Preliminary Screening of Geologic Potential for CO_2 Sequestration in Illinois

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By

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Abstract

The geologic storage of carbon dioxide (CO_2) is an important tool for the implementation of the *FutureGen* project. This is a preliminary screening of geologic potential for CO_2 sequestration in Illinois. Three subsurface options for sequestration are analyzed: coalbeds, oilfields, and a deep saline formation. A series of maps were created using a GIS.

Introduction

The federal government, through the U.S. Department of Energy (DOE), has announced plans for a demonstration of a near-zero emissions coal-fired electric generating plant based on the principles of coal gasification. This project, termed *FutureGen,* would demonstrate the capability to generate electricity without producing the volumes of sulfur dioxide (SO_2), nitrogen oxides (NOx), particulates, and other emissions that must be controlled at a conventional pulverized coal (PC) generating plant. Further, FutureGen will be designed from its initiation to incorporate geological carbon sequestration to avoid emissions of carbon dioxide (CO_2) that may have a major role in global climate change. The cost of developing *FutureGen* is estimated at $1 billion, with $800 million coming from federal funds and $200 million coming from private industry sources. Only one facility is envisioned to be built, with a capacity of about 275 megawatts (Mw) of generating capacity.

The competition for this facility is expected to be intense. While it is expected that multiple coals will be tested at FutureGen, coals in close proximity to the plant will likely be used most extensively. Illinois coal is mostly moderate to high in sulfur and PC plants using Illinois coals require scrubbers to remove SO_2 and meet clean air requirements. Coal gasification technology separates sulfur from the feedstock fuel prior to combustion therefore SO2 emissions are not generated by the plant. This could allow Illinois coals, with their high Btu content, to be utilized without air emissions concerns. Further, because the combustion products from coal gasification are primarily CO2 and water vapor, costly separation and concentration of dilute CO2 from flue gas streams of conventional PC plants will not be required, substantially reducing the cost of carbon sequestration.

Given the central role that carbon sequestration is expected to play in development of *FutureGen*, the Illinois Department of Commerce and Economic Opportunity (DCEO) and its Office of Coal Development (OCD) undertook a basic survey of the geological carbon sequestration opportunities in the Illinois Basin. The study involved compiling data using a Geographic Information System (GIS) that allowed visualization of the geological targets for carbon sequestration. GIS provides a means of comparing numerous parameters in map view by overlaying a series of data layers derived from existing databases. This report presents the results of a study done by the Illinois Sate Geological Survey (ISGS) to define possible locations for FutureGen based on the proximity and character of subsurface geological strata potentially suitable for carbon sequestration. The work was accomplished by screening a large area of central and southern Illinois, initially defined at 37 counties in extent, and determining a final area of 30 counties that may be most suitable. This project was based almost entirely on existing data therefore results must be considered a guideline for further detailed studies necessary to verify project conclusions. Some of those studies are now underway as part of a Regional Carbon Sequestration Partnership recently awarded to the ISGS by DOE.

Sequestration Background

While the potential for man-induced climate change continues to be assessed, the carbon dioxide concentration in the atmosphere is rising as a consequence of the combustion of fossil fuels. If CO_2 emissions are a driving force in climate change, which many researchers believe, then stabilization and ultimately reduction of rising CO_2 concentrations may be required. The Bush Administration has advocated continued research on both the potential for climate change and the possible responses while not adopting the Kyoto Protocol because of the significant economic impacts it would involve. The Department of Energy, Office of Fossil Energy, has been evaluating these possible responses, one of which would be to isolate carbon dioxide from the atmosphere. To achieve this goal, CO_2 would be captured from the atmosphere or directly from combustion processes for storage and isolation, a process that has been termed "sequestration". Sequestration options include increasing soil carbon and biomass, injection of captured CO_2 into the oceans, or geologic isolation in the subsurface, among others.

Geologic sequestration of carbon dioxide, through containment of CO_2 from man's activities, offers the largest land-based, verifiable potential to isolate CO_2 from the biosphere. In the Midwestern U.S. alone, the potential sequestration capacity of just one subsurface rock formation, the Mt. Simon Sandstone, has been estimated at 44 to 218 billion tons of carbon. Geologic sequestration includes three options: isolation in mature or depleted oil and natural gas reservoirs, adsorption within coal seams that are too deep to economically mine in the foreseeable future, and storage in deep, saline formations. The most important part of the process is the separation and capture from the power plant flue gas stream. This is usually a chemical separation process. The resulting CO_2 is then compressed and transported to injection wells. The proximity of a suitable bedrock or coal formation to a power plant site is important because the cost of the entire process increases greatly as the distance of transportation increases.

