MIDCONTINENT INTERACTIVE DIGITAL CARBON ATLAS AND RELATIONAL DATABASE (MIDCARB)

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Introduction

Current federal energy policy assumes that hydrocarbons will continue to be the primary source of energy for the United States and the world well into the 21st century. There is concern about increasing atmospheric concentrations of carbon dioxide and its possible role in global climate change. For this reason, it may become necessary to manage anthropogenic CO2. Sequestering CO2 in geological reservoirs may be one way to safely sequester carbon over long periods of time, if the proper tools to analyze the geological feasibility as well as the associated costs can be developed.

The ***Midcontinent Interactive Digital Carbon Atlas and Relational DataBase*** (MIDCARB), a digital spatial database for five states, will allow users to estimate the amount of CO2 available for sequestration in relation to a source supply, the geologic security and safety of a sequestration site, the long-term effects on a reservoir, and the cost of compression and transport of CO2 between source and sequestration site. MIDCARB will organize and enhance the critical information about CO2 sources, and develop the technology needed to access, query, model, analyze, display, and distribute natural-resource data related to carbon management.

Large stationary sources of CO2 emissions will be identified, located, and characterized by volume, temperature, pressure, and gas mix. Potential CO2 sequestration targets, including producing and depleted oil and gas fields, unconventional oil and gas reservoirs, uneconomic coal seams, and saline aquifers, will be characterized to determine quality, size, and geologic integrity. The economic impact and possible value of the CO2 sequestration to hydrocarbon recovery from oil and gas fields, coal beds, and organic-rich shales will also be considered.

Objectives

Overall, the CO_2 sequestration potential of the Midcontinent states of Illinois, Indiana, Kansas, Kentucky, and Ohio is large, but local variations suggest that any carbon management plan will have differential impact. Variations among states must be addressed (e.g., smaller oil and gas industry, but much larger coal industry). The spread of states in the proposed MIDCARB project has a wide range of populations, industry, agriculture, and fossil energy resources. Each of the five states in the MIDCARB consortium has a different mix and distribution of large, stationary CO_2 sources and potential geologic sequestration opportunities (Table 1 and figures 1, 2). All states have a responsibility to attempt to reduce potential costs, maximize potential revenue, guard public safety, and assure long-term effectiveness of carbon management policies. Carbon management will have significant and differential effects on economic activity and fuels used for energy generation among states and even among regions within a single state. Viable carbon management will need the best local knowledge of local geologic and energy economic conditions.

The study will develop natural resource information-systems tools that provide reliable and efficient access through spatial and intelligent queries across widely distributed databases to baseline information, and co-location of CO_2 sources and potential sequestration sites. Critical information includes:

- Understanding the economic impact and possible value of the CO_2 recovery and sequestration (e.g., enhanced oil or coalbed methane recovery),
- Analysis of the quality, size, and geologic integrity of potential sequestration sites and their location in relation to CO_2 sources,
- Evaluation of compression and transportation costs to move the CO_2 from source to sink,
- And assessments of the relation of potential capture technology to quantity and quality of CO_2 sources (e.g., PVT conditions and presence of contaminants).

Knowledge of our energy, economic, and geologic systems exists across a broad spectrum of institutions. This knowledge must be collected and integrated in a useful information-management system that will enable communities, the private sector, states and the nation to better manage fossil-fuel resources and understand the impact of possible carbon-management policies.

