TITLE: **NAT**ional **CARB**on Sequestration Database and Geographic Information System (**NATCARB**)**Former Title -** Midcontinent Interactive Digital Carbon Atlas and Relational Database **(MIDCARB)**

Cooperative Agreement No.: DE-FC26-00NT40936

Contractor Name and Address: The University of Kansas Center for Research Inc.

Date of Report: July 16, 2004

Award Date: September 28, 2000

DOE Cost of Project: $748,884 (Budget Year 3)

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Reporting Period: January 1, 2003—December 31, 2003

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FOREWORD

This report summarizes a cooperate project involving many different organizations. These organizations include the original members of the MIDCARB group – The geologic surveys in Illinois, Indiana, Kansas, Kentucky and Ohio. The people participating in the project are listed on the web at: http://www.midcarb.org/contacts.shtml. The project has been expanded beyond the Midcontinent participants and involves the regional carbon sequestration partnerships in a **NAT**ional **CARB**on Sequestration Database and Geographic Information System (**NATCARB** at (http://www.natcarb.org/).

ABSTRACT

This annual report describes progress in the third year of the three-year project entitled ***"Midcontinent Interactive Digital Carbon Atlas and Relational Database (MIDCARB)".*** The project assembled a consortium of five states (Indiana, Illinois, Kansas, Kentucky and Ohio) to construct an online distributed Relational Database Management System (RDBMS) and Geographic Information System (GIS) covering aspects of carbon dioxide (CO_2) geologic sequestration (http://www.midcarb.org). The system links the five states in the consortium into a coordinated regional database system consisting of datasets useful to industry, regulators and the public. The project has been extended and expanded as a ***NATional CARBon Sequestration Database and Geographic Information System (NATCARB)*** to provide national coverage across the Regional CO_2 Partnerships, which currently cover 40 states (http://www.natcarb.org). Advanced distributed computing solutions link database servers across the five states and other publicly accessible servers (e.g., USGS) into a single system where data is maintained and enhanced at the local level but is accessed and assembled through a single Web portal and can be queried, assembled, analyzed and displayed. This project has improved the flow of data across servers and increased the amount and quality of available digital data.

The online tools used in the project have improved in stability and speed in order to provide real-time display and analysis of CO_2 sequestration data. The move away from direct database access to web access through eXtensible Markup Language (XML) has increased stability and security while decreasing management overhead. The MIDCARB viewer has been simplified to provide improved display and organization of the more than 125 layers and data tables that have been generated as part of the project.

The MIDCARB project is a functional demonstration of distributed management of data systems that cross the boundaries between institutions and geographic areas. The MIDCARB system addresses CO_2 sequestration and other natural resource issues from sources, sinks and transportation within a spatial database that can be queried online. Visualization of high quality and current data can assist decision makers by providing access to common sets of high quality data in a consistent manner.

EXECUTIVE SUMMARY

The ***Midcontinent Interactive Digital Carbon Atlas and Relational dataBase (MIDCARB)*** is a joint project between the geological survey's of Illinois, Indiana, Kansas, Kentucky, and Ohio, with funding from the Department of Energy's National Energy Technology Laboratory (http://www.midcarb.org). The purpose of MIDCARB is to enable the evaluation of carbon sequestration potential in these states. The scope of the MIDCARB effort has been expanded to provide national coverage across the Regional CO_2 Partnerships, which currently cover 40 states. To reflect this expanded effort the MIDCARB effort has been renamed the ***NATional CARBon Sequestration Database and Geographic Information System (NATCARB)*** (http://www.natcarb.org). The digital spatial database allows users to estimate the amount of carbon dioxide (CO_2) emitted by source supplies (such as power plants, refineries and other fossil fuel consuming industries) in relation to geologic reservoirs that can provide safe and secure sequestration over geologic periods of time. MIDCARB is organizing and enhancing the critical information about CO_2 sources, and developing the technology needed to access, query, model, analyze, display, and distribute natural-resource data related to carbon management into a system that is robust and capable of being updated from multiple sources on a daily basis.

The project has significantly improved the reliability, efficiency, security, and flexibility of communication and data sharing among all the servers of the MIDCARB Consortium. In addition data are being incorporated from servers outside the consortium (e.g., digital elevation model from the USGS EROS Data Center). Data and information on CO_2 Sources and geologic sequestration sites are obtained from multiple and

heterogeneous servers and databases in five different states. The MIDCARB Internet Map Server processes data on remote servers and the results are assembled and displayed on the user's desktop (http://www.midcarb.org). The process is relatively seamless and response time has improved significantly. Web-database connectivity uses state-of-the-art tools to provide access to heterogeneous databases and software maintained independently on numerous servers in the five sites.

The project has developed improved tools to query, display and analyze CO_2 source, transportation and sink data. Data is obtained as web pages from the remote databases plotted and analyzed in real-time. The MIDCARB project remains a functional template for distributed data systems to address CO_2 sequestration and other natural resource issues that cross the boundaries between institutions and geographic areas. The MIDCARB system is capable of being easily expanded to access, query and display CO_2 sequestration data on any accessible server. Visualization of high quality and current data can assist decision makers by providing access to common sets of high quality data in a consistent manner.

PROJECT OBJECTIVES

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. However, 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 CO_2. Sequestering CO_2 in geological reservoirs may be one way to safely manage carbon emissions over long periods of time, if the proper data and 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) is a joint project between the Geological Survey's of Illinois, Indiana, Kansas, Kentucky, and Ohio, with funding from the Department of Energy National Energy Technology Laboratory. The purpose of MIDCARB is to enable the evaluation of carbon sequestration potential in these states. The digital spatial database allows users to estimate the amount of carbon dioxide (CO_2) emitted by source supplies (such as power plants, refineries and other fossil fuel consuming industries) in relation to geologic reservoirs that can provide safe and secure sequestration over geologic periods of time. MIDCARB is organizing and enhancing the critical information about CO_2 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 CO_2 emissions are identified, located, and characterized. Potential CO_2 sequestration targets, including producing and depleted oil and gas fields, unconventional oil and gas reservoirs, uneconomic coal seams, and saline aquifers are characterized to determine quality, size, and geologic integrity. All information is available online through user query. Information is provided through a single interface that will access multiple servers. The approach is one of the first demonstrations of large scale distributed natural resource databases and geoinformatics. Access to the up-to-date technical information can be used at the regional and national level as a tool to minimize the negative economic impact, and maximize the possible value of the CO_2 sequestration to hydrocarbon recovery from oil and gas fields, coal beds, and organic-rich shales.

PROJECT STATUS

Web-database connectivity has been improved significantly among the five consortium members using Internet Map Server (IMS), eXtensible Markup Language (XML), and custom tools developed in JAVA, FLASH, and Coldfusion. MIDCARB applications access large databases for the analysis of both CO_2 sources and potential geologic sequestration sites. Software on numerous servers across the five sites provides distributed processing for data analysis and display. Tools have been developed to provide complete distributed management of the system (i.e., data and coverages can be edited and loaded from anywhere in the MIDCARB system). The software systems developed as part of the MIDCARB project represent cutting edge approaches to online data access and management. The data assembled represents one of the most comprehensive data sets assembled to address questions of CO_2 sequestration.

ACCOMPLISHMENTS

This reports concentrates on selected major project accomplishments that occurred over calendar 2003. Where appropriate, future work is highlighted. Major MIDCARB project accomplishments are:

1) Maintained a distributed project team and management that cross both institutional and technical boundaries. The pooling of subject domain and computing technical expertise has resulted in a product that could not be completed by any of the individual participating research institutions. The distributed team provides both interaction and innovation within a focused area. The project structure serves as a model for addressing other natural resource issues that cross boundaries among institutional and geographic entities. This team has been expanded to encompass personnel in each of the CO_2 Regional Partnerships.

2) The project has developed an improved online distributed system architecture that provides reliable communication and sharing among all the various servers of the MIDCARB Consortium. The new architecture incorporates open-platform methodologies that allow improved data sharing across servers, and incorporation of open GIS Consortium/Web Map Service map services. Use of spatial data engines and relational databases is not required. The interactive Web-based applications allow the five states in the MIDCARB consortium to share, integrate, and display spatial data pertinent to CO_2 sources and geologic sequestration sites across the consortium states. Data remains local to be updated and expanded. However, data is available for use in regional analysis and to increase the accessibility of this information to all interested parties.

3) The improved MIDCARB web portal is more robust, provides improved performance and increased security by limiting data transfer to images and web

pages. The browser provides simplified organization and control with improved display capabilities to the online client.

4) The project has improved an online distributed system for the management of the MIDCARB system. Local site administrators for each of the consortium states have complete control to add or modify coverages. All modifications and additions are online through the Internet from any facility. The complete distribution of site administration provides better management of components to create a system that supports the distribution of high quality maps and GIS functionality on the Internet. It also provides the ability to scale the system for national coverage through the CO_2 Sequestration Partnerships and NATCARB.
5) The project has generated and assembled a very large quantity of data elements pertaining to CO_2 sources and potential geologic sequestration sites. The project has characterized critical properties to generate estimated CO_2 sequestration volumes for potential geologic sequestration targets (e.g., petroleum reservoirs, deep coal, saline aquifers and unconventional. Data includes over 125 layers, access through XML to millions of records across the consortium states for sources and sites. Each state in the MIDCARB Consortium is responsible for construction, enhancement, and maintaining the data. Data quantity is extremely large and constantly increasing. Specialized data and parameters have been generated and used to enhance coverages and analysis tools (e.g., corrected reservoir/aquifer temperature, minimum miscibility pressure for oil, and coalbed adsorption/desorption).

6) Sets of calculators have been developed and automated to provide analysis and display tools that can be accessed directly or through the MIDCARB layers. Tools allow clients to query and plot emissions through time for a single object to sum total emissions across an individual state, or group of sources. Additional tools allow the client to determine the estimated sequestration potential within a predetermined distance from an existing source or any other map location
7) We have provided technology transfer to the geologic and sequestration community and to the general public through talks papers and posters (see http://www.midcarb.org/events.shtml for a listing and examples).
8) We have worked to expand the extent of the MIDCARB model to encompass the 40 states within the seven CO_2 Regional Partnerships funded by DOE. We have renamed the MIDCARB effort as NATCARB (http://www.natcarb.org).

Short-Term Goals

Immediate short-term goals that will be realized prior to the end of the next project year are to:

1) Form working groups and work with the Regional CO_2 partnerships to expand coverages and databases to address sequestration on a national basis. Provide the initial data sets and coverages that can be used and enhanced by the partnerships. Add significant new coverages and databases that increase the richness of the NATCARB site. Assist in the expansion of coverage types in every state covered by the partnerships. Work to pioneer coverage and database types and spread the expertise to the other regions.

2) Develop and add new and improved query and analysis tools. The present tools represent a significant increase in capability, but still require improvement. The biggest need is to develop complex query capabilities that can be used to advance economic, technical, and environmental analysis of CO_2 sequestration potential at regional and state levels. Provide improve flexibility to designate scales of plots and displays. Provide improved download capabilities to move data and coverages to the client's machine for additional analysis.
3) Construct and demonstrate a working prototype of National Portal Database to evaluate CO_2 sequestration potential across multiple regions/states. Work to bring all the partnerships into national carbon sequestration information system coverage. Provide a new front-end browser that reflects a national scope.
4) Complete a prototype system to link to a selected subset of data pertinent to terrestrial sequestration.
5) Undertake focused workshops to provide the technical expertise to develop a high quality Web-Enable Relational Database and GIS that covers the US.
6) Provide a roadmap to maintain the communication and growth in the databases to for evaluation CO_2 sequestration beyond the end of the project.

OVERVIEW OF TECHNICAL PROGRESS

A major challenge of the MIDCARB project was to create an efficient, easy to access, and readily maintained knowledge management system with many millions of records pertaining to CO_2 sequestration that resides in the five states of the MIDCARB

Consortium (Illinois, Indiana, Kansas, Kentucky and Ohio). The MIDCARB system provides global access across the organizations to manipulate pertinent geologic and engineering data related to the issues involved in identifying and evaluating opportunities for geologic CO_2 sequestration. Databases and GIS coverages were developed in each state to characterize stationary sources of CO_2 and potential oil, gas, coal, and brine reservoirs for sequestration.

The MIDCARB Consortium has developed and improved a distributed approach to knowledge management. In year three the architecture of the MIDCARB system underwent significant improvements. As a result of these architectural changes, the MIDCARB system is more robust, responsive, scalable, and secure.

Significant new tools and coverages have been added to the MIDCARB system that enhances the ability to undertake economic, technical, and environmental analysis of CO_2 sequestration potential at regional and state levels. Derived coverages use "calculators" to estimate the quantity of CO_2 that could be sequestered under various physical conditions (e.g., temperature, pressure and salinity)

The MIDCARB system is one of the first distributed systems of natural resource data focused on CO_2 sources and potential geologic sequestration sites. Efforts are underway to expand the MIDCARB model through the Regional CO_2 Partnerships to provide national coverage. To reflect this change in scope the MIDCARB effort has been renamed as the ***NATional CARBon Sequestration Database and Geographic Information System (NATCARB)***.

MIDCARB PROJECT STRUCTURE AND MANAGEMENT

MIDCARB assembled a consortium of five states (Indiana, Illinois, Kansas, Kentucky and Ohio) to construct an online distributed Relational Database Management System (RDBMS) and Geographic Information System (GIS) covering aspects of carbon dioxide geologic sequestration (http://www.midcarb.org). The system links the five states in the consortium through a coordinated regional database system consisting of map coverages and datasets useful to industry, regulators and the public. The MIDCARB project organization is unique in that it is distributive, geographic and overlapping. The organization is structured along both geographic boundaries and broad functions. The geographic focus provides strong local expertise to characterize both CO_2 sources and potential geologic sequestration targets. The distributive focus provides a critical mass of technical people. A strong technical computing team was assembled across institutional boundaries and has developed unique hardware and software solutions. This computing group pools technical expertise from each institution to work collaboratively on issues that are on the edge of distributed computing. No one institution has the technical computing expertise to create and the more difficult task maintain a system such as MIDCARB. The technical computing leads keep the institutional management informed, and also interact closely with the individuals working on technical information concerning CO_2 sources and potential geologic sequestration sites (i.e., domain knowledge). The interaction of between computing and domain teams at the local level provided unique solutions to address challenges and advanced both areas. The flexibility provided by the distributive structure of the MIDCARB system allows for local experiments in data type, structure and display. Successful “experiments”, spread among the states.

This model is being expanded as part of the NATCARB effort through development of coordinated working relationships, and assistance to the database and GIS effort of the seven Regional CO_2 Partnerships. For NATCARB, the overall project organization is provided through the University of Kansas. Budgetary items are run through the Kansas University Center for Research (KUCR) and overall project coordination is provided through the Kansas Geological Survey.

Interaction between domain and computing technical experts within individual institutions and across institutions is on a daily basis. This is monitored through the local institutional leads and shared through email and through periodic phone conferences. Project integration is to a significant degree organic in that all information has the same geographic structure, and has a similar look and feel. However, the monthly phone conferences, workshops, and periodic meetings (usually associated with technical meetings) are used to improve working relationships across institutions and to provide a focus for periodic milestones.

MIDCARB **SYSTEM STRUCTURE**

In year three the architecture of the MIDCARB system underwent significant improvements. The MIDCARB system discarded the model using a single application server running ColdFusion and JAVA tools, and using Internet Map Server (IMS) and Spatial Data Engine (SDE) to query distributed and heterogeneous relational database management systems (RDBMS) and software maintained independently on numerous servers in the five sites. The new MIDCARB system architecture no longer communicates actual data. Instead, MIDCARB requests an image of the data from the remote servers. The remote servers contact their database and generate an image based on the request and send it back to the MIDCARB server. MIDCARB downloads, georeferences, and merges all of the remote layer images into a final layer that it sends to the client. This significantly reduces the quantity of data transmitted between servers as well as the amount of processing required at the MIDCARB portal. Attribute data is requested from the remote servers only when a user specifically queries information from a layer. The transfer of attribute data is undertaken through web services using XML in place of direct query of remote databases. As a result of these architectural changes, the MIDCARB system is more robust, responsive, scalable, and secure.

The management overhead associated with the multiple layers across multiple servers in the MIDCARB project has been significantly improved by moving to the new architecture. MIDCARB has built a metadata repository of connection and layer information for each partner. This is a dynamic database that is managed without central administration by the partner administrators of the various servers.

As the MIDCARB site grew to serve a large number of data layers (>125), presentation and integration within the MIDCARB viewer became cluttered and overwhelming to the user. The graphical user interface (GUI) and the database and mapping requests component were redesigned so that layers could be grouped and displayed in a more organized fashion, and allow a simplified and more flexible design to be presented to the online user.

The new MIDCARB structure provides the public, industry, legislators, federal agencies, etc. improved tools to access up-to-date maps, data, imagery, etc. to enhance their decision-making and scientific processes. Products can be tailored to the individual and collective requirements of the states and regions.

The improved interactive Web-based GIS applications allow the five states in the MIDCARB consortium to better share, integrate, manage and display spatial data pertinent to CO_2 sources and geologic sequestration sites across the consortium states. Data and management of the data remains local to be updated and expanded. However, data is available for use in regional analysis and to increase the accessibility of this information to all interested parties.

