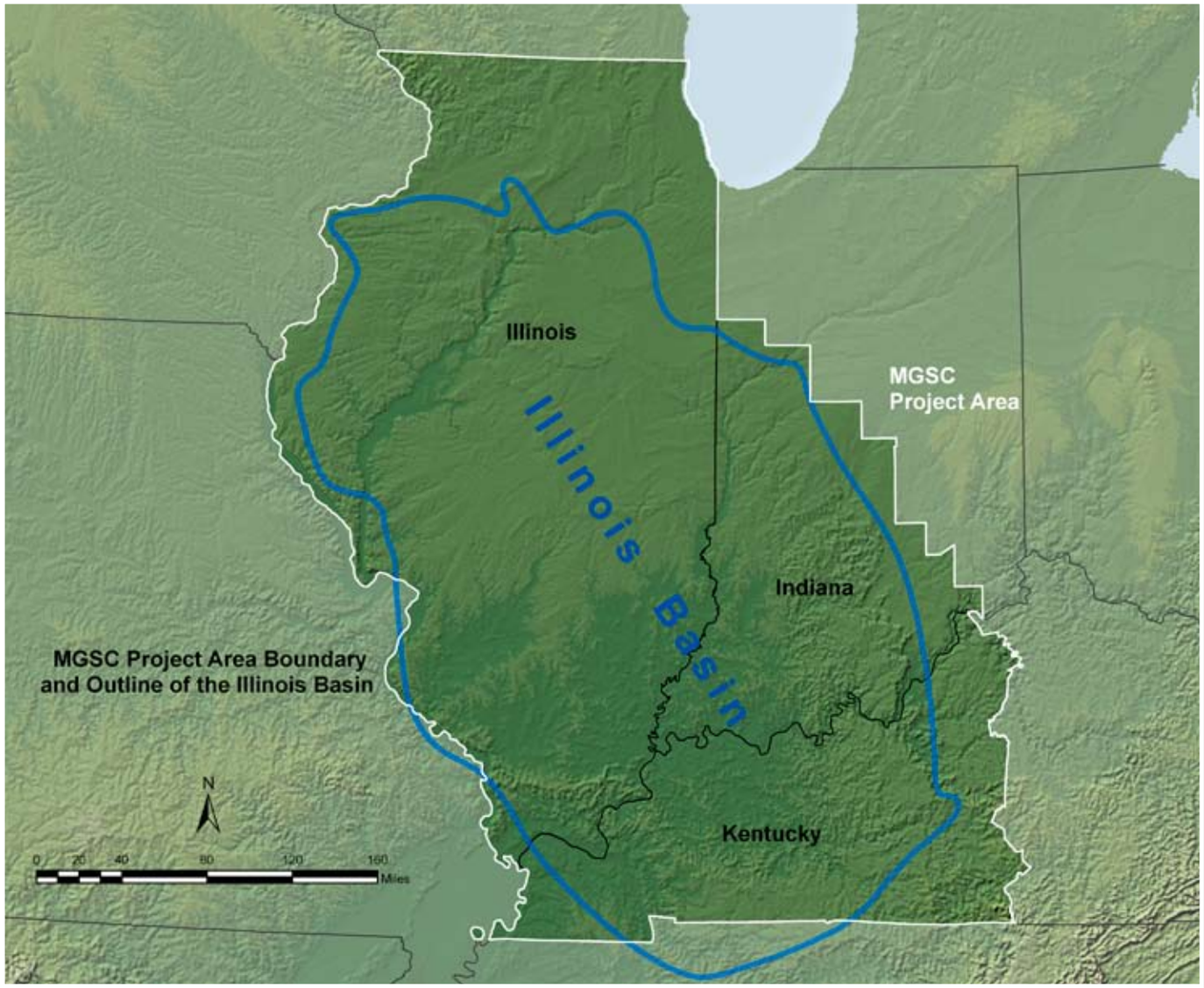


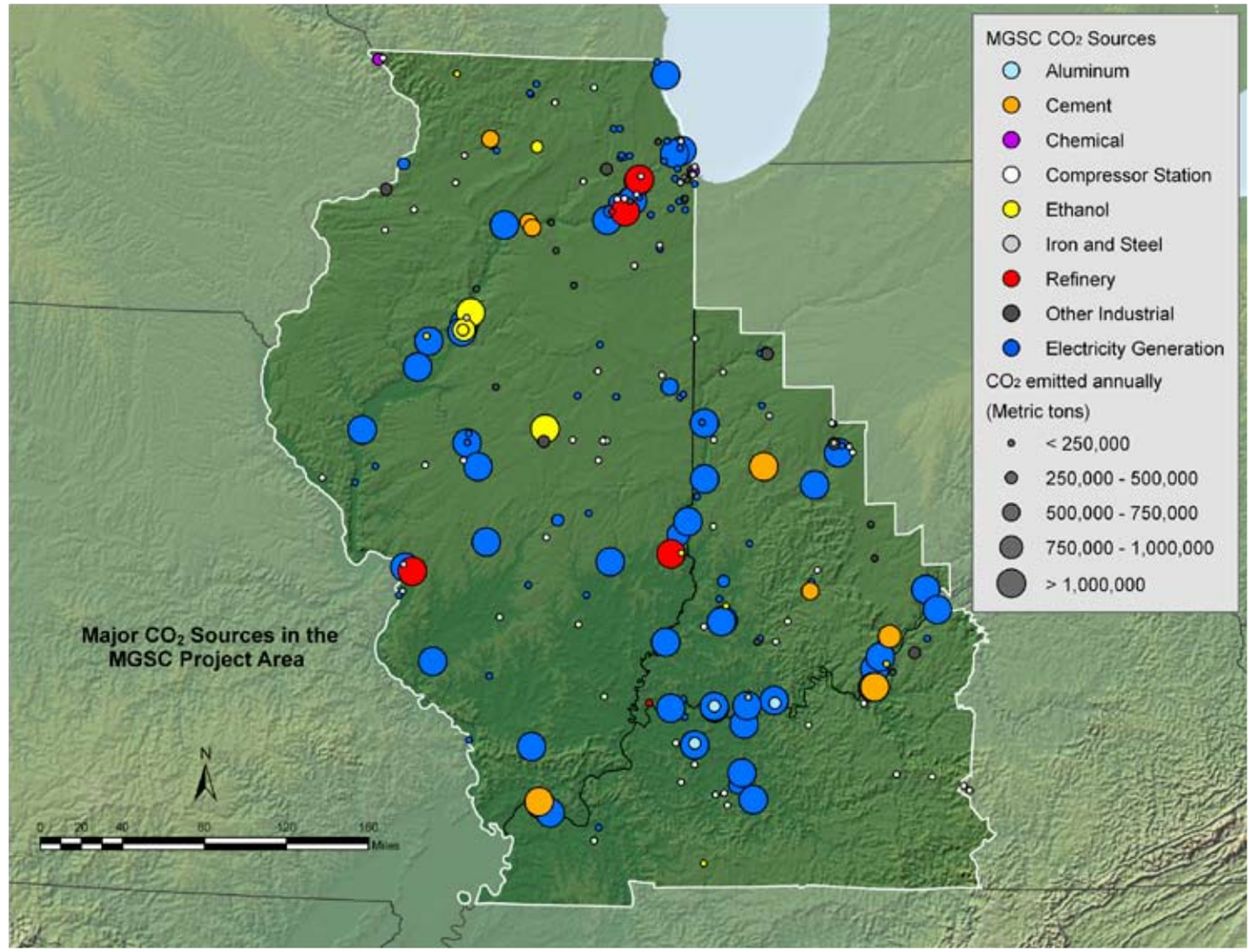
Midwest Geological Sequestration Consortium