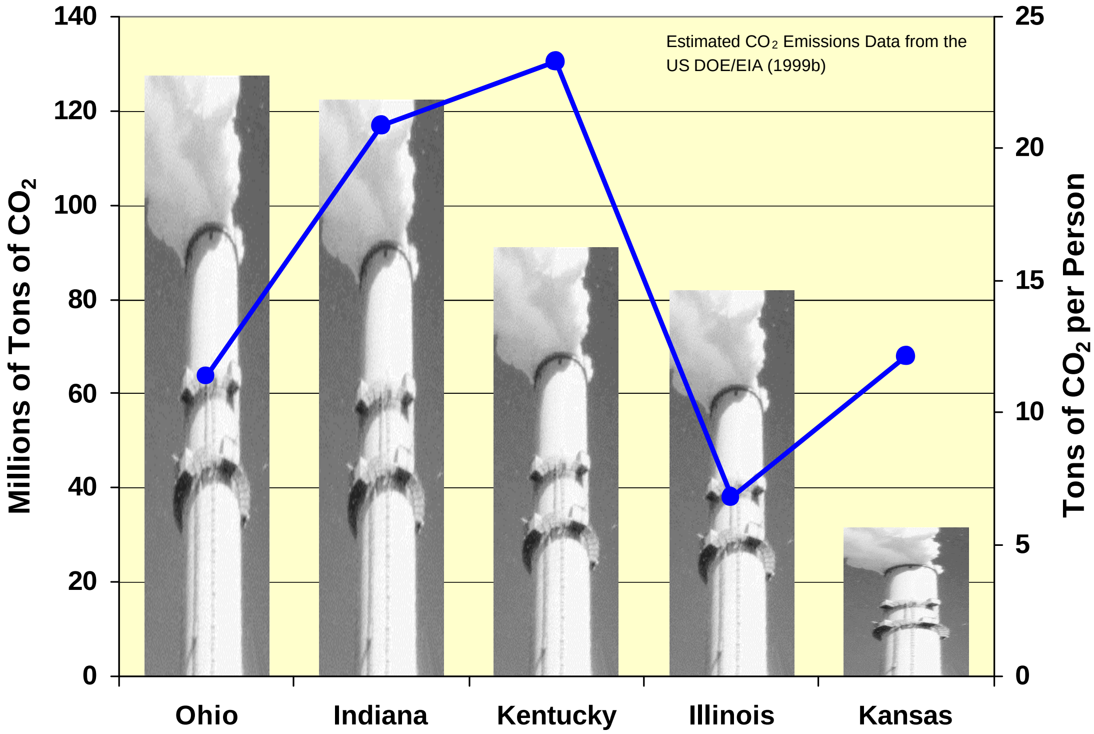
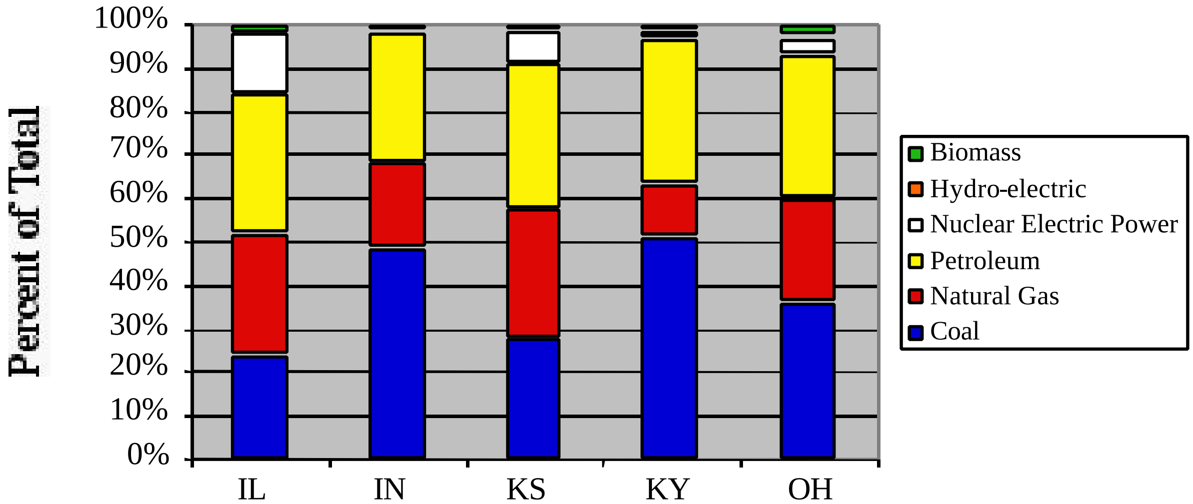


Figure 1 Variations in total (histogram) and per capita (line graph) amounts of CO_2 emitted by power plants in the states of the MIDCARB Consortium.

Table 1 - Five State Energy Consumption Comparison - 1997

	Thousand Tonnes	Million Cubic Meters	Thousand Cubic Meters	Million Kilowatthours			
	Coal	Natural Gas	Petroleum	Nuclear Electric Power	Hydro-electric	Biomass	Other
Illinois	43,201	30,497	38,499	51,069	NA	-	-
Indiana	59,912	15,772	25,366	0	NA	-	-
Kansas	16,005	9,599	11,184	8,430	NA	-	-
Kentucky	38,309	6,456	18,770	0	NA	-	-
Ohio	53,463	25,457	37,958	15,331	NA	-	-



Based on 1997 Data (Source: State Energy Data Report 1997, DOE/EIA-0241(97))

Figure 2 Variations of the energy mixes of each state of the MIDCARB Consortium.

Approach

The goals of the MIDCARB project are to collect, organize, and enhance the critical information sources relative to CO_2 sequestration, and to develop the information technology tools needed to access, query, model, analyze, display, and distribute natural resource data related to carbon management across five states, various organizations, and numerous databases. The project will require design and construction of relational databases and software systems that can access and integrate data across a large number of cooperating computers. Efforts will be needed to ensure access to coherent data collected by various organizations at various scales for widely different purposes.

Generally, the required information is available from public sources, but is in a variety of formats intended to serve divergent purposes such as:

- evaluation of natural resources (e.g., oil, gas, coal, water, alternative energy, nuclear),
- management of industries (e.g., electric, oil and gas production, pipeline transportation, etc.),
- regulatory purposes (e.g., state oil and gas commissions, environmental protection, public safety and public utility boards)
- regional conditions (rural, urban, industrial, agricultural, etc.),
- research and technical foci (e.g., water quality, climate change, enhanced oil production, etc.), and
- taxation (natural resources tax data).

Efficient access to usable regional and local data is critical to intelligently forming national and global models. In addition, the reasonable downscaling of national models for regional and local analyses will require access to regional and local data that has breadth and depth of coverage, and to new approaches to scientific and engineering visualization.

Project Description

MIDCARB will work across five mid-continent states with very different industrial, agricultural, demographic and natural resource characteristics. Work will concentrate on organizing and enhancing the critical information relative to CO_2 sources and potential sequestration sites. Information includes the quantity, quality and location of sources relative to security, safety and long-term effects on geologic sequestration sites. Finally, we are developing information technology tools needed to access, query, model, analyze, display and distribute natural resource data related to carbon management across five states, various organizations and numerous databases. We are attempting to provide the basis to evaluate the potential technical feasibility, costs and benefits of any proposed carbon management plan at both the regional, state and even local level.

MIDCARB will bring together the strength of five state geological surveys (i.e., Illinois, Indiana, Kansas, Kentucky, and Ohio). Each Survey is a proficient natural resource research organization that has demonstrated geographic information systems capabilities, and local experience with the fostering and monitoring of oil, coal and natural gas resources. Each state has large natural resource databases.