System Architecture

At the end of Year 2 of the MIDCARB project there were over 125 different map layers being served from MIDCARB server hosted at the Kansas Geological Survey. The data was being served through Spatial Database Engines (SDE). The Internet Map Server (IMS) located at the Kansas Geological Survey would request data from the distributed SDE servers in Kansas, Illinois, Kentucky, and Indiana (Figure 1). When a request was made the central IMS server would request all of the data (all geographic vector and raster data and all of the attribute data that went along with it) from the respective SDE server. Once the data was brought to central server maps were made and sent back to the client via IMS. Data transfer was in near real-time, but was dependant on network speed. Complete data transfer from remote servers; central processing and subsequent discard was a systems architecture bottleneck. In addition, it was difficult to incorporate new systems or modifications of existing systems at the local level. Also servers that were not running SDE and on a fast network connection slowed the entire MIDCARB system (Kansas, Indiana, Illinois, & Kentucky were able to communicate via Internet 2; Ohio was on Internet 1). To address this system architectural challenge the new MIDCARB server does not transfer actual data between servers for central processing. Instead, MIDCARB issues simultaneous requests for images of the data that are processed on the remote servers (Figure 2). Each remote IMS server contacts its local database and generates images based on the request and sends the image back to the MIDCARB server. The new MIDCARB architecture downloads, georeferences, and merges the remote layer images into a final layer that is sent to the client. This technique reduces by several orders of magnitude the quantity of data transmitted between servers and the amount of processing required at the portal. The new MIDCARB architecture provides the ability to implement open-platform methodologies (e.g., Open GIS Consortiums [OGC] Web Mapping Service [WMS] and Web Feature Service [WFS]).

Direct access to remote databases has been replaced by transferring information as an XML document (Figure 3). This allows the remote server to run any form of database and does not require a direct database connection (Figure 2). Attribute data attached to the image (e.g., CO_2 emissions data) are only requested from the remote servers when a user specifically queries information from a layer. XML is a standard format that allows access by standard web service programs. The local IMS requests emissions data from the local database based on the request from the MIDCARB IMS. Only the data requested is passed to the MIDCARB server for analysis or display web service as an XML document. This increases the speed of requests, security, and the stability of the entire system (i.e., only standard web pages are passed among the servers).

MIDCARB Viewer

As the MIDCARB site grew to serve a large number of data layers, presentation and integration within the MIDCARB viewer became cluttered and overwhelming to a user. The MIDCARB viewer was restructured so that layers were grouped and displayed in a more organized fashion (Figure 4). The new MIDCARB viewer is constructed to allow easier use for the client. The new portal is built as two distinct components—the viewer which is a graphical user interface (GUI) and the database and mapping requests component. The client GUI was built with Macromedia's Flash. Flash allows rich integration of text and graphics in a compact interface. Flash also has the advantage of being self-contained inside the browser. This means that it does not matter which browser a client uses, only that they are using the current version of Flash (Macromedia reports that 97% of Internet-enabled desktops worldwide contain Flash). The Flash GUI handles the map layout, layer grouping, and tool grouping.

Once the user selects a layer (or set of layers) from the ***Layer List*** to draw and then zooms to an area, the Flash viewer communicates to a series of Macromedia ColdFusion MX (CFMX) backend pages that handle the viewer-database-IMS interaction. The CFMX pages dynamically build XML requests based on Flash parameters and the metadata database. These XML requests are sent to the remote servers that generate the maps or data requests. The resulting images are returned through the MIDCARB server to the Flash client.

MIDCARB works by generating a series of Internet Map Server (IMS) requests based on the users input to the map portal. The portal simultaneously issues requests to each regional/national IMS server to create an image of the data. Requests are simultaneously issued to remote servers. Each local IMS server stores the requested images locally and creates a world file for each image (so that the images can be georeferenced). The IMS server at the MIDCARB Portal assembles the stored georeferenced images into a national map. The metadata catalog allows the portal to build "Intelligent" requests within a loosely coupled system on map services. The system accessed through the MIDCARB Portal can be thought of as a federation of map services.

As map services are added to the metadata catalog through the distributed MIDCARB Management System (see next section), the ***Layer List*** is updated as a dynamic system that is run off of the metadata repository. The MIDCARB portal uses the selected map services from the ***Layer List*** and the geographic extent of the map to develop eXtensible Markup Language (XML) requests that are simultaneously submitted to the servers in each regional partnership. XML is a standard format that provides easy access by web service programs. The MIDCARB Portal uses the IMS to produce the XML representation of the local database. For example, IMS is used to request the CO_2 emissions data from the database and pass that information to the graphing web service as an XML document.

System Management

Managing the integration of the multiple layers across multiple servers in the MIDCARB project resulted in a rapid increase in administrative overhead. If a new layer was built and loaded onto a partner server for distribution using the original MIDCARB architecture, a representative of the remote server would contact the Kansas Geological Survey to manually add the layer to the site. Once the layer was loaded the personnel add the remote site had the ability to modify the layer. However, this initial step of adding new layers became a bottleneck. The original MIDCARB architecture required hard-coded text configuration files. Each new layer added to the site required several (large) configuration files had to be edited.

The MIDCARB viewer (client view) was also built on technology (JavaScript) that made it difficult to interact with remote databases. The original MIDCARB viewer ran on a series of ordered lists versus dynamic database queries. These lists had to be incremented in order to be integrated with the site. These techniques were not scalable to large numbers of sources and layers. The modified MIDCARB architecture incorporates a metadata repository of connection and layer information for each partner (Figure 2). This is a dynamic database that is managed by all partner administrators of the various coverages and databases. The remote administrators use an Internet web page that is served by MIDCARB to enter the connection information for their own remote server (Figure 5A). The MIDCARB server automatically queries the distributed servers in order to locate all available layers (Figure 5B). The remote administrator can then manage these layers remotely, indicating which layers the site should allow users to view, which columns should be displayed or queried and how to group the layers. Only this management information is stored on the MIDCARB server in a relational database (Figure 2). All data processing is undertaken on the remote servers. A typical sequence of web pages for adding and managing a new layer to the MIDCARB server is shown in Appendix A.

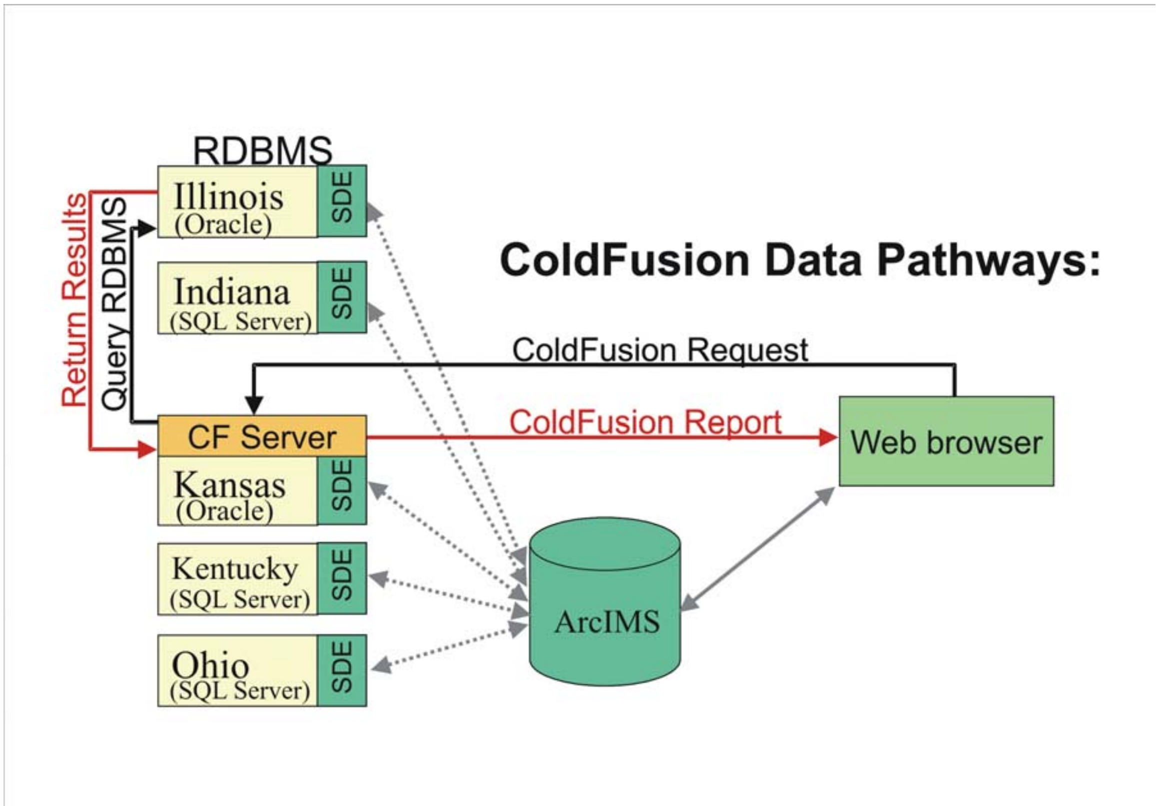


Figure 1 – Original MIDCARB system structure linked tabular databases from the five cooperating states using an Internet Map Server (IMS) and custom tools developed in ColdFusion and Java. The diagram shows how requests from the Web browser travel back to the ColdFusion or IMS server in Kansas for processing. The ColdFusion server then directly queries appropriate RDBMS databases or the IMS queries through a Spatial Data Engine (SDE), in this example the Illinois Oracle database. Results of the query are returned to the ColdFusion or IMS server in Kansas processing, and then delivered as a pure html report or GIS object image to the client's web browser.

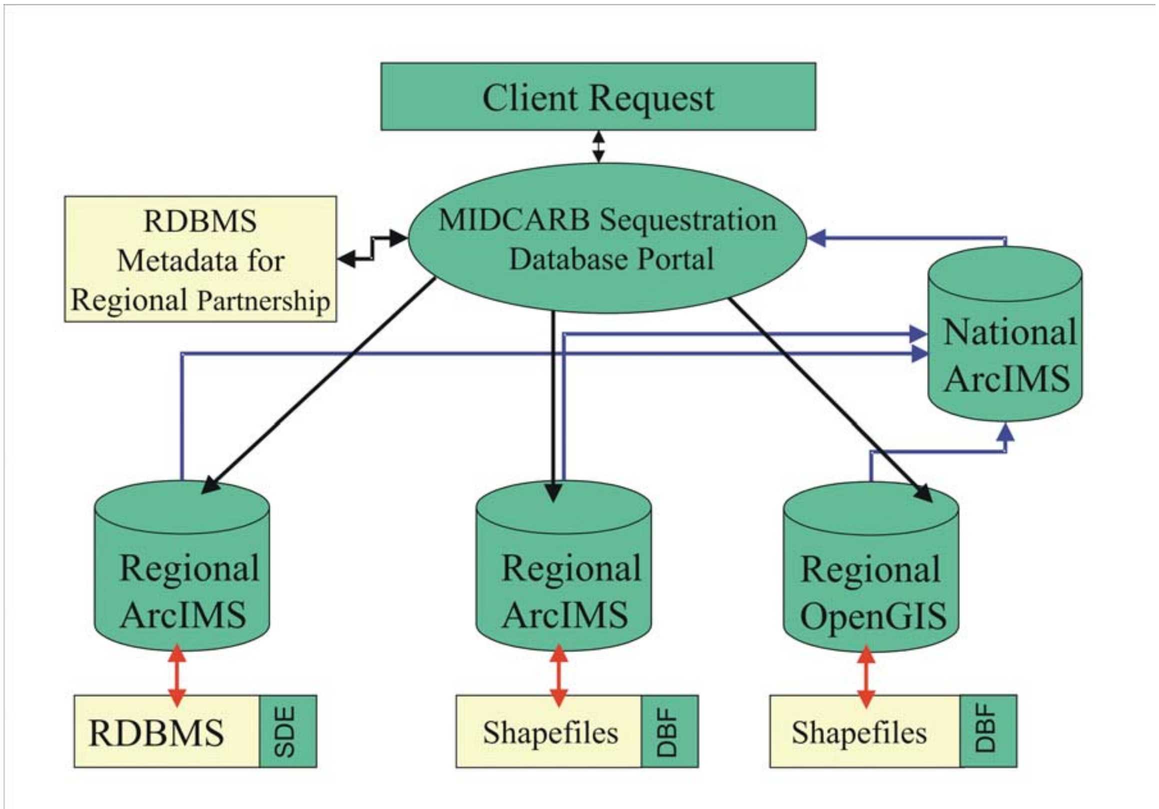


Figure 2. — New MIDCARB system structure links regional Internet Map Servers (IMS) from the cooperating states. Processing is undertaken on the regional servers and only the image is returned MIDCARB portal. Data queries are also processed on regional servers and data is returned using XML.

ArcIMS Request of CO2 information

This is what I submit to ArcIMS to have ArcIMS generate an xml file that has all of the emissions from a particular powerplant.

```
<ARCXML version="1.1">
    <REQUEST>
      <GET_FEATURES attributes ="true" beginrecord="0" outputmode="newxml" geometry="false" envelope="false" compact="false">
            <LAYER id="2" />
              <QUERY searchorder="attributefirst"
                            subfields="MIDCARB.FACILITIES_EMISSIONS.YEAR MIDCARB.FACILITIES_EMISSIONS.QUARTER
                                       MIDCARB.FACILITIES_EMISSIONS.CO2_TONS MIDCARB.FACILITIES_EMISSIONS.CO2_CONCENTRATION
                                       MIDCARB.FACILITIES_EMISSIONS.SO2_TONS MIDCARB.FACILITIES_EMISSIONS.NOX_TONS
                                       MIDCARB.FACILITIES_EMISSIONS.MERCURY_LBS"
                            where="MIDCARB.KS_FACILITIES_SDELAYER.FACILITY_ID = MIDCARB.FACILITIES_EMISSIONS.FACILITY_ID
                                   and MIDCARB.KS_FACILITIES_SDELAYER.FACILITY_ID = 1329"
                                    jointables="MIDCARB.FACILITIES_EMISSIONS">
         </QUERY>
      </GET_FEATURES>
    </REQUEST>
  </ARCXML>
```

ArcIMS Response

```
<?xml version="1.0" encoding="Cp1252"?>
<ARCXML version="1.1">
<RESPONSE>
<FEATURES>
<FEATURE>
<FIELDS>
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.YEAR" value="1997" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.QUARTER" value="4" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.CO2_TONS" value="43281.8" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.CO2_CONCENTRATION" value="0.119" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.SO2_TONS" value="186.5" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.NOX_TONS" value="0.57" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.MERCURY_LBS" value="" />
</FIELDS>
```

Figure 3. - Example of request generated by clicking on a particular CO_2 source (power plant) and the XML page that returns every emissions record that matches the id's for the CO_2 source(s). The XML is passed to the graphing or display routine for transfer by the web service on the client's browser. See plot of CO_2 emissions for an example of graphing web services and what a online user would see from this request (Figure ??).

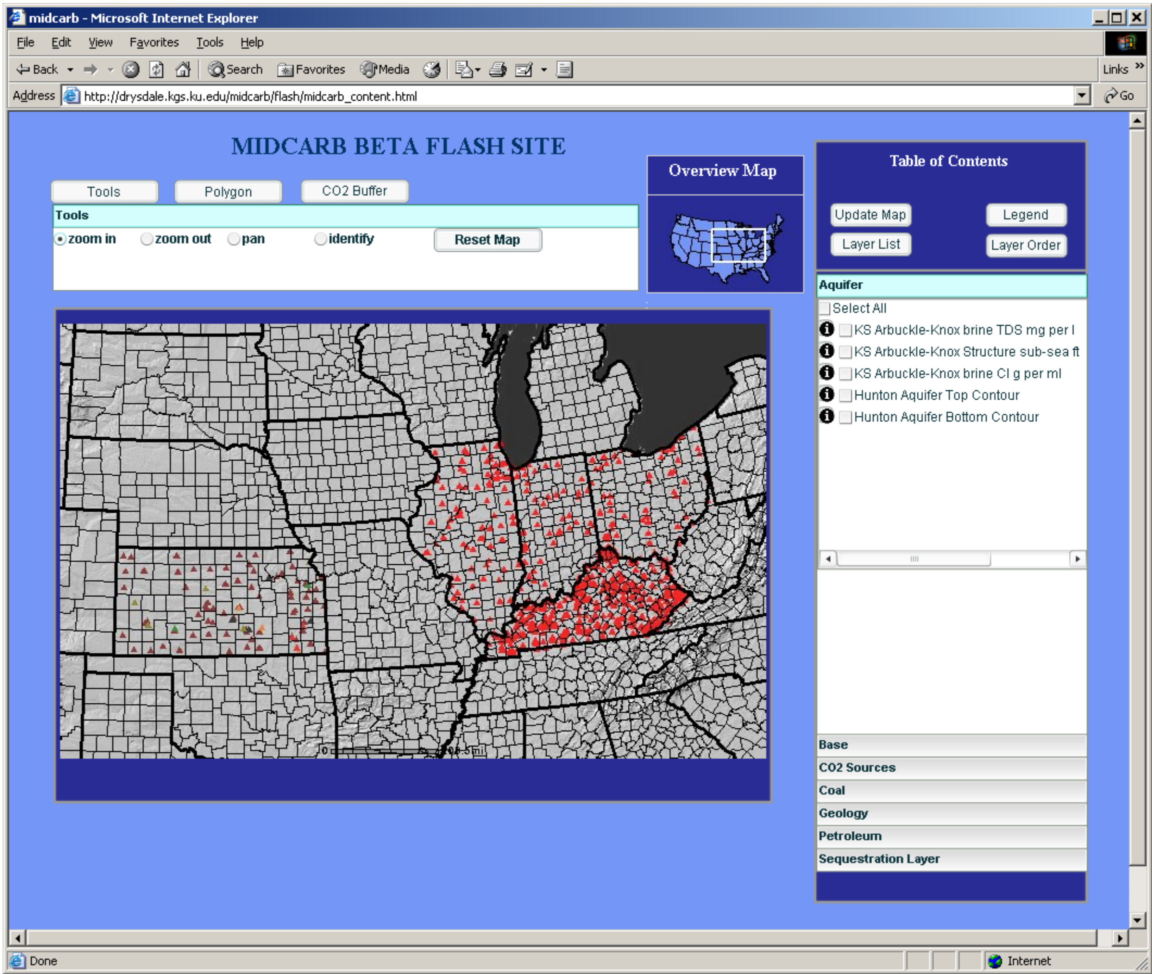


Figure 4. — The new MIDCARB browser uses an improved graphical user interface (GUI) and the database and mapping requests component to provide the client with a means to better organize the layers and control the appearance of the product. The ***Layer List*** groups coverages by subject. A complete view of the **Layer List** is provided in Appendix B.

