Carbon Storage Assurance Facility Enterprise (CarbonSAFE): Integrated CCS Pre-Feasibility
CarbonSAFE Illinois East Sub-Basin

Final Report

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The following table is a list of research scientists from the different organizations. They all made significant contributions to this research project and are authors of papers, presentations, and topical reports summarizing the project results.

Topical Report	Author	Affiliation
Summary of Carbon Storage Incentives and Potential Legislation: CarbonSAFE East Sub-Basin Project Subtask 3.1 - Topical Report: DOE/FE0029445-1	Chiara Trabucchi	Industrial Economics, Incorporated
An Assessment of Potential CO_2 Sources throughout the Illinois Basin: CarbonSAFE East Sub-Basin ProjectSubtask 5.1 – Topical Report: DOE/FE0029445-2	Vinodkumar Patel	Prairie Research Institute, Illinois Sustainable Technology Center
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	Christopher Korose	Prairie Research Institute, Illinois State Geological Survey
Transportation and Infrastructure Assessment: CarbonSAFE East Sub-Basin ProjectSubtask 5.2 - Topical Report: DOE/FE0029445-3	Andrew Sexton	Trimeric Corporation
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Policy, Regulatory, Legal, and Permitting Case Study: CarbonSAFE East Sub-Basin Project Subtask 3.2 – Topical Report: DOE-FE0029445-4	Christopher Korose	Prairie Research Institute
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Data Gap Assessment: CarbonSAFE East Sub-Basin Project Subtask 4.1 - Topical Report DOE-FE0029445-5	Curt Blakley	Prairie Research Institute, Illinois State Geological Survey
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An Assessment of the National Risk Assessment Program's CO_2 Sequestration Leakage Modeling Tools: CarbonSAFE East Sub-Basin Project Subtask 6.1- Topical Report: DOE/FE0029445-6	Carl Carman	Prairie Research Institute, Illinois State Geological Survey

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Evaluation of Geologic Carbon Storage Resource Estimates (SREs) of Cambrian Ordovician Units within the CarbonSAFE Prefeasibility Study Region: CarbonSAFE East Sub-Basin Project Subtasks 4.2 and 4.3 - Topical Report: DOE-FE0029445-7	Cristian R. Medina	Indiana Geological and Water Survey, Indiana University
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Stakeholder Analysis Report: CarbonSAFE East Sub-Basin Project Subtask 3.3 - Topical Report: DOE/FE0029445-8	Sallie Greenberg	Prairie Research Institute, Illinois State Geological Survey
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Developing CO_2 Source and Storage Opportunities across the Illinois Basin: CarbonSAFE East Sub-Basin Project Subtask 5.3 – Topical Report: DOE/FE0029445-9	Curt Blakley	Prairie Research Institute, Illinois State Geological Survey
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A Summary of CO_2-Enhanced Oil Recovery Options in the Illinois East Sub-Basin: CarbonSAFE East Sub-Basin Project - Topical Report: DOE-FE0029445-10	Curt Blakley	Prairie Research Institute, Illinois State Geological Survey
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Evaluation of Caprock Integrity of the Upper Ordovician Units within the CarbonSAFE Prefeasibility Study Region - CarbonSAFE East Sub-Basin Project Subtask 4.3 - Topical Report: DOE-FE0029445-11	Cristian R. Medina	Indiana Geological and Water Survey, Indiana University
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CarbonSAFE East Sub-Basin Site Feasibility Plan: CarbonSAFE East Sub-Basin Subtask 4.5 – Topical Report: DOE-FE0029445-12	Curt Blakley	Prairie Research Institute, Illinois State Geological Survey

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Executive Summary
Purpose of the project was to conduct a pre-feasibility assessment for commercial-scale CO_2 geological storage complexes in the East Sub-Basin of the Illinois Basin. This work will be used to advance the experience and knowledge about scaling up from demonstration to commercial-scale storage (CCS), and eventually readying sites for more than 50 million tonnes injection from one or more industrial sources. To accomplish this, the project formed a CCS coordination team with varied backgrounds to evaluate aspects of developing an integrated CCS project, including regulatory, legislative, technical, public policy, commercial and financial requirements. We developed a plan and strategy to address the technical and non-technical challenges to enable an economically feasible and publicly acceptable integrated CCS project. A significant output of this high-level technical evaluation of the East Sub-Basin was to identify suitable site(s) within the storage complex(es) that include detailed subsurface characterization and risk identification, along with evaluation of potential industrial CO_2 sources for sequestration.

Project Summary

Objectives

The CarbonSAFE Illinois East Sub-Basin is a broad area extending through east-central Illinois and west-central Indiana, generally trending from Marion and Fayette Counties (IL) in the southwest part of the study area through Vigo and Vermillion Counties (IN) in the northeast (1).

East Sub-Basin work has built upon the FutureGen DOE initiative, research of the DOE's Regional Carbon Sequestration program, and other DOE funded projects such as the evaluation of the Cambrian-Ordovician strata and reservoir characterization studies in the Mississippian Cypress Sandstone. Recent geological research has focused on a high porosity, arkosic zone within the Lower Mt. Simon Sandstone as a prospective storage resource play in the region.

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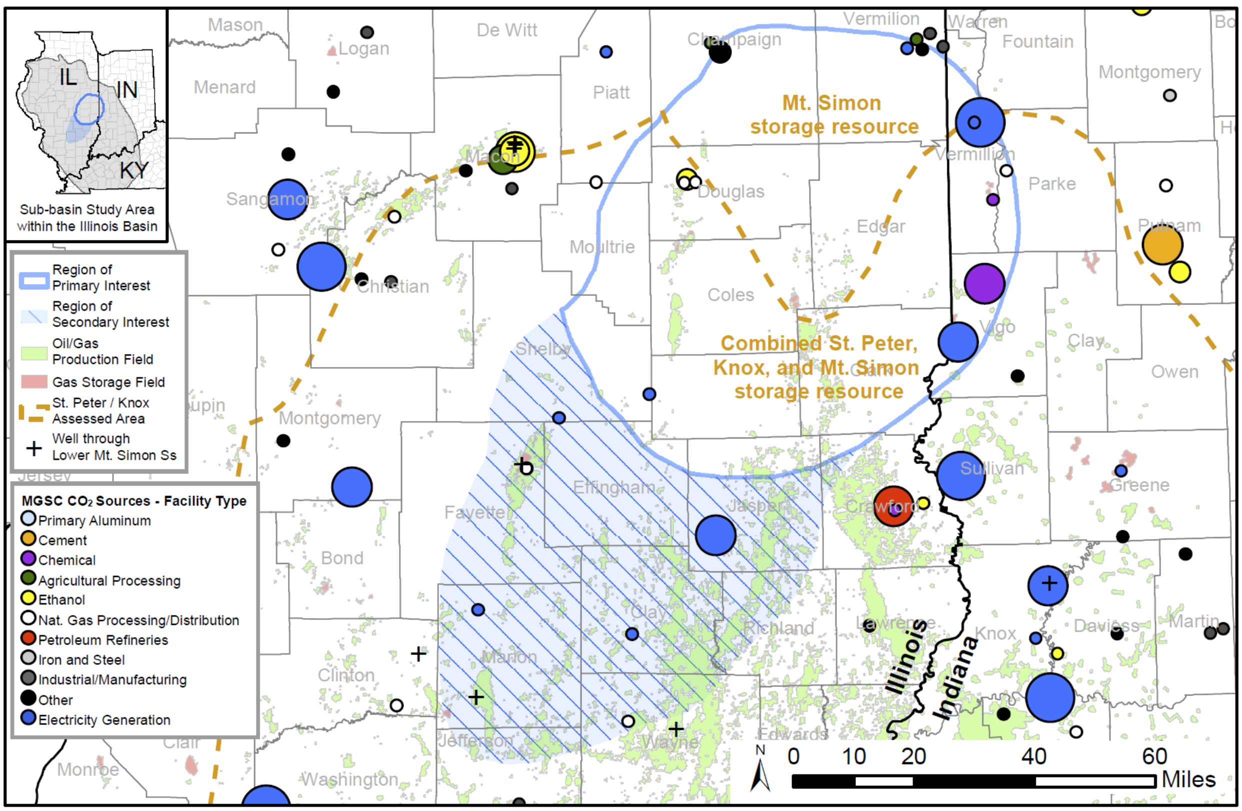

Figure 1. Pre-feasibility study area, CarbonSAFE Illinois East Sub-Basin. Major sources of CO_2 in the broad region are shown as circles, sized by relative emissions (modified from US EPA, 2017), and the area contains multiple saline storage complexes, regionally extensive seals, and opportunities for CO_2-EOR.

The East Sub-Basin study area has a number of potential geologic sequestration targets (1), including three significant deep saline reservoirs: (Mt. Simon Sandstone, Knox Group, St. Peter Sandstone), with multiple overlying seals (Eau Claire Shale, Maquoketa Shale, New Albany Shale). Additionally, potential carbon dioxide enhanced oil and gas recovery (CO_2-EOR and CO_2-EGR) and storage opportunities in Pennsylvanian and Mississippian strata exist in the region. CO_2-EOR recovery has the potential to be economically significant by improving oil recovery and providing possible storage of anthropogenic CO_2, and CO_2-EOR reservoirs could potentially be co-located (stacked) with saline storage options. Recent research has focused on a high porosity, highly arkosic zone within the Lower Mt. Simon Sandstone. Based on this work, we present a conceptual CO_2 source and storage network, which focuses on the arkosic zone in the Lower Mt. Simon as a prospective storage resource play in the Illinois East Sub-Basin region.

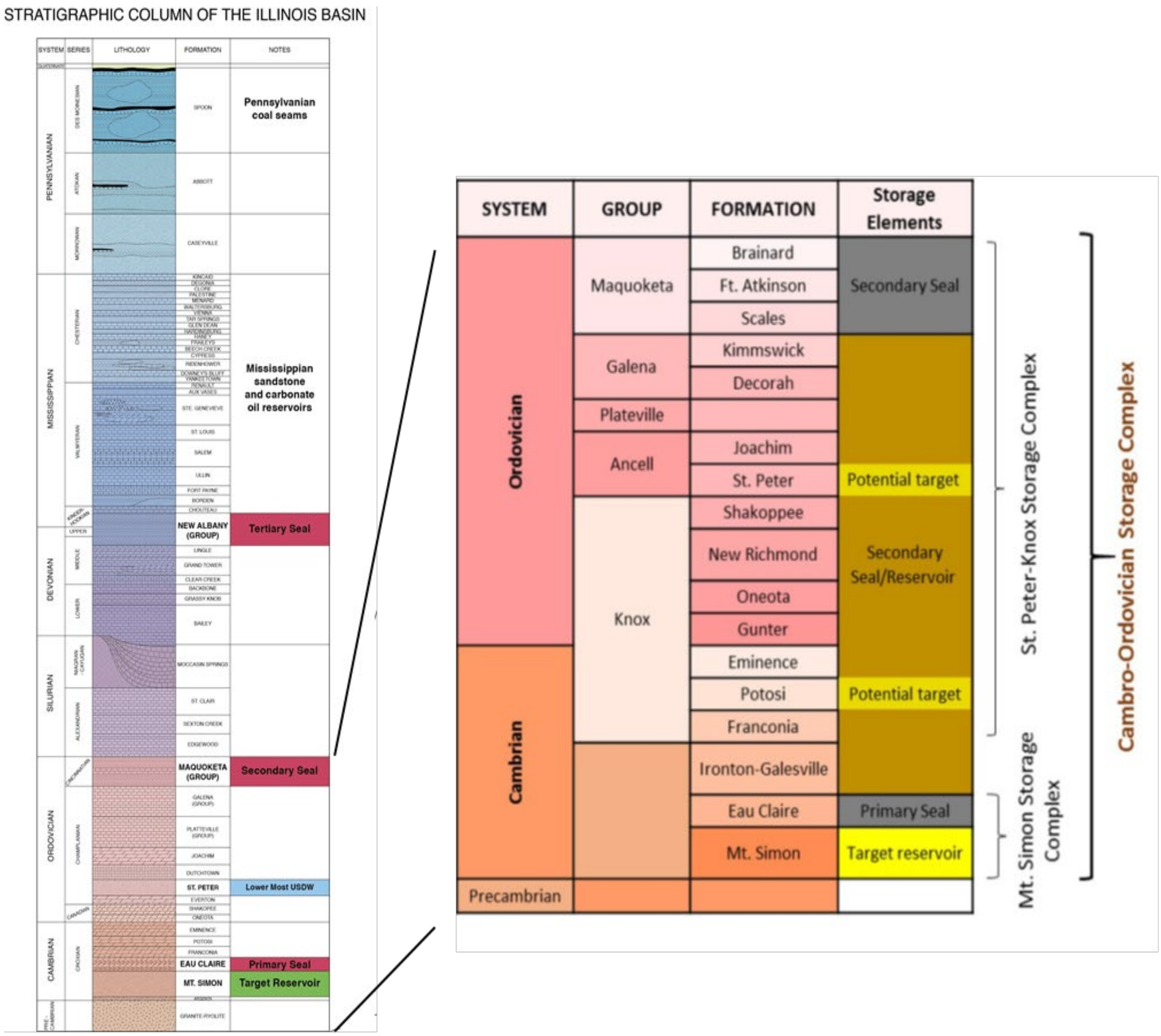

Figure 2. Generalized geologic column of the Illinois Basin (thickness not to scale) with storage complexes (reservoirs and seals) identified in Cambrian and Ordovician Strata in the Illinois Basin. Tertiary seal and oil reservoirs are identified in the overlying strata.

Commercialization of large-scale Carbon Capture and Storage in the Illinois Basin may be realized by taking advantage of CCS tax credits (under 26. U.S. Code § 45Q and 2018 FUTURE Act amendments) and potential revenue from sale of CO_2 for EOR. A 45-metric ton (50 million ton) CO_2 storage operation would primarily target capacious saline reservoirs able to store this large volume at a single location, the cost of which may be offset, at least partially, by regional CO_2 EOR interests in the long-term. Topical report DOE/FE0029445-1 provides a summary of carbon storage incentives and legislation of potential relevance to development of commercialization of large-scale carbon capture and impacts on this project.

Obstacles/hurdles to the adoption of commercial-scale CCS remain, however, e.g. in the US EPA Class VI Underground Injection Control permitting process for CO_2 injection wells, and pore space ownership and long-term liability for subsurface CO_2.

Accomplishments and Benefits of this Project

Identifying geological storage sites suitable for storage of over 50 million tonnes of CO_2 is essential for developing commercial-scale CCS projects to address greenhouse gas emissions from industrial sources. There are relatively few large carbon storage projects in deep saline reservoirs, and this gap in development knowledge is addressed by the research in this project. Our work shows that that the storage capacity is available for CCS commercial projects. The analysis of the different CO_2 sources suggests that there is a need for more drilling and 2D seismic reflection data in order to better understand the geologic and economic risk in each area. The data from this study is being used within the NRAP Toolkits to move toward validating technologies to ensure storage permanence and to improve reservoir storage efficiency. The knowledge gained will contribute to best practice manuals about CCS technology and issues that will be of broad use to other sites and future commercialization efforts.

The Pre-feasibilty CarbonSAFE Illinois East-Sub-Bbasin project resulted in the funding of the Feasibility Wabash CarbonSAFE project in Indiana (DE-FE0021626). Objectives of the Wabash project are to establish the feasibility of developing a commercial-scale geological storage complex at the Wabash Valley Resources (WVR) LLC's Wabash Integrated Gasification Combined Cycle (IGCC) plant in Vigo County, Indiana, for storage of 50 million tonnes or more of CO_2.

Pre-Feasibility Regional Assessment

Large-scale anthropogenic CO_2 sources (>100,000 tonnes/year) were catalogued for the CarbonSAFE Illinois East Sub-Basin project source assessment (Topical Report DOE/ FE0029445-2) to study the potential for commercial-scale (50 million metric tons or more) carbon capture and storage in the region. The portfolio of the source network is diverse, consisting of fossil-base power production, ethanol production operations, chemical development, and refinery facilities, most of which are relatively new or modernized (i.e. post year 2000) increasing the likelihood for successful transition to carbon capture capable.

Topical report DOE/FE0029445-9 ten facilities (Figure 3) are selected from the source network portfolio and reviewed as potential sources for commercial-scale geological storage in a regional CO_2 source and storage network study. (Blakley et al., 2019). Annual emissions data for each facility were collected from the Midwest Geological Sequestration Consortium and United States Environmental Protection Agency (US EPA) databases. Facilities listed in Table 1 , were considered in a regional commercial-scale CO_2 source and storage network study presented here.

Table 1. Selected large-scale anthropogenic CO_2 sources (>100,000 tonnes/year) considered in the CarbonSAFE Illinois – East Sub-Basin source and storage network study.