The Midwest Geological Sequestration Consortium (MGSC) is comprised of the geological surveys of Illinois, Indiana, and Kentucky, joined by private corporations, professional business associations, the Interstate Oil and Gas Compact Commission, two Illinois state agencies, and university researchers to assess carbon capture, transportation, and geologic storage processes and their costs and viability in the three-state Illinois Basin region. The Illinois State Geological Survey is the Lead Technical Contractor for the Consortium. The MGSC Partnership area covers all of Illinois, southwest Indiana, and western Kentucky.

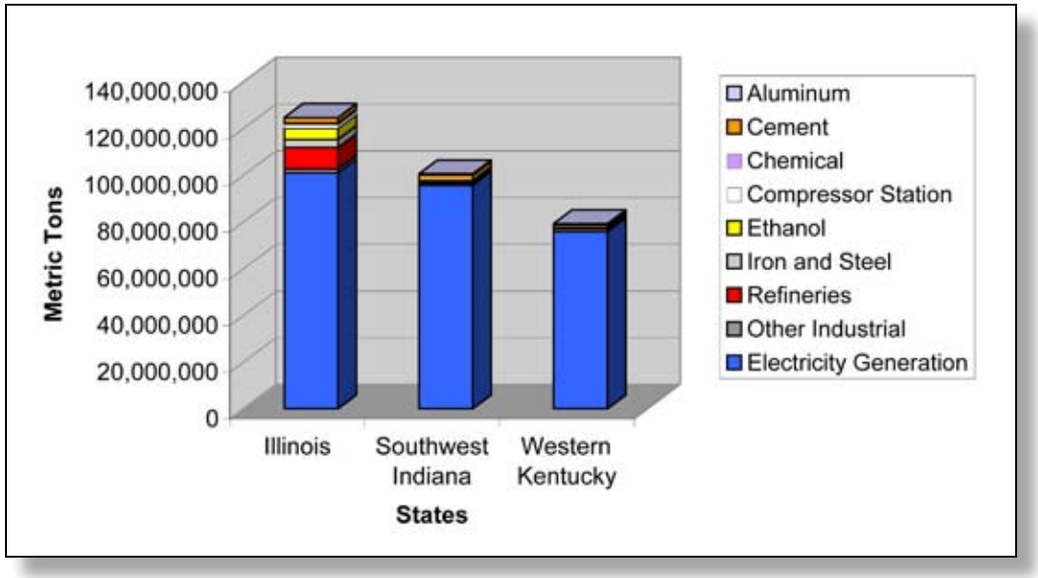
To reduce atmospheric release of CO_2 from fossil fuel combustion and thereby reduce the potential for adverse climate change, the MGSC is investigating options for geologic CO_2 sequestration in the 155,400-km^2 (60,000-mi^2), oval-shaped, geologic feature known as the Illinois Basin. Within the Basin are deep, uneconomic coal resources, numerous mature oil fields, and deep saline formations with the potential to store CO_2. MGSC's objective is to determine the technical and economic feasibility of using these geologic formations for long-term storage.

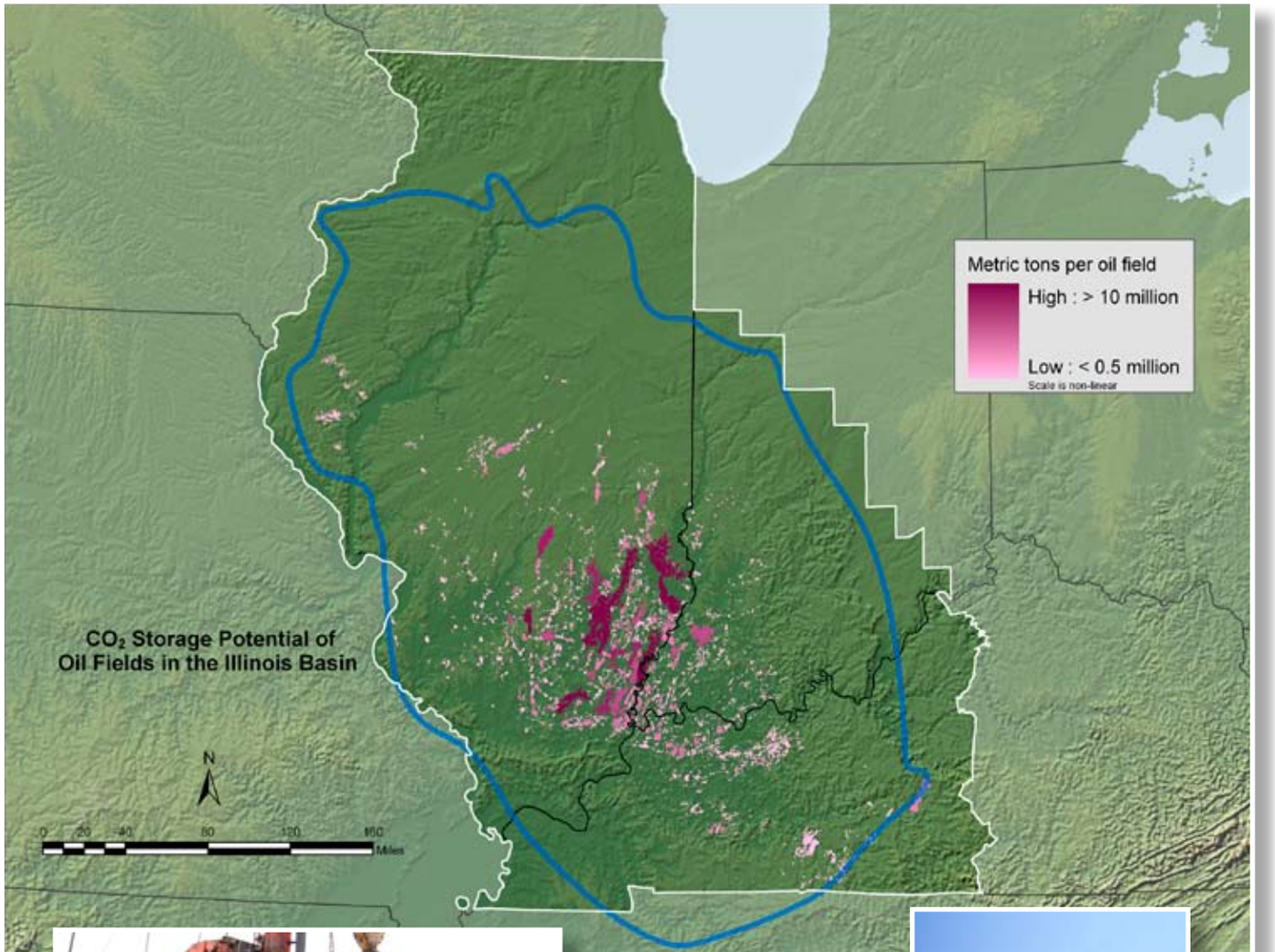
MGSC Stationary Anthropogenic CO_2 Sources