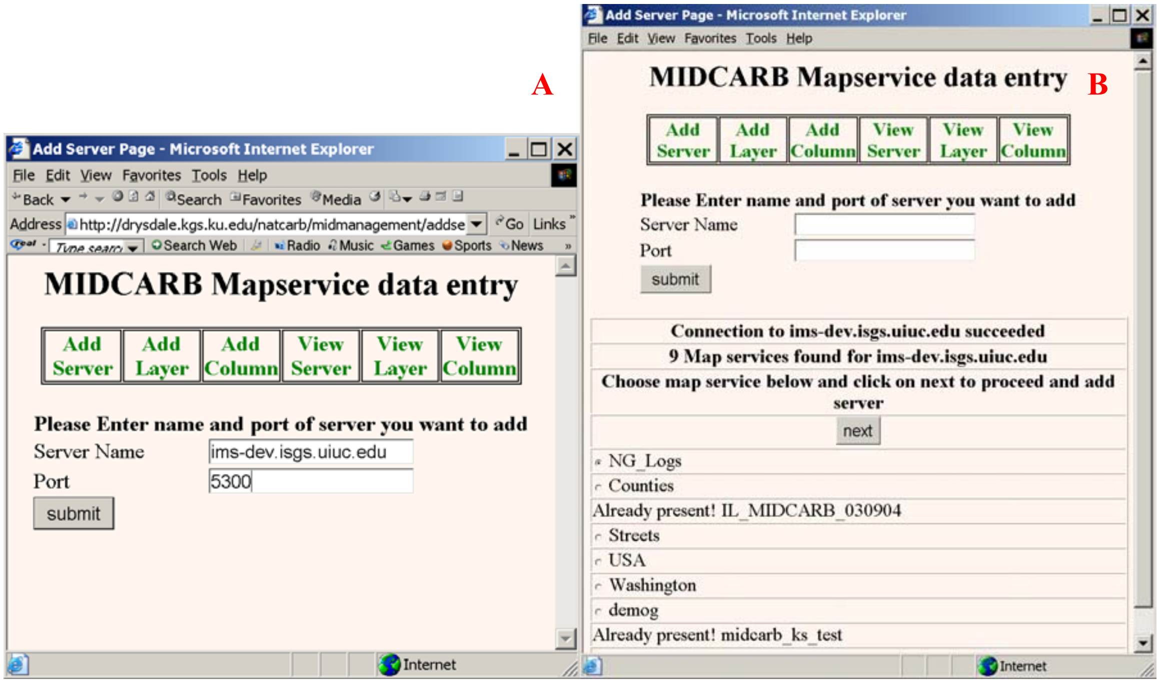


Figure 5. — Selected MIDCARB management pages. The local server administrator at any site can link the remote servers to the MIDCARB portal by entering the connection information for their own remote server (A). The MIDCARB server queries the local server for all available map services and allows the local administrator to select the local map services to connect to the MIDCARB server (B).

Future Work

The MIDCARB project continues to evaluate open-platform methodologies that allow improved data sharing across servers. We are working to develop XML standards to map individual state databases, develop document table definitions (DTD's) and implement front ends to respond to XML queries with data that can be processed by the requestor using either online or stand-alone software. This process involves cooperating to develop simple XML definitions for CO_2 entities and front-end software to map local databases onto XML responses to satisfy a query. The MIDCARB project is providing a mechanism for additional repositories of CO_2 sources and potential geologic sequestration sites to join the effort to distribute large volumes of locally maintained data. The current MIDCARB Internet Map Server is being expanded to support multiple map services beyond the states of the current consortium. The project is being extended and expanded as a ***NATional CARBon Sequestration Database and Geographic Information System (NATCARB)*** to provide national coverage across the Regional CO_2 Partnerships, which currently cover 40 states (http://www.natcarb.org). It is hope that the NATCARB system will be a tool for researchers to address carbon management issues, provide the information basis to develop a portfolio of strong carbon sequestration demonstration projects, and be a primary path of technology transfer and public outreach.

MIDCARB SYSTEM DATA ELEMENTS

MIDCARB Project data includes two types:

- Map Coverages
- Data Tables

Each type is processed locally and served through the MIDCARB server as an image or XML data page. Each state in the MIDCARB Consortium is responsible for construction, enhancement, and maintaining the data. Data quantity is extremely large and constantly increasing. Numbers of records are in the many millions, involve over a century of anthropogenic activity, and cover a range of natural resource types (e.g., aquifers, to petroleum to coal). The data is extremely important to general natural resources and environmental questions in each state. As a result, each institution tries to insure the highest degree of quality control. However, with any extremely large, long-term and heterogeneous data set, individual data items can be incorrect. As a general activity of the institutions, the data is being constantly corrected and enhanced. The MIDCARB Project leverages this state activity, by adding a CO_2 focus and providing data specific to geologic sequestration.

Map Coverages

There are currently over 125 coverage layers that are stored on the five consortium servers. Data fall into the following categories:

- CO_2 Sources
- Infrastructure
- Base
- Petroleum
- Coal
- Geology
- Aquifer
- Non-Conventional

The layers have been grouped in layer lists that are grouped by type. Each layer can be selected through the MIDCARB interface for display (Figure 4, Appendix B). The MIDCARB Browser Interface provides the user tools that can use web services to access data tables that include very large quantities of data that is pertinent to understand CO_2 emissions and potential geologic sequestration sites.

MIDCARB Data

The MIDCARB Project has used existing data tables of natural resource information and constructed new tables (e.g., CO_2 sources and estimated CO_2 sequestration quantities). In many cases existing data tables have been modified to include parameters that are critical to evaluation of potential geologic sequestration. Existing tables cover:

- Aquifers

- Coal
- Nonconventional Reservoirs
- Oil and Gas
- CO_2 sources
- Estimated CO_2 volumes for selected potential sequestration sites.

As an example in Kansas, data has been gathered on basic reservoir parameters (e.g., thickness, area, porosity, water saturation and volume of produced hydrocarbons). The Kansas data can be accessed, queried and displayed through the MIDCARB site. The data were also used to estimate the quantity of CO_2 that could be sequestered in any given square mile of Kansas that meet certain criteria (e.g., distance from a CO_2 source – See tools discussion). For example, similar tables and coverages have been developed for coals in Illinois, aquifers in Indiana and unconventional organic shale reservoirs in Kentucky. Data tables are populated with data from numerous sources including US Department of Energy (EGRID), Environmental Protection Agency and local sources.

The MIDCARB project has provided an assessment of the critical parameters for oil and gas reservoirs in each state and the data is online. We have collected and assembled information for estimating the volume of CO_2 that could be stored in a reservoir using either the amount of gas or oil produced which is a conservative estimate, or reservoir volumetrics (i.e., porosity, thickness, water saturation, area, shrinkage) a more realistic volume that should be larger than the first. We have also assembled depth, reservoir pressure, and temperature parameters for each reservoir. The density of CO_2 is very dependent on the temperature and pressure, making a big difference as to the tonnes of

CO_2 sequestered. We have developed a "calculator" that uses the assembled temperature and pressure data for each reservoir to calculate the tonnes of CO_2 that could be sequestered. This is used to generate a volume for each field (Ohio approach) or each square mile (Kansas approach). We have generated coverages of CO_2 sequestration volumes in petroleum reservoirs across the five states. The estimates can be used with the CO_2 buffer tool to generate the estimated quantity of CO_2 that could be sequestered within an arbitrary distance from any existing or potential CO_2 source. We continue to work toward merging each approach since we should be capable of generating the data in both forms to evaluate the available geologic sequestration potential in either a given area (distance from source) or reservoir. In addition, we have determined the Minimum Miscibility Pressure (MMP) for selected oils in each state. We can then use the MMP values to target oil reservoirs that have potential for miscible CO_2 EOR and would have potential for value-added CO_2 sequestration.

We have assembled data for several major aquifers in each state (Back in the four state area, this is Hunton, Knox and Mt. Simon. In Kansas, we have assembled data on the sub-unconformity Mississippian and Arbuckle (Knox equivalent). Again reservoir properties include the thickness, depth, pressure, temperature and porosity. In addition, data was assembled on salinity (Since amount of CO_2 the can be dissolved in a brine is highly dependent on salinity – Salt in beer effect). This has been completed for the Kansas saline aquifers by assembling a brine database and initial estimates have been generated for the eastern states on a saline aquifer level. Again a calculator is used to determine the amount of CO_2 that can be dissolved in brines of different salinity, temperature (warm beer effect) and pressure (cap off the beer effect). Data is online.

We have assembled the thickness, depth and area for all the major coals. This is especially true in the Illinois basin where numerous coals are present. We have assembled gas desorption data (scf/ton), along with very limit adsorption data to generate initial estimates of CO_2 that could be sequestered in individual coals. A similar procedure has been used to estimate the potential of organic shale in Indiana.

MIDCARB SYSTEM ANALYSIS TOOLS

As part of the MIDCARB Project a number of display and analysis tools were developed. All the tools work across the entire MIDCARB system and can be accessed through the MIDCARB browser. Tools include clients to query and plot CO_2 emissions or production through time for a single object (Figure 6) or to sum the estimated quantity of CO_2 that could be sequestered in a potential geologic sink (e.g., saline aquifer or petroleum reservoir) within a certain distance from any map point (See Appendix C). The Java based graphing web service uses the data from the selected CO_2 source(s) as an XML document. The Emission Plot contains a control panel that can be used to modify the plot (Figure 7 and Appendix C). Additional tools are under development. The control panel for the Java based graphing web service allows the user to do the following,

- Select an emission and plot the data in various units (e.g., Mcf, metric tonnes).
- Select annual emission vs. year plot or annual emission and raw emission data (monthly, quarterly or annual) vs. year plot (default: annual emission vs. year plot).
- Select either linear or log grid (default: log grid).
- Determine the range interval on the emission axis and year axis
- Divide the data by a factor to remove the scientific notation (default: divide by 1).

Either sum the data for all the CO_2 source(s) or plot each CO_2 source by itself (default: sum all facilities).

For the CO_2 solubility and the estimated physical state and density of CO_2 at different pressures and temperatures, macros were constructed to generate gridded estimates for saline aquifers, petroleum reservoirs, and non-conventional reservoirs (e.g., coal beds and organic shale). We have previously discussed the basis of the macros that use the assembled temperature and pressure data for each conventional reservoir to calculate the tonnes of CO_2 that could be sequestered. This has been used to generate a volume for each field (Ohio approach) or each square mile (Kansas approach). We have generated coverages of CO_2 sequestration volumes in petroleum reservoirs across the five MIDCARB states.

For non-conventional reservoirs (i.e. coal and shale), the proposed methodology for estimating CO_2 sequestration uses the standard methodology for *gas in place* calculation in non-conventional reservoirs used by the Gas Research Institute. In order to calculate the CO_2 storage potential of a coal seam (or a rock unit) a number of steps are required. The calculation is basically a series of simple mathematical operations on defined grids.

1) A number of grids (a through e) were created with point data (x, y):
   a. Depth (*ft*)
   b. Thickness (*ft*)
   c. Temperature (the estimated reservoir temperature is calculated with data from a simplified geothermal gradient map for Indiana and using the annual mean average surface temperature of 56 º F). Temperatures are then converted to Kelvin by using the formula

$$K = [0.5556 * (^{o}F-32)] + 273$$

d. <u>Pressure</u> (reservoir pressure in *atm*) is calculated as

$$P = 0.433\ psi/ft * \text{depth}\ (ft) / 14.6959\ psi/atm)$$

e. <u>Gas content</u> (*Mcf*) (applicable for coal and shale)

2) Grids are created for each attribute (depth, thickness, etc) using the geostatistical analyst of ArcGIS and a cell size of 1000x1000 meters was chosen.

3) Calculate the mass of 1 cell unit per foot (in this case a coal unit is used as example). This is exclusively dependent on the density (ρ) of the material (1 g/cm^3 = 1 Ton/m^3)

$$1\ \textit{cell unit}\ [\text{short}\ Ton] = 1000\ [m] * 1000\ [m] * 1\ [ft] * 0.3048\ [m/ft] * \rho_{\text{coal}}\ [Ton/m^3] * 1.1023\ [\textit{short Ton / Ton}]$$

4) Calculate a *conversion factor* [to estimate the volume of gas (*Mcf*) that can be stored in 1 *short Ton* of rock at reservoir conditions]. This factor is a function of depth and temperature; for consistency, it should be calculated using the grid calculator (ArcGIS). At standard conditions (1 *atm* and 60ºF) this factor is 17.25 *Mcf*. At reservoir conditions, the following formula should be applied:

conversion factor = 0.059734 * Temperature (*K*) / Pressure (*atm*) [*Mcf/short Ton*]

5) Considering that the grid Gas content is given in *scf/short ton*, and that is a grid with the same cell dimensions as the *cell unit* above (2), it is possible to calculate the net Gas in Place (*GIP*) value *per cell unit* by using ArcGIS grid calculators and the following formula:

$$GIP = 1\ cell\ unit\ [short\ ton] * \frac{gas\ content\ [scf]}{short\ ton} * \frac{1\ Mcf}{1000\ [scf]} * \frac{1\ short\ Ton}{conversion\ \ factor\ [Mcf]}$$

6) Once the volume has been calculated for one *cell unit*, it is necessary to calculate the net vertical volume per cell. Using the grid calculator (ArcGIS), multiply the grid Thickness times the *GIP* value per cell unit estimated above (5)

Vertical volume per cell = Thickness * *GIP*

7) In the case of coal, based on measured adsorption isotherms, CO_2 seems to have a preferential adsorption over CH_4, with a ratio between 2 and 5 approx. (preliminary results of Mastalerz et al., Illinois Geological Survey pers. comm.). One could therefore, consider three case scenarios (2, 3.5, and 5), where these values represent the factor by which the *GIP* (CH_4) can be multiplied in order to obtain the sequestration potential volume in coal seams for CO_2

CO_2 sequestration potential = (2, 3.5, or 5) * Vertical volume per cell

8) A custom script was developed to add all the individual vertical volumes per cell (7) and therefore provide the net volume per seam. This script includes a boundary condition in which one could limit the minimum vertical volume per cell to be added. This feature allows the user to define a minimum unit thickness, density, and preferential adsorption value.

We have used this approach to generate coverages of the CO_2 sequestration potential for coals and organic shale across the states of the MIDCARB consortium. If our understanding of sequestration of CO_2 in non-conventional reservoirs changes, these procedures could be easily modified and reapplied to the gridded data.

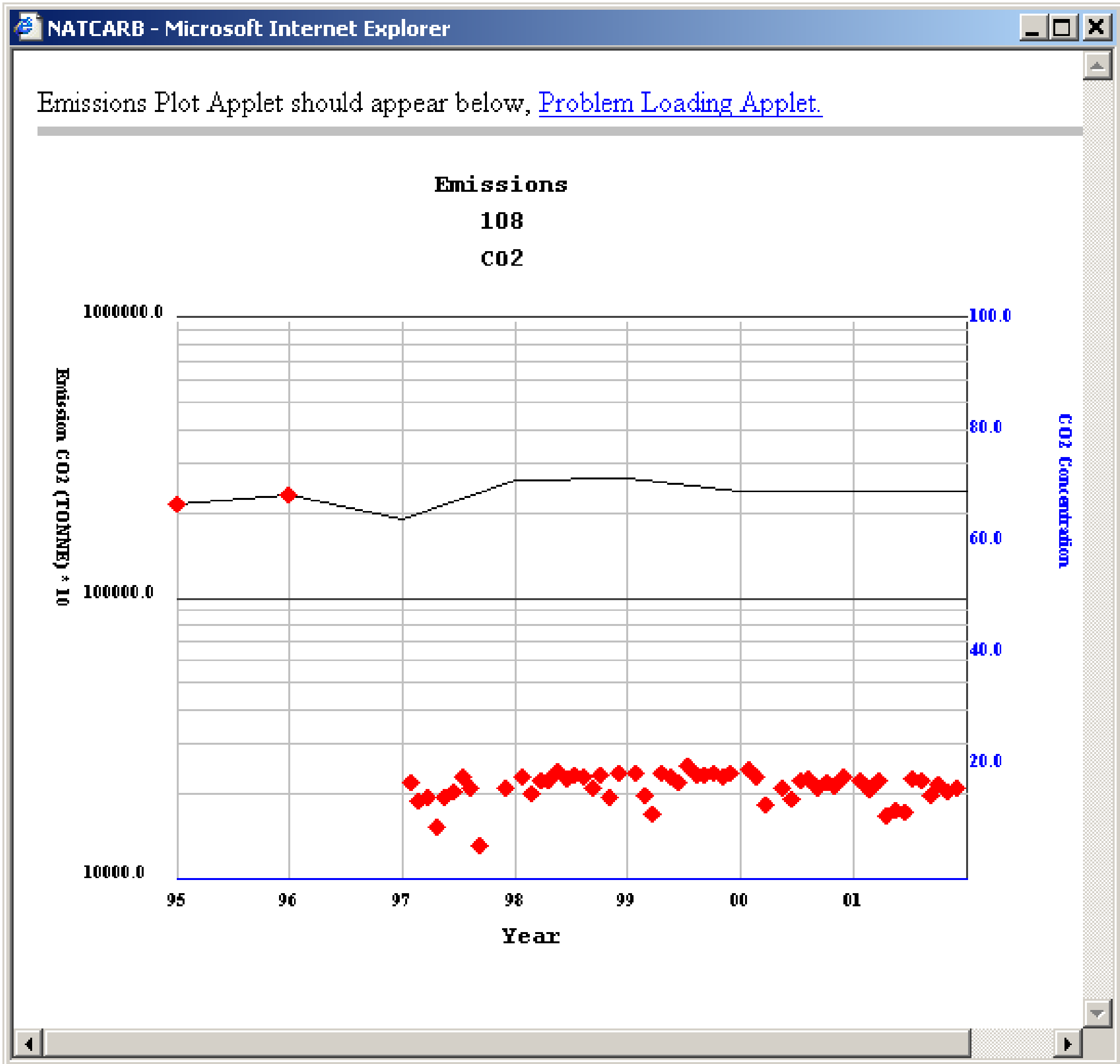


Figure 6.— Example of graph of emission plot from a selected CO_2 source. The online user has control of the appearance of these plots through control panels. Emission scale was set to metric tonnes and divided by 10 (Tons * 10), and minimum set at 100,000 tonnes. The annual scale was set to 1995 to 2002 and plotted at one-year intervals. Annual emission and raw emission data (monthly, or annual) are plotted versus year. A more complete demonstration of the graphing tool is provided in Appendix C.

