important to understand the existing supply mechanism that supports the current CO_2-EOR industry. As such, the CO_2-GIS contains detailed information regarding the existing CO_2 supply and delivery infrastructure serving U.S. and some Canadian EOR projects. As displayed in Figure 5, this includes five major natural CO_2 domes, several natural gas processing plants, a fertilizer plant, a coal gasification plant, and the more than 2,300 miles of dedicated pipelines that deliver the CO_2 to the oil fields for injection. The location and performance characteristics of these CO_2 sources, and in particular their economics of production and transport, are significant factors that must be considered when attempting to craft a corporate or national emissions reduction strategy.

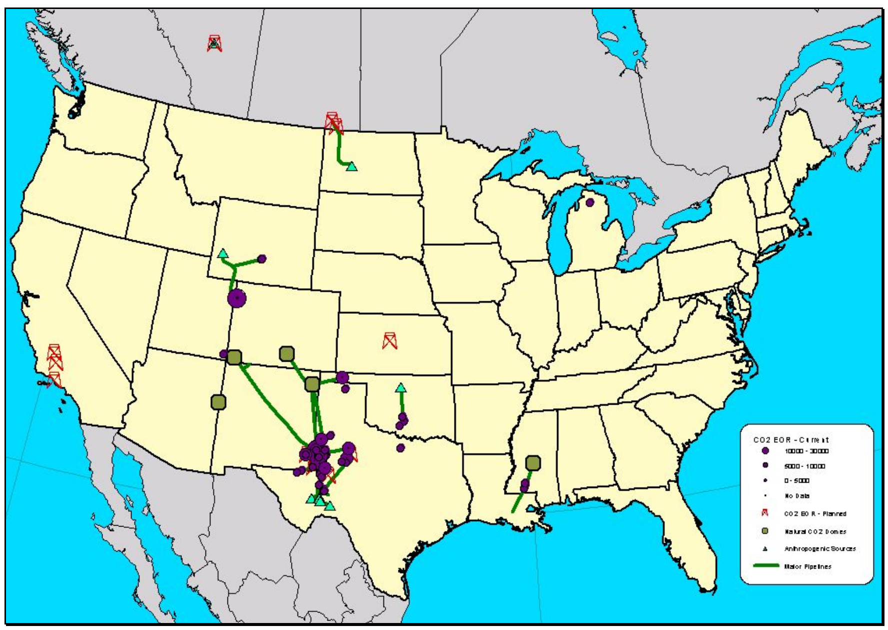

Figure 5. Current CO_2 Sources, Pipelines, and EOR Projects

Application

The CO_2-GIS provides an easy-to-use decision screening mechanism for carbon capture and sequestration. The database contains a wealth of data critical to the analysis of such opportunities. Not only does it allow the storage of key data, but enables visual and interactive display and retrieval of the data as well as a wide array of analysis capability. Users are able to screen and query any combination of available parameters and view the spatial relationships of the results.

Having these properties, the system can provide an abundance of information to help industry identify sequestration opportunities. It is planned that the system will be used to aid in the selection of target sites for capture and sequestration demonstrations, and eventually for fullscale technology deployment. Utilities can benefit from examining which sequestration options (pathways) exist near each of their plants. This information can help at a plant or corporate level in the development of a sound greenhouse gas strategy. Specifically, we believe this system will be of tremendous value for large power generation companies, whose operations span numerous states and regions, encompassing a mix of power generation technologies and available sequestration opportunities.

Additionally, oil field operators and coalbed methane producers could utilize the CO_2-GIS to identify nearby sources of anthropogenic CO_2 for use in profitable EOR and ECBM processes. Operators desiring to initiate CO_2 injection but who are far from existing domes and supply infrastructure will benefit by being able to more clearly understand their supply options. They will be able to compare alternative strategies for securing adequate CO_2 supplies, and analyze the conditions for which it might be cost-effective to do so. Existing EOR operators now supplied with inexpensive CO_2 from natural formations can employ the system to assist in contingency planning and preparation for the day when natural CO_2 is no longer extracted from the domes, due either to regulatory fiat or because future carbon taxes eliminate the economic advantage.

The potential analysis scenarios and benefits are far too numerous to detail here, and will only fully reveal themselves over time as the system and industry evolve. The following scenarios are examples of how the system might be employed to answer key questions in the near future. They are solely for illustrative purposes, intended to show the capabilities of the CO_2-GIS and demonstrate ways it might be used to answer real-world carbon management questions. They by no means constitute an endorsement of any particular company or the sequestration potential of a given region or pathway over any other.

Example Scenario 1:
Which potential sequestration pathways exist within 80 miles of Xcel Energy's large fossil-fired power plants?

> Xcel Energy was formed in August 2000 with the merger of New Century Energies and Northern States Power. According to the CO_2-GIS database they operate 20 plants across the five states of Texas, New Mexico, Colorado, South Dakota, and Minnesota. A quick visual inspection of the location of Xcel's plants shows that several are very close to EOR projects in the Permian Basin of West Texas. In addition, other plants in Colorado and even the upper Midwest are not too far from major coal basins. Running a query to select all potential carbon sinks within an 80-mile radius of each plant confirms that forty active and three planned CO_2-EOR projects in Texas and New Mexico, and four coal basins in Colorado, Wyoming, and New Mexico, are within the specified distance (as seen in Figure 6). None, however, are within the specified distance of the plants in Minnesota and South Dakota, the closest of which is some 120 miles from the Forest City coal basin. This information would be valuable to a company such as Xcel Energy in developing their carbon management strategy, and in responding to supply needs of nearby operators.