All three geological options involve injection of CO_2 through wells into the receiving rock or coal layer. The CO_2 is in a supercritical state under pressure, essentially a liquid. In the case of mature oil fields, CO_2 flooding may help produce additional oil prior to final abandonment of the reservoir. Coal seams may adsorb CO_2 and release methane (CH_4) as a recoverable product to augment natural gas supplies. Sequestration in deep, saline formations offers no economic product in return, but has the advantage of providing possible sequestration options close to numerous CO_2 emission sources, such as coal-fired power plants. Saline formations also offer the volumetrically largest CO_2-storage potential among the three geologic sequestration options. The Illinois Basin may offer all three of the geologic sequestration possibilities.

Geological Sequestration Targets in the Illinois Basin

Coalbed Sequestration

Coal mining in Illinois has been concentrated around the margins of the basin where the major Springfield and Herrin coal seams can be readily and economically accessed. However, these coals extend across much of the basin where they occur at up to 1,200 feet in depth. Other seams lie even deeper. Most underground coal mining in Illinois has been at depths of 300 feet or less, infrequently to 500 feet. Enormous resources, capable of supporting mining activities at current rates for hundreds of years, lie at depths of 500 to 1,500 feet, but will likely remain uneconomic relative to other coal resources within this time frame. Some of these seams are simply too thin to mine. However, these deep coal beds may contain methane (CH_4) that is producible from wells, and the coal may also be capable of retaining CO_2. The CH_4 content of coal seams in Illinois has recently been shown to be 25 to 100 percent greater than previously thought. The CO_2-retention characteristics of these coals are yet to be studied. If these coals were ultimately mined the CO_2 would again be released, but the mining would proceed more safely because the methane would already have been stripped from the coal.

Depleted Oil Fields

Many mature and depleted oil fields exist in southern and central Illinois. These fields have been developed over decades, and many are in the last phases of their economic life after primary and, in some cases, secondary (waterflood) production. Illinois oil production peaked around 1941 and is now at a level less than 10 percent of that peak. Injection of CO_2 has been used in many oil-producing areas of the U.S. to enhance production, especially in West Texas. A large number of Illinois fields may be too shallow to achieve the pressure necessary for the most efficient additional recovery of oil if CO_2 were to be injected (miscible flooding). However, many Illinois fields would be able to achieve a somewhat less efficient process termed immiscible flooding that would recover oil otherwise left in abandoned fields. This process should be evaluated in Illinois and may allow access to a significant oil resource for the future, depending on the price path and demand for world oil resources. The use of CO_2 to enhance oil production in Illinois is a topic that needs further study to identify those oil fields that would offer both an economic benefit and an ultimate repository for CO_2 once finally abandoned.

Deep Saline Formations

The largest CO_2 sequestration option among the geologic possibilities in Illinois and nationwide is likely to be injection into deep, saline formations. The water in some of these formations, for example in the depth range of 3,000 to 5,000 feet in the Illinois Basin, has two to three times the salinity of sea water and hence is not usable as a potable resource. Injection of CO_2 into these formations, where they would be contained in the same way that natural gas and oil have been contained for millions of years (until sought by man), offers enormous sequestration potential. In fact, with certain innovative combustion technologies now under study, NOx and SOx emissions also might be economically sequestered along with a CO_2-rich flue-gas stream. This approach could offer large economic benefits and reduce air pollution in the future if these combustion technologies prove viable and are combined with sequestration.

One of the major geologic units potentially suitable for CO_2 sequestration is the Mt. Simon Sandstone, a rock unit that underlies much of northern, central and southern Illinois. In northern Illinois, it contains potable water resources. In other areas, such as central Illinois, it is used for seasonal injection, storage, and withdrawal of natural gas to supply Illinois' winter heating needs. The geology of the Mt. Simon makes it an excellent storage unit and the cap-rock seal of the Eau Claire Shale has proven its performance as a seal in containing natural gas. For example, the Manlove gas storage complex in northwest Champaign County can hold 153 billion cubic feet of gas at depths of about 4,000 feet. A central location contains offices, gas treatment facilities, pumps and pipeline connections; however, the gas is stored under about 27,500 leased acres of farmland. Other subsurface rock formations, such as the St. Peter Sandstone, may also be suitable for CO_2 sequestration. One of the key issues in assessing the Mt. Simon will be the availability of data in areas of southern Illinois where it has not been drilled. As part of this project, detailed data based on studies of natural gas storage fields (Morse and Leetaru, 2003) have been compiled and used for the first time to help assess the suitability of the deep Mt. Simon in southern Illinois.