A major challenge of the MIDCARB project is to bring together into an efficient knowledge management system the millions of records that pertain to CO_2 sequestration, residing in each state of the MIDCARB Consortium. A knowledge system can provide global access and manipulation of pertinent geologic and engineering data to evaluate specific CO_2 sources and sequestration sites, improved predictive models, and the necessary tools to reduce carbon management implementation costs. A relational database will be developed that can be used to site and characterize stationary sources of CO_2 and potential oil, gas, coal, and brine reservoirs for sequestration. Through flexible online queries users will be able to obtain the technical data to evaluate the potential costs and benefits to capture, transport, and sequester CO_2 using the best-known data and technologies. The consortium will use web-based standard queries and spatial database management systems to provide spatial and relational query capabilities for data loaded into relational database management systems (RDBMS). An example of present RDBMS systems includes the oil and gas query system of the Kansas Geological Survey (Figure 4). This RDBMS system allows the online user to query and join data contained in multiple tables for over 300,000 wells. Queries are processed online and results returned as web pages. Due to programming within the RDBMS system, response times are extremely rapid. All five organizations involved in MIDCARB have demonstrated capabilities in geographic information systems (GIS), RDBMS, and web access.

Geographic information systems allow users to compose customized maps consisting of selected spatially related data elements (i.e., themes). A theme is a map that shows data for a single subject matter. Examples of themes could include: (1) points showing locations of major CO_2 sources, (2) lines showing existing pipelines, (3) polygons showing geologic sequestration reservoirs, and (4) images showing structural relief on a geologic horizon and reservoir net-pay thickness. In addition to displaying spatial data as maps, a GIS allows retrieval of descriptive information (attributes) about the geographic features in a theme. For example, one could develop a system that could not only view a map of major CO_2 sources, but also by pointing to any given CO_2 source with the cursor, retrieve the flue-gas data for that source. Examples of high-quality GIS capabilities for each MIDCARB organization can be found online (Table 2).

As part of the proposed project, the MIDCARB Consortium will develop an Internet Map Server (IMS) site and RDMBS focused on both CO_2 sources and potential CO_2 sequestration sites. The system will provide pre-selected map themes, custom map themes, and flexible query capabilities. The IMS is a scalable and failure-resistant system that can issue spatial queries to a spatial database engine sitting on top of the RDBMS on each of the cooperating computers maintained by each MIDCARB organization. The system to be built will be highly reliable and efficient with programming focused on interface technologies that will be of particular benefit to end-users in particular discipline areas, policy makers, and the interested public. Work will also focus on designing adequate metadata standards to assure data quality and consistency. Online users will see a single window to enter queries and receive results. However, the technical and spatial information on both CO_2 sources and potential CO_2 sequestration sites will reside and be maintained at the local level (i.e., the individual states).

A series of prototype linear/log Plot Servlets have been completed and tested. These Plot Servlet routines are a generic linear plot class that will accept any x-y array and labels. The Servlets also have the capability to plot data acquired from numerous databases. An example of the plot routine using oil production for Allen County in the Bronson-Xenia Oil & Gas Field was generated (Figure 5). It will be used to provide display and analysis capabilities of data from distributed MIDCARB relational database management systems.

The goal is to increase the utility and scope of the online information pertaining to CO_2 sequestration by improving the quality and the amount of material and the ease of access. The project will permit users to identify and fully assess, at the local and regional level, promising, novel, and advanced concepts for sequestration technologies and the evolving technologies necessary to support them. Activities that will be greatly enhanced by access to the high-quality information of the MIDCARB project include: system studies; exploratory research; technical, economic, and environmental assessments; full fuel-cycle analyses; expert workshops; and outreach activities to seek promising new ideas and to communicate findings and results to industry, academia, and the public.

Technology transfer will be intrinsic to the MIDCARB Project. However, specific efforts will include distributing software or other technology developed in the course of the project, so that other states will be able to build upon the success of the project.