TECHNOLOGY TRANSFER

The development of the MIDCARB atlas is in itself a technology transfer activity, and will be ongoing from project initiation. In addition the members of the consortium have been very active in presenting results. The following technology transfer activities have occurred during calendar year 2003:

1) Jeremy Bartley, Jeremy and Timothy R. Carr, Dynamic Mapping of Kansas Oil and Gas Data with ArcSDE and ArcIMS, ESRI Petroleum Users Group Annual Meeting, March 10-12, 2003, Houston Texas, http://www.midcarb.org/Documents/ESRI%20March%202003/Dynamic%20Mapping%20of%20Kansas%20Oil%20and%20Gas%20Data.pdf
2) White, Scott W., Timothy R. Carr, James A. Drahovzal, Brandon Nuttall, John A. Rupp, Beverly Seyler, Ernie Slucher, and Joe Wells, An Update on the Midcontinent Interactive Digital Carbon Atlas and Relational dataBase (MIDCARB) and its Future, Second Annual Conference on Carbon Sequestration: Developing and Validating the Technology Base to Reduce Carbon Intensity, May 5-8, 2003, Alexandria, VA, http://www.midcarb.org/Documents/NETL-May-2003.pdf
3) Dubois, Martin K., Scott W. White, Timothy R. Carr, Co-generation, Ethanol Production and CO_2 Enhanced Oil Recovery: A Model for Environmentally and Economically Sound Linked Energy Systems: Developing and Validating the Technology Base to Reduce Carbon Intensity, May 5-8, 2003, Alexandria, VA, http://www.carbonsq.com/pdf/5B1.pdf
4) Solano-Acosta, Wilfrido, Charles W. Zuppann, and J.A. Rupp, Assessment of Oil and Gas Fields in Indiana for CO_2 Sequestration, Online Tools to Evaluate Oil and Gas Fields for CO_2 Sequestration; AAPG Annual Meeting 2003, May 11-14, 2003, Salt Lake City, Utah, http://www.midcarb.org/Documents/AAPG-May-2003/Oil&Gas_Fields_Indiana.html
5) Wickstrom, Lawrence H., James McDonald, Ronald A. Riley, Timothy R. Carr, Brandon Nuttall, John A. Rupp, Wilfrido Solano-Acosta, Charles W. Zuppann,

and Beverly Seyler, Online Tools to Evaluate Oil and Gas Fields for CO_2 Sequestration; AAPG Annual Meeting 2003, May 11-14, 2003, Salt Lake City, Utah, http://www.midcarb.org/Documents/AAPG-May-2003/Online_Tools-Oil&Gas.pdf

6) Carr, Timothy R., Lawrence H. Wickstrom, Christopher P. Korose, R. Stephen Fisher, Wilfrido Solano-Acosta, and Nathan Eaton, Online Tools to Evaluate Saline Aquifers for CO_2 Sequestration, AAPG Annual Meeting 2003, May 11-14, 2003, Salt Lake City, Utah, http://www.kgs.ku.edu/PRS/publication/2003/ofr2003-33/index.html
7) Slucher, Ernie R. and Vinciguerra, Mark, GIS Technology: A Pathway for Regional Geospatial Analysis of Coalbed Methane Assessment and Future Energy Resource Development, AAPG Annual Meeting 2003, May 11-14, 2003, Salt Lake City, Utah, http://www.midcarb.org/Documents/AAPG-May-2003/GIS-technology.pdf
8) Drahovzal, J.A., 2003, "Energy and Environment", talk, May Meeting of the Lexington Torch Club, May 15, 2004, Lexington.
9) Drahovzal, J.A., 2003, "Energy and Environmental Programs", talk, Kentucky Geological Survey 43rd Annual Meeting, Research Highlights and Innovations in the Use of Digital Geologic Maps, May 16, 2003, Lexington. http://www.midcarb.org/Documents/Energy-and-the-Environment-May-2003.pdf
10) White, S. W., T. R. Carr, J. A. Drahovzal, J. Hickman, B. Nuttall, R. Riley, J. A. Rupp, B. Seyler, and E. Slucher, An Update on the MIDCARB Project, AAPG Eastern Section Meeting**,** September 6-10, 2003, Pittsburgh, PA http://www.midcarb.org/Documents/AAPG-Eastern-2003/MIDCARB_Update.pdf
11) Riley, R. A., J. J. Wells, J. McDonald, L. H. Wickstrom, Assessment of CO_2 Sequestration for Enhanced Recovery in Ohio, AAPG Eastern Section Meeting**,** September 6-10, 2003, Pittsburgh, PA http://www.midcarb.org/reports.shtml
12) Bartley, J. D., T. Carr, K. Nelson, and C. Korose, Managing the MIDCARB GIS DATA, ESRI International User Conference, July 7-11, 2003, San Diego, CA, plus numerous posters, http://www.midcarb.org/reports.shtml

13) Nuttall, B. C., J. A. Drahovzal, C. F. Elbe, R. M. Bustin, Analysis of the Devonian Shale in Kentucky for Potential CO_2 Sequestration and Enhanced Natural Gas Production, November 1, 2003, GSA Annual Meeting, http://www.uky.edu/KGS/emsweb/devsh/GSA2003/index.htm

Appendix A

Typical management pages to add and manage a new layer from a remote server to the MIDCARB Server. The remote administrator can then manage these layers remotely, indicating which layers the site should allow users to view, which columns should be displayed or queried, and how to group the layers. Only this management information is stored on the MIDCARB server in a relational database. All data processing is undertaken on the remote servers. All data remains on the local servers.

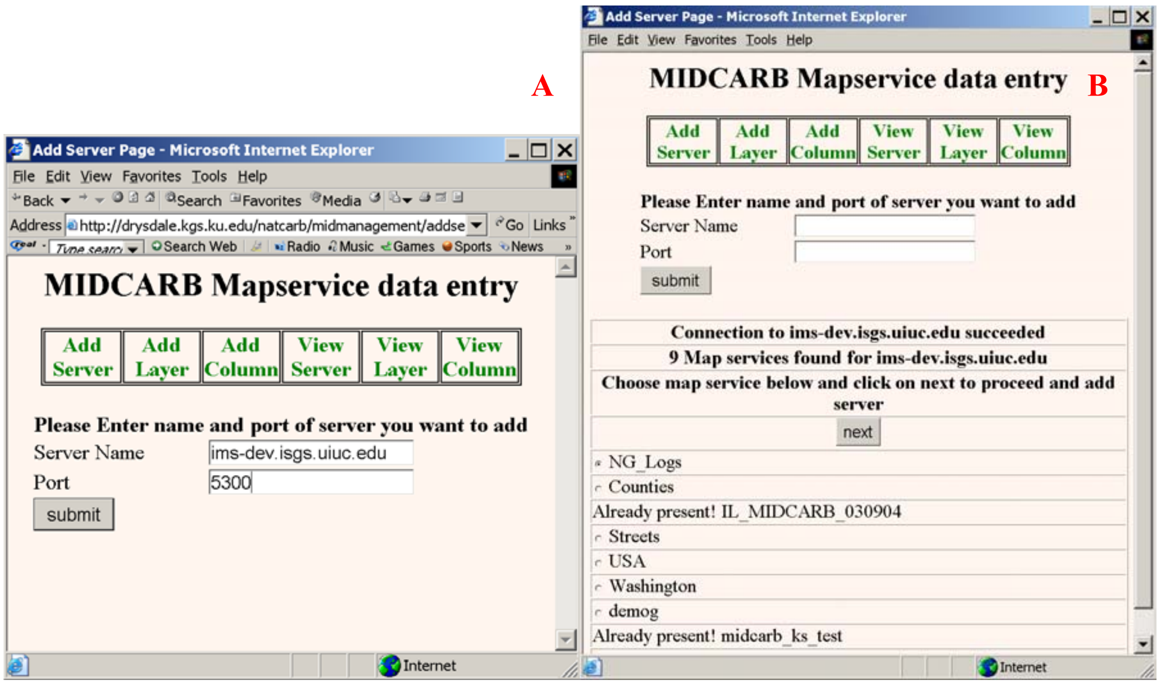


Figure 7. — Link the remote servers to the MIDCARB portal by entering the connection information for their own remote server (A). The MIDCARB server queries the local server for all available map services and allows the local administrator to select the local map services to connect to the MIDCARB server (B).

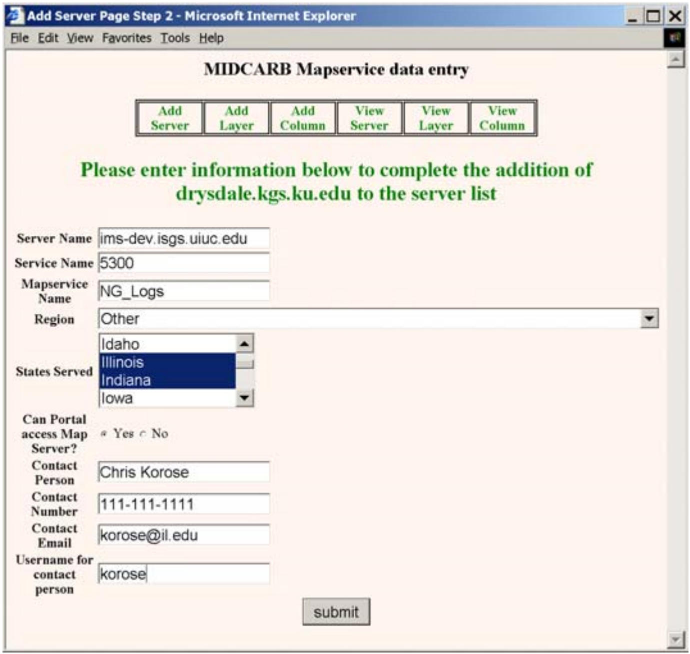


Figure 8. — Page to collect minimal contact information for the remote server that is linked to the MIDCARB portal.

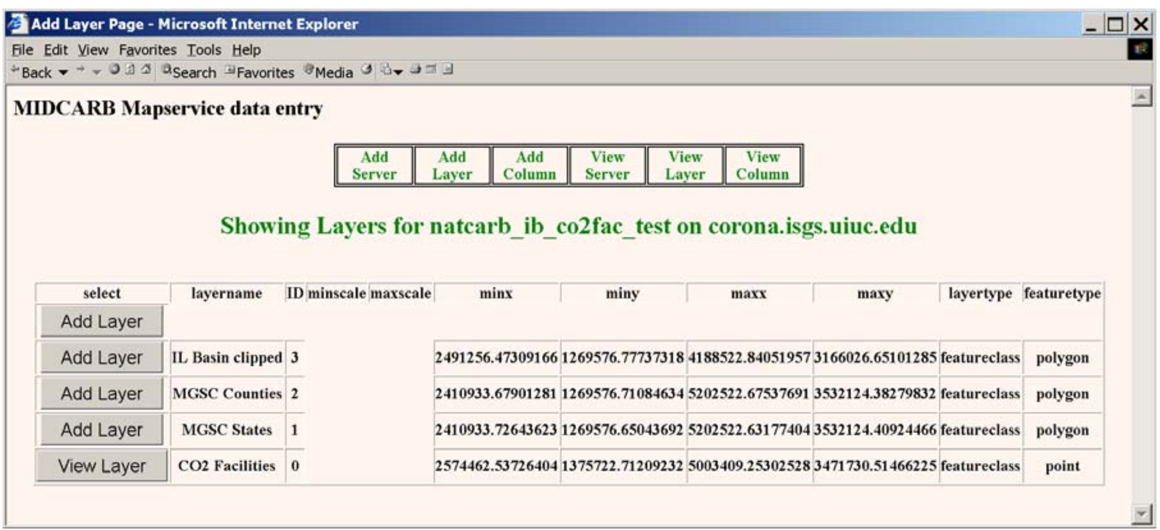


Figure 9. — Page to select layers to add, view and modify from remote server.

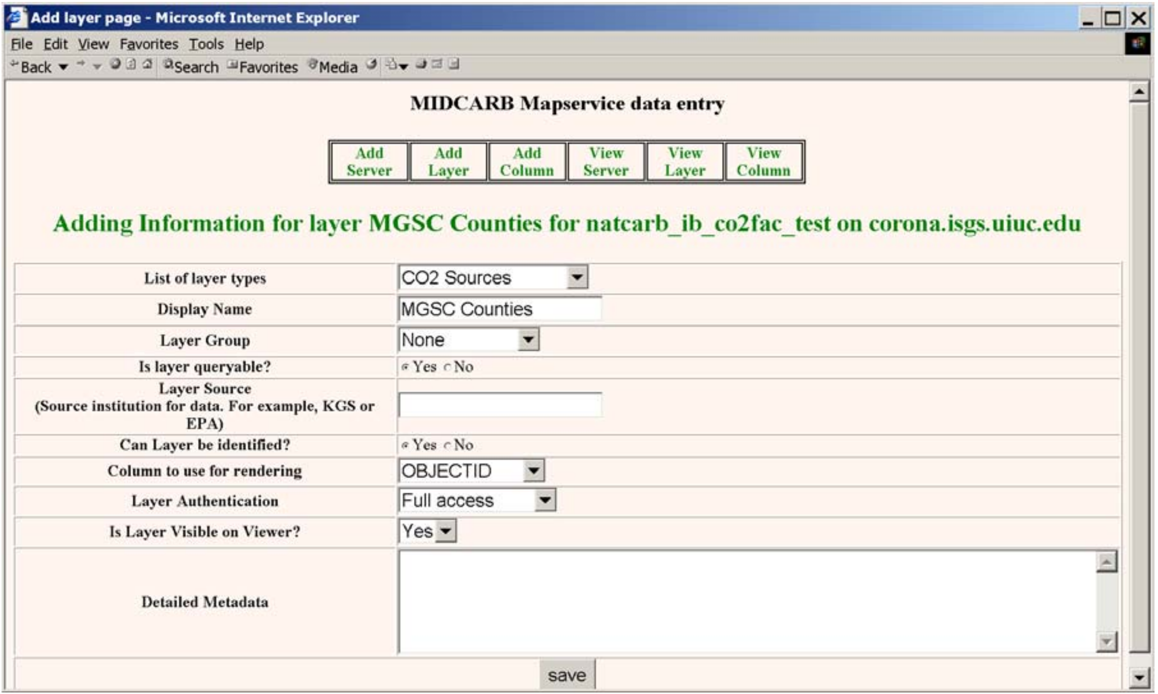


Figure 10. — Page to collect detailed metadata and display information for layer from remote server that is to linked to the MIDCARB site.

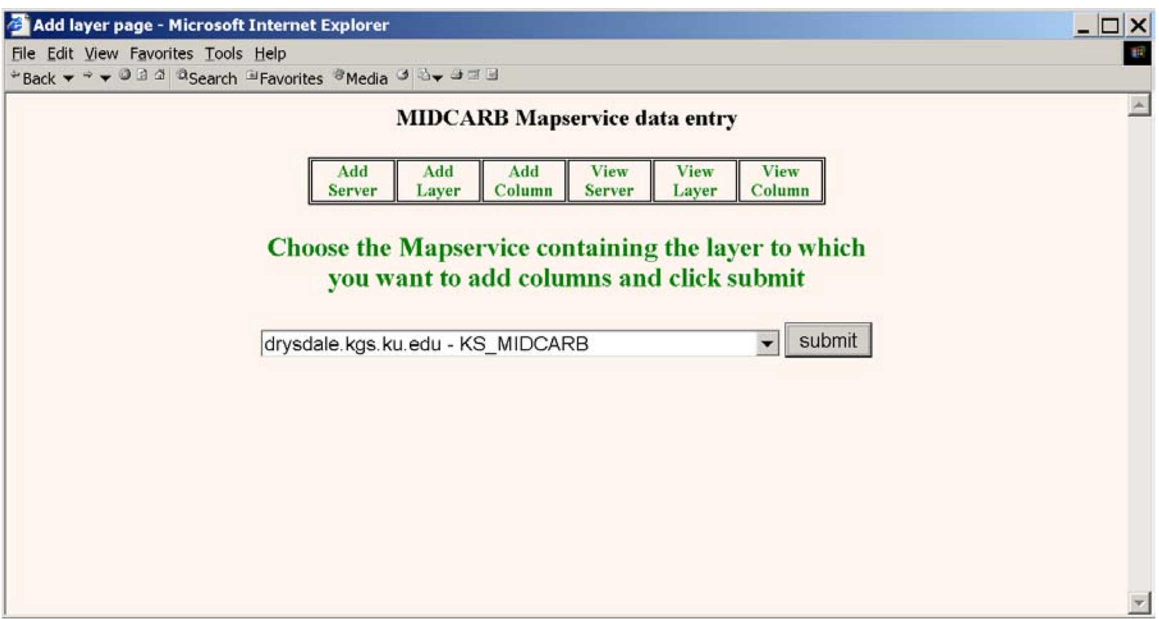


Figure 11. — Page to select layer to add or modify columns for a layer on a remote server that is to linked to the MIDCARB site.