Facility/Company	Class	City	County	State	CO_2 Tonnes	Source	Feedstock/Fuel
Abbott Power Plant (University of Illinois)	Power Plant, Steam Generation	Champaign	Champaign	IL	236,628	EPA (2017)	Natural Gas, Fuel Oil, Coal
Archer Daniels Midland Co.	Ethanol Production, Injection of CO_2 Waste	Decatur	Macon	IL	4,490,465	EPA (2017)	Coal, Corn
City Water, Light, & Power	Power Plant	Springfield	Sangamon	IL	2,631,577	EPA (2017)	Coal
Cronus Fertilizer Plant (in development)	Urea, Ammonia	Tuscola	Douglas	IL	N/A	N/A	Natural Gas
Edwardsport Power Station	Power Plant	Edwardsport	Knox	IN	3,431,750	EPA (2017)	Coal, Petcoke
Gibson Generating Station	Power Plant	Owensville	Gibson	IN	16,331,848	EPA (2017)	Coal
Gibson City Energy	Ethanol Production, Waste	Gibson City	Ford	IL	175,020	EPA (2017)	Natural Gas, Fuel Oil, Corn
Prairie State Generating Company	Power Plant	Marissa	Washington	IL	11,086,886	EPA (2017)	Coal
Marathon Petroleum Co. Robinson Refinery	Petroleum Refinery, Petroleum Product Supplier	Robinson	Crawford	IL	1,723,628	EPA (2017)	Natural Gas, Crude oil
Wabash Valley Resources (in development)	Ammonia	Terre Haute	Vigo	IN	1,570,000	Company Projection	Coal, Petcoke

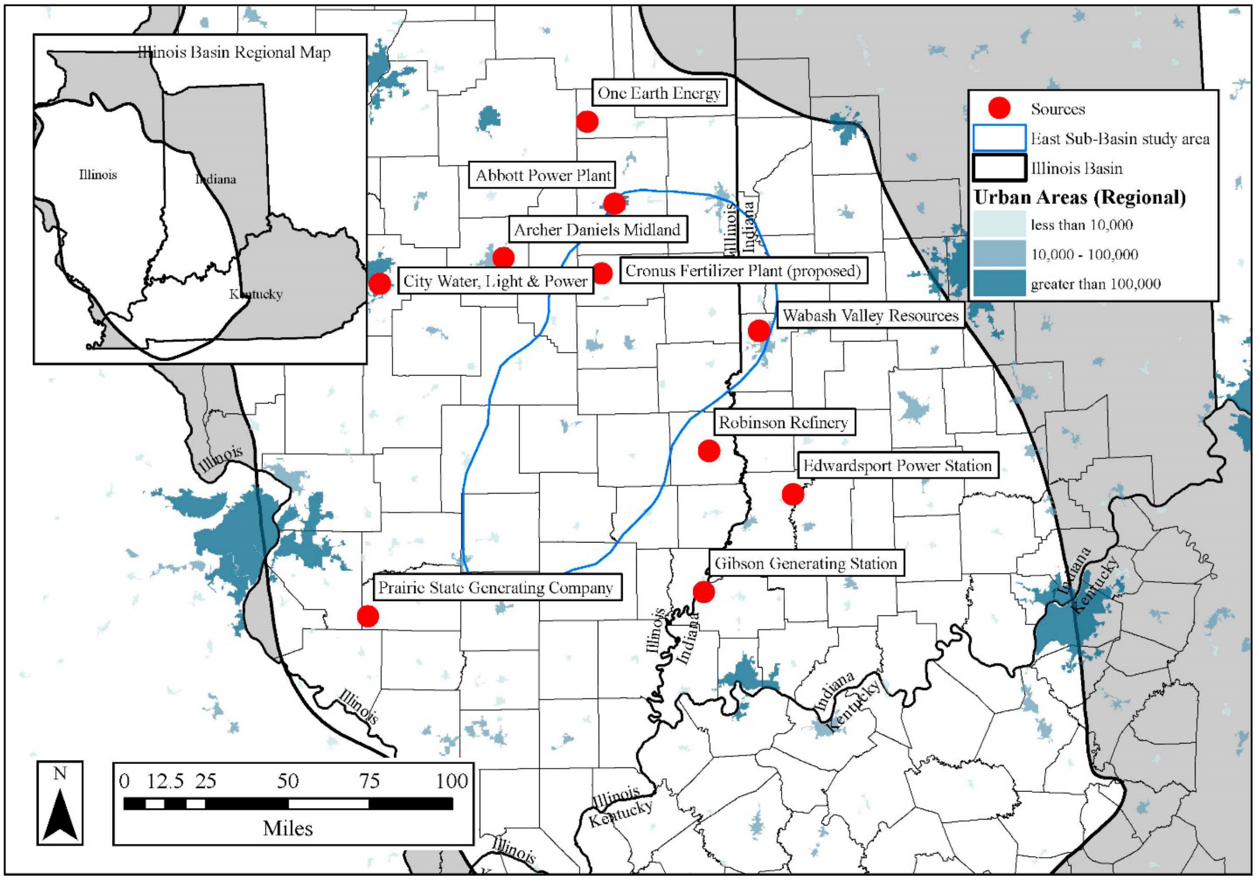

Figure 3. Selected anthropogenic CO_2 sources in the CarbonSAFE Illinois – East Sub-Basin region (CO_2 emissions greater than 100,000 tonnes/year) are shown as red circles and include plant names.

Regional Geologic Assessment

The study area has numerous potential geologic sequestration targets, including three deep saline reservoirs with corresponding seals, and there is potential enhanced oil recovery (EOR) opportunities within shallower Mississippian reservoirs. Recent research has focused on a high porosity, highly arkosic zone within the Lower Mt. Simon Sandstone. Based on this work, we present a conceptual CO_2 source and storage network, which focuses on the arkosic zone in the Lower Mt. Simon as a prospective storage resource play in the Illinois East Sub-Basin region.

The DOE/FE0029445-9 topical report summarizes the regional geology and potential geologic sequestration targets of the East Sub-Basin including three significant deep saline reservoirs with corresponding seals, and potential CO_2-EOR opportunities (Figure 2). Recent geological research has focused on a high porosity, arkosic zone within the Lower Mt. Simon Sandstone as a prospective storage resource play in the region. No actual CCS project would proceed far without site-specific data, but the regional-scale inferences about both reservoir and caprock quality will help project operators identify Midwestern subregions that may provide suitable sequestration targets for specific CO_2 sources.

Deep Saline Storage

Mt. Simon Sandstone

The Mt. Simon Sandstone is considered the most significant sequestration target in the Midwest of the United States and is present throughout the study area. The Mt. Simon Sandstone is the prime storage reservoir target for CO_2 storage in the Illinois Basin because of its thickness, available pore space, depth and saline water content. Characterization of the Mt. Simon was performed largely through extensive evaluation within the Illinois Basin by the Midwest Geological Sequestration Consortium (MGSC) as part of the Regional Carbon Sequestration Partnership (RCSP) program. Several reference studies have assessed the physical characteristics of the Mt. Simon relative to storage capacity (Medina et al., 2011; Medina and Rupp, 2012), rate of injection (Barnes et al., 2009; Birkholzer and Zhou, 2009), reactivity of CO_2 (Bowen et al., 2011; Liu et al., 2011), and Mt. Simon mineralogy (Lovell and Bowen, 2013).

The Mt. Simon Sandstone is the target reservoir for two CCS demonstration projects. The Illinois Basin – Decatur Project (IBDP) located at the Archer Daniels Midland (ADM) facility in Decatur, IL, began CO_2 injection into the Mt. Simon Sandstone in late 2011 at a rate of 1,000 metric tons/day (1102 tons/day) over a 3-year period for a total of 1 MT (1,102,311 million tons) CO_2.

The IBDP project is now in post-injection monitoring phase through 2020. Illinois Industrial Carbon Capture and Storage Project (IL-ICCS) 1 mile north of IBDP, began injecting 2,000 - 3,000 metric tons/day (2,205 – 3,307 tons/day) in April 2017 for an expected five-year duration and cumulative storage of 4.75 MT (5.24 million tons). To date the IL-ICCS project has injected over 1,175,000 metric tons (1,295,216 tonnes) CO_2 in the Mt. Simon Sandstone.

Brine salinity affects CO_2 solubility and brine density and is important in understanding the storage capacity of the formation. The map of brine salinity within the Mt. Simon Sandstone in Illinois and Indiana shows a complex distribution of total dissolved solids and suggest that the northern and parts of the western areas of Illinois are unsuitable for storage since they salinities are less than 10,000 mg/l which is the US EPA definition of potable water.

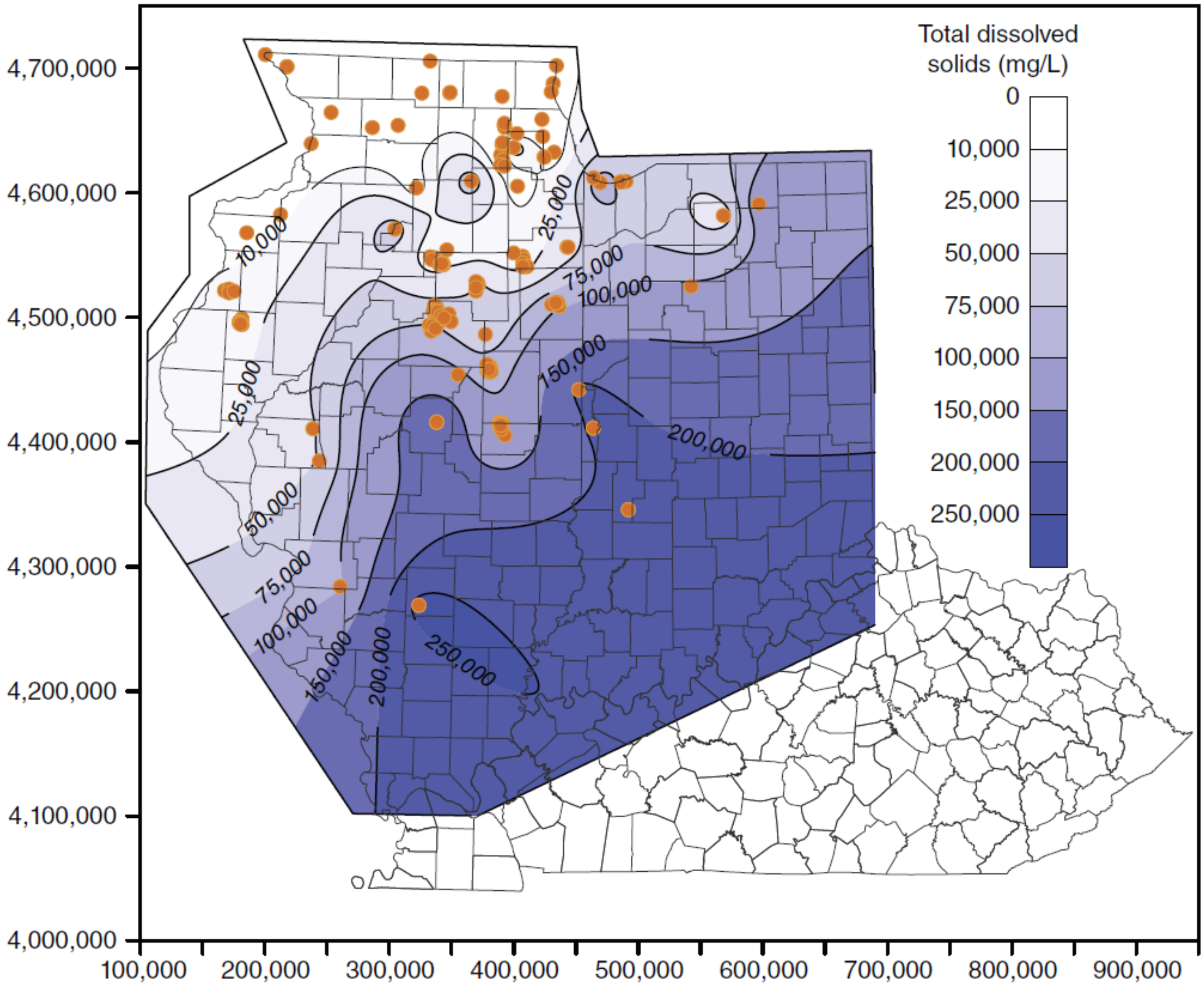

Figure 4. Concentration of total dissolved components in the Mt. Simon Sandstone reservoir waters increases from fresh water in the north to concentrated brines in the south (from Mehnert and Weberling, 2014).

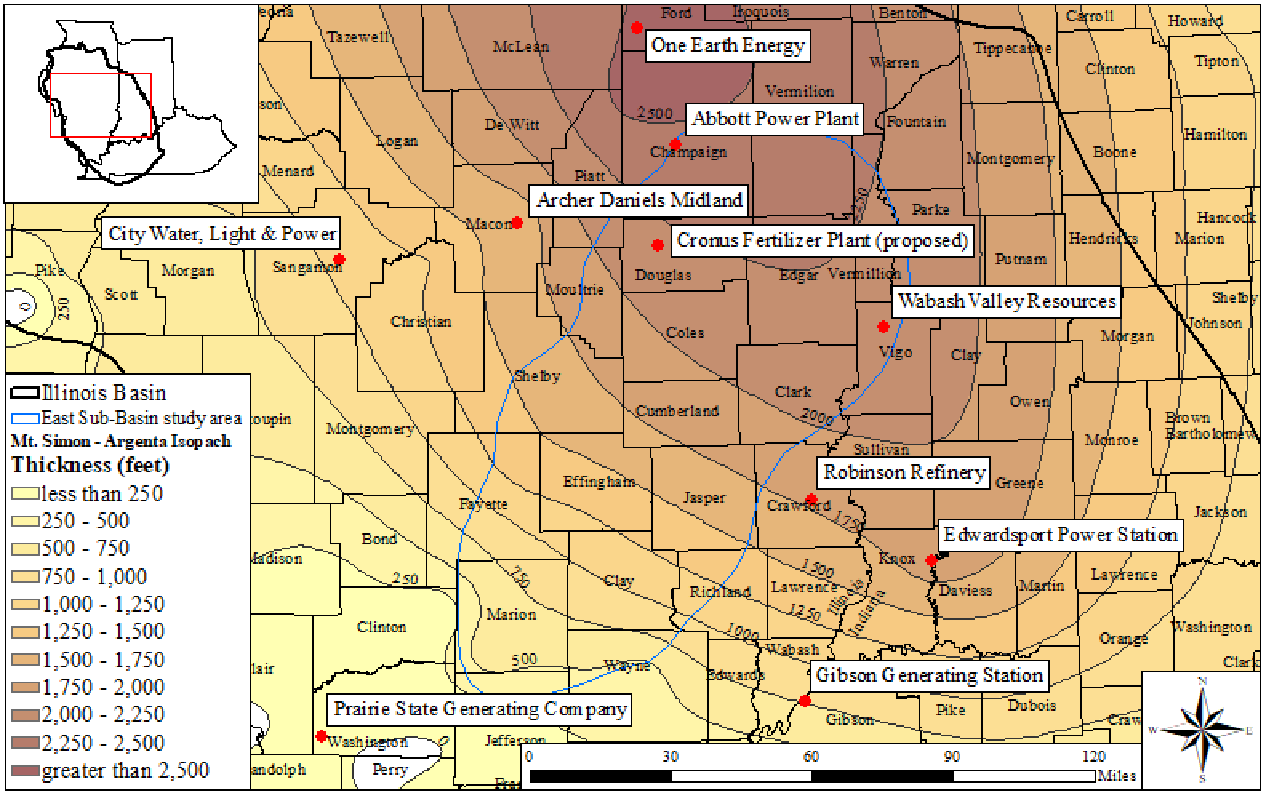

Figure 5. Regional thickness of combined Mt. Simon Sandstone and Argenta formations.

In the East Sub-Basin study area, the Mt. Simon Sandstone can be 1,000 to over 2,000 feet (305 to over 610 m) in thickness (Figure 5) occurring 6,000 to 10,000 feet (1829 to 3048 m) in depth (Figure 6). The north-central portion of the study area has the thickest Mt. Simon Sandstone, whereas the western and southern flanks of the Illinois Basin have a Mt. Simon that either thin or not present (Leetaru and McBride, 2009). The Mt. Simon Sandstone can be divided into Lower, Middle, and Upper sections based on petrophysical, depositional and diagenetic attributes (Leetaru and McBride, 2009; Medina and Rupp, 2012; Freiburg et al., 2016).

The Lower Mt. Simon is considered the best potential reservoir for carbon storage, with the highest quality reservoir found within an arkosic zone. Lower Mt Simon well logs and regional trends indicate porosity and permeability are 16.3% and 11.1 mD (Mehnert et al., 2014). The Hinton #7 well, located in the Manlove Natural Gas Storage Field, Champaign Co., Illinois, has 215 feet (66 m) of excellent quality reservoir in the arkose zone with porosity and permeability values up to 25% and 600 mD. At IBDP and IL-ICCS the Lower Mt. Simon Sandstone has porosity and permeability as high as 27% and 400 mD, and a mean (log) porosity of 16.6%. Lateral continuity of the reservoir in the Lower Mt. Simon is uncertain because of limited well control, but most wells within the southern half of the Mt. Simon depocenter that penetrate the Lower Mt. Simon show the occurrence of a porous zone (Figure 7).

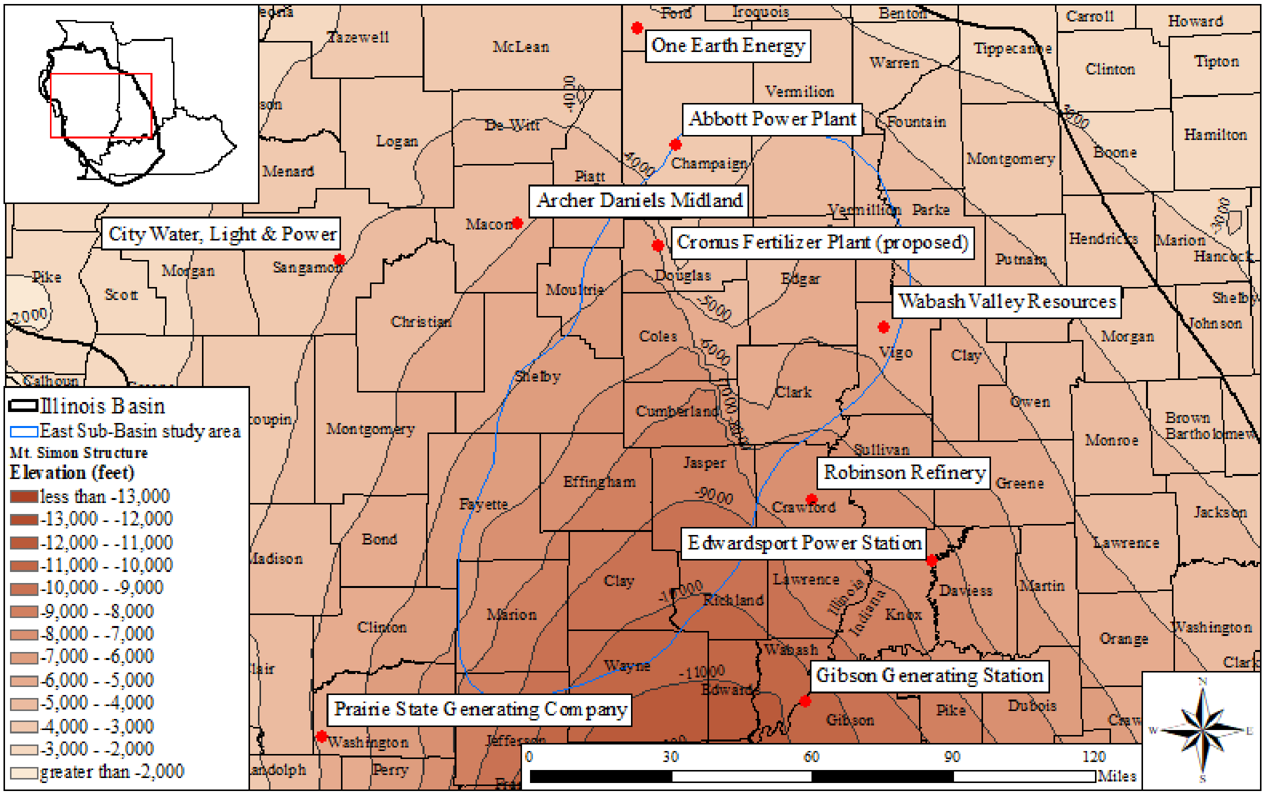

Figure 6. Regional Structure (elevation in feet) of the Mt. Simon Formation in the expanded East Sub-Basin study area.