The Illinois Basin Region has annual emissions exceeding 300 million metric tons (335 million tons) of CO_2 (> 83 million metric tons [91 million tons] carbon equivalent) primarily from over 250 stationary sources. Coal-fired, electric generation facilities are the dominant stationary source, some of which burn almost 4.5 million metric tons (5 million tons) of coal per year. The distribution of emissions from these plants is highly skewed. The 4 largest plants, in megawatt capacity, emit about 22 percent of total CO_2 emissions; the 13 largest plants emit > 50 percent of total CO_2 emissions; and the 30 largest plants emit > 80 percent of total CO_2 emissions. The Illinois Basin contributes about 11.4 percent of the total CO_2 emissions from electric power generation plants in the United States. Coal is the dominant fossil fuel for electric power plants and contributes 98 percent of the Illinois Basin CO_2 emissions from stationary sources. CO_2 emissions from manufacturing industries in the Illinois Basin vary from industry to industry.



Illinois Basin (MGSC) CO_2 Emissions by State and CO_2 Source Type				
Source Type	**Illinois Basin Annual CO_2 Emissions (million metric tons)**			
	Illinois	Southwest Indiana	Western Kentucky	Total
Aluminum	0	0.5	0.7	1.2
Cement	2.5	2.6	1.1	6.2
Chemical	0.7	0	0	0.7
Compressor Station	1.4	0.3	0.3	2.0
Ethanol	4.8	0.2	0.2	5.2
Iron and Steel	3.5	0.1	0.1	3.7
Refineries	9.1	0.2	0	9.4
Other Industrial	1.7	0.9	1.1	3.6
Electricity Generation	101.0	95.7	75.8	272.5
TOTAL	124.6	100.5	79.2	304.4





Oil wells in the Illinois Basin.

MGSC: Illinois Basin Oil and Gas Formations

Because of the established effectiveness of CO_2 EOR, oil reservoirs offer the most potential for economic offset to the costs associated with carbon sequestration in the Illinois Basin. To assess this potential, a Basin-wide EOR estimate was made based on new understanding of the original oil-in-place (OOIP) in the Basin, the CO_2 stored volume, the assessed EOR resource, the geographic distribution of EOR potential, and the type of recovery mechanism (miscible vs. immiscible). The oil resource target for EOR is 137 to 207 million m^3 (860 to 1,300 million barrels [bbl]) recoverable oil with a consequently sequestered volume of 140 to 440 million metric tons (154 to 485 million tons) of CO_2.

With cumulative oil production for the Basin of about 0.67 billion m^3 (4.2 billion bbls), nearly 1.5 billion m^3 (10 billion bbls) of resources remain, primarily as unrecovered oil resources in known fields. To assess the recovery potential of a part of this resource and the concurrent stored CO_2 volumes, reservoir modeling and compositional reservoir simulation were carried out. Sections of nine fields were used to create generic geologic models for the most prolific oil-bearing reservoirs in the Basin, the Aux Vases, the Cypress Sandstones, and the St. Genevieve Limestone. These models incorporated data from > 1,000 total wells, 120 wells with core, > 2,000 core sample points, 12,000 field acres, and 20 flow zones. Structure and isopach maps were developed deterministically from well logs, whereas porosity and permeability distributions were developed geostatistically from core analysis data for the reservoir simulator. Processes simulated were miscible and immiscible flooding, based on reservoir pressure and temperature, and both continuous and water-alternating-gas CO_2 injection.

State	Potential CO_2 Storage Resource (million metric tons)	Estimated EOR* (million barrels)
IL	106 to 358	632 to 979
IN	20 to 47	124 to 162
KY	14 to 35	104 to 138
TOTAL	140 to 440 million metric tons	860 million to 1.3 billion barrels

* The EOR volume was estimated based on a series of oil recovery factors for specific geologic units and miscibility types that were applied to the OOIP as assessed per oil field.