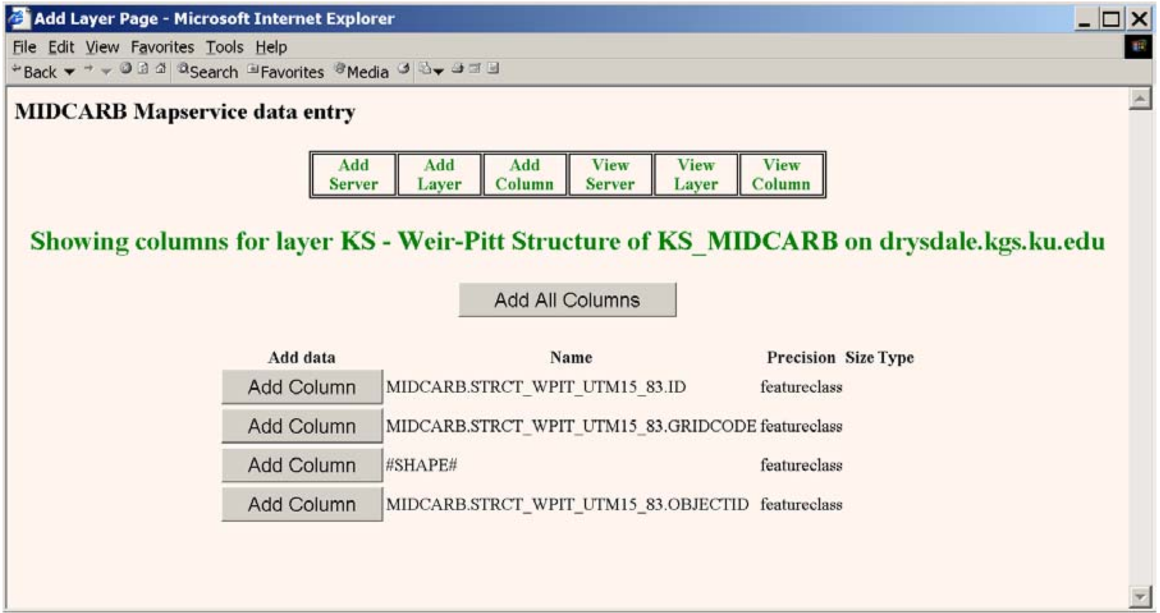


Figure 12. — Page to select columns from a designated layer from remote server to add, view and modify.

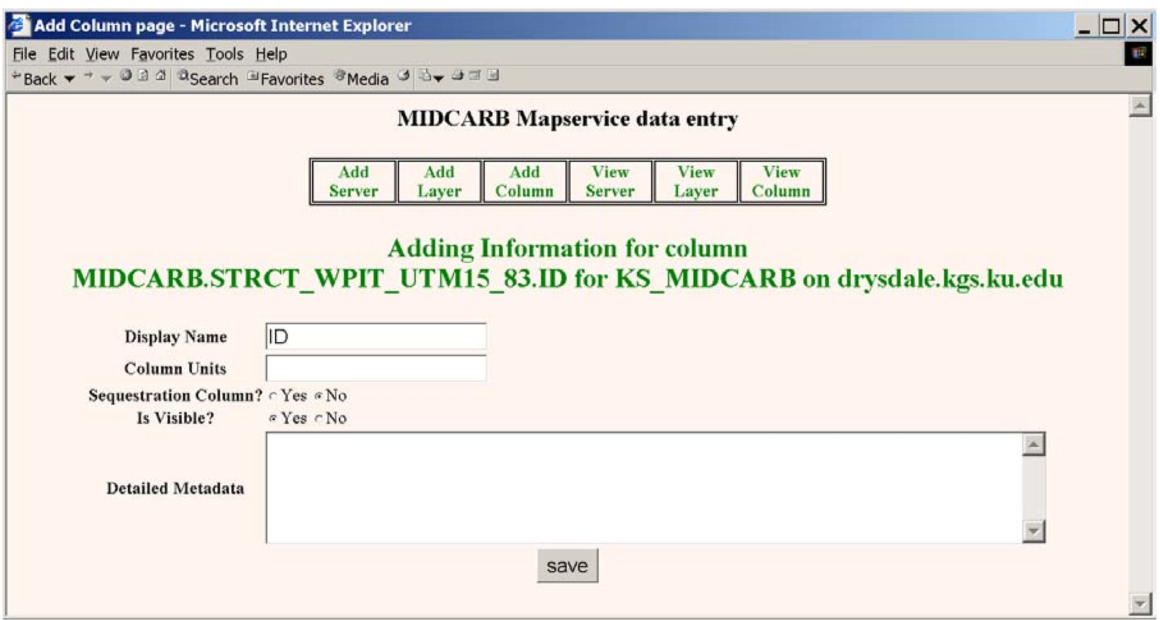


Figure 13. — Page to collect detailed metadata and display information for column on a layer from remote server that is to linked to the MIDCARB site.

Appendix B

Layer lists showing the map coverages available through the new MIDCARB browser by subject. Similar individual map coverages have been grouped. Each layer can be selected. Clicking on the ***i*** symbol provides access to layer metadata.

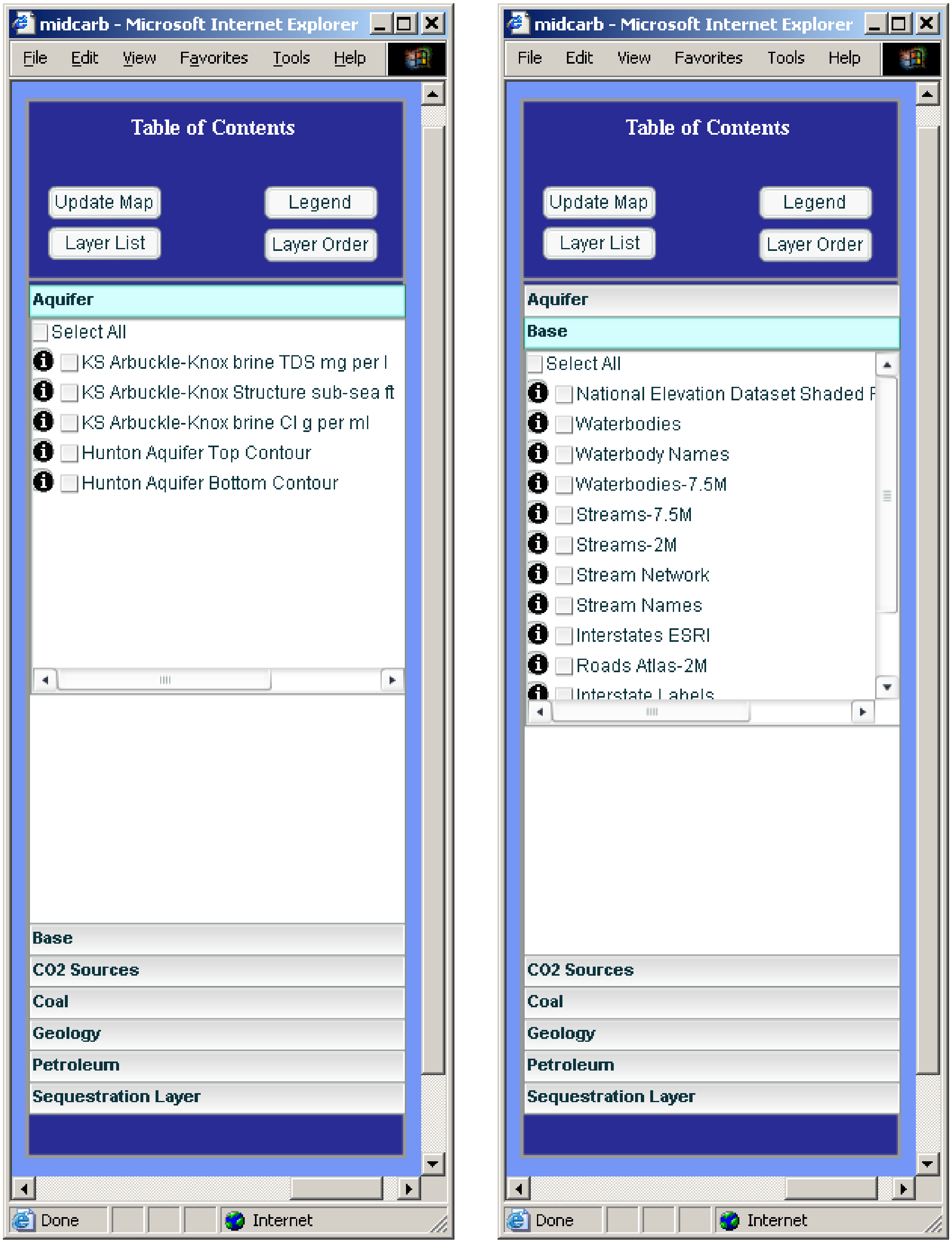


Figure 14. — Layer lists for ***Aquifer*** (5) and ***Base*** (13) showing coverages that can be selected from the different servers in the states and outside the MIDCARB group (e.g., USGS Surface Geology).

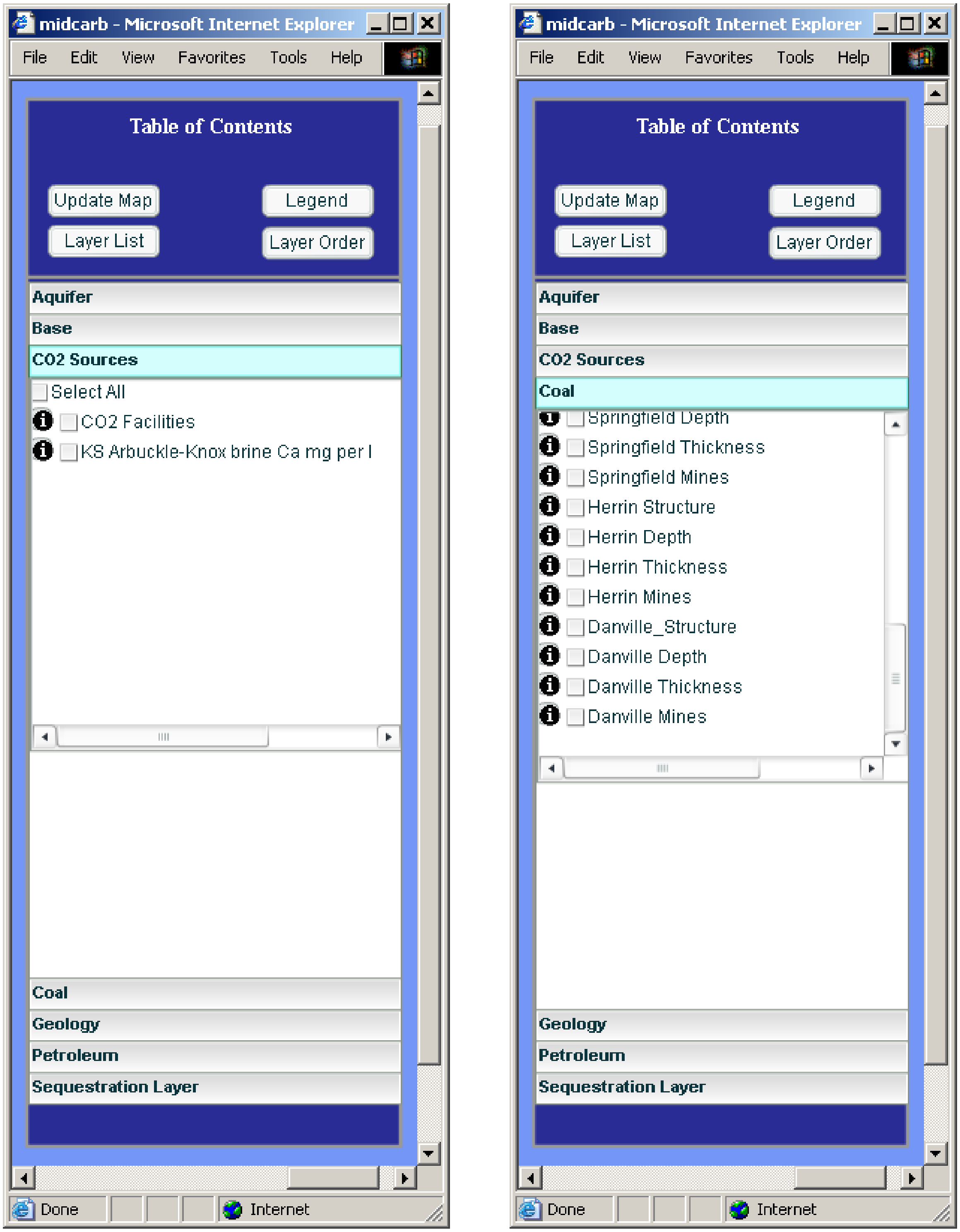
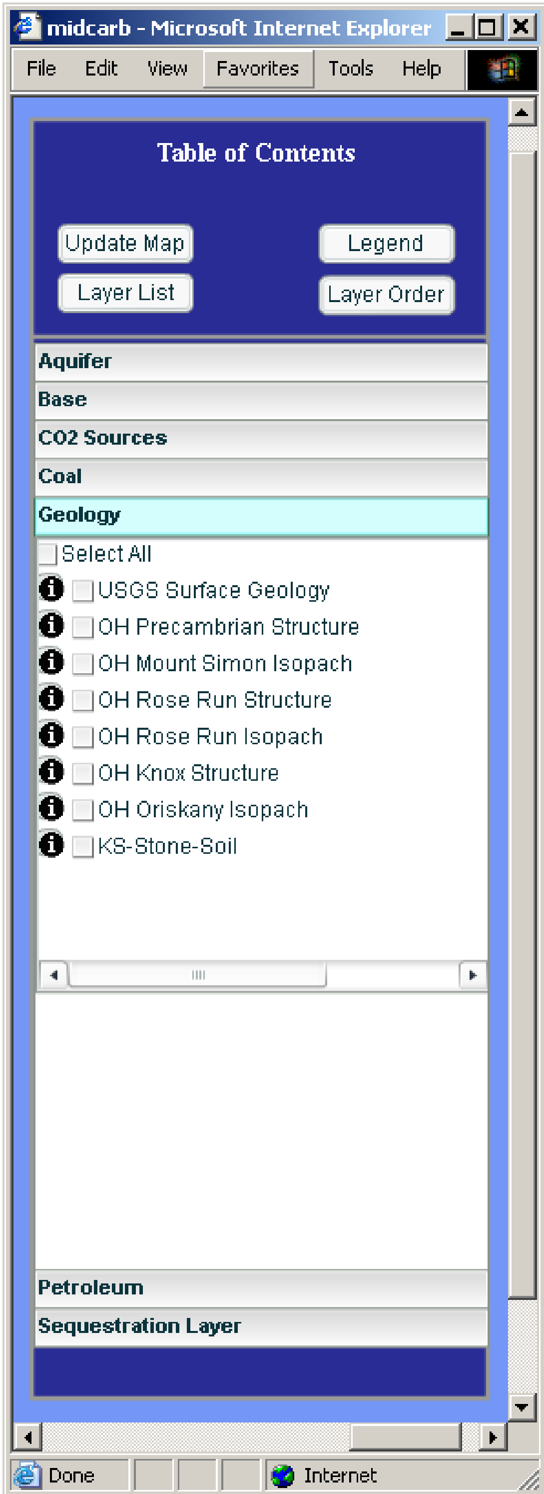


Figure 15. — Layer lists for ***CO2 Sources*** (2) and ***Coal*** (31) showing coverages that can be selected from the different servers in the states and outside the MIDCARB group (e.g., USGS Surface Geology).