The Middle and Upper Mt. Simon generally demonstrate poorer reservoir properties except in thin tidal flat channel sands in the Upper Mt. Simon where they are utilized for natural gas storage (Morse and Leetaru, 2005). The Middle Mt. Simon is the tightest section of the Mt. Simon, with porosity below 10% and permeabilities below 10 mD. Regional log averages of Upper Mt. Simon porosity and permeability are 8.5% and 5.4 mD, respectively, although more porous and permeable units are present.

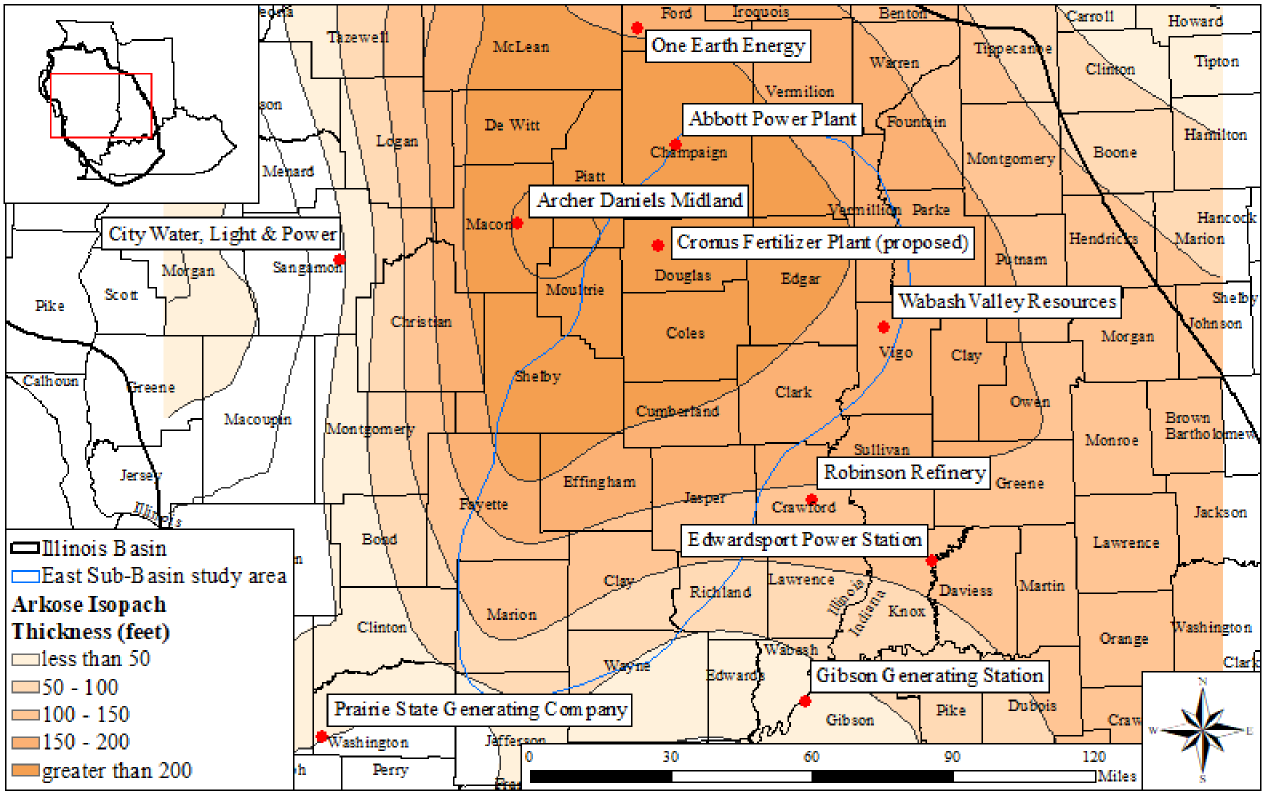

Figure 7. Mapped extent of the regional thickness (feet) of the highly arkosic zone in the Lower Mt. Simon Sandstone.

Cambro-Ordovician Knox Group and the St. Peter Sandstone

The Knox project (DE-FE0002068) conducted studies during 2009–2014 to investigate and validate the utility of the Cambro-Ordovician Knox Group and St. Peter Sandstone geologic strata for underground storage of carbon dioxide in the Illinois and Michigan Basins covering the states of Illinois, Indiana, Kentucky, and Michigan. In the subsurface of the midwestern United States, the Knox and associated strata extend continuously over an area approaching 500,000 sq. km, about three times as large as the State of Illinois (DE-FE0002068). In the southern part of the study area sequestration opportunities in the Cambrian and Ordovician Knox Group and the Ordovician St. Peter Sandstone.

Knox Carbonates

The Knox Dolomite Megagroup comprises the Cambrian, Lower Ordovician, and lowermost Middle Ordovician rocks of the Illinois Basin which overly the Mt. Simon Sandstone (Buschbach, 1975). The Knox Group is an attractive target for CO_2 sequestration as these strata are laterally extensive and contain beds of porous and permeable dolomites and sandstones with overlying tight shale and carbonate beds. The Knox succession thickens in a southeast direction; its thickness ranges from nearly 800 ft (243 m) in the extreme northwest to nearly 8,000 ft (2,430 m) in the Reelfoot Rift in the extreme southeastern part of Illinois (DE-FE0002068). There are over 2,000 feet (610 m) of Knox carbonates present in most of the East Sub-Basin. The Potosi Dolomite, a formation within the Knox, is characterized by up to 7 feet (2 m) thick vuggy intervals and brecciated zones that suggest a paleokarst environment (Freiburg and Leetaru, 2012), and is a viable storage target as reservoir modeling suggests that it could contain approximately 90 million metric tons (99 million tons) of CO_2 from a single injection well (Will et al., 2014). A comprehensive evaluation of the lateral and vertical lithologic variations of the rocks within the Upper Cambrian through Lower Ordovician succession (Sauk II–III sequences) deposits in Illinois that could serve as a reservoir or seal for CO_2 storage is presented in Lasemi and Khorasgani, 2014.

St. Peter Sandstone

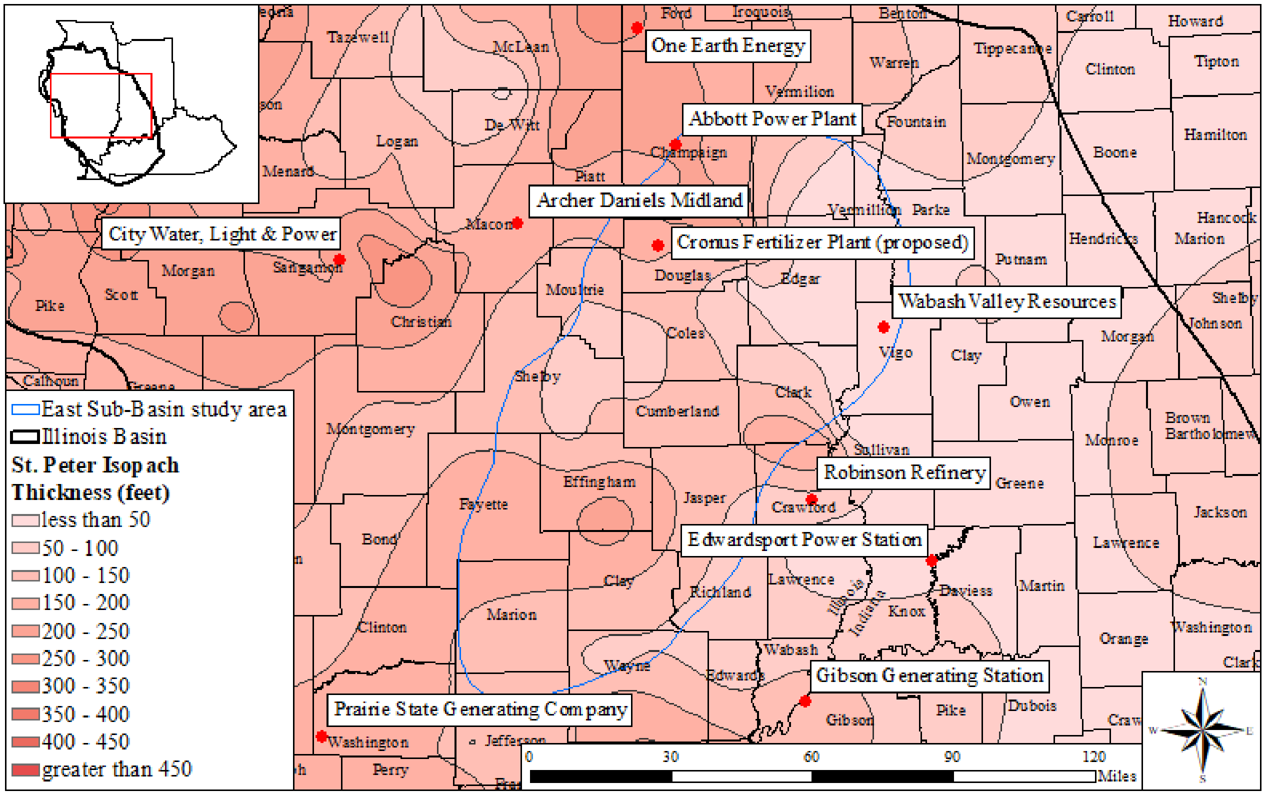

Figure 8. Regional thickness (feet) of the St. Peter Sandstone.

The St. Peter Sandstone (Figure 8) provides another alternative storage target, although reservoir conditions are unsuitable for long term CO_2 storage regionally. The Middle Ordovician-age St. Peter Sandstone is a widespread, lithologically distinct, typically pure quartz arenite lithostratigraphic unit found throughout the upper Midwest, USA (DE-FE0002068). The topical report DOE/FE0002068-6 summarizes the stratigraphy of the St. Peter Sandstone (Barnes and Ellett, 2014). In the northern part of the Illinois Basin, the St. Peter Sandstone is a major aquifer where it is around 325 ft (~100 m) thick, occurring at shallow depths with less than 10,000 mg/L TDS (total dissolved solids) making it unsuitable for any storage project. Additionally, where the St. Peter Sandstone occurs near surface it is extensively mined for silica sand where it occurs near the surface an important silica sand source.

Topical report DOE/FE0002068-7 (Will et al., 2014) addresses the question of whether or not the St. Peter Sandstone may serve as a suitable target for CO_2 sequestration at locations within the Illinois Basin, where it lies at greater depths (below the underground source of drinking water [USDW]). The following may be inferred from reservoir flow simulation using the rock properties expected in the study area (Will et al., 2014): at depths of 3,500 ft. (1065 m) an injection rate of 3.2 MTPA for a 30 year period may be achieved with a single well; at 4,000 feet (1220 m) and deeper, two or more injection wells would be required. In the southwestern part of the study area where the Mt. Simon Sandstone is unsuitable for long term commercial storage the St. Peter may provide a viable storage reservoir. St. Peter Sandstone thins eastward and southward throughout the basin into Indiana and Kentucky where the formation pinches out rapidly and is therefore not suitable as a CO_2 storage target.

CO_2-EOR and Storage Possibility in Illinois East Sub-Basin

The Illinois Basin is a hydrocarbon-bearing intracratonic basin with regionally significant CO_2 storage resources and commercial development potential. In terms of CO_2 storage resources, the Illinois Basin has 1.6 to 3.2 billion metric tons (1.8 to 3.5 billion tons) of estimated storage in coal seams, 140 to 440 million metric tons (154 to 485 million tons) in mature oil reservoirs (US DOE 2012), and 41 to 421 billion metric tons (45 to 464 billion tons). of estimated CO_2 storage resources in saline reservoirs (US DOE 2015). Conventional oil reservoir resource target for CO_2-EOR in the ILB is 0.9 to 1.3 billion barrels recoverable (MGSC 2005), not including potential residual oil zones (ROZs).

CO_2-EOR recovery in the Illinois Basin has the potential to be economically significant by improving oil recovery and providing possible storage of anthropogenic CO_2, and CO_2-EOR reservoirs could potentially be co-located (stacked) with saline storage options. CO_2-EOR interests in the wider region may assist the economics of a storage project long-term, via potential revenue from sale of CO_2 for EOR and/or by taking advantage of Carbon Capture and Storage (CCS) tax credits under 26. U.S. Code § 45Q (and 2018 FUTURE Act amendments).

The topical report DOE-FE0029445-10 discusses the potential development and implementation of CO_2-EOR and CO_2-EGR opportunities that may be available in the Illinois Basin that could supplement deep saline storage. Enhanced oil recovery through miscible, near miscible, and immiscible CO_2 flooding in the ILB can be economically significant because it would improve recovery from oil fields and will result in storage of anthropogenic CO_2. Reservoir flow simulation suggested that there could be between 6 to 12% additional oil recovered using CO_2 injection in both immiscible and miscible conditions.
The Ordovician through Pennsylvanian succession in southern Illinois contains several sandstone, limestone, and dolomite reservoirs that are prolific oil producers (Figure 9) in a number of oil fields in which both stratigraphic and structural controls were responsible for petroleum entrapment. Carbonate reservoirs selected for CO_2-EOR include the reservoir intervals developed in the Ordovician "Galena/Trenton" (Kimmswick Limestone), Devonian Geneva Dolomite Member of the Grand Tower Limestone, and Mississippian Ullin, Salem, St. Louis, and St. Genevieve limestone units. Siliciclastic reservoirs including, Aux Vases, Yankeetown ("Benoist"), Bethel, and Cypress sandstones are also good candidates for miscible/near miscible CO_2-EOR.

From 2003-2005, the MGSC assessed oil reservoirs and fields in the Illinois Basin (Finley, 2005). Data were assessed at the reservoir level, e.g. average reservoir properties to estimate original oil in place (OOIP) and temperature and pressure gradients were applied to average reservoir depths to estimate miscibility classification. Similarly, CO_2 storage and oil recovery factors (derived from oil production results and simulation work) were applied to the OOIP values, based on reservoir groupings of similar lithologies and whether the CO_2-miscibility type was miscible or immiscible. The combinations of

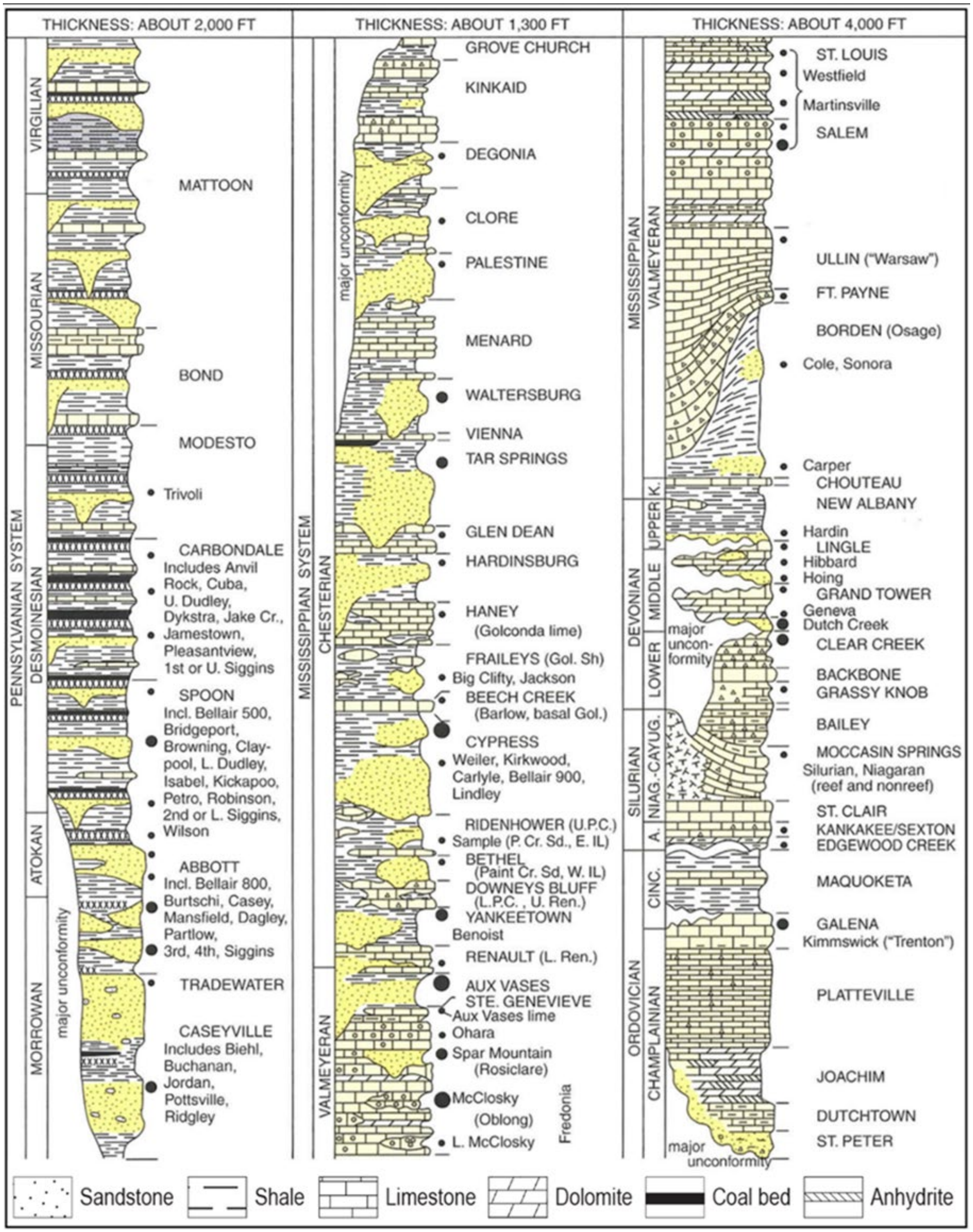

Figure 9. General stratigraphic column of the Ordovician through Middle Pennsylvanian succession in southern Illinois showing formal and informal units. Oil productive intervals are shown as solid circles (modified from Huff and Seyler, 2010).

temperature and pressure creating the largest near-miscible range were used as criteria for assigning miscibility classes to the oil reservoirs based on depth. Estimations between 240 to 380 million barrels of oil (MMBO) are potentially recoverable in CO_2-miscible reservoirs, with a miscible- CO_2-flooding storage potential of 58 to 180 million metric tons (64 to 198 million tons).