Methodology-Results

Coal

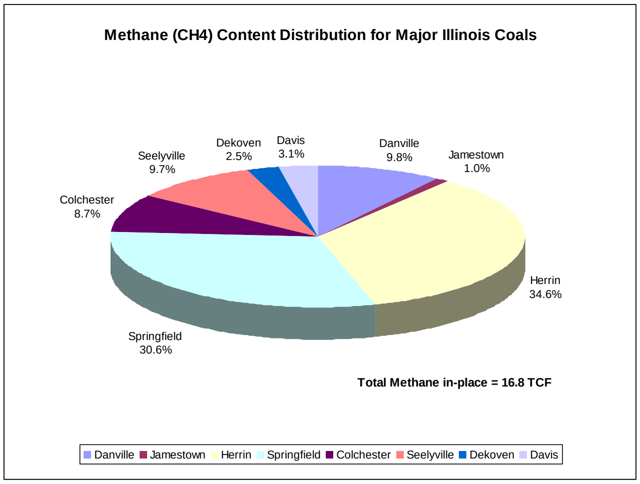
Eight separate coal seams were investigated in this study in order to identify the most suitable areas for CO_2 sequestration. Listed in youngest to oldest order, they are the Danville (#7), Jamestown, Herrin (#6), Springfield (#5), Colchester (#2), Seelyville, De Koven and the Davis. Available GIS coal seam layer data were obtained from previous work by the ISGS Coal Section. Each coal seam was studied using a depth-contour layer, a mined-out layer and a coal thickness layer. The structure contour layer was used to re-classify the coal as to Shallow (<200 ft), Moderate (200 ft ≤ Depth > 900 ft) and Deep (≥ 900 ft). Each coal was then reclassified by thickness: (0”~17”), (18”~ 41”) and (42”~ 66”). Generally, the coal mining industry regards coal that is deeper than 900’ or thinner than 42” as un-mineable coal (therefore probably available for CO_2 sequestration). These classes were applied because they are normally used by industry as economic factors associated with both surface and subsurface mining operations. Below is a graphic display of this dual classification. These reclassified layers were then overlain with each other permitting areas fitting our model to be computed. The classification chart below follows a color scheme used for the mapping, making it easier to locate each class. No coals classed as

Shallow contain any area that would be available for CO_2 injection. The Moderate depth classification contains coals with thicknesses between 18"~41" as possibly available for CO_2 sequestration. Thinner coals at this depth would not be used and coals between 42"~66" would be available for subsurface mining. The Deep seams contain two classes that are available or probably available for CO_2 sequestration.

Classification Chart

Depth	Thickness	Class
Shallow (Depth < 200 ft)	0" ~ 17"	Thin Coal Seam
	18" ~ 41"	Coal Seam Probably Available for Mining Only
	42" ~ 66"	Coal Seam Available for Mining Only
Moderate (200 ft ≤ Depth < 900 ft)	0" ~ 17"	Thin Coal Seam
	18" ~ 41"	Coal Seam Possibly Available for CO2 Sequestration
	42" ~ 66"	Coal Seam Available for Mining Only
Deep (Depth ≥ 900 ft)	0" ~ 17"	Thin Coal Seam
	18" ~ 41"	Coal Seam Available for CO2 Sequestration
	42" ~ 66"	Coal Seam Probably Available for CO2 Sequestration

Empirical data, such as density and average adjusted methane contents were obtained from the ISGS CBM Testing: 2001-2002 drill holes project (Demir, et al 2002). These area figures can then be assigned methane content numbers from the ISGS study to ultimately produce a methane content distribution for each coal seam. These volumes can then be combined to produce a total methane, in-place number for Illinois. Each individual coal seams' total methane content is shown as a percentage of the whole in the graph below and then listed with total methane as a volume and percentage in the table. A further compilation derived from the GIS shows each coal seam's in-place methane content by class (see below).