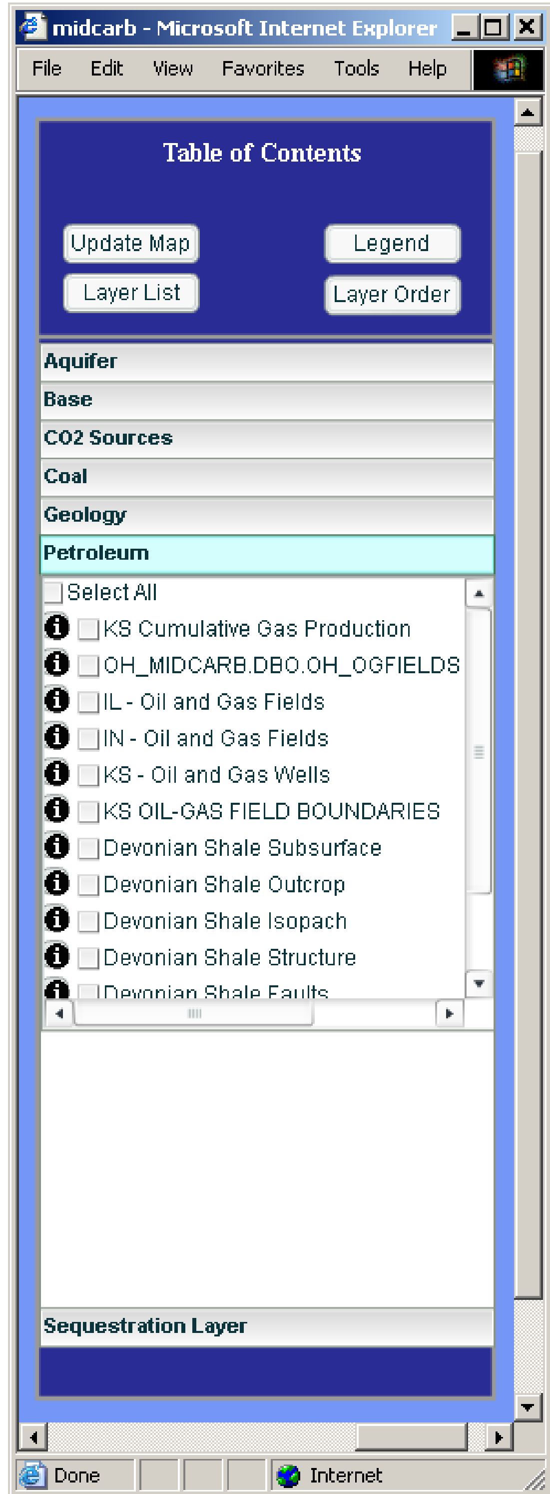


Figure 16. — Layer lists for ***Geology*** (8) and ***Petroleum*** (13) showing coverages that can be selected from the different servers in the states and outside the MIDCARB group (e.g., USGS Surface Geology).

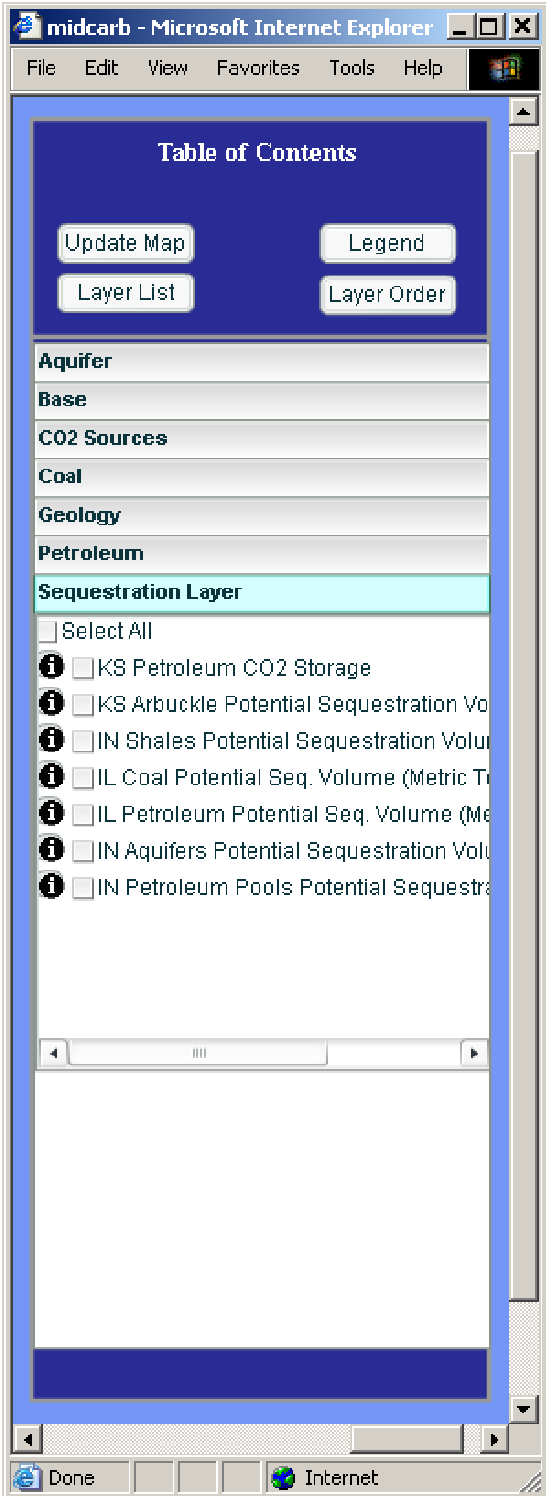


Figure 17. — Layer list for ***Sequestration*** showing coverages (7) for volumes of CO_2 for selected potential geologic sequestration sites (e.g., petroleum reservoirs, saline aquifers and deep coals).

Appendix C
Tour of MIDCARB PORTAL

The MIDCARB Portal Beta Flash site is available at: http://drysdale.kgs.ku.edu/midcarb/flash/midcarb_content.html. You will need the latest version of the FLASH add-in for it to properly function. Newer browsers have this add-in. For older browsers go to Macromedia and download the free FLASH Player add-in (http://www.macromedia.com).

The site is subject to continuous program modification, which periodically may restrict availability. If you want to show this site to someone and want to make sure it is available, contact Tim Carr (tcarr@kgs.ku.edu) or Jeremy Bartley (jbartley@kgs.ku.edu).

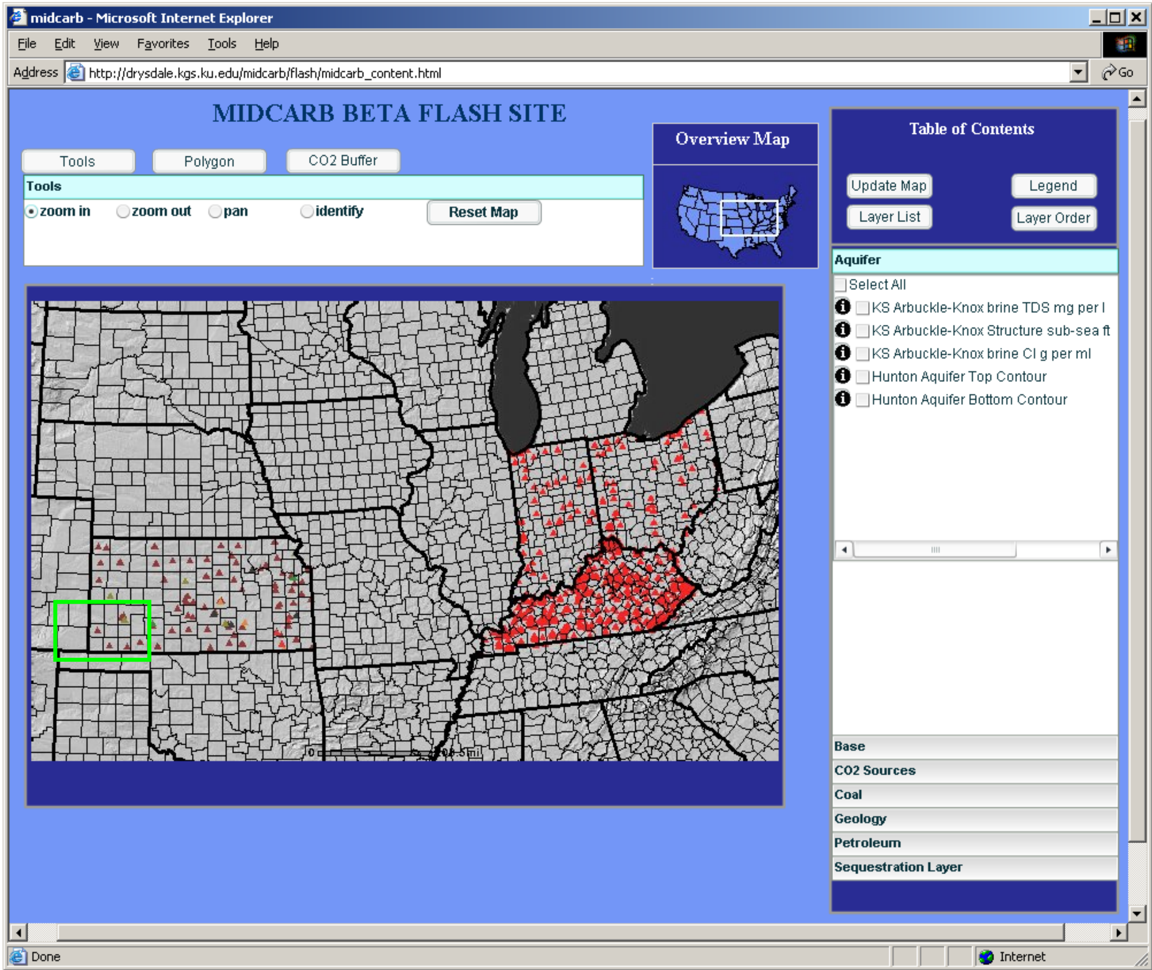


Figure 18.—MIDCARB Portal Flash site showing CO_2 emission sources in Indiana, Kentucky, Ohio and Kansas, county outlines and national digital elevation data (http://drysdale.kgs.ku.edu/midcarb/flash/midcarb_content.html). All data is acquired in real-time from remote servers. For example, the Kansas CO_2 source data is from the Kansas IMS server, the Ohio CO_2 source data is from the Ohio IMS server housed at the Ohio Geological Survey, and the national digital elevation data is from the U. S. Geological Survey, EROS Data Center (http://edc.usgs.gov/). The absence of Illinois CO_2 Sources is because the Illinois server is offline. However, the system functions The tools are radial buttons that can be used to modify the geographic extent of the view (*zoom in*, *zoom out* and *pan*), and to identify map objects (*identify*). The **green box** shows the zoomed in view for Figure 19. The ***Layer List*** contains the list of map services that have been linked to the MIDCARB Portal using the management tools (Appendix A). Services can be turned on by clicking the appropriate boxes. The ***Layer List*** is dynamic and map services can be arranged by *type* or *state/region*. Clicking on the category heading (e.g., Petroleum) displays the available services of a particular type or in a particular region.

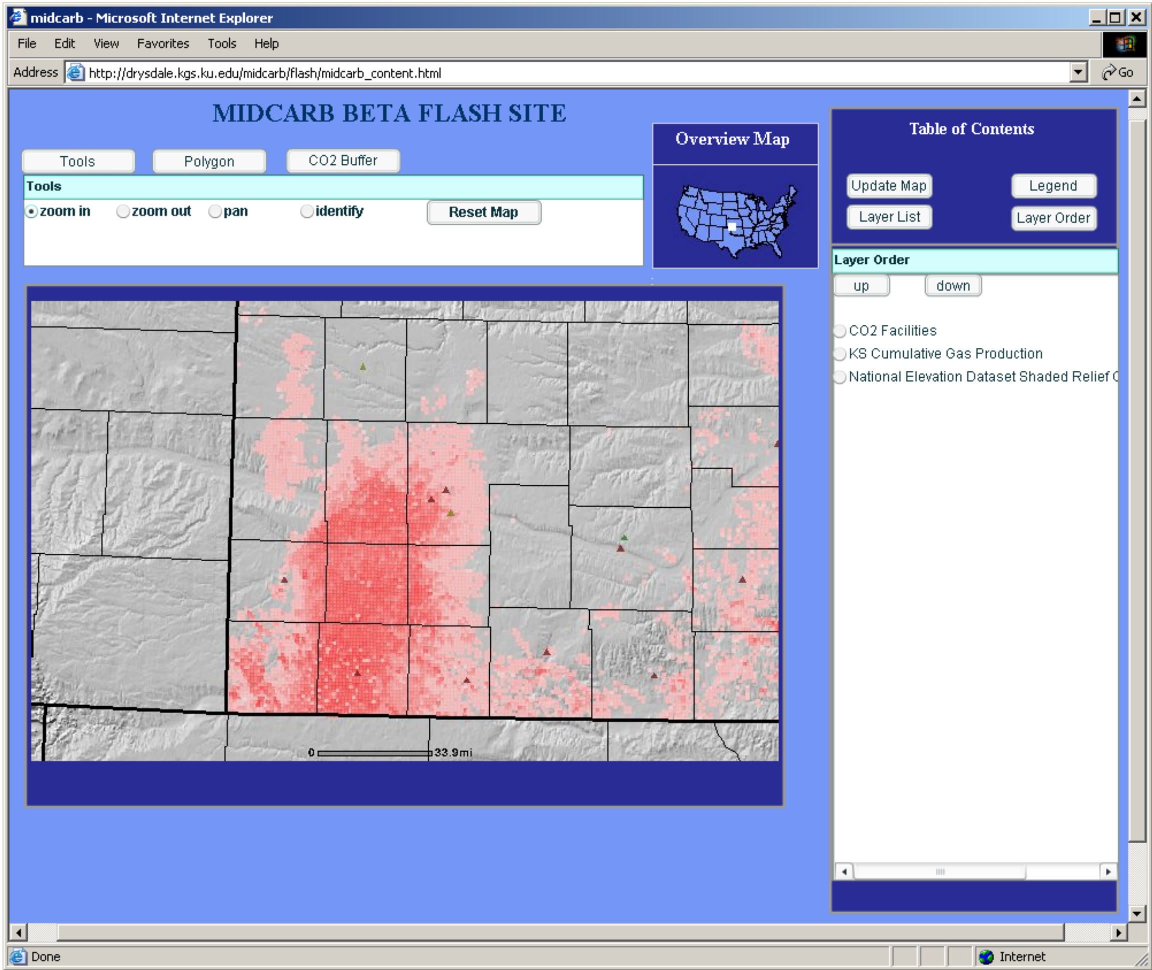


Figure 19.—Zoomed in view of eastern Colorado and western Kansas showing Kansas CO_2 sources and cumulative gas production per square mile in Kansas. Layer types selected from the ***Layer List*** panel (See previous figure) and shown with ***Update Map*** button. Overlay is of county outlines and digital elevation data. The order of the layers is controlled by using the up and down controls on the ***Layer Order*** panel. Digital elevation data is obtained on demand from the U. S. Geological Survey, EROS Data Center (http://edc.usgs.gov/).

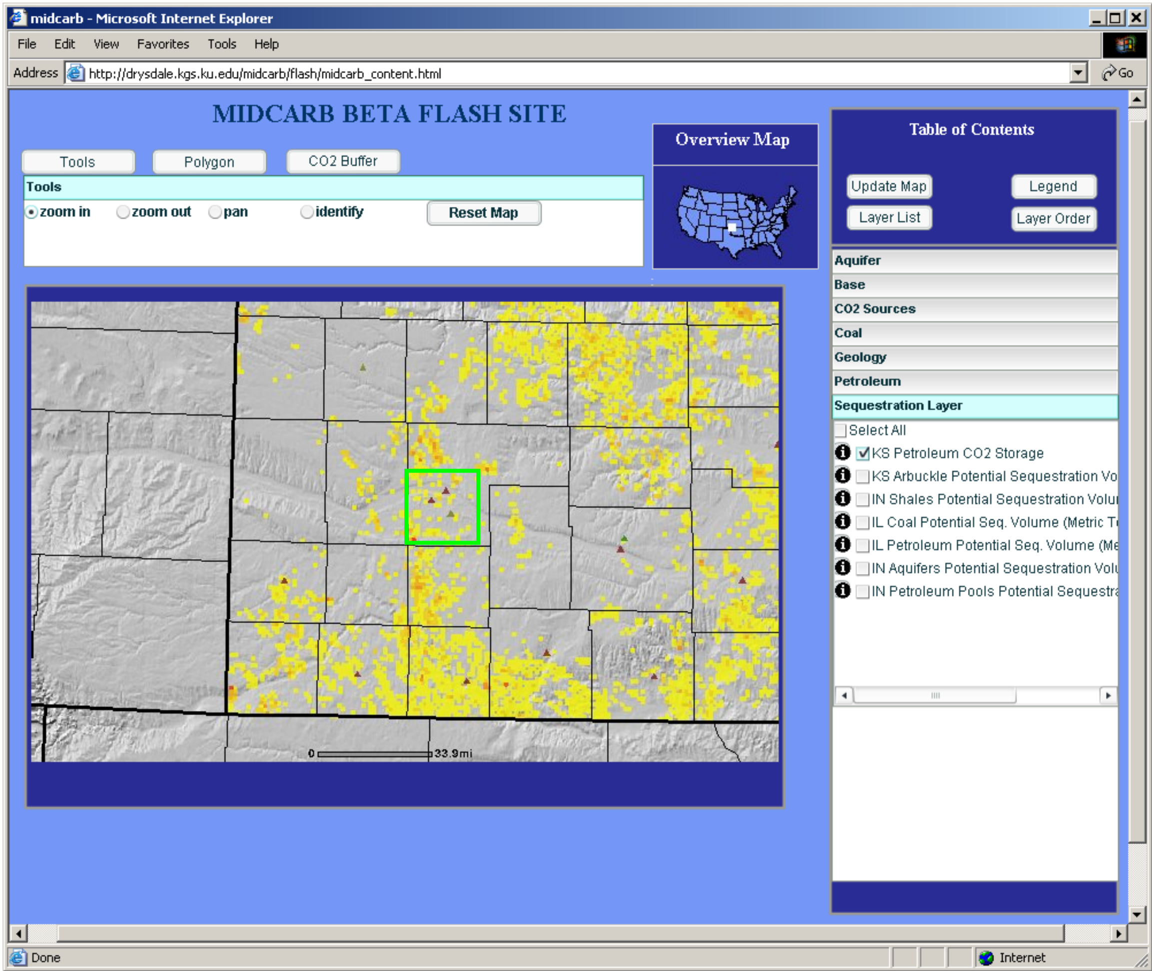


Figure 20.—Identical view of eastern Colorado and western Kansas as Figure 2, except that the computed CO_2 sequestration potential of *Kansas Petroleum Fields* from the *Sequestration Layer* type has been substituted. The **green box** shows the zoomed in view for Figure 22.