The MGSC regional CO_2-EOR results have largely been presented in map form (Figure 10), at the field-summary level. Although this representation has been an effective tool for illustrating the regional CO_2-EOR overview in the Illinois, but it tends to draw a focus to the deeper center of the basin where fields with predominantly miscible conditions are located, and the field-level representation masks additional conditions for miscibility in the outer-lying (and generally, shallower) belts of predominantly near-miscible and immiscible oil fields.

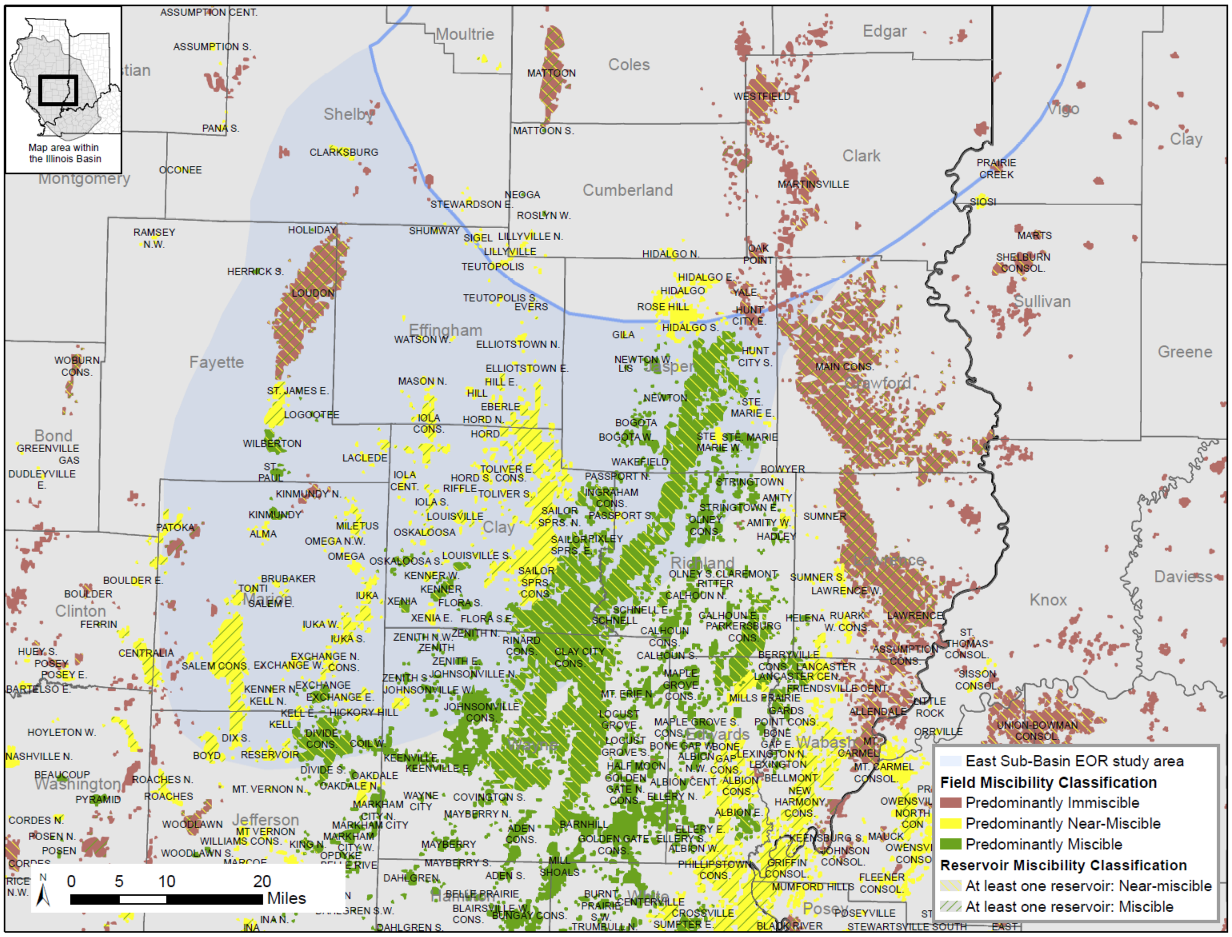

Figure 10. CarbonSAFE Illinois East Sub-Basin CO2-EOR area of study. Field-level results (solid colors) from MGSC Phase I work (Finley, 2005) were supplemented with reservoir-level results (hachured lines), showing an additional level of CO2-miscibility information for oil fields in the area.

For example, by supplementing the field representations with reservoir-level results, fields outside the predominantly miscible zone in the deeper center of the Illinois Basin (Figure 10, i.e. predominantly near-miscible and some predominantly immiscible fields) are shown to have at least one reservoir with miscible conditions for CO_2 flooding. Similarly, the deeper fields in the center of the basin shown to be predominantly miscible (e.g. Clay City Consolidated) also contain shallower reservoirs in the near-miscible and immiscible categories.

In addition, related studies have identified and assessed ROZs in sandstone and carbonate formations throughout the region to determine the CO_2 storage and EOR resource potential. ROZs have large associated storage potential, especially because they are believed to occur in regional fairways with multiple, stacked, porous and permeable formations separated by laterally extensive caprocks. ROZs do not exist in isolation: because potential ROZ fairways in different formations overlap, there is potential for vertically stacked ROZs at any given site. Chesterian sandstones, including the Cypress, Benoist, Hardinsburg, and Waltersburg Sandstones (Figure *9*), have analogous lithology and texture, and form thick and extensive sandstone belts in the Illinois Basin. Likewise, thick, coarser textured sandstone belts with thin oil reservoirs and vast CO_2 storage potential are also known to occur, albeit at shallower depths, within the Caseyville and Tradewater Formations of the Lower and Middle Pennsylvanian. Additional ROZ potential exists in thick, water-bearing Lower and Middle Mississippian and Lower Paleozoic formations as well. The Carper Sandstone is an example of this type of reservoir, which, despite some oil production in brownfield settings, is relatively understudied. Finally, certain carbonate formations such as the Mississippian Ullin Limestone and the Devonian Geneva Dolomite (Figure *9*) are also thick and extensive with characteristics indicative of ROZs, including oil shows with high water cut in areas where production is attempted.

Ongoing studies will highlight key reservoirs in primary fields of interest and provide the basis for targeted oilfield and site-specific work in assessing the feasibility of industrial-scale CO_2 storage and CO_2-EOR. In areas without known oil fields, numerous opportunities exist for saline reservoir storage – both as strict saline storage and as storage associated with ROZs. The associated storage potential in these ROZ fairways, not accounting for main pay zones or underlying brine formations, is estimated to 6.9 billion tonnes for continuous CO_2 flooding.

Seals

Eau Claire Shale

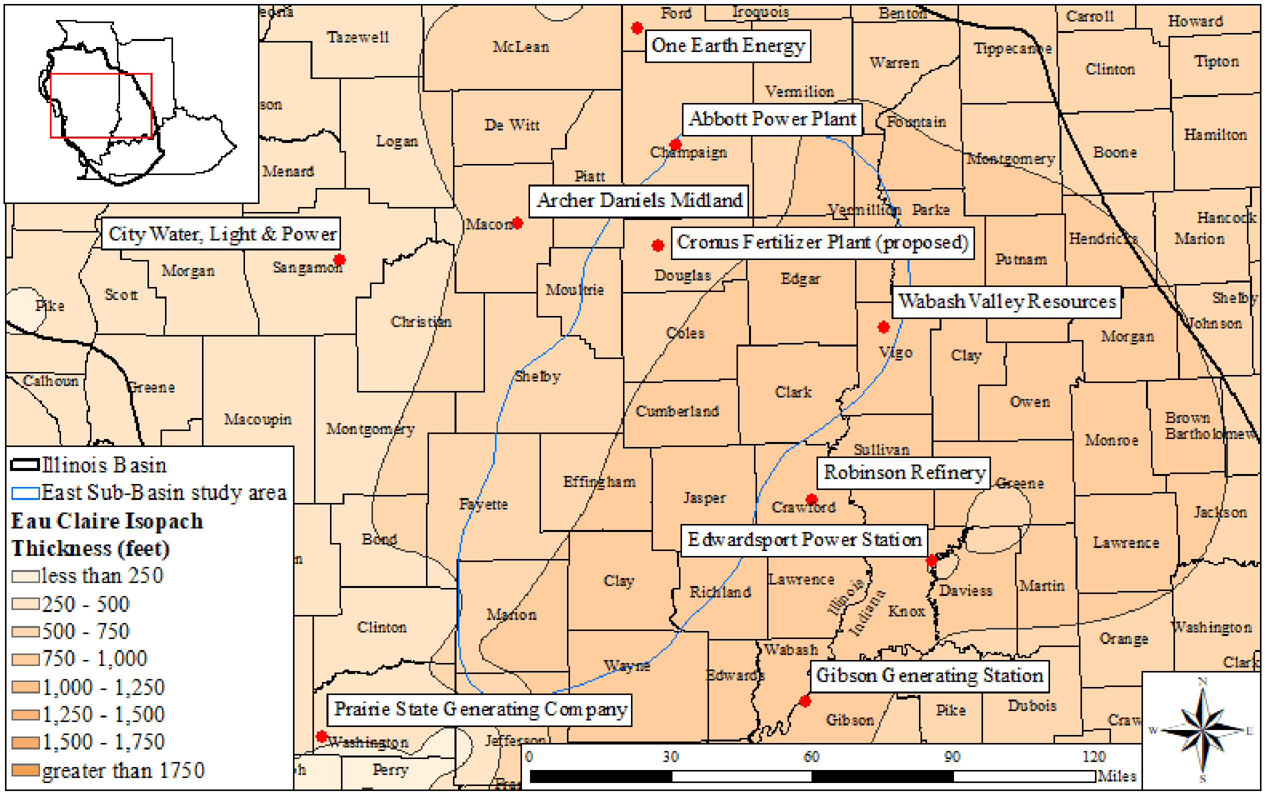

Figure 11. Regional thickness of the Eau Claire Shale.

The Eau Claire Formation (Figure 11) has been identified as the primary seal that would prevent the upward migration of supercritical CO_2 following injection into the underlying Mount Simon Sandstone (Leetaru and McBride, 2009; Medina et al., 2011; Medina and Rupp, 2012; Carroll et al., 2013; Lahann et al., 2014). The Eau Claire consists of dolomite, dolomitic sandstone, siltstone, and shale, with regional variations in dominant lithology across the Basin. In east-central Illinois and west-central Indiana, the lowermost Eau Claire facies, directly overlying the Mt. Simon, is dominated by shale and tight siltstone. The Eau Claire Formation and laterally equivalent Bonneterre Formation extend across the Midwest, existing at least in some parts in Indiana, Ohio, Kentucky, Michigan, Wisconsin, Illinois, Iowa, and Missouri (Gutstadt, 1958). The Eau Claire ranges in thickness from approximately 100 feet (30 m) in western Illinois to more than 1,200 feet (300 m) in southern Illinois (30 to 300 m) reaching maximum thickness of approximately 2,750 ft. (838 m) in the Rough Creek Graben of western Kentucky (Sargent 1991).

Maquoketa Shale

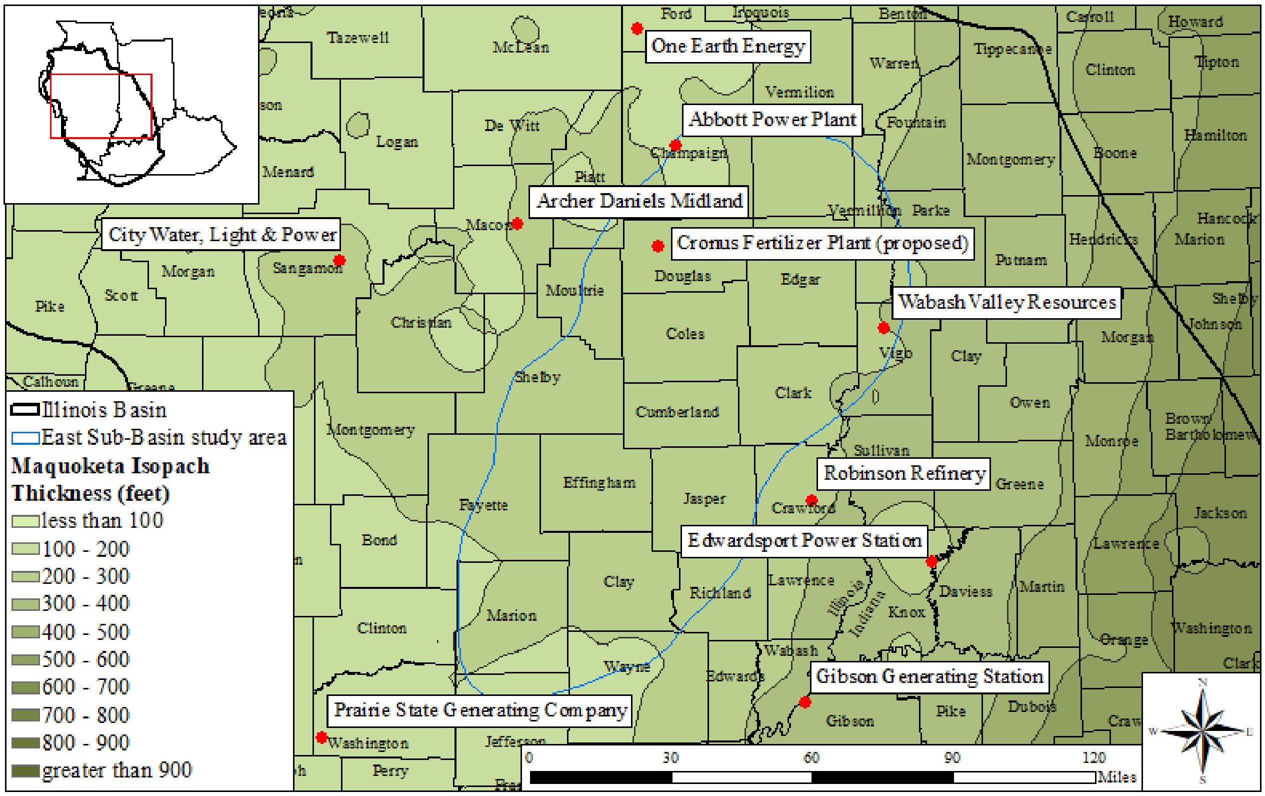

Figure 12. Regional thickness of Maquoketa shale formation.

The Ordovician Maquoketa Shale (Figure 12) is a laterally continuous impermeable confining layer composed of a heterogeneous sequence of carbonates, silts, and clay-rich rock units which functions as a seal in the Cambro-Ordovician storage complex in the Illinois Basin.

Topical report DOE-FE0029445-11 provides a regional evaluation of the seal capacity of the Maquoketa Shale Group in the CarbonSAFE-Illinois Basin (IB) study area (Figure 13). A regional-scale lithofacies model was developed, based on the wireline response of gamma-ray (GR), neutron (NPHI), and density (RHOB) logs. Two control wells in Macon Co., IL and Gibson Co., IN, provided Elemental Log Analysis (ELAN) log, a probabilistic mineralogical model based on the observed log response from multiple borehole geophysical tools based on known values of mineral responses to such tools (Medina et al., 2019) and portable X-ray fluorescence (pXRF) for elemental compositional analysis that were used to calibrate and verify the log-based interpretations.

Mercury injection capillary pressure (MICP) analysis were performed on 28 samples from 3 wells in White Co., Gibson Co., and Pike Co., in southwest IN to examine the rock grain density, porosity, and permeability. Data from thin sections, additional pXRF, and X-ray diffraction (XRD) from this sample set was incorporated into the regional lithofacies analysis.

The Maquoketa Group was separated into five lithofacies: (1) limestone; (2) muddy limestone; (3) calcitic/dolomitic shale; (4) silty shale; and (5) shale. These five lithofacies can be grouped into three major units consisting of an upper clastic, middle carbonate, and lower clastic, which is consistent

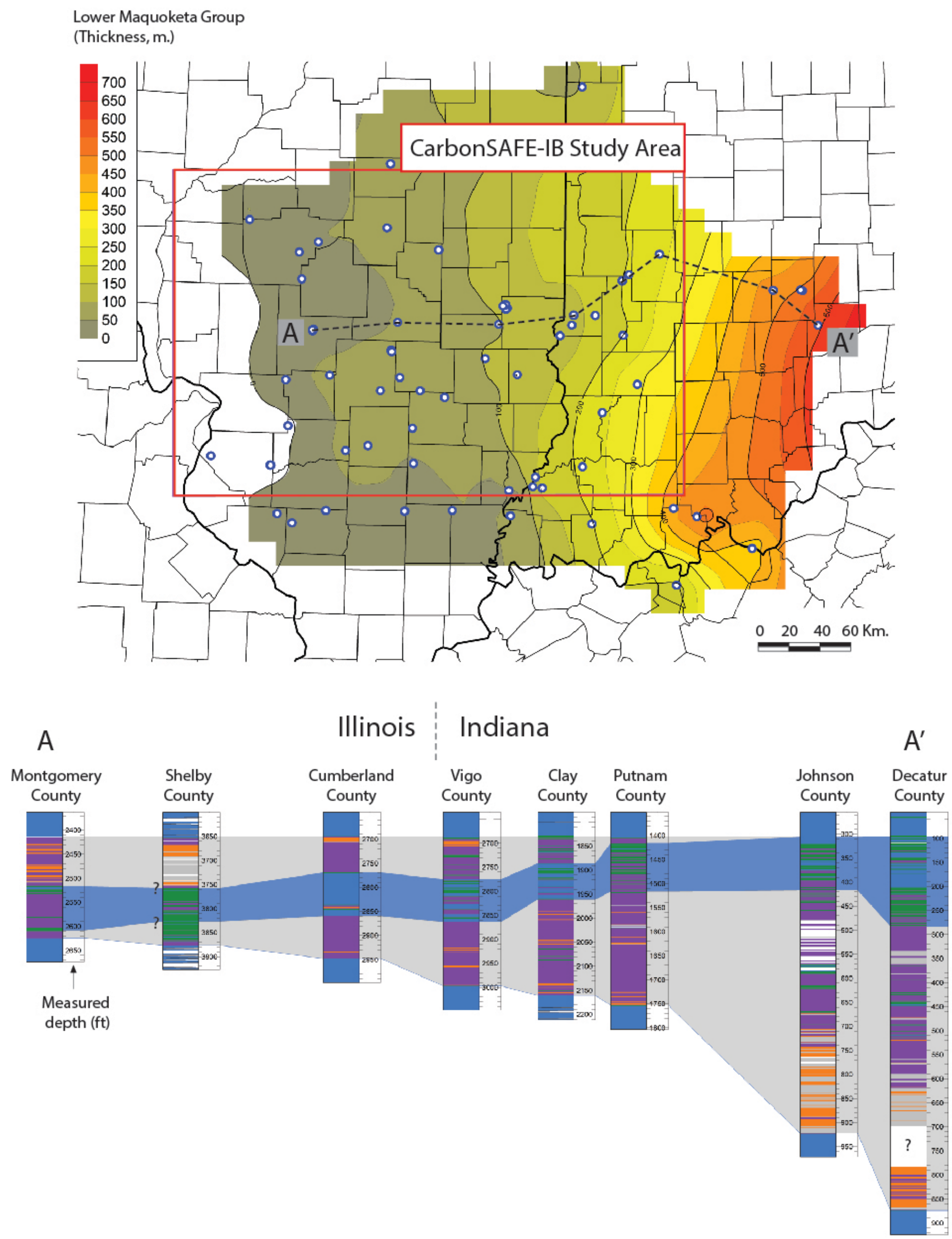

Figure 13. Isopach map of the Lower Maquoketa Group in the CarbonSAFE-Illinois Basin (IB). The cross section illustrates the relative position of the Middle Unit that enhances the thickening of the Lower Unit. The red rectangle indicates the prefeasibility study area.