Methane (CH_4) Content Distribution for Major Illinois Coals

Coal	Total Methane (CH4) in CF	Total Methane (CH4) in %
Danville	1657309411600	9.8%
Jamestown	160405557000	1.0%
Herrin	5833943827000	34.6%
Springfield	5147308664000	30.6%
Colchester	1471588900000	8.7%
Seelyville	1637335301000	9.7%
Dekoven	419928471000	2.5%
Davis	516790225800	3.1%
Total	**16844610357400**	**100.0%**

Methane (CH_4) Distribution for Each Class of Major Illinois Coals (in Million Cubic Feet, MMCF)

Coal	Thin Coal Seam	Coal Seam Probably Available for Mining Only	Coal Seam Available for Mining Only	Coal Seam Possibly Available for CO2 Sequestration	Coal Seam Probably Available for CO2 Sequestration	Coal Seam Available for CO2 Sequestration	Total
Danville	381629	156333	328099	553925	80453	156871	1657309
Jamestown	0	2019	92658	63046	556	2127	160406
Herrin	73012	251756	3433273	1024038	823563	228302	5833944
Springfield	226656	251121	2125418	1266957	1023904	253254	5147309
Colchester	526540	471348	54524	419177	0	0	1471589
Seelyville	942	0	531052	513592	513592	78158	1637335
Dekoven	13830	8254	23077	111426	36011	227331	419928
Davis	13736	3756	124195	50124	180808	144171	516790
Total	**1236345**	**1144586**	**6712294**	**4002285**	**2658887**	**1090214**	**16844610**

This completed series of coal maps (refer to CD-ROM, Maps/Coal_Maps) clearly identify by color the most suitable potential areas for CO_2 sequestration.

Oil Fields

The purpose of this phase of the study was to identify producing and/or depleted oil fields that might be suitable for a CO_2 enhanced oil recovery (EOR) project. A further limitation was made to study only fields that meet the miscible flood threshold and cover a minimum of 2000 acres. This was done in order to limit sequestration to the largest fields which might have the most favorable economics. Oil field data were obtained from previous work by the Oil and Gas Section of the ISGS.

There are a total of 602 separate oil fields in Illinois that collectively have produced over 4.5 billion barrels of oil. Of these, only 43 met our minimum criteria. These fields have a mean average size of 11,636 acres (slightly over 18 square miles) and have produced in excess of 2.9 billion barrels of oil. Below is a listing of these fields ranked by size that includes location and cumulative production in M barrels of oil.

Selected Oil Fields Suitable For CO2 Sequestration

FIELD_NAME	DISC_YEAR	LOCATION	AREA	PROD_CUM
CLAY CITY CONS.	1937	1-7N, 1-2S, 6-11E	109350	360106.8
MAIN CONS.	1906	5-8N, 10-14W	65890	259219
LAWRENCE	1906	2-5N, 11-13W	37540	395236
NEW HARMONY CONS.	1939	1N, 1-5S, 13-14W		

29020	178828.2		
LOUDEN		1937	6-9N, 2-4E
26090	390068.2		
SAILOR SPRS. CONS.		1938	3-6N, 6-8E
22740	67460.6		
DALE CONS.		1940	5-7S, 4-7E
19610	103764.7		
SALEM CONS.		1938	1-2N, 1S, 1-2E
13910	394885.7		
ROLAND CONS.		1939	5-7S, 8-9E
12830	63423.3		
ALLENDALE		1912	1-2N, 11-13W
11000	27659.1		
ALBION CONS.		1940	1-3S, 10-11E, 14W
10290	38665.4		
JOHNSONVILLE CONS.		1940	1N, 1S, 6-7E
9600	58419.1		
GOLDEN GATE CONS.		1939	2-4S, 9-10E
9380	21375.7		
PHILLIPSTOWN CONS.		1939	3-5S, 10-11E, 14W
8900	38800.4		
HERALD CONS.		1940	6-8S, 9-10E
8590	21739.4		
PARKERSBURG CONS.		1941	1-3N, 10-11E, 14W
7810	13633.4		
MATTOON		1939	11-12N, 7-8E
6570	22330.9		
DIVIDE CONS.		1943	1S, 3-4E