MGSC: Illinois Basin Unmineable Coal Seams

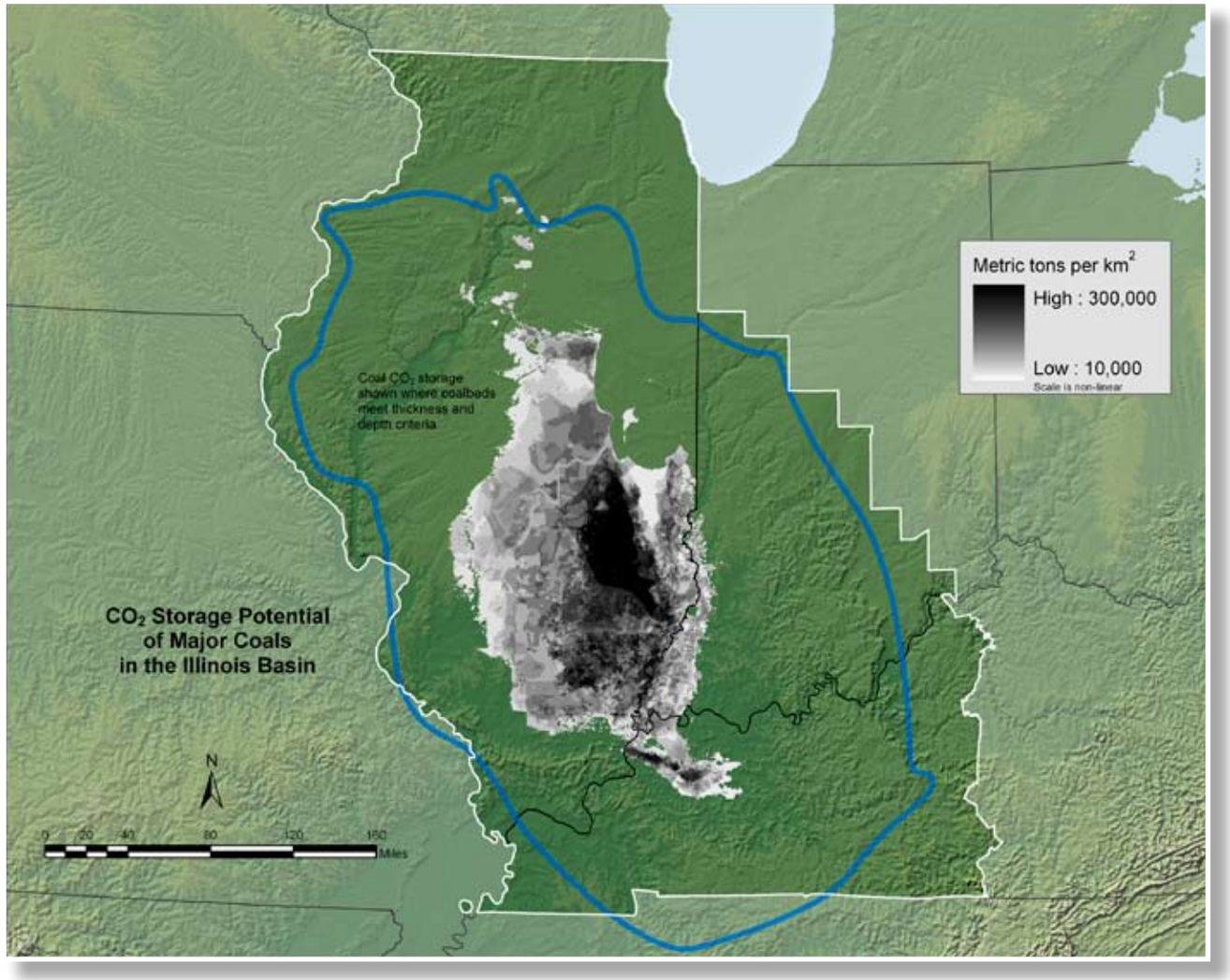
The Illinois Basin includes substantial coal resources, totaling 258 billion remaining metric tons (284 billion tons). Extraction techniques range from surface mining to room-and-pillar and longwall subsurface methods, with most mining occurring around the margins of the Basin. Most of the Basin's remaining coal resources are moderate to high in sulfur content. Consequently, market share has been lost to low-sulfur, western coal from the PRB, and Illinois coal production has declined by half since 1990. The opportunity to sequester CO_2 in coal seams currently considered to be unmineable is based on both technical and economic considerations and could be supported by production of coalbed methane displaced from these coals.

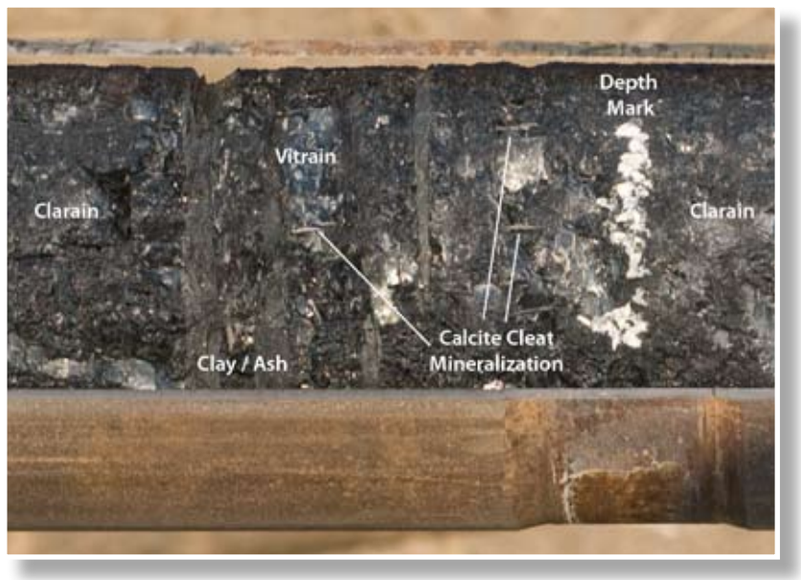
With respect to defining unmineable coal, no consideration is given to coals at depths < 152 m (< 500 ft). From 152 to 305 m (500 to 1,000 ft) in depth, coals from 0.48 to 1.1 m (1.5 to 3.5 ft) in thickness are considered sequestration targets. A seam < 1.1 m (< 3.5 ft) in thickness is currently not underground mineable with existing equipment. It would be costly to develop new equipment compared to mining seams of greater thickness, which remain as an abundant part of the resource base. For depths greater than 305 m (1,000 ft), all seams > 1.1 m (> 1.5 ft) in thickness are considered a sequestration target.

Key characteristics of seven coals were mapped throughout the Illinois Basin, including thickness, depth, elevation, moisture content, ash content, heating value, temperature, and expected reservoir pressure. Most data were available for the Herrin and Springfield coals, the major coal seams in the Basin. Gas contents for Illinois Basin coals are in the range of 3.12 to 4.68 m^3/metric ton (100 to 150 standard cubic feet [scf]/ton) for the better samples. CO_2 adsorption capacity can range from 14.1 to 21.9 m^3/metric ton (450 to 700 scf/ton) at 2,068 kPa (300 psi).