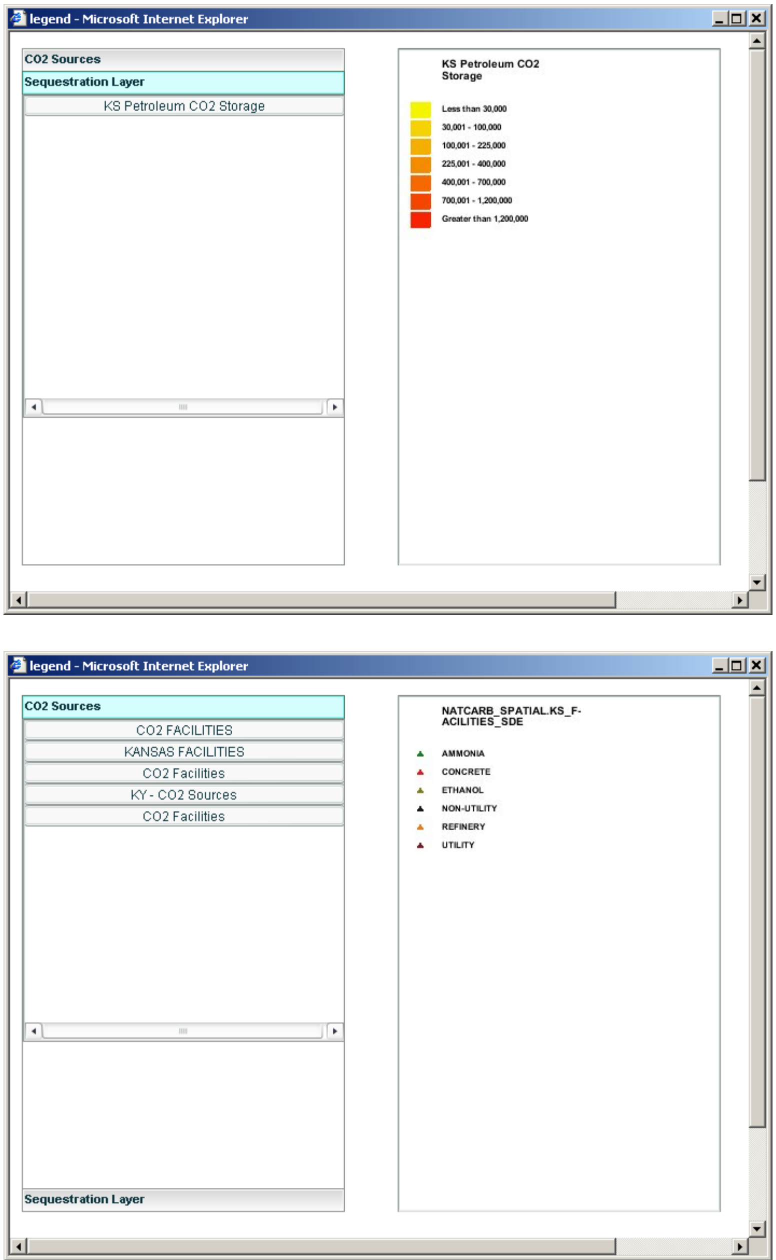


Figure 21.—*Legend Window* showing legends for **(A)** estimated quantity of CO_2 that could be sequestered in Kansas Oil fields (metric tons), and **(B)** Kansas CO_2 facilities by type. Legend window is generated dynamically from user-selected layers that are being displayed and the layer information provided through the management tools.

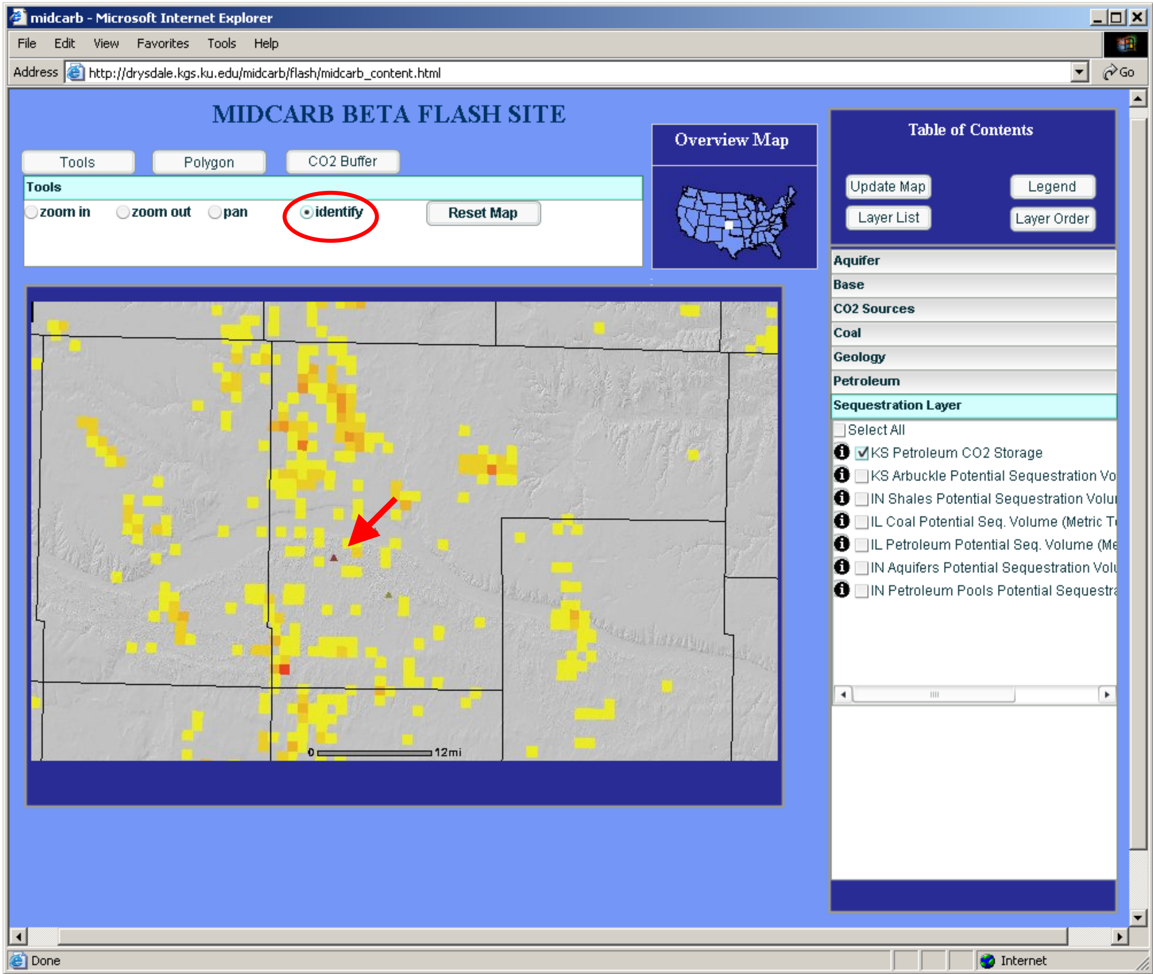
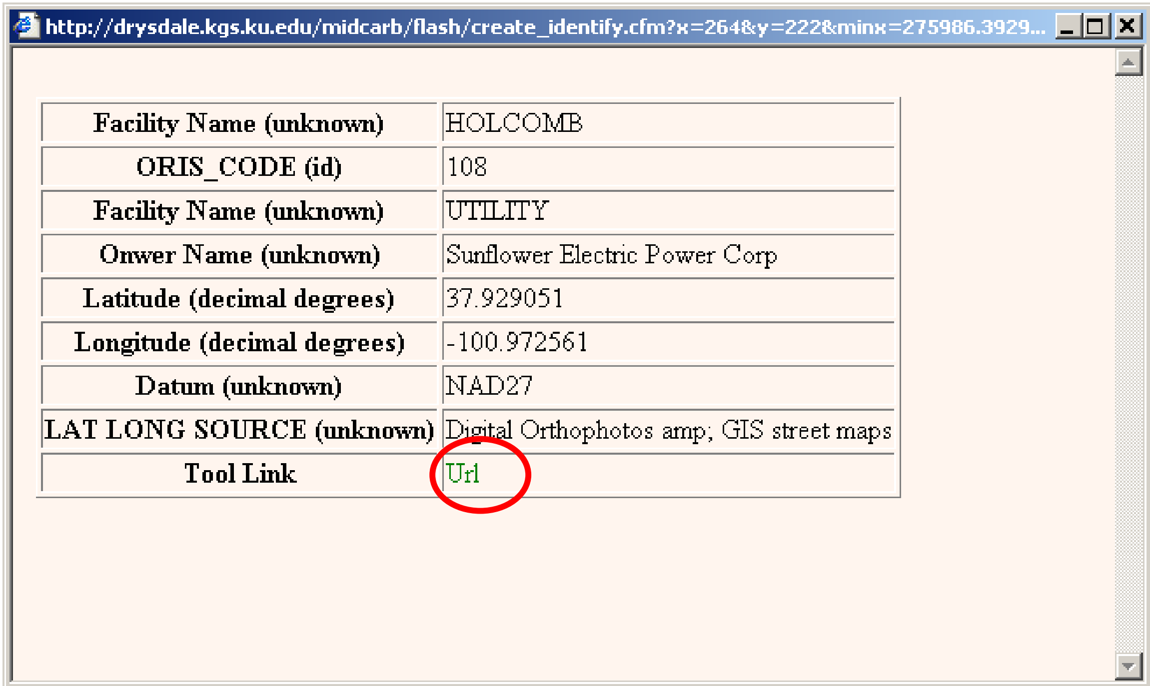


Figure 22.—Zoomed in view of part of Haskell County, Kansas showing computed storage potential of *Kansas Petroleum Fields*, and *Kansas CO_2 sources*. Overlay is of county outlines and digital elevation data. Digital elevation data is obtained on demand from the U. S. Geological Survey, EROS Data Center (http://edc.usgs.gov/). The Arkansas River valley is clearly shown. The *Identify* tool (**Red Ellipse**) is activated and clicking on the CO_2 source (**Red Arrow**) generates an eXtensible Markup Language (XML) request that is submitted to the Kansas server. The MIDCARB Portal uses the IMS to produce the XML representation of the local database, which is returned to the user (Figure 23). In this example, IMS requests the CO_2 emissions data for a single source from the database.



Facility Name (unknown)	HOLCOMB
ORIS_CODE (id)	108
Facility Name (unknown)	UTILITY
Onwer Name (unknown)	Sunflower Electric Power Corp
Latitude (decimal degrees)	37.929051
Longitude (decimal degrees)	-100.972561
Datum (unknown)	NAD27
LAT LONG SOURCE (unknown)	Digital Orthophotos amp; GIS street maps
Tool Link	Url

ArcIMS Request of CO2 information
This is what I submit to ArcIMS to have ArcIMS generate an xml file that has all of the emissions from a particular powerplant.


```
<ARCXML version="1.1">
    <REQUEST>
      <GET_FEATURES attributes ="true" beginrecord="0" outputmode="newxml" geometry="false" envelope="false" compact="false">
            <LAYER id="2" />
              <QUERY searchorder="attributefirst"
                            subfields="MIDCARB.FACILITIES_EMISSIONS.YEAR MIDCARB.FACILITIES_EMISSIONS.QUARTER
                                       MIDCARB.FACILITIES_EMISSIONS.CO2_TONS MIDCARB.FACILITIES_EMISSIONS.CO2_CONCENTRATION
                                       MIDCARB.FACILITIES_EMISSIONS.SO2_TONS MIDCARB.FACILITIES_EMISSIONS.NOX_TONS
                                       MIDCARB.FACILITIES_EMISSIONS.MERCURY_LBS"
                            where="MIDCARB.KS_FACILITIES_SDELAYER.FACILITY_ID = MIDCARB.FACILITIES_EMISSIONS.FACILITY_ID
                                   and MIDCARB.KS_FACILITIES_SDELAYER.FACILITY_ID = 1329"
                                    jointables="MIDCARB.FACILITIES_EMISSIONS">
         </QUERY>
      </GET_FEATURES>
    </REQUEST>
  </ARCXML>
```


Figure 23.—View of information returned to user. The names are column headings and table designations from the database. Clicking on the URL (**Red Ellipse**) will pass emission data from this site to the Java based graphing tool web service as an XML document (Figure 24). The ArcXML use to generate the emissions from a CO_2 source is shown below the image (The XML is not visible to the user).

ArcIMS Response


```xml
<?xml version="1.0" encoding="Cp1252"?>
<ARCXML version="1.1">
<RESPONSE>
<FEATURES>
<FEATURE>
<FIELDS>
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.YEAR" value="1997" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.QUARTER" value="4" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.CO2_TONS" value="43281.8" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.CO2_CONCENTRATION" value="0.119" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.SO2_TONS" value="186.5" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.NOX_TONS" value="0.57" />
<FIELD name="MIDCARB.FACILITIES_EMISSIONS.MERCURY_LBS" value="" />
</FIELDS>
```

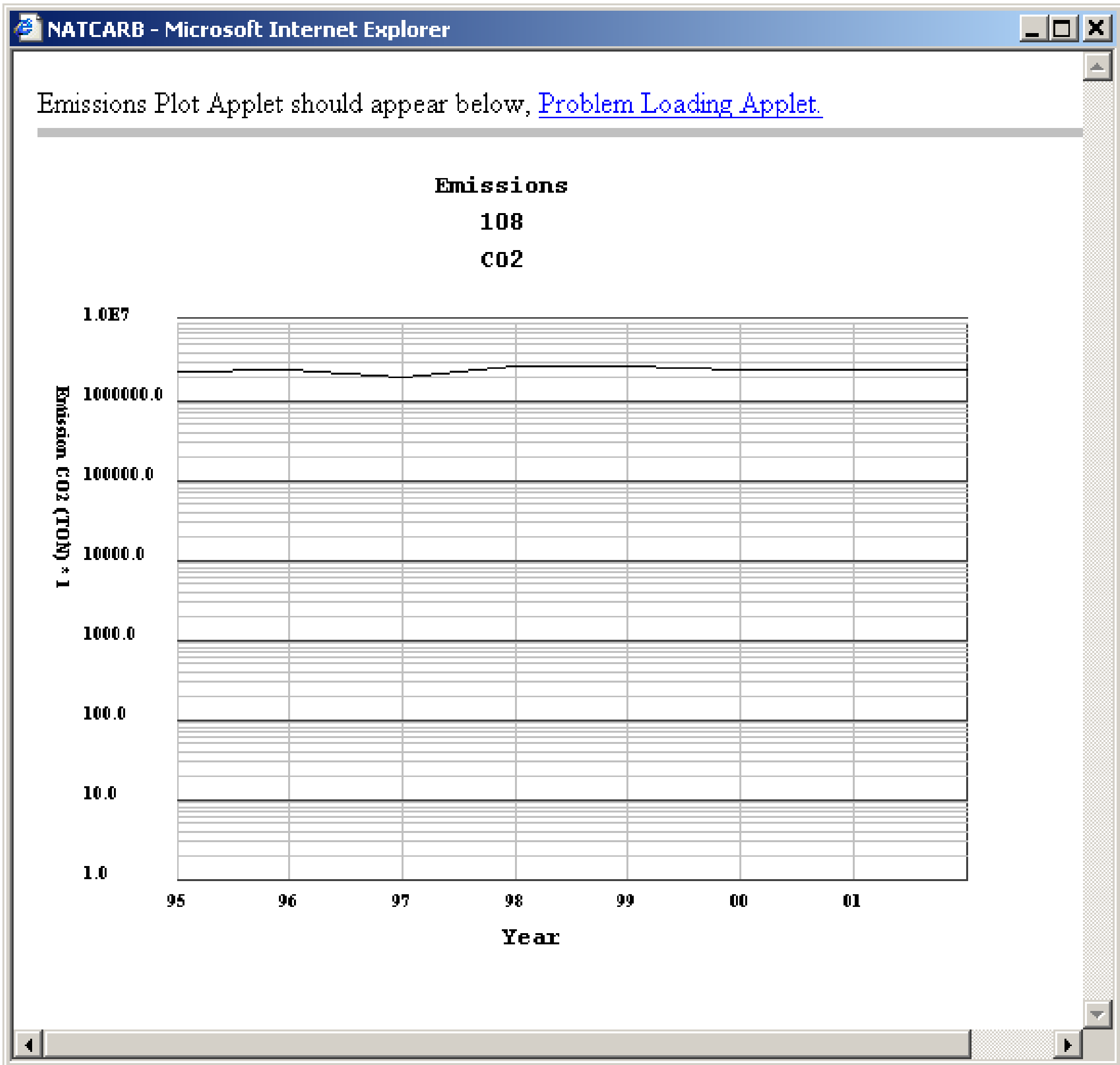



Figure 24.— The Java based graphing web service uses the data from the selected CO_2 source(s) as an XML document. The Emission Plot contains a control panel (Figure 25) that can be used to modify the plot. A modification of this plot is shown in Figure 26. The request returns every record for every emission that matches CO_2 source(s) ID. This is passed to the Java based graphing web service for plotting. In addition to the plot, a partial extract for data for a single CO_2 source for a single year is shown (Not visible to online user).