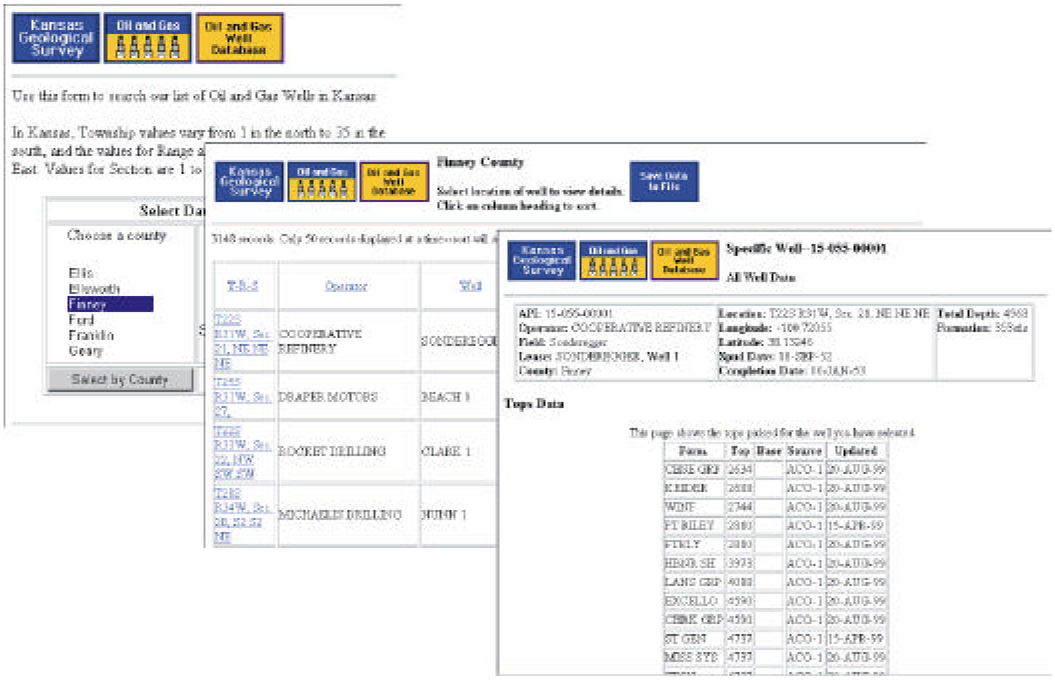


Figure 4 Example query of the Kansas Geological Survey Qualified oil and gas well relational database management system. Database tables contain information on over 300,000 wells. Data can be efficiently joined and provided to the user. Web address is http://magellan.kgs.ukans.edu/Qualified/index.html

Table 2 MIDCARB Organization's GIS Web Sites	
Illinois Geological Survey	**http://www.isgs.uiuc.edu/nsdihome/ISGSindex.html**
Indiana Geological Survey	**http://adamite.igs.indiana.edu/indsurv/products/index.htm**
Kansas Geological Survey	**http://gisdasc.kgs.ukans.edu/dasc_net.html**
Kentucky Geological Survey	**http://www.uky.edu/KGS/gis/kgs_gis.html**
Ohio Geological Survey	**http://www.dnr.state.oh.us/odnr/geo_survey/**

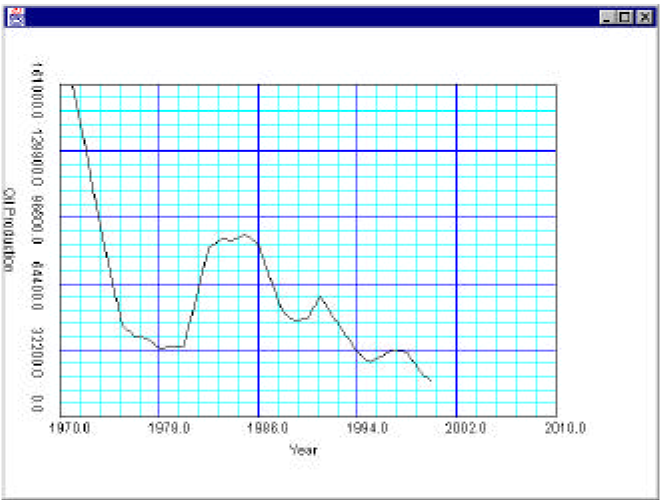


Figure 5 A generic linear/log Plot Servlet that will accept any x-y array and labels. The following is an example of the Plot Routine using Oil Production Plot for Allen County in the Bronson-Xenia Oil & Gas Field. Data such as CO2 production will be plotted from query to the MIDCARB databases

Results

The MIDCARB Project is assembling an online relational database system containing the necessary data to fully evaluate CO_2 resources and potential geologic sequestration sites at both the local and regional levels. The database model maintains the ownership and maintenance of the data within each state (Figure 6). The relational database systems, the analysis and display tools (e.g., GIS and servlets) and online access are used to provide the user online query capabilities to evaluate both CO_2 resources and potential geologic sequestration sites across the region.

CO_2 Resources

On a national level, electricity generation is the major source of carbon emissions from stationary sources. Although electricity produces no emissions at the point of use, generation accounted for 37 percent of total carbon emissions in 1998, and its share is expected to increase to 38 percent in 2020 (EIA, 1999a). The data needed to assess the CO_2 resource of each state includes information on each stationary source (e.g. unit type, location, capacity size, energy source, and energy or fuel quantities). For U.S. electric utilities, the U.S. Department of Energy website provides the name, owner, county of location, capacity, energy source, and plant type for each electric utility plant. The data for non-utility power generating units is limited to state, owner, facility, and nameplate capacity. Detailed locations of facilities can be extracted from the Environmental Protection Agency's (EPA) databases that list latitude/longitude of all regulated facilities. The research organizations involved in MIDCARB have strong relationships to state regulatory agencies, local organizations, and generating facilities in order to supplement publicly available information.

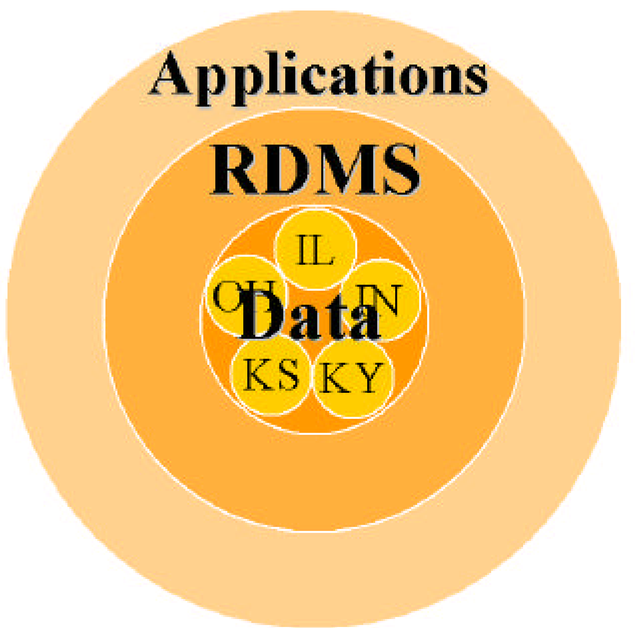


Figure 6 Data relationship model for the MIDCARB. Data on CO_2 resources and potential geologic sequestration sites is maintained in each of the five states and served through a common system.