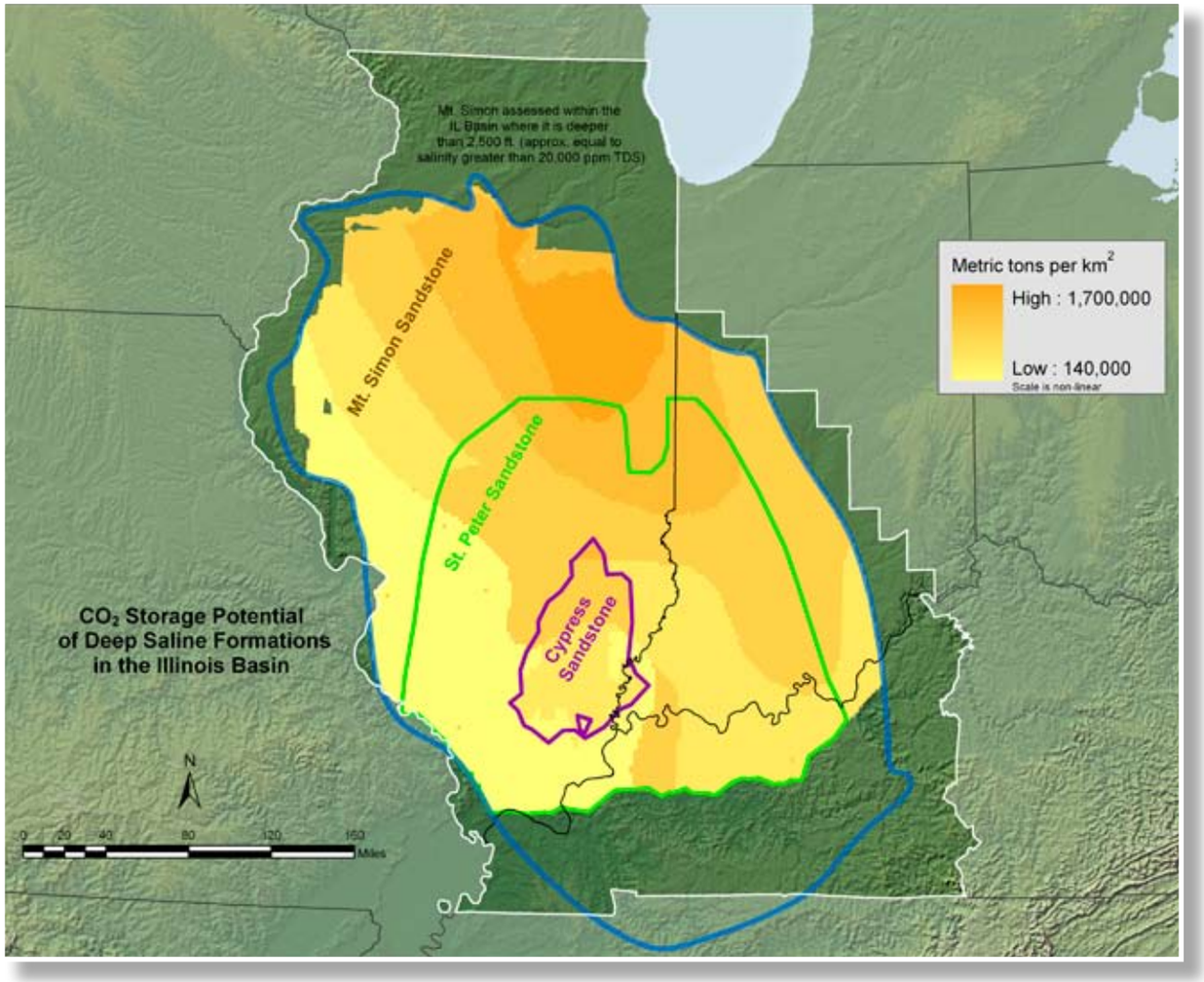
State	Potential CO_2 Storage Resource (million metric tons)	Estimated ECBM* (billion scf)
Illinois	1,500 to 2,140	2,700 to 9,800
Indiana	88 to 126	150 to 600
Kentucky	70 to 100	130 to 470
TOTAL	1.7 to 2.4 billion metric tons	3.0 to 10.9 trillion scf

* ECBM was estimated based on a methane recovery factor that was applied to the original gas-in-place volume per coal seam for unmineable coal areas as described above.



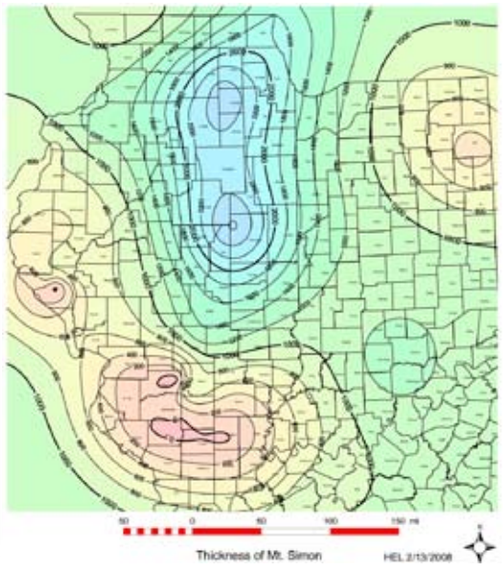


Banded horizons in Springfield Coal core. Core was drilled vertical and is shown rotated 90 degrees.



Reservoir	Potential CO_2 Storage Resource (billion metric tons)
Cypress Sandstone	0.4 to 1.7
St. Peter Sandstone	1.6 to 6.4
Mt. Simon Sandstone	27 to 109
TOTAL	29 to 117 billion metric tons

State	Potential CO_2 Storage Resource (billion metric tons)
Illinois	20 to 79
Indiana	7.9 to 32
Kentucky	1.5 to 6.3
TOTAL	29 to 117 billion metric tons



Regional thickness of the Mt. Simon sandstone.

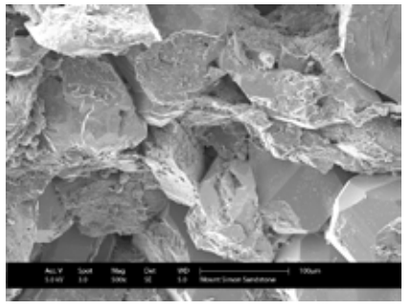
MGSC: Illinois Basin Deep Saline Formations

Three saline formations in the Illinois Basin were studied for CO_2 storage potential: the Mississippian Cypress Sandstone, the Ordovician St. Peter Sandstone, and the Cambrian Mt. Simon Sandstone.

The Cypress Sandstone is the most widespread and prolific petroleum-bearing sandstone in the Illinois Basin, with production exceeding one billion barrels of oil to date. Areas with thick Cypress tend to have a large water-bearing zone that may be considered a saline storage target. The porous and permeable sandstone can reach a thickness of 61 m (200 ft), although it is generally less than 30 m (100 ft) thick and displays considerable variation in thickness and lateral extent. It is the shallowest of the three saline formations assessed, and is found at depths up to approximately 910 m (3,000 ft) in parts of the Illinois Basin. Shale beds and a laterally continuous carbonate, the Beech Creek (Barlow) Limestone, form the overlying seal for the Cypress Sandstone.

The St. Peter Sandstone is a widespread, porous, and permeable quartz sandstone that is generally fine-grained with good lateral continuity. Seals above the St. Peter Sandstone include several hundred feet of dense limestone and dolostone overlain by 45.7 to 76.2 m (150 to 250 ft) of Maquoketa Shale.