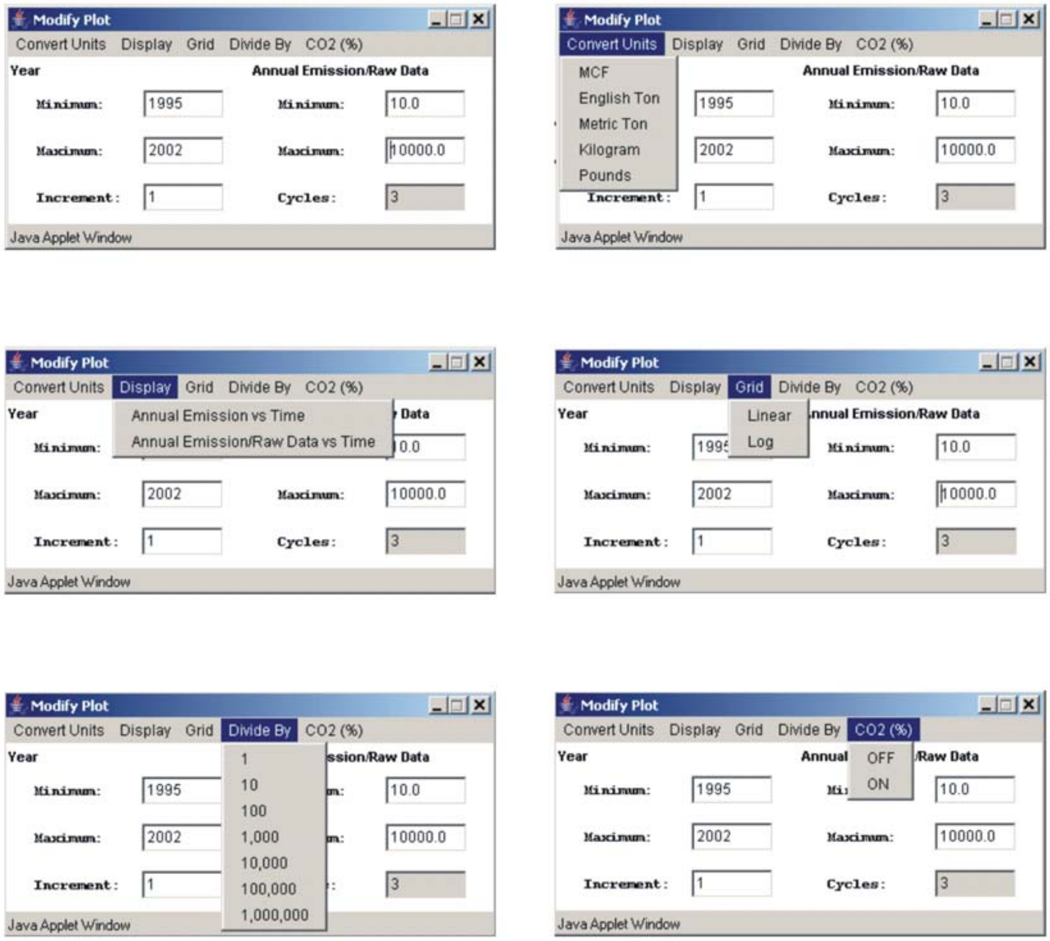


Figure 25.— Examples of the control panel for the Java based graphing web service allows the user to do the following,

A. Select units (MCF, English tons, metric ton, etc.).

B. Select annual emission vs. year plot or annual emission and raw emission data (monthly, quarterly or annual) vs. year plot (default: annual emission vs. year).

C. Select either linear or log grid (default: log grid).

D. Determine the range interval on the emission axis and year axis

E. Divide the data by a factor to remove the scientific notation (default: divide by 1).

F. Either sum the data for all the CO_2 source(s) or plot each CO_2 source by itself (default: sum all facilities).

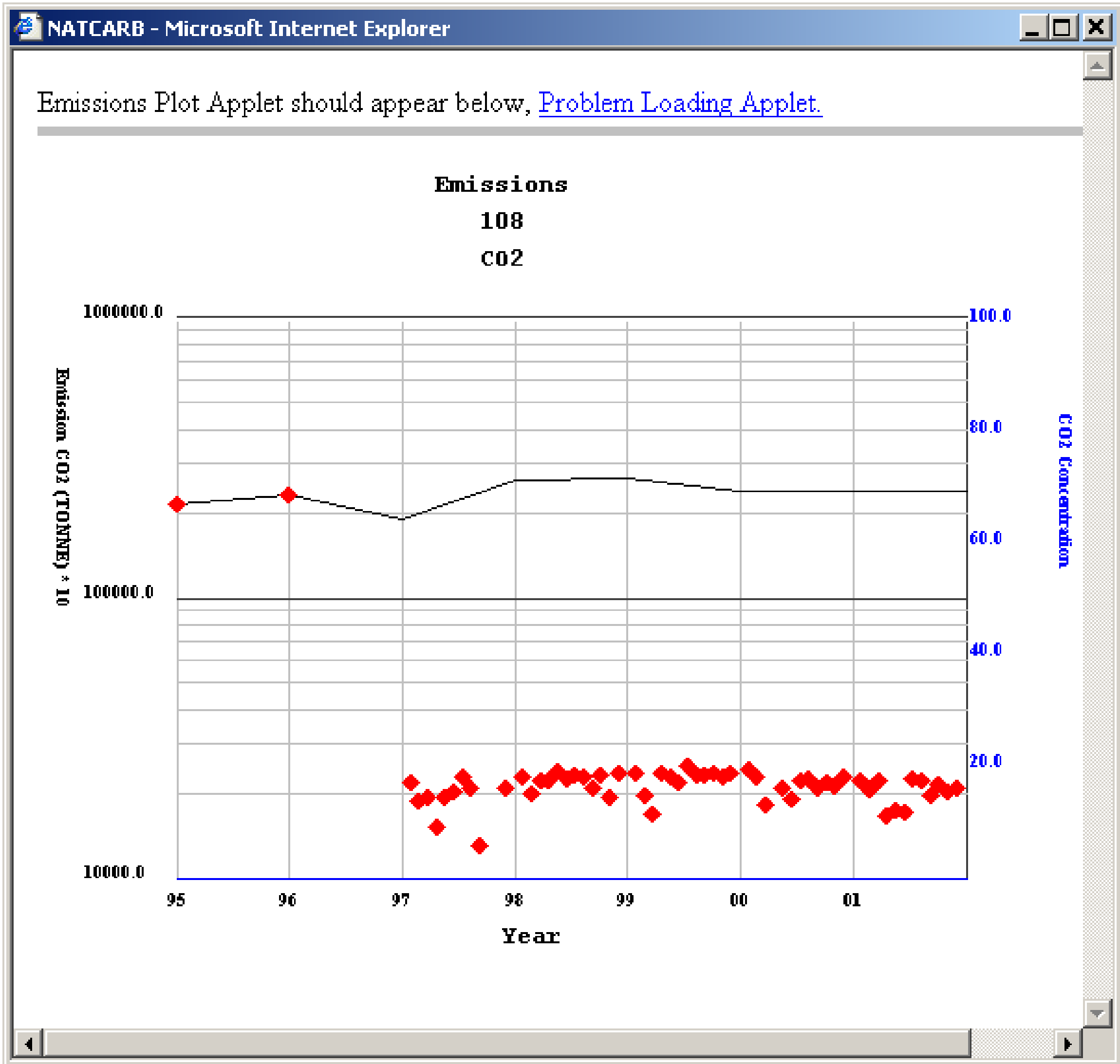
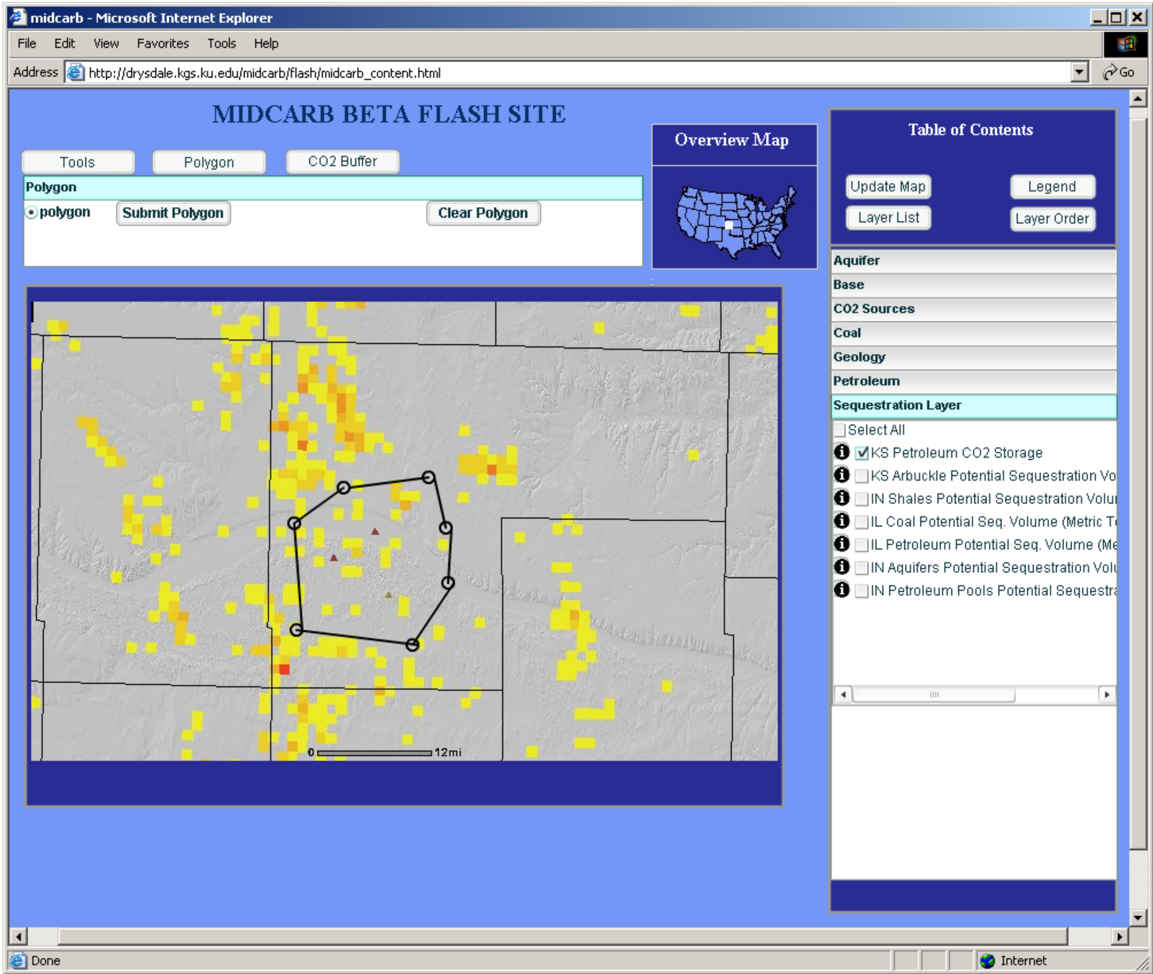
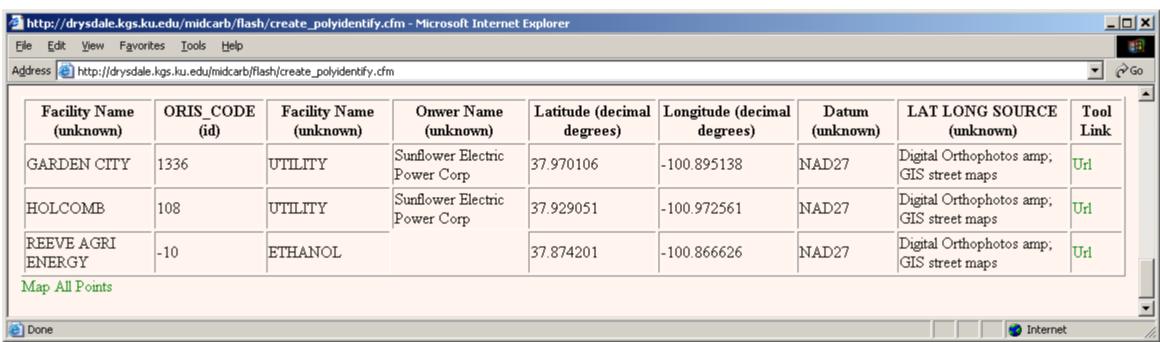


Figure 26.— Example of modified graph of emission plot from CO_2 source shown in Figure 24. Emission scale was set to metric tonnes and divided by 10 (Tons * 10), and minimum set at 100,000 tonnes. The annual scale was set to 1995 to 2002 and plotted at one-year intervals. Annual emission and raw emission data (monthly, or annual) are plotted vs. year.





Facility Name (unknown)	ORIS_CODE (id)	Facility Name (unknown)	Onwer Name (unknown)	Latitude (decimal degrees)	Longitude (decimal degrees)	Datum (unknown)	LAT LONG SOURCE (unknown)	Tool Link
GARDEN CITY	1336	UTILITY	Sunflower Electric Power Corp	37.970106	-100.895138	NAD27	Digital Orthophotos amp; GIS street maps	Url
HOLCOMB	108	UTILITY	Sunflower Electric Power Corp	37.929051	-100.972561	NAD27	Digital Orthophotos amp; GIS street maps	Url
REEVE AGRI ENERGY	-10	ETHANOL		37.874201	-100.866626	NAD27	Digital Orthophotos amp; GIS street maps	Url

Figure 27.— Use of the polygon tool to return information on multiple CO_2 sources. Each source can be plotted as in figures 24-26.

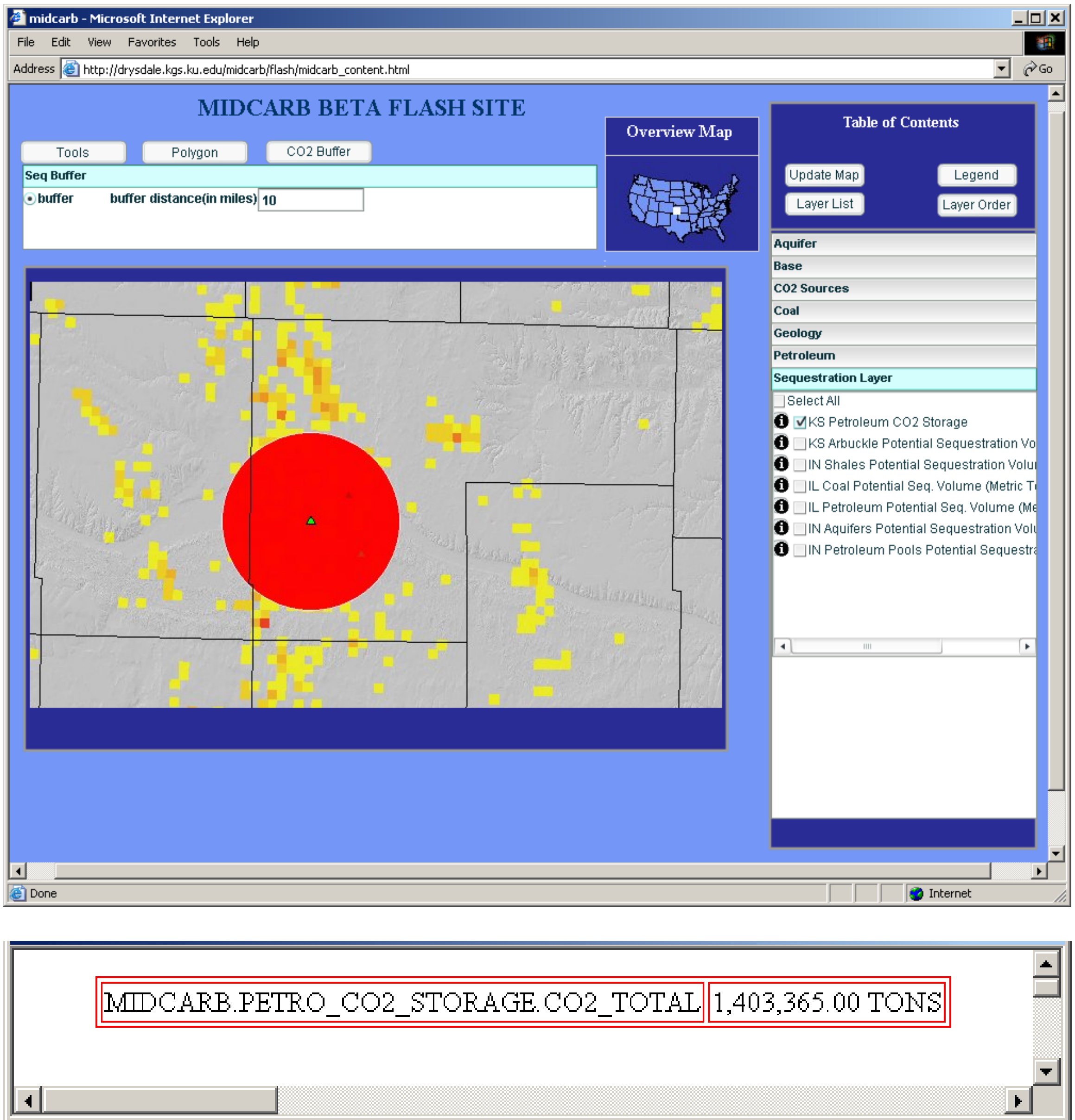


Figure 28.— Use of the CO_2 buffer tool to return information on the estimated amount of CO_2 in metric tonnes that could be sequestered in petroleum reservoirs within a designated distance (10 miles).