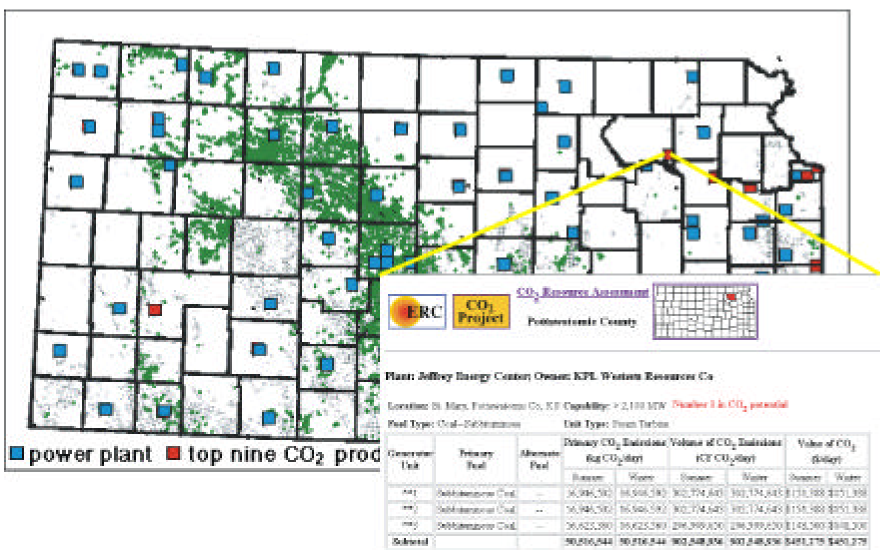


Figure 7 Map showing location of power plants in Kansas overlain on oil leases producing from the Lansing-Kansas City groups. Both the blue and red squares signify the location of power plants. The red squares specify the nine largest power plants, based on yearly emissions of CO_2. In the digital version of this figure (http://www.kgs.ukans.edu/CO2/resource/lansing.html), click on the map to view information on CO_2 production from the plants. Example shown is for the Jeffery Energy Center in Pottawatomie County.

CO_2 resource characterization will also require data on flue-gas pressure, temperature, gas concentrations, and output patterns (baseload, seasonal, or peaking). The acquisition of this data will require the cooperation of individual facilities and local organizations (e.g., public utility commissions). For those facilities that are unable to provide accurate information, reasonable estimates will be made based on fuel type, fuel characteristics (sulfur contents, heat content), and output-patterns history. A crude and very incomplete example of a CO_2 resource characterization is available online for Kansas (Figure 7).

Geological Sequestration Sites

MIDCARB concentrates on the geographic distribution and technical aspects of geologic storage options for CO_2 sequestration, including those that recycle carbon back to its source in natural geologic formations. These include CO_2 storage in geologic structures such as oil and gas reservoirs, coal seams, and saline aquifers.

Producing oil reservoirs offer some of the most attractive targets for CO_2 sequestration. To evaluate the feasibility of CO_2 miscible and immiscible flooding of oil reservoirs, a database of reservoir fluid and rock properties will be compiled for representative reservoirs. Critical technical variables include oil gravity, viscosity, minimum miscibility pressures (MMP), reservoir structure, depth, net pay thickness, porosity, permeability, irreducible water saturation, residual oil saturation after waterflood, relative fracture and matrix properties, and potential well-injection rates.

Much of this data is available in various databases from each of the five states in the MIDCARB consortium. However, critical variables such as the MMP and potential to achieve MMP in the reservoir are typically not available, but can be generated for representative reservoirs and reservoir fluids. The MMP is defined as the pressure where oil recovery ceases to increase significantly with increasing flooding pressure. At CO_2 flooding pressures equal to or above the MMP, oil recovery is on the order of 90% of the oil in the portion of the reservoir contacted by the carbon dioxide (Figure 8). However, significant additional oil recovery can be achieved at pressures less than MMP.

As an example, technical data and assessment of the potential for application of CO_2 miscible flooding in Kansas reservoirs was evaluated for pilot-site(s) appropriate to test and prove the CO_2 flooding process. The MMP for several reservoir intervals in Kansas has been determined (Figure 8). The MMP for Lansing Kansas City (LKC) oils were measured from the Hall-Gurney Field, Russell County, Kansas. Tests indicate that MMP values are less than 1,250 pounds per square inch (psi). A MMP of 1,250 pounds is near the initial reservoir pressures of numerous LKC reservoirs in Kansas and appears achievable. Based on initial screening, application of CO_2-miscible flood technology is technically feasible in Lansing-Kansas City reservoirs in central Kansas. Table 3 summarizes the reservoir properties for Hall-Gurney Field and the type of data that will be required for reservoirs throughout the MIDCARB area.

Relative simple and efficient streamtube simulations such as CO_2 Prophet (USDOE, 1993) will be used to estimate oil recovery from carbon dioxide miscible and immiscible flooding in representative patterns (Figure 9). The initial calculations will be done in the square mile sections of high potential for a wide range of reservoir properties. Where possible, initial calculations will involve history that matches oil production from the preceding waterflood.

Economic models of carbon dioxide miscible and immiscible flooding will be developed using the screening calculations. Cost data will be developed for pilot-scale projects as well as representative field-wide and large-scale implementation. Economic feasibility will be determined by integrating cost projections with oil production predictions (Figure 10). Sensitivity calculations will be performed to identify the parameters that have a major influence on the technical and economic uncertainties in overall project economics.