With previously proposed stratigraphic subdivisions of the Brainard Shale, Fort Atkinson Limestone, and Scales Shale, respectively (Gray, 1972).

Overall, the thickness of the Lower Unit of the Maquoketa Group increases to the east in the study area; Figure 13 illustrates that trend. The relative stratigraphic position of the middle unit (carbonate-rich), varies from middle to lower (relative to the entire Maquoketa Group) in the west (shallower portions of the Illinois Basin), to upper in the deeper portions of the Illinois Basin towards the east.

New Albany Shale

The Devonian-Mississippian New Albany Shale is an important hydrocarbon source and impermeable, laterally continuous seal for CCS in Illinois Basin. The New Albany Shale is more than 460 ft thick in the southern part of the Illinois Basin in southeastern Illinois and western Kentucky. Along the margins of the Illinois Basin it thins with the exception of west-central Illinois where it can reach thickness of more than 300 ft.

Storage Complexes in the East Sub-Basin

The Mt. Simon has excellent properties for large-scale carbon storage: it is deeply buried with pressures and temperatures maintaining CO_2 as supercritical; contains highly saline formation fluids; has storage capacity (12 to 172 GT; US DOE, 2015); is overlain by numerous laterally extensive sealing formations; and has suitable petrophysical characteristics for injection.

The Knox Project DE-FE0002068 developed regional CO_2 storage resource estimates for the Knox [DOE/FE0002068-19 (Harris et al., 2014)] and St. Peter Sandstone [DOE/FE0002068-6 (Barnes and Ellett, 2014)] for use in future version of the DOE's North American CO_2 Storage Resource Atlas. US DOE regional study assessed the potential storage capacity of these units, through numerically simulated CO_2 injection, at various reservoir conditions (Leetaru, 2014a). Simulation determined that each reservoir independently has capacity to store almost 90 million tonnes of CO_2 at a single site.

Although many CO_2-EOR reservoirs could potentially be co-located (stacked) with saline storage options, the Cypress Sandstone will be used as a proxy for CO_2-EOR reservoirs for this discussion. The Cypress has numerous opportunities for saline reservoir sequestration in the East Sub-Basin areas without oil fields – both as strict saline storage and storage associated with ROZ.

Recent work in the East Sub-Basin region has focused on a high porosity, highly arkosic zone within the Lower Mt. Simon Sandstone. Because of the sparsity of wells in the Illinois Basin that penetrate the Lower Mt. Simon, the lateral extent of this reservoir is not well known. Figure 7 shows the preliminary interpolated regional extent and thickness of this 'arkosic zone,' from which updated CO_2 storage resource estimates were derived.

Previous regional storage estimates of the Mt. Simon Sandstone assumed a conservative 8% porosity over the entire Mt. Simon thickness. However, log analysis shows the arkosic zone in the Lower Mt. Simon has average porosities approaching 19%. Using an average porosity representative of the arkosic zone (20%) yields total Mt. Simon CO_2 storage resource estimates ranging from 2.0 to 27.5 billion tonnes over the East Sub-Basin project area (primary and secondary areas of interest). The incremental storage (0.4 to 5.0 billion metric tons or 0.44 to 5.5 billions tons) in the refined arkosic zone map represents roughly a 22% increase in the estimated Mt. Simon storage resource over the East Sub-Basin study area, and highlights the importance of this reservoir zone as a prospective storage resource play (SPE, 2016) within the Lower Mt. Simon Sandstone in the eastern Illinois Basin.

Table 2. Regional CO_2 storage resource estimates (million metric tons) for saline formations in the Illinois East sub-basin. *The P50 scenario was not assessed for the Knox group, but a reasonable P50 approximation is 36% of the P90 storage value. Figures have been rounded.

Reservoir	CO_2 Storage Resource - East Sub-Basin (Mt)		
	P10	P50	P90
Cypress Sandstone	8	38	105
St. Peter Sandstone	83	325	877
Knox Carbonate	1,662	5,157*	14,325
Mt. Simon Sandstone	1,997	9,988	27,468
Total	3,750	15,508	42,775

Regional data in the US DOE's NATCARB system were used to estimate the CO_2 storage resource of the four reservoirs in the East Sub-Basin (Table *2*): the Mt. Simon Sandstone, Knox Group, St. Peter Sandstone, and the Cypress Sandstone. The storage resource estimates are based on regional assessment work for the US DOE-NETL (RCSP and American Recovery and Reinvestment Act (ARRA) Site characterization programs and are supplemented with new mapping focused on the lower Mt. Simon Sandstone.

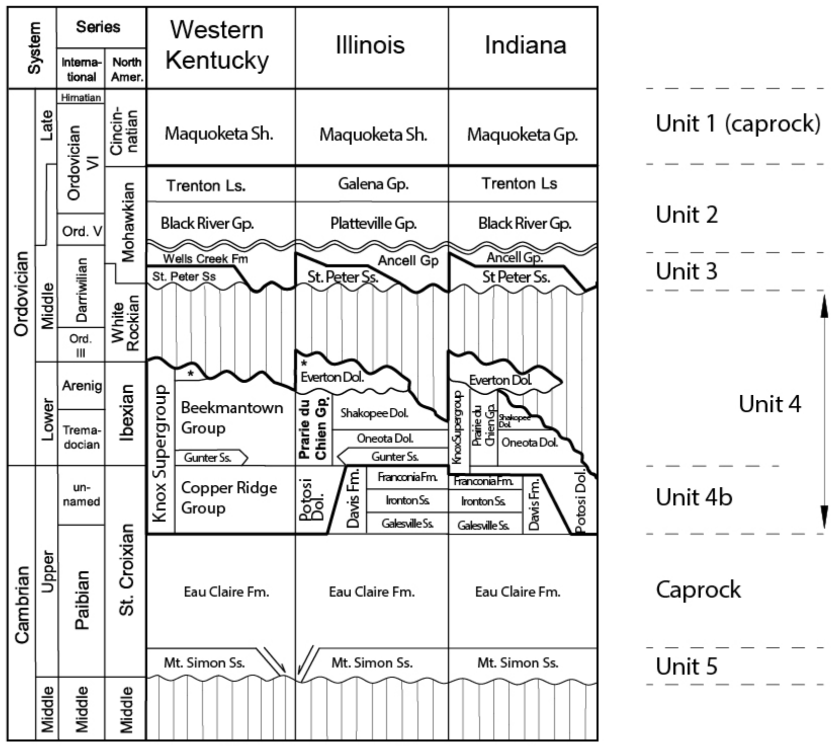

Figure 14. Stratigraphic correlation chart for the main units under assessment in the CarbonSAFE prefeasibility region.

Topical Report: DOE-FE0029445-7 assesses the storage resource estimate (SRE) for the Paleozoic units in this study focused on five intervals as reservoirs: 1) limestone and dolomite from the Trenton/Black River Group (Upper Ordovician), 2) the Middle Ordovician St. Peter Sandstone, 3) primary target reservoir rocks of the upper Cambrian and Lower Ordovician and Upper Cambrian Knox Supergroup, including a separate assessment for the lower Knox Potosi Dolomite (Unit 4b), and 5) Mount Simon Sandstone (Figure 14).

A comprehensive data set consisting of wireline logs, petrophysical information (core measured porosity and permeability), stratigraphic information, and existing well location data was complied. The IGWS finished the calculation of Storage Resource Estimates (SRE's) using 5 methodologies: (1) SREs using a fixed value of porosity; (2) using an average porosity (per well, per unit) from wireline-derived porosity; (3) using an average porosity for each unit, for the entire region, from wireline-derived porosity; (4) a depth-dependent porosity model for the St. Peter and Mt. Simon Sandstones only; and (5) SREs using National Energy Technology Laboratory's CO_2 ¬Storage Prospective Resource Estimation Excel Analysis (CO_2-SCREEN). NETL's CO_2 Storage Prospective Resource Estimation Excel Analysis (CO2-SCREEN) (Goodman et al., 2016). CO_2-SCREEN is a tool developed by the US-DOE-NETL and is intended to aid users with SRE estimation in saline aquifers. The number of data points varies from method to method, and, in general, tends to decrease with depth and older stratigraphic intervals (Table 3).

Table 3. Number of wells used in each method.

		# of Wells				
		Unit 2	Unit 3	Unit 4	Unit 4b	Unit 5
Method I	Average porosity	162	147	60	22	27
Method II	Wireline logs (per well)	49	48	28	11	11
Method III	Wireline logs (regional average)	162	147	60	22	27
Method IV	Diagenetic model	--	147	--	--	27
Method V	DOE/NETL SCREEN	50	50	28	11	11

The report displays resultant SREs volumes using georeferenced produced maps (using ArcMap 10.5.1) and boxplots. Figure 15, Figure 16, and Figure 17 illustrate total storage potential estimates for the St. Peter Sandstone, Knox Supergroup, and the Mt. Simon, respectively. Boxplots allow for comparing data statistics (mean values and variability) between five methods employed for the SRE calculations. Differences observed in SRE results from the five methods are mainly attributable to differences in the data used for porosity in each method.

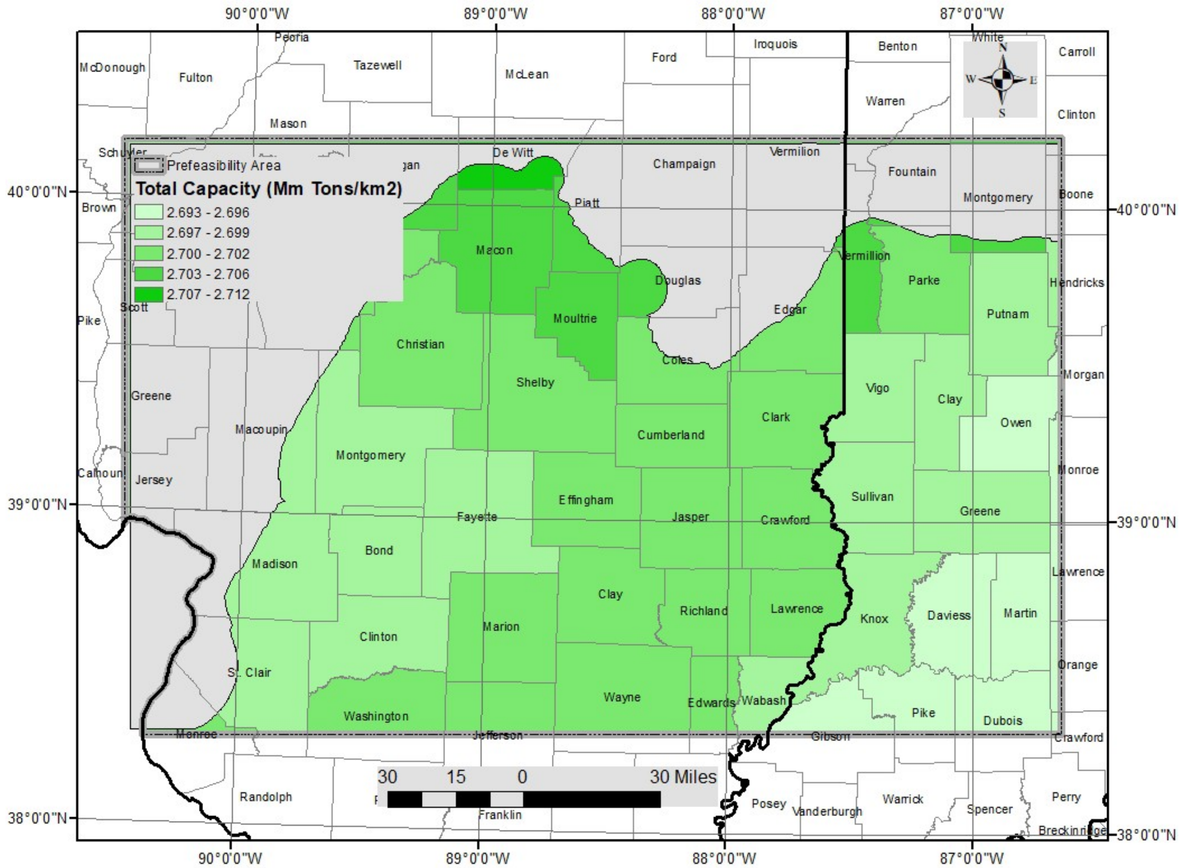

Figure 15. Storage resource estimates (SREs) for the St Peter Sandstone (unit 3). This map represents results with efficiency factor E p100 (E=1). Values are total storage capacity per unit area, per county.

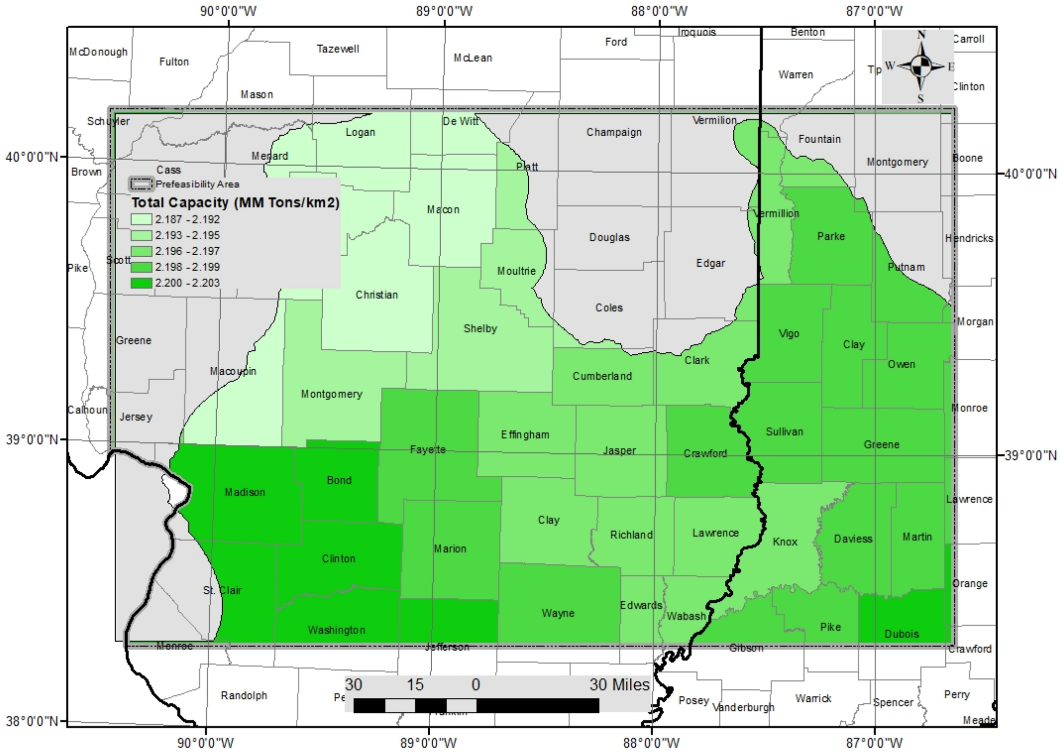

Figure 16. Storage resource estimates (SREs) for the Knox Supergroup (unit 4). This map represents results with efficiency factor E p100 (E=1). Values are total storage capacity per unit area, per county.

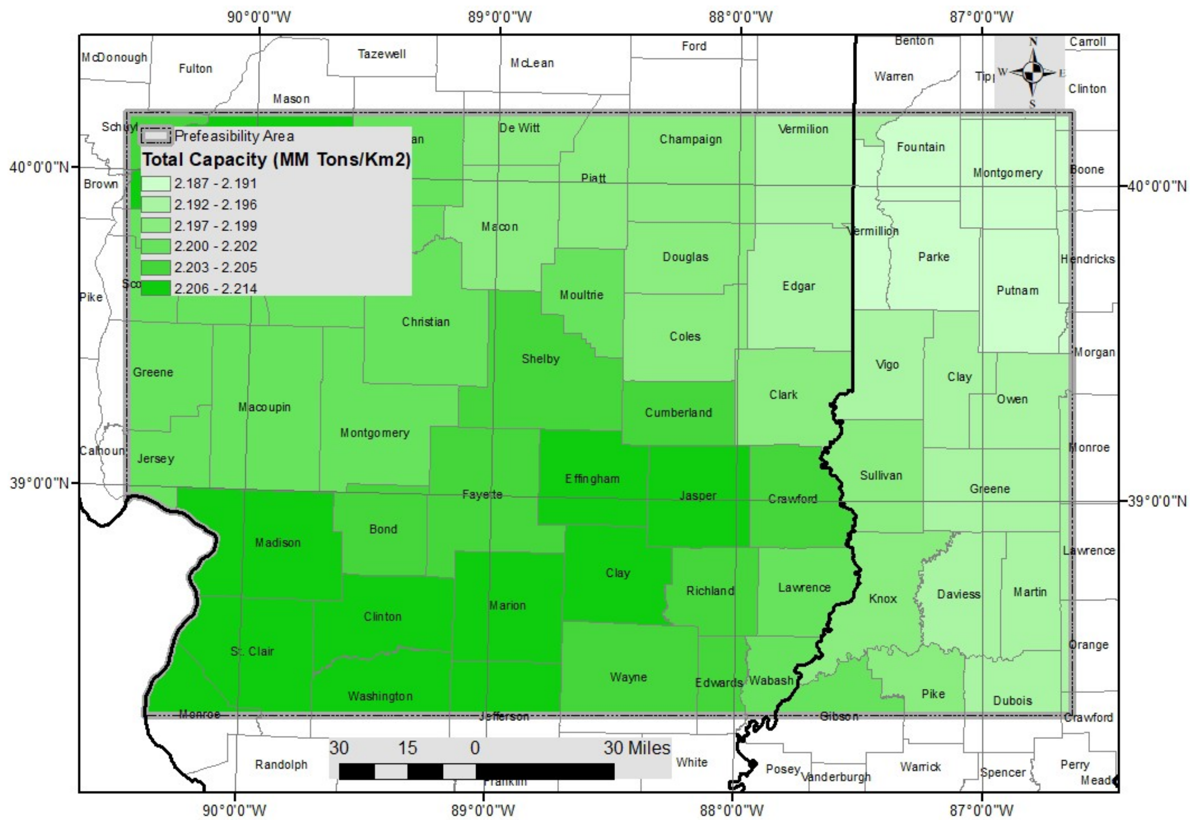

Figure 17. Storage resource estimates (SREs) for the Mount Simon Sandstone (unit 5). This map represents results with efficiency factor E p100 (E=1). Values are total storage capacity per unit area, per county.