The Mt. Simon Sandstone is commonly used for natural gas storage in the Illinois Basin and has fair to good permeability and porosity. Overlying strata contain impermeable limestone, dolomite, and shale intervals. The depth of the Mt. Simon Sandstone ranges from approximately 610 to 4,267 m (approx. 2,000 to 14,000 ft) below the surface; in the southern half of the Basin the reservoir is brine-filled, and no oil or natural gas resources have been discovered in this unit. At its greatest thickness in the Illinois Basin, the Mt. Simon Sandstone is over 793 m (2,600 ft) thick. The Mt. Simon does not outcrop in Illinois, but correlative units are exposed in southern Wisconsin, southeastern Minnesota, and Missouri. The Mt. Simon exists in the subsurface throughout much of Indiana, Iowa, Michigan, and Ohio. In the southern region of the Basin, the potential CO_2 reservoir facies are either very deep or are absent in the paleotopography.

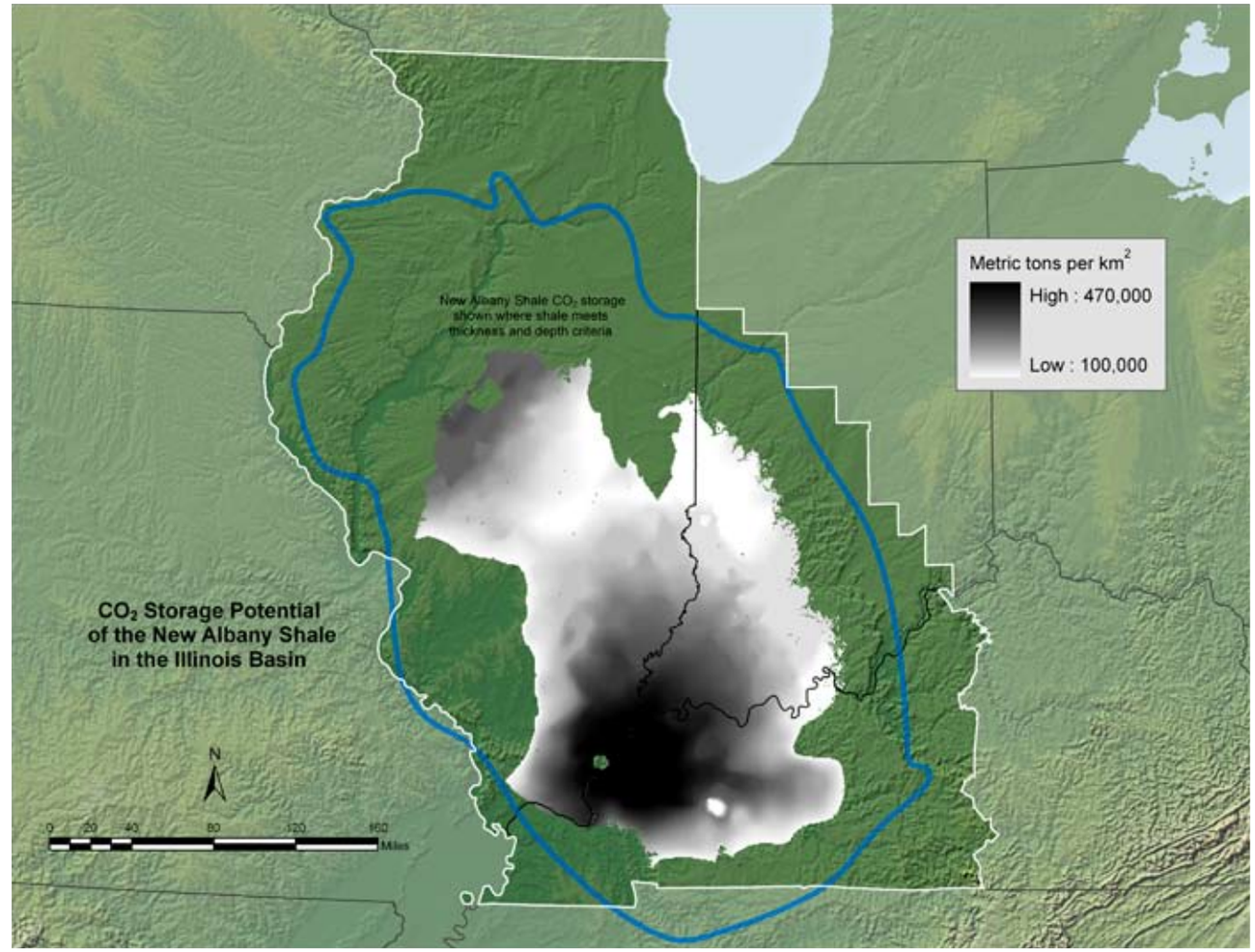


Photomicrograph of the Mt. Simon sandstone, 500X.

Depths less than 762 m (2,500 ft) for the Cypress, St. Peter, and Mt. Simon sandstones were not considered as sequestration targets due to anticipated lower salinity, potentially potable water resources in these areas, and temperatures and pressures insufficient to maintain dense-phase CO_2. However, a CO_2 storage resource is available and should be considered on a site-by-site basis.