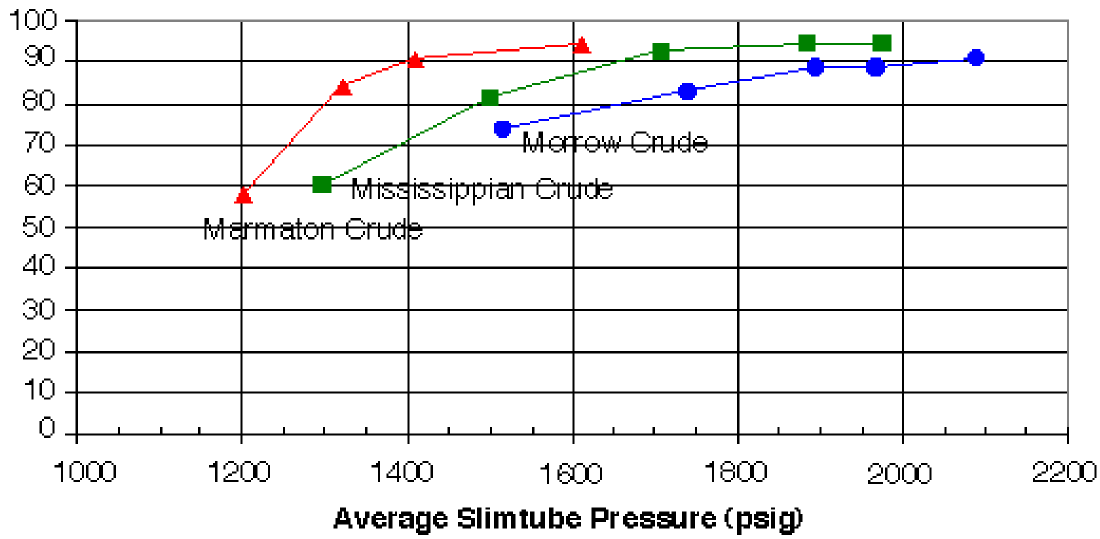


Figure 8 Example of determination of crude oil minimum miscibility pressures from Southwest Kansas (http://www.kgs.ukans.edu/CO2/evaluation/slide13.html). Vertical axis is percentage of recovered oil.

Table 3 Hall-Gurney Lansing/Kansas City Reservoir Properties
Depth = ~915 meters (~3000 ft)
Net Thickness = 10 ft (L/KC "B" zone)
Porosity = 15.5 %
Permeability = 50 md (L/KC "B" zone)
Reservoir Pressure = 1300 psi
MMP = 1230 psi
Residual Oil Saturation = 33%
Oil Gravity = 39 °API
Oil Viscosity = 2.71 cp
Gas Oil Ratio = 60 SCF/STB

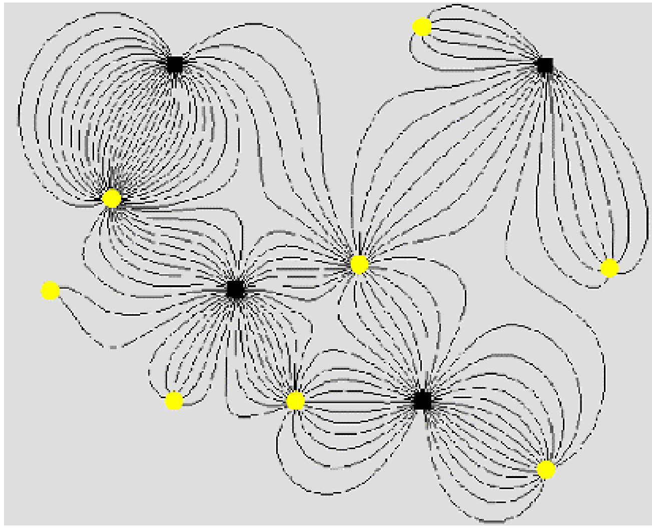


Figure 9 CO_2 Prophet streamtube model showing simulated sweep of a portion of the Hall-Gurney Field (NW/4 27-14S-14W). Black dots are oil-producing wells and yellow dots are injection wells. (http://www.kgs.ukans.edu/CO2/evaluation/slide16.html)