Regional Screening

Guidelines for regional screening assessment were adapted from the FutureGen proposal that dealt with site selection criteria, where the land above a proposed target formation(s) must not intersect dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features. This East Sub-Basin regional screening level assessment will consider the location and proximity to structural features, natural gas storage areas (active and inactive), and Class 1 injection wells. In addition, proximity to groundwater resources are considered here, primarily pertaining to the areal extent of the Mahomet Sole Source Aquifer.

Site-specific sensitive features and protected areas such as wetlands, national or state parks, protected or historical areas, Native American tribal lands, species-sensitive areas, dams, reservoirs, etc., are excluded from this regional screening assessment. Site-specific data and information regarding proximity to existing natural gas storage areas, structural features, surrounding municipal infrastructure development, groundwater resources, environmental monitoring, and local sensitive biological areas are summarized later in the report in the attached site assessment summary tables (Appendix).

Structural Elements

Regional mapping has identified structural features and closures known in the East Sub-Basin study area (Figure 18). The USGS seismic hazard maps indicate much of the East Sub-Basin study area to be less than 20% (Peak acceleration expressed as a percent of gravity (%g) based on the USGS hazard map.

Topical report DOE/FE0002068-11 (Hickman, 2014) describes how finding suitable sites are problematic in areas such as the southern Illinois Basin, which have been affected by numerous tectonic episodes since at least the late Precambrian, leading to countless faults throughout the region.
Site-specific characterization efforts would be a requirement before development of any sequestration project.

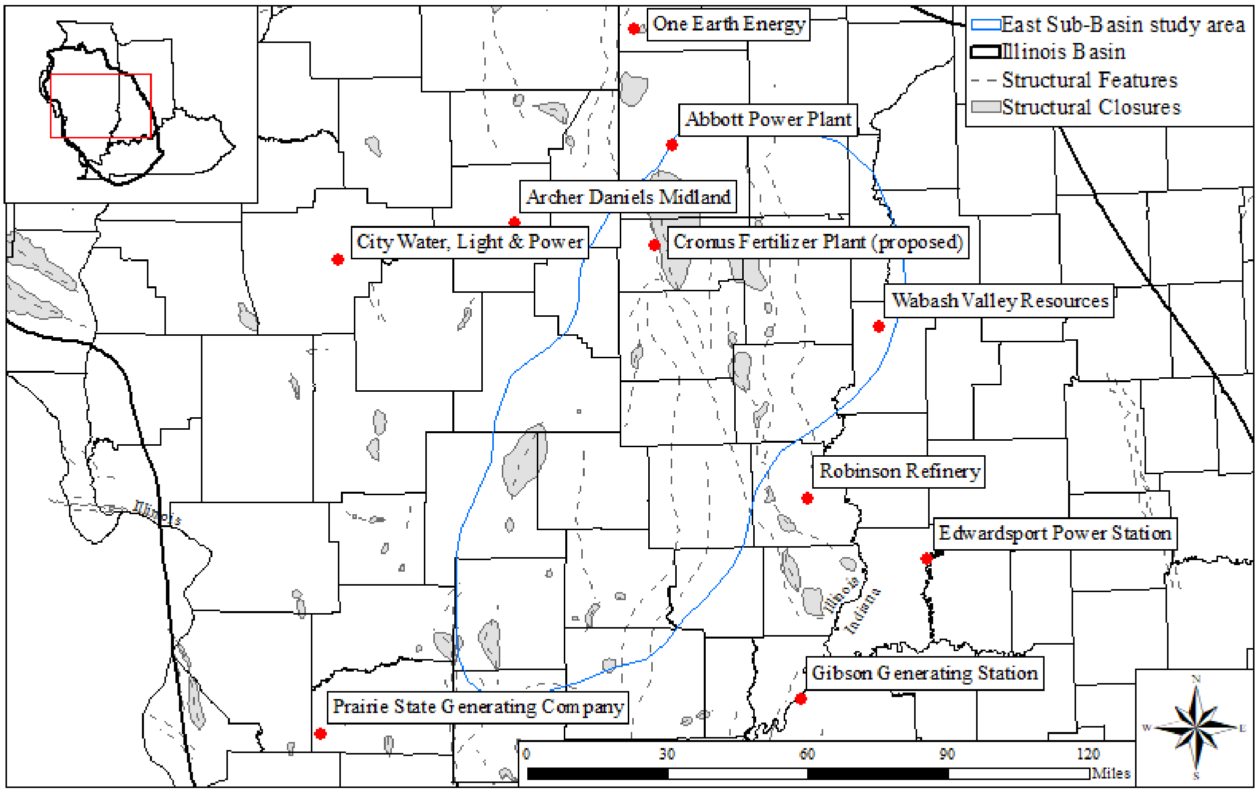

Figure 18. Mapped regional structural features.

Natural Gas Storage Fields

Illinois has 28 underground natural gas storage fields with a total storage capacity just over 1 trillion cubic feet of natural gas, which is more than one-tenth of the U.S. storage total (U.S. EIA Annual, 2012-17). The state of Indiana has 21 natural gas storage fields with a combined total capacity of 113 billion cubic feet (U.S. EIA Annual, 2012-17). Natural gas storage fields in Illinois and Indiana have used a variety of Cambrian to Pennsylvanian age strata for underground gas storage reservoirs for the past 60+ years (Table 4).

Table 4. Gas Storage Fields in Illinois and Indiana (EIA-191 Monthly Underground Gas Storage Reports, 2019).

State	County	Gas Storage Field	Company	Reservoir	Status	Total Field Capacity (Mcf)
IL	Champaign	Manlove Field	Peoples Gas Light & Coke Company	Mt. Simon	Active	179,061,167
IL	Coles	Ashmore	Ameren Illinois	Pennsylvanian	Active	3,706,523
IL	Coles	Eden	Ameren Illinois	Cypress	Active	1,403,351
IL	Coles	Freeburg	Ameren Illinois	Cypress	Active	6,935,776
IL	Coles	Glasford Storage Field	Ameren Illinois	Niagarian	Active	12,734,923
IL	Coles	Hookdale	Ameren Illinois	Benoist	Active	1,027,106
IL	Douglas	Cooks Mills	Natural Gas Pipeline Co Of America	Cypress, Rosiclare	Active	6,750,000
IL	Fayette	Loudon	Natural Gas Pipeline Co Of America	Devonian	Active	80,000,000
IL	Gallatin	Mills	Egyptian Gas Storage Corporation	Tar Springs	Active	1,075,000
IL	Kankakee	Herscher	Natural Gas Pipeline Co Of America	Galesville, Mt Simon	Active	114,500,000
IL	Kankakee	Herscher Northwest	Natural Gas Pipeline Co Of America	Mt. Simon	Inactive	17,500,000
IL	La Salle	Troy Grove	Nicor	Mt. Simon	Active	79,976,000
IL	Livingston	Ancona	Nicor	Mt. Simon	Active	172,826,000
IL	Livingston	Pontiac	Nicor	Galesville	Active	18,737,000
IL	Livingston	Pontiac	Nicor	Mt. Simon	Active	42,864,000
IL	Logan	Lincoln Storage Field	Ameren Illinois	Lincoln	Active	12,335,029
IL	Logan	Lincoln Storage Field	Ameren Illinois	Niagarian	Active	12,335,029
IL	Logan	Shanghai	Ameren Illinois	Galesville	Active	12,096,636
IL	Madison	St. Jacob	Enable Mississippi River Trans Corp	St. Peter	Active	4,100,000
IL	Marion	Centralia	Ameren Illinois	Petro	Active	654,231
IL	McDonough	Sciota	Ameren Illinois	Mt. Simon	Active	5,269,415
IL	Mclean	Hudson	Nicor	Mt. Simon	Active	46,854,000
IL	Mclean	Lake Bloomington	Nicor	Mt. Simon	Active	49,538,000
IL	Mclean	Lexington	Nicor	Mt. Simon	Active	52,185,000
IL	Morgan	Waverly	Southwest Gas Storage Company	St. Peter	Active	51,100,000
IL	St. Clair	Hillsboro	Ameren Illinois	St. Peter	Active	28,122,101

IL	St. Clair	Tilden	Ameren Illinois	Cypress	Active	2,697,615
IL	Williamson	Johnston City	Ameren Illinois	Tar Springs	Active	1,744,648
IL	Winnebago	Pecatonica	Nicor	Mt. Simon	Active	3,286,000
IN	Cass	Grass Creek	Northern Indiana Public Svc	Mt Simon	Inactive	17,880,050
IN	Cass	Royal Center	Northern Indiana Public Svc	Trenton, Mt. Simon	Active	16,621,217
IN	Clark	Sellersburg	Indiana Gas Company Dba Vectren	Knox	Active	1,444,517
IN	Clark	Wolcott	Indiana Gas Company Dba Vectren	Trenton	Active	7,389,240
IN	Daviess	Loogootee	Southern Indiana Gas & Electric	Bethel Sand	Inactive	296,006
IN	Greene	Dixon	Citizens Energy Group	Devonian	Active	2,780,000
IN	Greene	Howesville	Citizens Energy Group	Devonian	Active	4,250,000
IN	Greene	Mineral City	Citizens Energy Group	Devonian	Active	2,083,000
IN	Greene	Simpson Chapel	Citizens Energy Group	Devonian	Active	2,200,000
IN	Greene	Switz City	Citizens Energy Group	Devonian	Active	5,635,000
IN	Greene	Worthington	Citizens Energy Group	Devonian	Active	13,200,000
IN	Knox	Monroe City	Southern Indiana Gas & Electric	Mansfield	Active	5,338,377
IN	Knox	Monroe City	Southern Indiana Gas & Electric	Staunton	Active	173,738
IN	Knox	Oaktown	Texas Gas Transmission Corporation	Stanton	Active	1,051,852
IN	Lawrence	Leesville	Texas Gas Transmission Corporation	Geneva	Active	3,800,000
IN	Monroe	Hindustan	Indiana Gas Company Dba Vectren	Muscatatuck	Active	2,907,561
IN	Monroe	Unionville	Indiana Gas Company Dba Vectren	Muscatatuck	Active	12,842,969
IN	Pike	Alford	Texas Gas Transmission Corporation	Cypress	Active	2,518,753
IN	Pike	White River	Indiana Gas Company Dba Vectren	Cypress Sand	Active	800,000
IN	Posey	Oliver	Southern Indiana Gas & Electric	Sebree	Active	150,150
IN	Posey	Oliver	Southern Indiana Gas & Electric	Staunton	Active	2,696,066
IN	Spencer	Midway	Southern Indiana Gas & Electric	Tar Springs	Active	3,064,543
IN	Sullivan	Wilfred	Texas Gas Transmission Corporation	Geneva	Active	4,787,966

Class I Disposal Wells

Well location and injection reservoir information for active Class I disposal wells (hazardous or non-hazardous waste) for Illinois and Indiana were previously obtained from the US EPA Region 5 and are presented in Table 5. The majority of the wells listed in the Table 5 are outside of the East Sub-Basin study area. In the Illinois Basin, tens-of-millions of gallons of wastewater have been injected annually into the Potosi Dolomite of the Knox Group. The Potosi's excellent reservoir properties have been further documented by a chemical waste disposal project at Tuscola, Douglas County, IL, that has injected over 50 million metric tons (55 million tons) of CO_2 equivalent of liquid chemical waste into the Potosi through the Cabot-Tuscola #2 well (Leetaru, 2014). Although outside of the study area, approximately 100 miles to the south CO_2 was successfully injected into numerous intervals within the Knox at the Blan well in Hancock County, Kentucky (Bowersox, 2013).

Table 5. Class I Disposal Well Data from Illinois and Indiana.

State	County	Well Name	Company	Formations
IL	Vermilion	Allied Chemical Corp 1	Allied Chemical Corp	Eminence, Potosi & Franconia
IL	Douglas	US Industrial Chemical 1	US Industrial Chemical	Eminence, Potosi
IL	Douglas	Cabot Corp. Tuscola 1	Cabot Corp	Eminence, Potosi
IL	Douglas	Cabot Corp. Tuscola 2	Cabot Corp	Eminence, Potosi
IL	Douglas	Cabot Corp. Tuscola 3	Cabot Corp	Oneota, Eminence, Potosi
IL	Clark	Velsicol Chemical Corp 1	Velsicol Chemical Corp	Salem
IL	Clark	Velsicol Chemical Corp 2	Velsicol Chemical Corp	Devonian
IL	Clark	Velsicol Chem Corp. Obs. 1	Owner	Devonian
IL	Putnam	Waste Disposal 1	Jones and Laughlin Steel	Elmhurst-Mt. Simon
IN	Allen	Leuenberger 1	Northern Indiana Public Service Co	
IN	Allen	Wakeland 1	Northern Indiana Public Service Co	
IN	Cass	Burton 1	Northern Indiana Public Service Co	Mt. Simon
IN	Cass	Conn 1	Northern Indiana Public Service Co	Mt. Simon
IN	Cass	Finell 1	Northern Indiana Public Service Co	Mt. Simon
IN	Cass	Johnson 0-85	Northern Indiana Public Service Co	Mt. Simon
IN	Cass	Schmaltz 2	Northern Indiana Public Service Co	Mt. Simon
IN	Cass	Skinner 1	Northern Indiana Public Service Co	Eau Claire
IN	Elkhart	Hoskin Mfg WD-1	Hoskin Mfg.	Mt. Simon
IN	Fulton	Burns 1	Northern Indiana Public Service Co	Mt. Simon
IN	Fulton	Morphet 1	Northern Indiana Public Service Co	Mt. Simon
IN	Fulton	Sommers 2	Northern Indiana Public Service Co	Mt. Simon
IN	Fulton	Todd 0-121	Northern Indiana Public Service Co	Mt. Simon
IN	Porter	Bethlehem Steel WD-1	Bethlehem Steel	Eau Claire, Mt. Simon
IN	Porter	Bethlehem Steel WD-1C	Bethlehem Steel	Eau Claire, Mt. Simon

IN	Porter	Bethlehem Steel WD-2C	Bethlehem Steel	Eau Claire, Mt. Simon
IN	Porter	INDOT DW-1	Indiana Dept. of Transportation	Eau Claire, Mt. Simon
IN	Porter	Indiana General WD-1	Stoltemberg Construction Co	Mt. Simon
IN	Porter	Pfizer Chemical Co 2	Pfizer Chemical Co	Mt. Simon
IN	Porter	Midwest Steel WD-1	Midwest Steel	Eau Claire, Mt. Simon
IN	Porter	Steel Midwest Steel WD-2	Midwest Steel	Mt. Simon
IN	LaPorte	Criterion Catalyst Co WD-1	Criterion Catalyst Co	Mt. Simon
IN	LaPorte	Criterion Catalyst Co WD-2	Criterion Catalyst Co	Mt. Simon
IN	Lake	Inland Steel Co WD-1	Inland Steel Co	Mt. Simon
IN	Lake	Inland Steel Co 2	Inland Steel Co	Mt. Simon
IN	Lake	Midco Remedial Corp WD-1	Midco Remedial Corp	Mt. Simon
IN	Lake	US Steel WD-1	US Steel	Mt. Simon
IN	Posey	General Electric Co 1	General Electric Co	Bethel
IN	Posey	General Electric Co WD-2	General Electric Co	Bethel, Cypress
IN	Elkhart	Hoskin Mfg WD-1	Hoskin Mfg.	Mt. Simon
IN	Vermillion	Newport Chemical Plant WD-1	Food Machinery and Chemical Co	Mt. Simon

Groundwater resources

Regional information about Illinois and Indiana aquifer resources in the East Sub-Basin study area (separated into shallow unconsolidated aquifers material, Shallow Bedrock Aquifers and Cambrian-Ordovician Sandstone Aquifers) were reviewed. Site specific aquifer information is summarized later in the report in the site assessment summary tables. Within the East Sub-Basin screening area, and within 30 miles of 5 of our reviewed CO_2 sources, is the Mahomet Sole Source Aquifer (SSA) (Figure 19). The SSA designation would affect project planning if any Federal financial assistance was involved; proposed projects that are funded entirely by state, local, or private concerns are not subject to SSA review by EPA (see notes below from US EPA Notice of Final SSA Determination, 3/19/2015). However, a US EPA Underground Injection Control Program Class VI permit would be required for CO_2 injection, to assure the protection of groundwater resources at the site location.