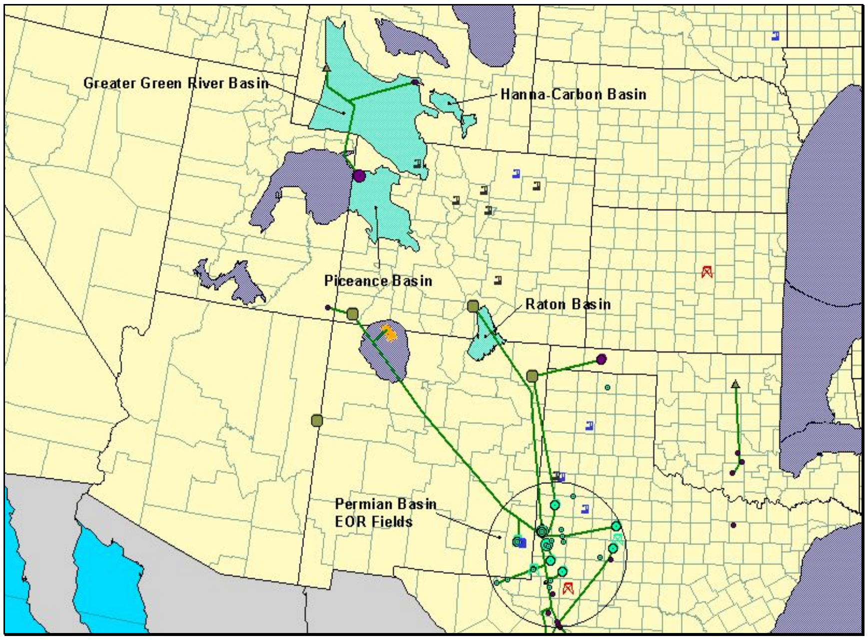

Figure 6. Possible Sequestration Pathways for Xcel Energy Plants

Example Scenario 2:
Locate all power generating units emitting at least 4 million tons of CO_2 per year within 200 miles of the Powder River Basin or Black Warrior Basin.

Suppose that gas prices and carbon taxes were such that coalbed methane operators in these coal basins were contemplating enhancing production with CO_2 injection and needed to secure a stable supply of CO_2. Using the spatial analysis capabilities of the CO_2-GIS we find that there are a total of 33 power generating units at 16 plants within 200 miles of the Powder River Basin. Querying these units based on CO_2 emissions, we find that 13 of these units emitted at least 4 million tons of CO_2 in 1999. Looking at the selected units and sorting based on emissions, we see that the two units with the highest CO_2 emissions are located at the same plant and have combined emissions of over 12.7 million tons. Furthermore, the units have only been in service for about 15 years, and the plant is actually located directly over the northern end of the basin. Capture opportunities from this or another nearby plant may be worth pursuing.

For the Black Warrior Basin, a similar analysis yields 148 units within the 200-mile radius of the basin, of which 23 meet the emissions criteria. The units are all operated by one of only four different utilities. One plant has two units that emitted a combined 18+ million tons of CO_2 in 1999. The plant is about 150 miles from the coal basin, and both units are equipped with flue gas desulfurization technology, which may simplify capture. However, there are other units meeting the screening criteria that are considerably closer to the coal basin. To reduce transport costs, these units should also be considered, weighing parameters such as capacity factor and vintage against distance when developing supply strategy.

Again, these are just two examples illustrating the use and flexibility of the CO_2-GIS in providing valuable insight into the developing U.S. carbon capture and sequestration landscape. The results of each inquiry were found quickly with only a few keystrokes and mouse clicks. Simply asking the system for the desired combination of data and instructing it to calculate distances between features provides the resulting information and displays it on the map, often revealing key relationships that would otherwise remain obscured.

Future Activities

In the face of impending climate change there are many options available. One involves the development of a proactive carbon management strategy incorporating capture and sequestration technologies, yet many questions remain. The CO_2-GIS provides an information system and screening tool to help answer some of those questions. It allows the power generation sector, along with EOR/ECBM operators and other interested parties, to analyze their unique situations and formulate an informed and sustainable strategy regarding the deployment of such technology.

The primary activity planned for the CO_2-GIS will be to use it for carbon management decision development and support. However, in order for the system to remain a valuable tool, the data it contains must be kept current. Therefore, maintaining the very latest data and keeping abreast of recent utility mergers, ECBM developments, and other industry news will be a critical on-going endeavor. As new information develops from further research and demonstration projects, relevant findings will be incorporated into the CO_2-GIS, keeping it on the leading edge of carbon capture and sequestration decision screening capability. In addition, there are plans to expand the functionality of the system as well as its geographic coverage to ensure that it remains state-of-the-art.

As the system develops, other major sources of anthropogenic CO_2 will be added, along with additional sequestration and utilization pathways. Examples include data on industrial sources and users of CO_2, priority deep saline aquifers (currently being incorporated), depleted oil and gas wells, and ocean depth contours. Cost factors for capture, transport, and sequestration of CO_2 will be incorporated, and an automated screening process developed to facilitate economic analysis of competing options leading to selection of least-cost pathways. The value of a future carbon tax or other sequestration incentives could also be factored into the analyses.

Finally, to enable screening of capture and sequestration options beyond the borders of the United States, data will be added as available for other regions of the world. Fossil-fired electric generating units in Canada, Mexico and other nations will be added to the system, and the EOR and ECBM characterizations will be expanded worldwide as well. The power of GIS is in its visual data display, analysis capability, and expandability, and as such it is our goal to continue development of the CO_2-GIS to meet the needs of industry and government in support of effective carbon management strategies.

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