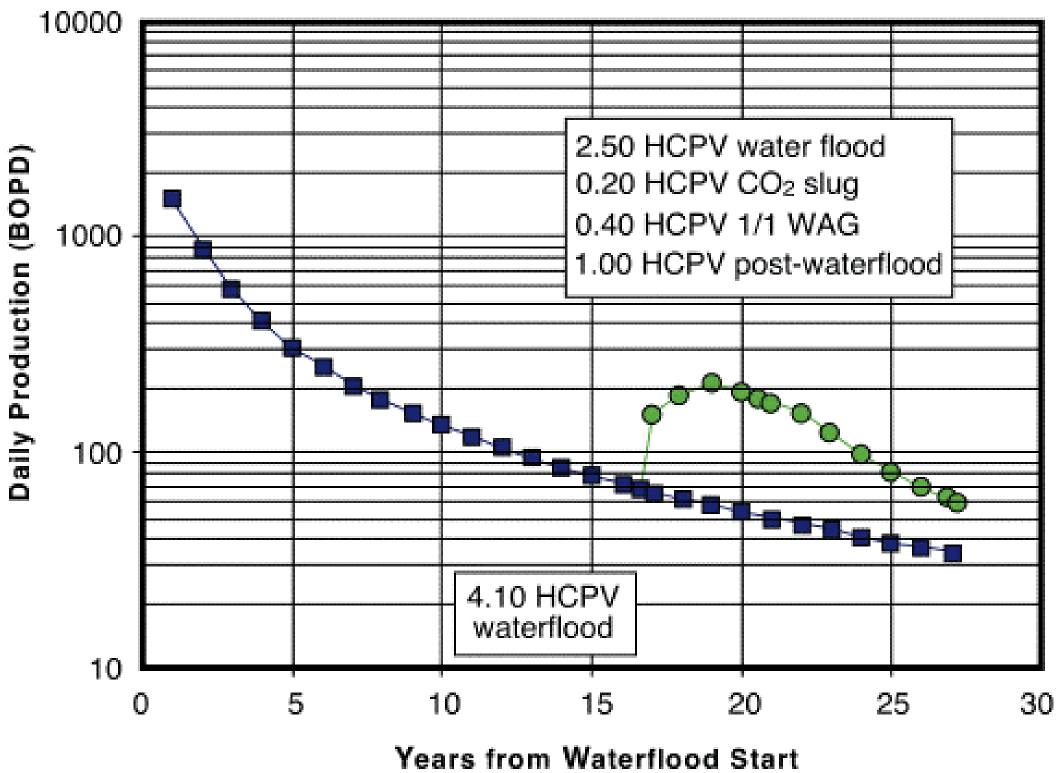


Figure 10 Simulation of daily production with long-term waterflooding (black boxes) and impact of CO_2 flooding (green circles) using a streamtube model (Figure 9), and known reservoir parameters (Table 3) on a lease in the Hall-Gurney Field (NW/4 27-14S-14W). HCPV = hydrocarbon pore volume. http://www.kgs.ukans.edu/CO2/evaluation/slide16.html

The broad objectives will be to compile the necessary oil reservoir data concerning fluid and rock properties, potential reservoir characteristics, regional resource, optimum sequestration sites, and predicted recovery response to verify the potential for recovered oil as a byproduct of CO_2 sequestration. Principal specific objectives within the project are:

- Collect representative oil samples from major oil reservoirs and determine the MMP and basic properties of these oils
- Compile a database and determine an approximate measure of the CO_2 miscible flood recovery potential of reservoirs
- Collect a representative suite of advanced rock properties to understand reservoir properties and provide input to reservoir characterization and screening simulations of the potential sites
- Perform reservoir characterization of potential sequestration sites within each state to identify the optimal sites for CO_2 sequestration
- Perform screening simulations to assess CO_2 miscible flood response and sequestration potential at selected sites
- Develop an economic model of the demonstration sites and for the regional potential sequestration sites
- Prepare a report summarizing the technical and economic evaluation of carbon dioxide sequestration and enhanced oil recovery in oil reservoirs.

Saline Aquifers

Saline aquifers have great potential capacity for the long-term sequestration of greenhouse gas emissions including CO_2. All MIDCARB states have extensive saline aquifers that have high potential for aquifer disposal of CO_2. Many of these aquifers form a continuous regional hydrodynamic system with known oil and gas reservoirs (e.g., Arbuckle Group and Mississippian in Kansas). Trapping of CO_2 for geologic periods of time within these regional saline aquifers is by hydrodynamic processes and possible mineral trapping (i.e., conversion to carbonate minerals). This project will fill the information gap between investigations using isolated studies of idealized aquifers, and the often poorly known and inaccessible properties of real aquifers (e.g., Hitchon and others, 1999). All MIDCARB states have extensive information on local hydrogeology. Our effort will develop an accessible database of saline aquifers in the five states where geological conditions and proximity to stationary CO_2 sources promote the greatest probability of success for sequestration projects. Disposal aquifers will be identified and characterized to satisfy conditions of depth, regional seal integrity (aquitard), permeability, injectivity, and storage capacity. Standard techniques for hydrocarbon and hydrogeologic analysis will be combined to map natural flow regimes and evaluate the potential disposal aquifers at the basin and local scales.

A preliminary evaluation of the potential for sequestering CO_2 in saline aquifers will include:

- Locations of recharge and discharge regions for each candidate aquifer,
- Fluid salinity, chemistry, temperature, and pressure,
- Porosity and permeability,

- Estimated age of water or travel time from recharge to discharge regions,
- Estimated aquifer volume.

Enhanced Gas Recovery and Coalbed Sequestration

Carbon dioxide sequestration in unmineable coal seams, like CO_2 enhanced oil recovery, would provide both a place to store CO_2 and a method to increase production of a highly usable fossil fuel. Carbon dioxide when introduced to a coal matrix displaces methane and adheres to the coal. Previous studies on CO_2 sequestration and methane recovery indicate that two molecules of CO_2 can be injected for every one molecule of CH_4 released from the coal bed. This shows that on average a little more than twice as much CO_2 can be stored on a volumetric basis than the amount of CH_4 extracted. The production of methane from these seams will offset costs of sequestering CO_2. The use of unmineable coal seams will also provide a larger area in which CO_2 can be sequestered. Sequestration in coal beds is the basis of a proposed efficient null-greenhouse-gas emission power plant fuelled either by mineable coal or coalbed methane from deep unmineable coal (Wong and Gunter, 1999). The produced CO_2 from the power plant would be injected into coal beds to produce more methane. In addition, the CO_2 would be geologically sequestered in the coal beds (Wong and Gunter, 1999).

Burlington Resources has demonstrated the success of enhanced gas recovery (EGR) to recover methane by injecting CO_2 into the relatively high permeability coal beds in the San Juan Basin for several years (Schoeling, 1999). Coalbed methane production has been stimulated while injected CO_2 has not broken through to production wells. The injected CO_2 appears to be adsorbed into the coal matrix displacing methane, and remains in the ground. An additional project is underway to further test the EGR process in the relatively low permeability coal beds in Alberta, Canada.