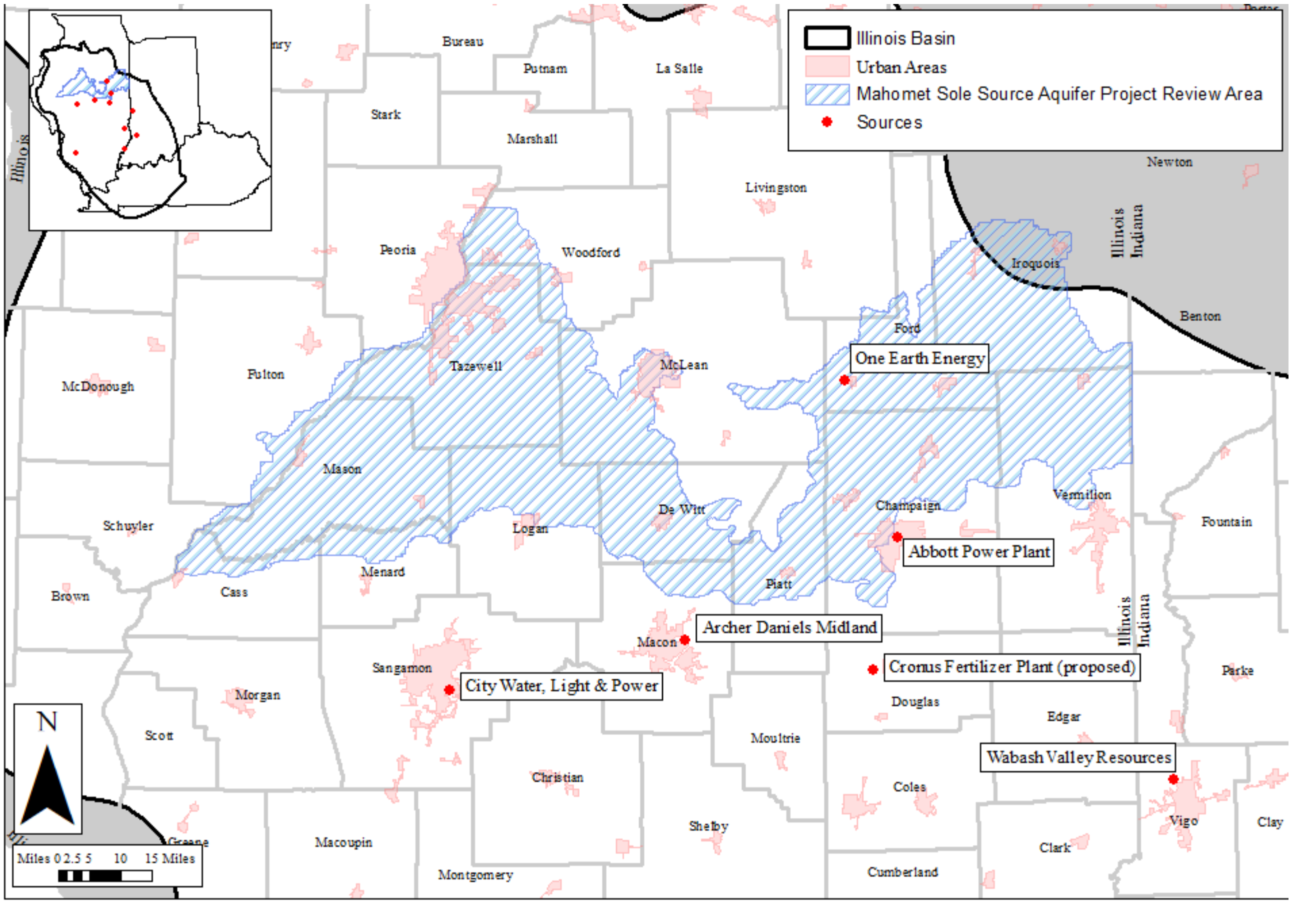

Figure 19. Location of assessed CO_2 sources in relation to the Mahomet Sole source aquifer in blue (source US EPA).

<u>Legal definitions from US EPA (FRL–9923–75–Region 5, 2015):</u>
Following publication of this determination, "no commitment for Federal financial assistance (through a grant, contract, loan guarantee, or otherwise) may be entered into for any project which the Administrator determines may contaminate such aquifer through a recharge zone so as to create a significant hazard to public health, but a commitment for Federal financial assistance may, if authorized under another provision of law, be entered into to plan or design the project to assure that it will not so contaminate the aquifer." 42 U.S.C. 300h-3(e). EPA may review any such proposed projects and, where possible, make suggestions or recommendations to plan or design the project to ensure it will not contaminate the aquifer system to create a significant hazard to public health. Proposed projects that are funded entirely by state, local, or private concerns are not subject to SSA review by EPA.
The project review area for this SSA consists of the designated SSA area plus three watersheds adjacent to the designated SSA area that provide recharge to the Mahomet Aquifer System. These watersheds are the Sugar Creek, the Sangamon River near Fisher, and the Tributary to the Middle Fork Vermilion River.

Site-specific sensitive features related to groundwater resources such as proximity to dams, reservoirs, and community water supply wells are not included in this regional screening assessment, although would need to be considered for CO_2 project site selection and screening.

Assessment of the National Risk Partnership's CO_2 Sequestration Leakage Modeling Tools

The CarbonSAFE Illinois East Sub-Basin team explored and assessed the carbon sequestration site characterization National Risk Assessment Partnership (NRAP) Toolset, developed by the National Energy Technology Laboratory (NETL), Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and Pacific Northwest National Laboratory (PNNL). Specifically, the Integrated Assessment Model (IAM) tool was run using inputs derived from verified regional geologic data.

The St. Peter Sandstone was identified as the most practical underground source of drinking water (USDW) for the CarbonSAFE East Sub-Basin assessment. Brine and CO_2 leakage rates as well as total brine and CO_2 leaked from a hypothetical injection well borehole into the USDW were estimated at a hypothetical monitoring well. Multiple scenarios were run to investigate: 1) the impact of increasing the distance of the monitoring well from the injection well, and 2) the effect of low vs. high permeability borehole cement.

Several issues and recommendations were produced from the assessment and provided to PNNL for consideration and/or implementation in the subsequent generation of the NRAP Toolset software. Additional details on the simulations performed are available in the topical report number DOE/ FE0029445-6.

Wabash CarbonSAFE Feasibility Project

The CarbonSAFE Illinois East Sub-Basin is a broad area extending through east-central Illinois and west-central Indiana, generally trending from Marion and Fayette Counties (IL) in the southwest part of the study area through Vigo and Vermillion Counties (IN) in the northeast (Figure 1).

Within the East Sub-Basin region, there is the potential to develop several carbon capture and/or storage projects. One such project site, the Wabash CarbonSAFE site, is located just north of the municipality of Terre Haute (population ~61,000) in northern Vigo County, Indiana. Vigo County is largely rural with mixed agricultural and woodland areas but dominated by the city of Terre Haute (Figure 20) which lies on the east side of the Wabash River.

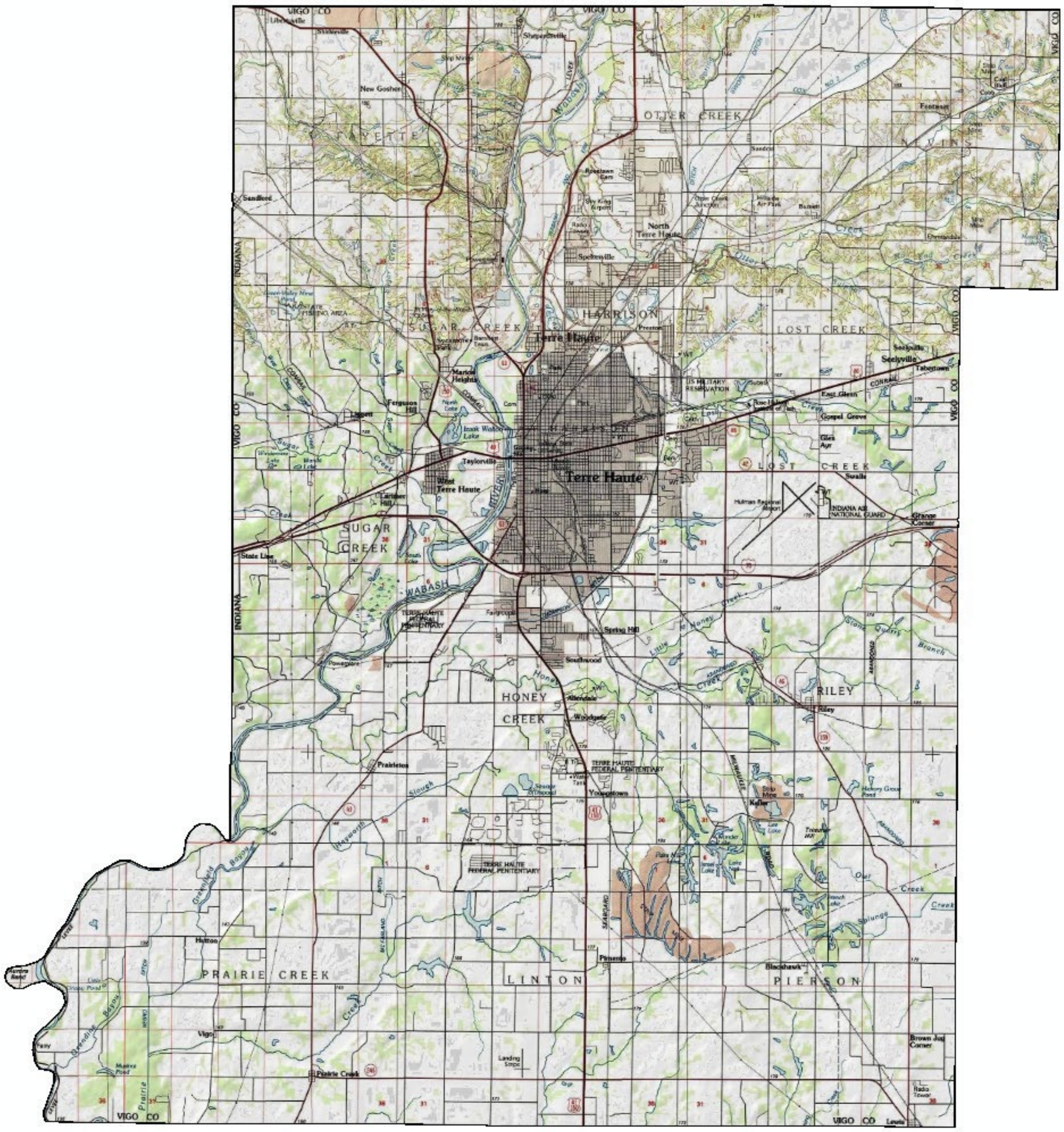

Figure 20 . Topographic map base for Vigo County, Indiana (source Esri).

Terre Haute and the surrounding region has a long history of industrial development and subsurface natural resource activities, both of which are technologically related. It has been an industrial and manufacturing hub for many years and has a long legacy of underground coal mining and oil and gas production. Consequently, the populous is accustomed to the application of new technologies, including specifically drilling and injection. There are active oil and gas production operations and storage fields in the county. Additionally, the county contains many rail lines, electrical transmission lines and numerous large, high volume oil and gas pipelines. At the intersection of an interstate highway, a major US highway corridor and numerous state roads, the population is familiar with heavy truck traffic and associated commercial and transportation elements.

Effective stakeholder engagement has been proven to be a critical component in the success of numerous CCS activities and is essential if the technology is to be widely developed in the future. Topical report DOE/FE0029445-8 report contains a stakeholder assessment and highlights some engagement activities conducted during the CarbonSAFE Illinois East Sub-Basin Prefeasibility study that is intended to lay the groundwork and provide recommendations for the Wabash CarbonSAFE Feasibility project. The analysis sets the stage for identifying and understanding the concerns of key stakeholders, describes actions currently underway, highlights perceptions of potential benefits and risks of project activities, and provides recommendations for short- and long-term forms of engagement.

Case study work for the Illinois East Sub-Basin has focused on Wabash Valley Resources (WVR) ammonia plant retrofit taking place at the former US DOE Integrated Gasification Combined Cycle (IGCC) plant located near Terre Haute, IN, as a CO_2 source for further feasibility study and site characterization.

Recommendations for consideration when developing the stakeholder engagement strategy for projects in the Illinois East Sub-Basin in general and related to the Wabash CarbonSAFE project specifically include: drawing clear lines of responsibility between Wabash Valley Resources and ISGS-led Wabash CarbonSAFE that allow the projects to manage integration and messaging; the need for ISGS and other partners to maintain objectivity and remain trusted sources of information; monitoring of social media and continuing to engage with key stakeholder groups; and providing support for key stakeholders to become sources of project information and project champions.

Business, Legal, and Permitting Landscape in Indiana

Topical Report: DOE-FE0029445-4 summarizes the policy, regulatory, legal, and permitting requirements to-date for the siting of a CO_2 injection and storage project in the CarbonSAFE Illinois East Sub-Basin pre-feasibility study area. Where applicable, the East Sub-Basin case study focuses on a proposed CCS site location in West Terre Haute, Indiana.

Commercialization of large-scale Carbon Capture and Storage in the Illinois Basin may be realized by taking advantage of CCS tax credits (under 26. U.S. Code § 45Q and 2018 FUTURE Act amendments) and potential revenue from sale of CO_2 for EOR. A 45-metric ton (50 million ton) CO_2 storage operation would primarily target capacious saline reservoirs able to store this large volume at a single location, the cost of which may be offset, at least partially, by regional CO_2 EOR interests in the long-term.

Obstacles/hurdles to the adoption of commercial-scale CCS remain, however, e.g. in the US EPA Class VI Underground Injection Control permitting process for CO_2 injection wells, and pore space ownership and long-term liability for subsurface CO_2. At the WVR plant site, the current owner of the subsurface rights has extensive holdings and is known, but confidential at this time. In the broader region, pore space owners may need to be identified.

Wabash Valley Resources have taken steps to move toward CCS commerciality, having had recent discussions with the Indiana State Legislature and involvement in the drafting and adoption of Indiana Senate Bill 442, signed into Public Law 291 by the Governor of Indiana on May 8, 2019. The law establishes that CCS operations at WVR would be a pilot project in need of Class VI Underground Injection Control permit by the US EPA; provides for the use of eminent domain, if needed, for the pooling of subsurface pore space for CO_2 injection; and provides for the assumption of long-term ownership of the injected CO_2 by the State of Indiana. From the Indiana General Assembly (2019), the law:

> Provides that if the operator of the pilot project is not able to reach an agreement with an owner of property to acquire: (1) ownership of underground strata or formations located under the surface of the property; or (2) ownership or other rights to one or more areas of the surface of the property for purposes of establishing and operating monitoring facilities required by the EPA; the operator of the pilot project may exercise the power of eminent domain to make the acquisition. Provides that the pilot project operator's acquisitions by eminent domain must be made through the law on eminent domain for gas storage, which provides that a condemnor, before condemning any underground stratum or formation, must have acquired the right to store gas in at least 60% of the stratum or formation by a means other than condemnation. Amends the law on eminent domain for gas storage to make it applicable to the pilot project operator's acquisitions by eminent domain. Provides that the state of Indiana, upon the recommendation of the director of the department of natural resources and review by the state budget committee, may obtain ownership of: (1) the carbon dioxide stored in the underground strata and formations; and (2) the underground strata and formations in which the carbon dioxide is stored; 12 years after pilot project underground injections begin or, if the underground injections cease in less than 12 years, after the underground injections cease. Urges the legislative council to assign to an appropriate interim study committee for the 2019 interim the task of studying the geologic storage of carbon dioxide.

The data, analyses, and modeling generated by geological characterization as part of feasibility studies at the WVR site will be the foundation information for potential US EPA Class VI injection well permitting and will aid continued steps toward commercial-scale CCS at the WVR site and in the wider Illinois East Sub-Basin region.

Wabash Valley Resources LLC

In 2016, Wabash Valley Resources LLC (WVR, formerly Quasar Syngas LLC) acquired the Wabash Integrated Gasification Combined Cycle (IGCC) Plant north of Terre Haute, IN (Figure 21), the initial step in repurposing the facility for the production of ammonia for the domestic fertilizer market by 2021. DOE/FE0029445-3 addresses a screening level estimate of capital and operating costs for CO_2 compression and dehydration surface equipment for the Wabash Valley Resources facility near Terre Haute, IN to support the business development assessment of the economic viability and explore conditions under which CCS project therein might be revenue positive. Although the assessment was preliminary, this estimate is based upon a significant amount of Trimeric in-house project experience and data extracted from projects of a similar nature that are applicable to the CarbonSAFE project. Trimeric completed the following tasks as part of this analysis:

1. Created a simulation to model the process to compress and dehydrate CO_2 evolved from a Rectisol® CO_2 capture system at 1 psig to typical pipeline pressure of 2,200 psig
2. Estimated purchased equipment costs for CO_2 compression using the power requirements estimated in Item 1 and a previous budgetary quotation provided by MAN Turbo in February 2017 for an integrally geared centrifugal compressor at similar inlet and outlet conditions
3. Estimated purchased equipment costs for CO_2 dehydration using in-house cost data from prior CO_2 dehydration projects

4. Estimated fixed capital investment for CO_2 compression and dehydration equipment using typical Lang factors used on past projects
5. Estimated fixed and variable annual operating costs using rules of thumb published in literature and used in prior projects

The WVR facility is located directly adjacent to a main railroad line and near an existing nearby ammonia pipeline. The facility can accept coal or petcoke, as feedstock, from several refineries in the region. The feedstock will be converted in the gasifier to syngas and then the hydrogen used to produce ammonia. The syngas will be purified using the Rectisol process to removes acid gases (H_2S and CO_2), which results in a very pure CO_2 stream that can be readily compressed and transported for storage or other utilization. The separated CO_2 will be greater than 95% pure, and WVR has increased the separation and planned capture of CO_2 from 65% to 95% of the gas stream, which equates to 179 tonnes/hour or, nominally, 1.57 MT/year.