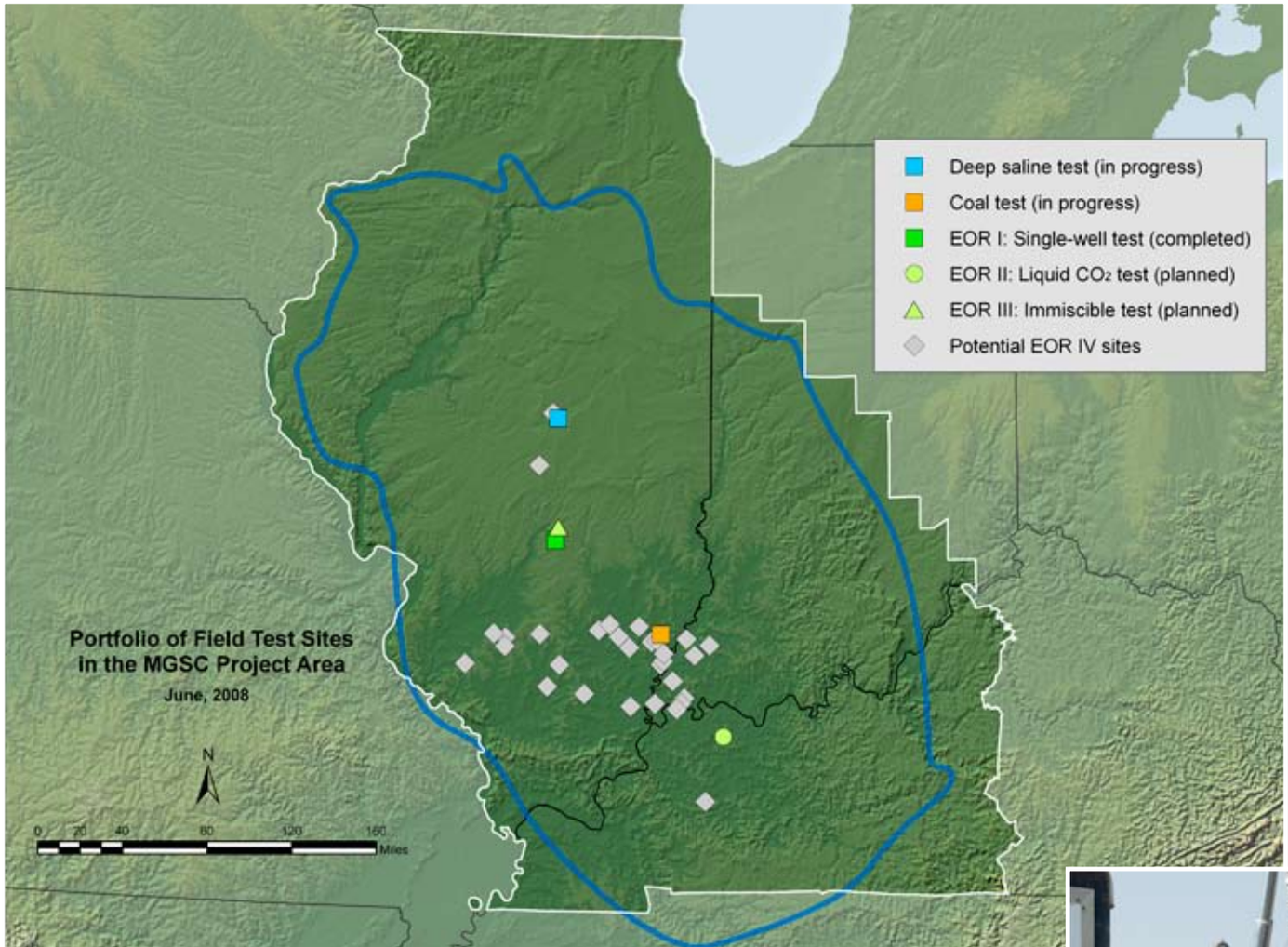
MGSC: Illinois Basin Deep Shales

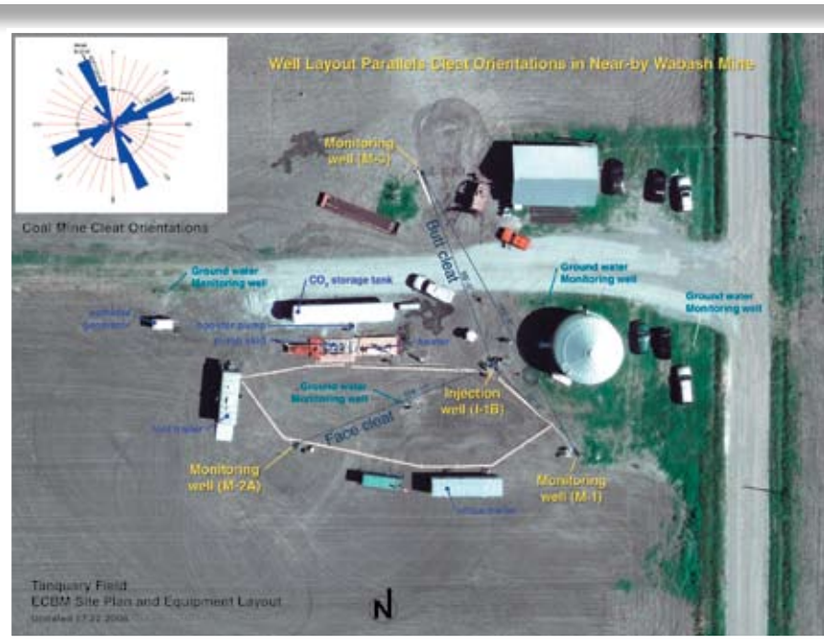
Organic-rich shales in the Illinois Basin will be assessed from two perspectives. The Devonian New Albany Shale in the Illinois Basin is potentially commercially productive of natural gas in the same way as the stratigraphically equivalent Antrim Shale in the Michigan Basin, a play that currently supports over 7,600 producing wells, and the Devonian Ohio and related shales of the Appalachian Basin support over 10,000 wells in eastern Kentucky. New Albany reservoirs exist in Indiana and Kentucky, and samples are currently being tested for their CO_2 adsorption capacity. Organic carbon content of the shale is directly related to the CO_2 adsorption capacity. Injection of CO_2 into the organic shales may result in adsorption of CO_2 and possibly associated enhanced production of methane gas, similar to coalbeds. The New Albany Shale is the primary seal for Silurian and Devonian oil and gas reservoirs, and it may act as a secondary seal for sequestration in deeper Paleozoic reservoirs, like the Mt. Simon and St. Peter Sandstones. Initial volumetric estimates indicate that up to 15 billion metric tons of CO_2 could be sequestered in the organic-rich shales of the Illinois Basin. This estimate is being refined by considering the distribution and quantity of organic matter in the shale, injectivity, and displacement efficiencies during the Validation Phase.



Regional shale outcrop.

Regional shale outcrop.





Layout of coal test site. Inset shows coal cleat orientation at a nearby mine.

MGSC Validation Phase Field Tests

The MGSC, along with its industry partners, is conducting a series of six field validation tests in the Illinois Basin to assess the potential for CO_2 storage in oil reservoirs, coal seams, and deep, saline water-bearing formations. Added-value benefits for CO_2 storage in oil reservoirs and coal beds are the potential for EOR and ECBM production, respectively. The planned deep saline "Mt. Simon Sandstone" test has been expanded into the MGSC large-scale demonstration project for the Development Phase. The Mt. Simon Sandstone is expected to have the most storage of all geologic formations.

The MGSC effort focuses on a series of field tests, beginning with a one-well, inject/soak/produce oil reservoir test and culminating with drilling to a deep saline formation and injecting CO_2. Between these end members, an ECBM test and mature oil field tests will involve well conversion(s) and drilling of one or more new injection wells to evaluate pattern flooding. Test sites will incorporate miscible and immiscible flooding and assess Illinois Basin sandstone and carbonate reservoirs to provide both comparison and contrast to the Permian Basin (West Texas) experience, which is dominated by miscible carbonate floods.

Collecting core at coal test site.

Coalbed Methane

The coalbed methane project was initiated in July 2007. This pilot project includes one injection and three monitoring wells. Two monitoring wells are located 50 and 100 feet in the butt cleat direction on each side of the injection well; the third monitoring well is 100 feet from the injection well in the face cleat direction. Two wells were drilled in July 2007; the remaining two wells were drilled in May 2008, prior to CO_2 injection in the summer of 2008. A multi-well water and CO_2 pressure transient test will be used to better understand CO_2 sequestration in coal.