Extensive Carboniferous coal-bearing strata underlie all five states in the MIDCARB consortium. Although many coal seams are mineable, numerous seams are currently uneconomic and inaccessible due to coal quality, sulfur content, and technological or land use restrictions. The coals of the Midcontinent are relatively flat lying, undisturbed by large faults, and commonly bounded above and below by several feet of rock with low permeability. The potential is high that Midcontinent coals can act as high-quality, long-term geologic sinks for CO_2 while enhancing methane gas recovery. However, little detailed information is accessible concerning geographic location, depth, sequestration capacity, and enhanced gas recovery (EGR) potential of *in situ* Midcontinent coals. This project will bring together critical, but scattered, incomplete, and hard to get information that pertains to CO_2 adsorption and EGR. Such factors include; depth, seam thickness, moisture content, coal petrographic composition, cleat directions, cleat spacing, and gas content.

In addition to the potential for sequestration of CO_2 in virgin seams, there are in all five states thousands of square miles of abandoned underground coal workings. These mines commonly used room and pillar methods and represent thousands of miles of man-made “fracture systems” in the coal. As a result of exposure to the mine air some de-watering and de-gassing of the coal left as pillars has taken place, factors that may improve the capacity of the coal to adsorb CO_2. The project will provide an easily queried regional and detailed inventory and evaluation of coal beds as a potential geologic sink.

Natural Gas Reservoirs

Unconventional and depleted or nearly depleted natural gas reservoirs may be used to sequester CO_2 at a ratio of one-to-one of methane previously produced. Depleted gas fields could be ideal reservoirs for CO_2 sequestration due to their proven ability to store gases for geologic time periods. While traditional gas fields that are still producing may not be ideal due to the possible CO_2 breakthrough and degradation of methane content, careful reservoir characterization and injection design may enhance continued production of low-pressure gas. Gas fields, such as the Hugoton Gas Area of Kansas, contain enormous quantities of methane at extremely low reservoir pressures (i.e. estimated 283 billion m^3 [10 tcf] remaining gas in place at reservoir pressures of 80 psi or less). These fields could benefit from pressure maintenance and EGR of well-designed CO_2 flooding and sequestration. These older gas fields may also have existing infrastructure that could significantly decrease sequestration costs and environmental impacts (e.g., gathering systems, compression facilities, and pipeline connections to large urban centers and associated CO_2 sources).

Unconventional gas reservoirs such as the organic-rich fractured Devonian black shales of the Midcontinent are additional potential sites for carbon sequestration. Existing gas production in the Devonian shale reservoirs could benefit from the application of CO_2 enhanced recovery technologies. Kentucky alone produces about 2.3 billion cubic meters (80 bcf) of natural gas per year and most of this production is from Devonian shales in the Appalachian Basin. In Kentucky, shale gas reserves are estimated at 1.8 trillion m^3 (63 tcf) gas-in-place (Hamilton-Smith, 1990), and cumulative production from the shale is more than 113.3 billion m^3 (4 tcf). An estimated 226.6 billion m^3 (8 tcf) of CO_2 could be sequestered in the shale to replace natural gas already produced. Using an estimated recovery factor for natural gas of 17 percent (Boswell, 1996), an additional 141.6 billion m^3 (5 tcf) is available for primary production from the shales and approximately 1.4 trillion m^3 (50 tcf) available for enhanced recovery. Little is known of the behavior of miscible and immiscible CO_2 flooding of organic rich shales (i.e., possible adsorption potential and EGR as in coalbed methane production). Sequestration in these reservoirs in Kentucky alone could result in as much as an additional 849.5 million m^3 (30 bcf) in annual production for natural gas, and annual CO_2 sequestration of 1.7 billion m^3 (60 bcf).

Benefits

The ***M**idcontinent **I**nteractive **D**igital **C**arbon **A**tlas and **R**elational Data**B**ase* (MIDCARB) will be a unique product that brings together the strength of five states with strong natural resource research organizations (i.e., Illinois, Indiana, Kansas, Kentucky, Ohio). MIDCARB will provide both private- and public-sector decision-makers on-line access to digital and hard copy information, digital databases, new cutting-edge scientific and policy studies, and geographic locations of CO_2 sources and potential CO_2 sinks. The atlas will provide a sound information base to use in the evaluation of technologies for CO_2 sequestration on a regional and local basis in order to maximize economic and environmental returns. Information will be available when and where needed in an easily interpretable form using online access to database query and geographic information systems (literally on the decision-maker's desk). Completion of the project for the Midcontinent will provide a tool to evaluate the impact of CO_2 sequestration on an important region of the country. The demonstration of the digital atlas will enable similar projects in other areas. Digital access to pertinent information will be critical to evaluating CO_2-mitigation policies, directing needed research, and understanding the technical, economic, social, and environmental challenges of CO_2 sequestration.

This database will assist decision makers in addressing questions regarding the profitability of CO_2 separation. Whether the information in the database is used for commercial purposes will depend on other factors. First, commercial entities will need an incentive, via natural market mechanisms or federal mandate, to capture and separate CO_2 from flue gases, as well as sequester it. It is widely held in industrial and scientific circles that the current market does not favor capture and sequestration of CO_2 from flue gas. Second, a significant decrease in the costs associated with CO_2 capture and sequestration will be needed. Current costs of CO_2 have been estimated as ranging from $35/tonne CO_2 to $264/tonne CO_2 (USDOE, 1999a). A cost of $10/tonne CO_2 is widely believed to be the target for capture and sequestration technologies being commercially viable (USDOE, 1999b). This database will help others make decisions regarding the profitability of CO_2 sequestration.

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