5925	13904		
STORMS CONS.		1939	5-6S, 9-10E
5180	24132.5		
INMAN E. CONS.		1940	7-8S, 10E
5110	23286.4		
MT. CARMEL		1939	1N, 1S, 12W
5070	20756.4		
SIGGINS		1906	10-11N, 10-11E, 14W
4430	36000		
MILL SHOALS		1939	2-4S, 7-8E
4330	14501.1		
INMAN W. CONS.		1940	7-8S, 9-10E
4320	10753.8		
OLNEY CONS.		1938	4-5N, 10E
4070	8790.3		
ELDORADO CONS.		1941	8S, 6-7E
3950	12698.8		
IOLA CONS.		1939	5-6N, 5-6E
3770	17995.3		
MAPLE GROVE CONS.		1943	1-2N, 9-10E
3680	6175.6		
BUNGAY CONS.		1941	4S, 7E
3590	15401.5		
ST. JAMES		1938	5-6N, 2-3E
3350	23083.2		
COOKS MILLS CONS.		1941	13-14N, 7-8E
3240	3231.7		
BARNHILL		1939	2-3S, 8-9E
3130	7831.7		
HIDALGO S.		1964	8N, 10E

3000	1186.4		
CENTRALIA		1937	1-2N, 1E, 1W
2980	58726.1		
BENTON		1941	6S, 2-3E
2880	42646.4		
MARTINSVILLE		1907	9-10N, 13-14W
2780	27000		
ADEN CONS.		1938	2-3S, 7E
2540	13831.4		
JOHNSON N.		1907	9-10N, 14W
2510	27000		
INGRAHM CONS.		1942	4N, 8E
2360	5275.3		
MAUNIE N. CONS.		1941	5-6S, 10-11E, 14W
2300	5423.5		
CONCORD CONS.		1942	6S, 10E
2290	9397.2		
WALPOLE		1941	6-7S, 6E
2260	10859.1		
CALHOUN CONS.		1944	2-3N, 9-10E
2200	4301.7		

This CD-ROM contains a map showing the results of the above investigation (reference Maps/Oil_Field_Map).

Deep Saline Formations

The only deep saline formation examined in detail was the Mt. Simon Sandstone. This decision was based on the inability of the St. Peter to be effectively capped at one major gas storage field. Possibly this should not be a limiting factor deeper in the basin and requires further study. Information needed to create the Mt. Simon structure and thickness maps was queried from the ISGS Oracle Database. Additional subsurface information, primarily including core derived porosity and permeability data, were taken from the Morse and Leetaru (2003) study.

Only 136 wells out of nearly 180,000 total wells drilled in Illinois penetrate the top of the Mt. Simon Sandstone. This subsurface information was used to create a new structure map drawn on the top of the Mt. Simon (CD/Maps/Mt_Simon_Maps/Structure_Top_MtSimon). The GIS software generated a statewide raster map using this limited number of data points. This map show structural contours that range from less than 1,000 feet sub-sea in the northern portion to more than 13,000 feet sub-sea in the southeastern portion of the state. The blue dots indicate the location of well data used to generate this map. This map is generalized in that faults have been eliminated.

Only 33 wells statewide penetrated the entire Mt. Simon Sandstone section and used to create a thickness map. The wells are shown with yellow circles on the map (CD/Maps/Mt_Simon_Maps/Isopach_MtSimon). The isopach values range from thicker than 2,500 feet southwest of the Chicago Area to areas in the far southern region with no Mt Simon present.

A porosity distribution map was created using 55 data points with core analysis results. The deepest core derived porosity was 5,900 feet. Four additional data points below this level used geophysical logs to obtain porosity values. These values were then combined and the GIS software created a statewide porosity map (CD/Maps/Mt_Simon_Maps/Porosity_MtSimon). These values range from a high of 14% in the shallower parts of the Illinois Basin and continue to decrease with increased depth of burial to near 3%. The latter may not be representative of data over wider areas, however.

Conclusions

The results of this study can best be described while viewing the map showing the combined layers (CD/Maps/Mt_Simon_Maps/Combined_Map/Total CO2 Sequestration Potential). This map displays representative layers from the three geologic sequestration options. The maps background shows the Mt. Simon Porosity distribution along with the different well control used to create these Mt.Simon maps. Shown in blue are the 43 selected oil-fields that might represent the best candidates for CO2-EOR projects. Also, the location of each coal seam deeper than 900 feet is outlined.

How to Use this CD-ROM

This CD contains two main folders, Document and Maps. The document folder contains this report. The Maps folder is further divided into Coal_Maps, Oil_Field_Maps, Mt_Simon_Maps, and a Combined_Map folders. These folders contain the individual maps referred to above in portable document format (pdf).

Acknowledgements

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References

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Morse, D. and H. Leetaru. 2003. *Reservoir Characterization & 3D Models of Mt Simon Gas Storage Fields in the Illinois Basin*. Champaign, IL: Illinois State Geological Survey.