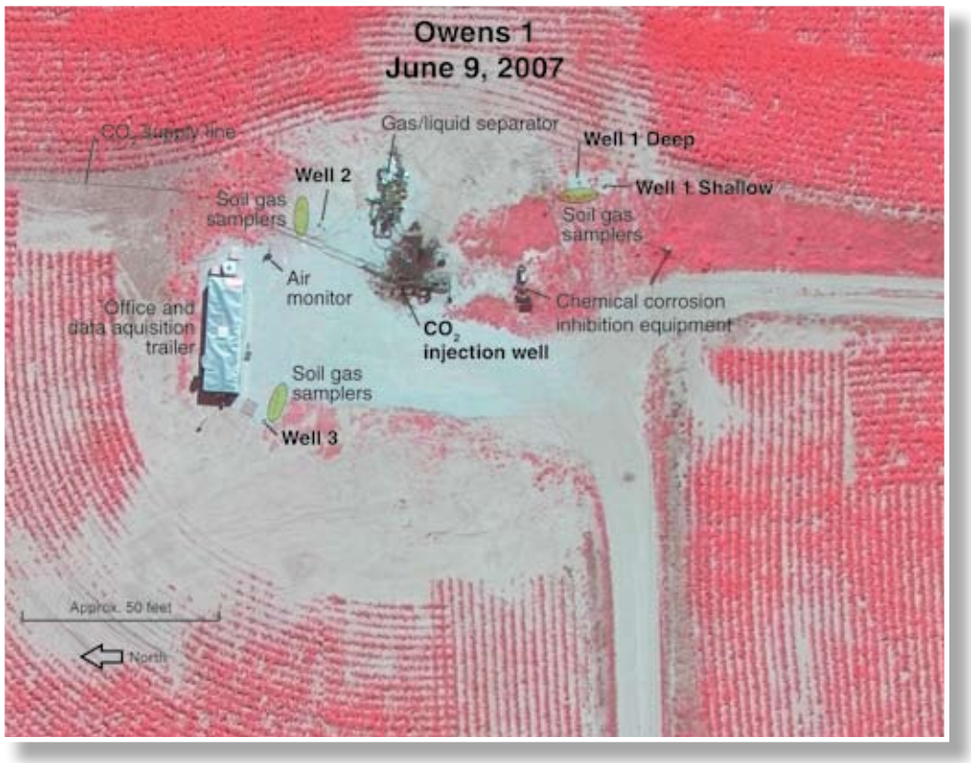
Drill stem test gas sample collection at coal site.

Enhanced Oil Recovery

The first mature oil field test, known as a "Huff 'n Puff," was conducted in March 2007 to evaluate the potential for geologic sequestration of CO_2 in mature Illinois Basin oil reservoirs as part of an EOR program. During the process, CO_2 was injected into a producing well (the "Huff" phase), the well was shut in, allowing CO_2 to mix with the in situ crude oil, and then the well was placed back on production (the "Puff" phase). Site evaluation, evaluation of well data, CO_2 injection, modeling, and MVA efforts are now complete. The primary location is within the Loudon Field in Fayette County, Illinois. Forty-three tons of CO_2 were injected over a five-day period into the Mississippian Cypress Sandstone at a depth of approximately 472 m (1,550 ft).

Accomplishment Highlights:

- Forty-three tons of CO_2 were injected over a five-day period.
- Incremental oil production during the first two months following the soak period was approximately 15 m^3 (95 barrels).
- Results indicate that the Illinois Basin oilfield may have an added-value benefit as a precursor to build and invest in the infrastructure to establish a sequestration industry within the Basin.



Layout of EOR I site in the Loudon oilfield, Fayette County, Illinois.

Casing gas production manifold and portable separator at EOR I site.

CO_2 storage tank, inline header, and pump equipment at EOR I site.

Aerial view of the Illinois Basin – Decatur Project, deep saline test site, Decatur, IL.

MGSC Development Phase Demonstration Project

In view of recent increased attention being placed on global climate change and geologic carbon sequestration, the MGSC, the Archer Daniels Midland Company (ADM), and Schlumberger Carbon Services have joined as partners to expand the originally planned Validation Phase small-scale deep saline formation CO_2 injection into a large-scale deep saline formation CO_2 injection. The newly combined Validation Phase and Development Phase effort will be a large-scale multiyear deployment of geologic sequestration of 1 million metric tons (1.1 million U.S. tons) of CO_2 over 3 years. This large-scale injection project is planned at the ADM plant site in Decatur, Illinois. Injection will be at a depth of 1,830 to 2,390 m (6,000 to 7,000 ft) into the Mt. Simon Sandstone saline formation—one of the most significant potential carbon storage resources in the United States. Two-dimensional seismic data were acquired in October 2007 in preparation for drilling the injection well planned for the fourth quarter of 2008. The Underground Injection Control (UIC) permit application has been completed, a public hearing was held in September, 2008, and the permit is pending final approval from the Illinois EPA. The well location was staked and the MVA program initiated in May of 2008. Injection of CO_2 is expected to begin late 2009.

View of deep saline test site (pre-drilling).

Setting up the Eddy Covariance tower at the Illinois Basin – Decatur site.

MGSC Commercialization Opportunities

The states within the Illinois Basin region are actively considering initiatives that would facilitate deployment of geologic sequestration. The tri-state area is engaged in promoting clean coal technology research and commercialization studies. The Region had two of the semi-final FutureGen sites. Mattoon, Illinois was ultimately selected as the preferred national site by the FutureGen Industrial Alliance. Commercial opportunities for sequestration and coal gasification in concert continue to be considered. CO_2 EOR is currently not active in the Region. The State of Illinois is funding a CO_2 pipeline feasibility study slated to begin in late 2008. In addition to the pipeline study, private sector development of a pipeline to transport CO_2 from the Illinois Basin to the Gulf Coast is under consideration. The MGSC and partners continue to engage in sequestration research and in supplying information to interested commercial parties.

Progress continues on the construction of Duke Energy's integrated gasification combined cycle generation facility at Edwardsport, Indiana. This commercial scale (632 MW) facility will use carbon capture and sequestration technologies to reduce the emission of some of the ~4.5 million metric tons (~5 million tons) of CO_2 to be produced annually. CO_2 will therefore be available for enhanced recovery operations in the Region including potential enhanced gas recovery from the New Albany Shale.

The Kentucky State Legislature provided funding support to conduct an immiscible CO_2 EOR project. A consortium is being formed and industry partners identified to conduct a deep saline injection demonstration project in the Illinois Basin portion of the Kentucky Commonwealth. The newly reorganized Kentucky Cabinet for Energy and Environment is continuing a program to assess sites for development of coal-to-liquids, coal gasification, IGCC, and other clean coal technologies with specific consideration for carbon storage and EOR opportunities.

Aerial image of ADM Plant, Decatur, Illinois.