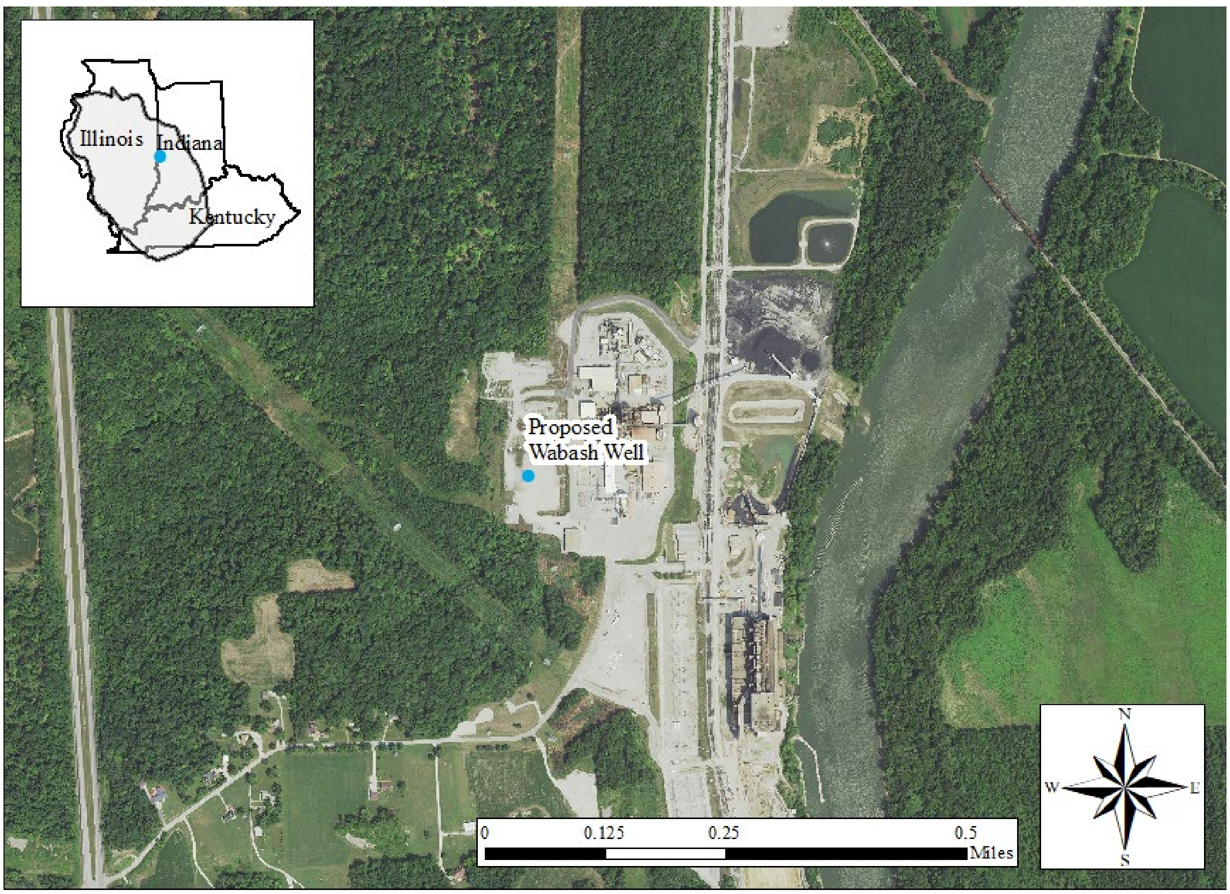

Figure 21. Aerial view of the WVR IGCC plant site, showing location of proposed stratigraphic test well. Inset map shows the site's location within the Illinois Basin.

The reliability of the existing gasification infrastructure, simplicity of the design modifications for CO_2 separation, high purity of their CO_2 streams, and experience of the operations and management team are all advantages to this proposed carbon management project.

Topical report DOE-FE0029445-12 develops the feasibility plan that draws upon regional assessment work in the East Sub-Basin as it pertains to risk and data needs to characterize the WVR site, highlights plans for data acquisition to support characterization efforts. Site-specific data gathering has included assessing proximity to existing natural gas storage areas, structural features, surrounding municipal infrastructure development, groundwater resources, environmental monitoring, and local sensitive biological areas. Structural feature information was compiled from Nelson (1995). Aquifer information was compiled from University of Illinois (2019) and Indiana Department of Natural Resources (2019). Information has been summarized in Table 6 with possible associated risks and impacts to potential CCS development. Site-specific screening criteria data has been summarized in Appendix A for the each of the facilities highlighted in Topical Report DOE/FE0029445-9 Regional Roadmap for Source Network and Storage Deployment.

Table 6. Site screening criteria (modified from Quintessa 2019).

Site Assessment Summary: Wabash Valley Resources (WVR)					
Risk Element Likelihood					
Very Unlikely	**1**	<1% chance during the project			
Unlikely	**2**	3% chance			
Possible	**3**	10% chance			
Likely	**4**	30% chance			
Very Likely	**5**	>= 90% chance during the project			
Impact Severity					
Light	**-1**				
Serious	**-2**				
Major	**-3**				
Catastrophic	**-4**				
Multi- Catastrophic	**-5**				
Description of Characteristics	**Recommended**	**Site Evaluation**	**Likelihood**	**Severity**	**Importance**
Reservoir Analysis					
Distance to suitable geologic formation	Site must be located within 50 miles (80 kilometers (km) of a suitable geological storage area	The Mt. Simon Sandstone is the primary sequestration reservoir at the Wabash Valley Resource (WVR) site. The nearest deep well into the Mt. Simon surface, at nearly 5,450 feet (1661 m) deep, is the Newport Chemical Plant #WD-1 approximately 22 miles (35 km) north of WVR. site. A stratigraphic test well is necessary to verify the characteristics of the Upper and Lower Mt. Simon Sandstone in the absence of nearby deep well data.	1	-5	-5

Reservoir Thickness	Location must have reservoir with 20 feet (6 m) or greater of <10% porosity	Regional thickness (Figure 5) map of the Mt Simon Sandstone indicate estimated thickness between 2,000 to 2,250 feet (610 to 686 m) thick at the WVR facility. The nearest deep well penetrating the Lower Mt. Simon is the Duke Energy Indiana #1 IGCC, approximately 51 miles (82 km) south of the WVR site. In the Duke Energy well the Mt. Simon Sandstone is nearly 2,000 feet (610 m) thick with the Lower Mt. Simon over 800 feet (244 m) thick.	3	-3	-3
Injection Rate Capacity	The proposed geologic formation for sequestration must support a CO_2 injection rate of 1 MT (1,102,311 tons) of CO_2 per year for up to 30 years.	There are no nearby wells that have penetrate the lower Mt. Simon Sandstone and the reservoir quality is unknown in this location. Due to the fact of limited regional data for the Lower Mt. Simon deeper well data is still needed.	3	-3	
Depth and capacity of Saline Formation (if Saline Formation is the preferred sequestration option)	If a deep saline formation is the sequestration target, the formation must have in-situ hydrostatic pressure and temperature conditions above the CO_2 supercritical point (31º C at 73 atm). The deep saline formation must have sufficient storage capacity for the planned life of the plant (30 years) under these conditions.	Regional structure (Figure 6) map of the Mt. Simon Sandstone indicate estimated depth between 5,000 to 6,000 feet (1524 to 1829 m) deep. Top of Mt. Simon is estimated to be approximately 6,100 feet (1859 m) deep at the site	3	-4	-4
Availability of secondary reservoirs	Not required	Regional thickness map for the St. Peter Sandstone (Figure 8) estimated to be less than 50 feet (15 m) thick. At the WVR site, the St. Peter is expected to be porous but less than 50 feet (15 m) thick.	3	-1	-1
Proximity to Oil Fields	If CO_2 enhanced oil recovery (CO_2-EOR) reservoirs are the target, then the site must be 50 miles (80 km) or closer to oil fields that are deep enough for miscible EOR methods.	The WVR facility is near the northern extent of the most significant oil producing region in the Illinois Basin (Figure x). The potential may exist for stacked CO_2-EOR and saline storage.	2	-1	-1
Seismic Risk	Must not be in an area of high seismic hazard (per USGS).	There is a 2% probability that the Peak Ground Acceleration due to seismic activity will exceed 14% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second).	1		
Seal Analysis					
Relation of Primary Seal to Active or Transmissive Faults	The primary seal must not be intersected by any known historically active or hydraulically transmissive faults. The proposed seal must have a low differential in-situ caprock or target formation stress and high mechanical seal strength relative to injection pressure	The La Salle Anticlinorium (Figure 18) is approximately twenty miles to the west of the WVR site. New seismic reflection data acquired over the site suggest no resolvable faults within a 10-mile (16 km) radius of the site.	1	-4	-5

Primary Seal	The primary seal must have sufficient thickness (greater than 20 feet or 6 m), be regionally extensive, and be continuous over the entire projected CO_2 plume boundary after injection of 50 MT (55 million tons) of CO_2. It must have sufficiently low vertical permeability and have sufficiently high capillary entry pressure to provide a barrier to migration of CO_2 out of the target formation.	Regional thickness map for the Eau Claire Shale (Figure 11) is estimated to between 750 to 1000 feet (229 to 305 m) thick. The Newport Chemical Plant #WD-1 well is (22 miles [35 km] to the north) has over 850 feet (259 m) of Eau Claire Formation and has safely served as a disposal well that accepted millions of gallons of wastewater. The Eau Claire at the WVR site is expected to be around 900 feet (274 m) thick.	1	-5	-5
Secondary Seal	Not required but preferred. Secondary seal should overlie the primary caprock seal, be largely continuous, be greater than 10 feet (3 m) thick throughout and cover at least 75 percent of the projected plume after injection of 50 MMT CO_2.	Regional thickness map of the Maquoketa Shale (Figure 12) indicates thickness range between 200 to 300 feet (61 to 91 m). The Maquoketa Shale is over 275 feet (84 m) thick at this location.	1	-2	-2
Tertiary Seal	Not required	The New Albany Shale is estimated be approximately 100 feet (30 m) thick at this location.			
Gas Storage	Gas storage reservoirs cannot be within the estimated CO_2 plume radius.	State Line Gas Storage Field (abandoned) is approximately 7 miles (11 km) to the southwest of the WVR site in Vigo Co., IN. Wells in the field are relatively shallow, with a maximum depth of approximately 2,181 feet (665 m) into the Silurian.	2	-3	-9
Seismic data availability	Is there any seismic reflection data available at this site? This is not a requirement, but it reduces subsurface uncertainty.	There is over 20 miles (32 km) of recent 2D seismic reflection data across the site.			
Reservoir salinity	Injection reservoir must be over 10,000 mg/L	Mt. Simon reservoir has a salinity of over 200,000 mg/L at Newport Chemical Plant 22 miles (35 km) to the north); the WVR site is expected to have Mt. Simon salinities (Figure 4) similar to Newport chemistry data.	1	-2	-2
Boreholes penetrating injection reservoir	Abandoned boreholes penetrating the reservoir interval may allow leakage into shallower horizons	None within 22 miles (35 km). Information summarized in Data Assessment Section.	1	-2	-2
Seal becomes target for unconventional petroleum production	Identify a potential scenario where primary seal becomes a target for shale gas production, and operators object to CCS injection	The Eau Claire Formation is not organic rich and the Maquoketa Shale (secondary seal) is unlikely to be an unconventional petroleum target in this area	2	-2	-4
Legal/regulatory permitting issues	Permitting time and requirements cause economic delays	This must be addressed during the permitting of the well and is dependent on the regulatory agency.	3	-3	-5
Near Surface Impacts					

Sensitive features above sequestration area	The land above the proposed sequestration formation must not intersect large dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features.	No known sensitive surface features or protected biological species.	2	-3	-6
Sequestration impacts on drinking water	Proposed target formation for CO_2 sequestration must not be an underground source of drinking water	Unconsolidated/surficial deposits above bedrock at the site are estimated to be approximately 50 feet (15 m) thick. Indiana DNR Aquifer Systems Maps denote the Pennsylvanian Carbondale Group as the predominant bedrock aquifer system in the area. The WVR site is not located in a drinking water protection area, or above a sole source aquifer.	3	-5	-5
Access to sequestration area for CO_2 leakage monitoring	There must be sufficient access to the land surface above the proposed sequestration area to implement a CO_2 leakage monitoring program.	Area is flat lying and appears to have no issues with access	1	-3	-3
Mineral Rights in the CO_2 sequestration area	The proposed CO_2 sequestration area must be located where the project can obtain, purchase, or get a waiver of subsurface mineral rights. (unless recovery of coal-bed methane or oil is a part of the sequestration process).	Needs to be addressed by Wabash Valley Resources			

Data Assessment

Data sets were compiled in the CarbonSAFE Illinois East Sub-Basin study area to assess the state of data availability (DOE-FE0029445-5) documenting penetration into or through the Ordovician system and the Cambrian Eau Claire Shale. Any available datasets for the Mt. Simon within 50 miles (80 km) of the Wabash Valley Resources facility were compiled and assessed to determine data deficiency.

The deepest drilled well nearest the WVR plant penetrates the Upper Mt. Simon and is the Newport Chemical Plant #WD-1 (Table 7), located approximately 22 miles (35 km) north. It has fair reservoir quality and was used as a disposal well for millions of gallons of wastewater. This well only penetrated the top 900 feet (274 m) of the Mt. Simon, so the Lower Mt. Simon remains unexplored in the local Wabash area. Data for Newport Chemical Plant #WD-1 include geophysical logs (Gamma, Neutron, SP, and Resistivity) collected in 1960, Mt. Simon core analysis, and a single brine sample analysis. Outside our study area, the Duke Edwardsport, Knox County, IN and Gibson Power Plant well, Gibson County, IN located 50 and 75 miles (80 and 121 km) south of the WVR facility, respectively] penetrated the fair quality reservoirs of Upper Mt. Simon. Modern log suites and well documentation is available for each well.

Allied Chemical Corporation, Vermillion, IL is the nearest penetration into the Lower Mt. Simon at 41.5 miles (67 km) north of the WVR site approximately 1.65 miles (2.66 km) outside of the East Sub-Basin study area]. Modern log suites and well documentation is available for that well. There are relatively few well penetrations into the Lower Mt Simon within the Illinois Basin.

Table 7. Nearest wells to the proposed site which penetrate selected formations.

API	Well Name	Latitude (DD)	Longitude (DD)	Distance (miles)	Total Depth (ft)	State	County	Penetration
120192399601	Hinton	40.263803	-88.412651	72	6,550	IL	Champaign	Argenta
164778	Duke	38.7997551	-872531572	51	10,050	IN	Knox	Precambrian
117407	Pensinger	39.2612274	-87.0925092	26	6,751	IN	Clay	Mt. Simon
125110	Newport	39.85023	-87.422848	21	6164	IN	Vermillion	Mt. Simon
157501	Summers	39.616094	-87.048861	22	4668	IN	Parke	Eau Claire
124283	Biglow & Millikin	39.527835	-87.311665	6	3490	IN	Vigo	Knox
124289	Lovelace	39.559684	-87.387565	3	3160	IN	Vigo	St. Peter

The Hinton #7 well, located in Manlove Gas Storage Field, Champaign Co., Illinois, 75 miles (121 km) northwest of the Wabash site. Data from the Hinton #7 include geophysical logs (Gamma, Neutron, SP, and Resistivity), Mt. Simon core analysis, and brine sample analysis. Rotary sidewall plug samples from the Hinton #7 Mt. Simon were acquired from the ISGS Samples Library inventory and thin sections were prepared (Figure 22). A major focus has been on the characterization of the Lower Mt. Simon, considered the best potential reservoir for carbon storage, with the highest quality reservoir found within a high porosity, highly arkosic zone.

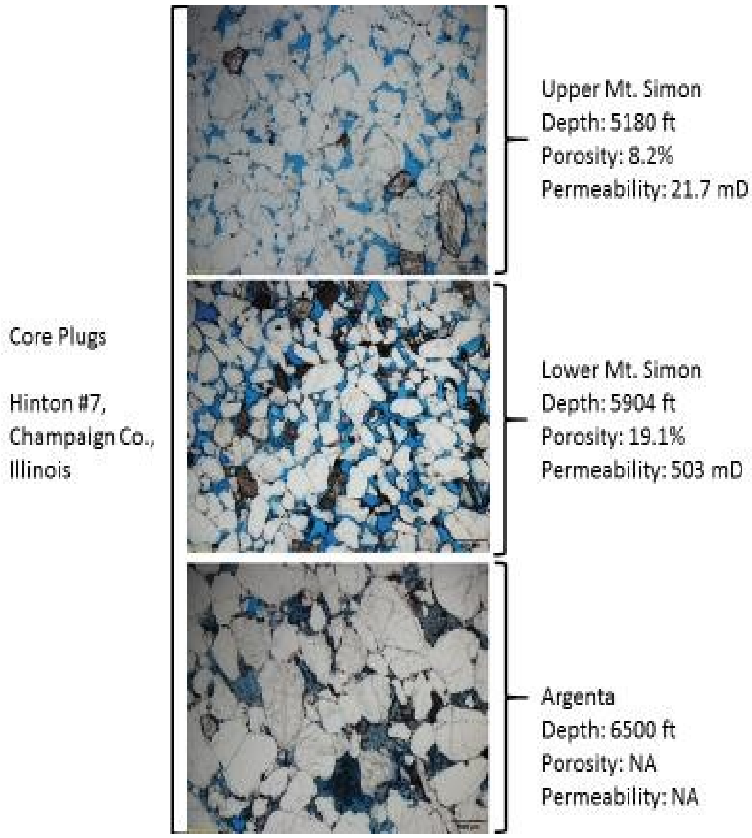

Figure 22. Thin Section photomicrographs of Hinton #7 well core plugs in the Mt. Simon Sandstone.

Lower Mt Simon well logs and regional trends indicate porosity and permeability are 16.3% and 11.1 millidarcies [mD]) (Mehnert et al., 2014). The Hinton #7 well, has 215 feet (66 m) of excellent quality reservoir in the arkose zone with porosity and permeability values up to 25% and 600 mD. At IBDP and IL-ICCS injection sites, the Lower Mt. Simon Sandstone has porosity and permeability as high as 27% and 400 mD, and a mean (log) porosity of 16.6%. Lateral continuity of the high-quality reservoir in the Lower Mt. Simon is uncertain because of limited well control, but most wells within the southern half of the Mt. Simon depocenter that penetrate the Lower Mt. Simon show the occurrence of a porous zone.

Deep wells (that penetrate the Maquoketa or Knox formations above the Mt. Simon) within 10 miles (16 km) of the site are listed in Table 8.

Table 8. Locations and well information for wells within ten miles of the proposed stratigraphic test well drill site which penetrate the Maquoketa or Knox formations.

API	Lat. (DD)	Long. (DD)	TD (ft)	TD Formation (ft)

166909	39.47124	-87.4017	3561	Knox*
124283	39.52784	-87.3117	3490	Knox
124289	39.55968	-87.3876	3160	St. Peter
157261	39.56867	-87.268	3000	St. Peter
124214	39.46217	-87.4183	2980	Trenton
124049	39.40416	-87.3893	2933	Trenton
166365	39.46422	-87.2916	2760	Trenton
124985	39.63516	-87.398	2577	Black River
124981	39.64009	-87.4525	2566	Trenton
124943	39.65123	-87.3288	2466	Trenton
123994	39.40683	-87.3986	1950	Muscatatuck
124039	39.40427	-87.387	1803	Muscatatuck

Data Acquisition

2-D seismic reflection profiles

The ISGS has acquired a 2D seismic reflection profile was acquired in the southern portion of the East Sub-Basin study area through western Richland Co., IL., across Noble Oil Field. Noble Field lies along a major structural feature called the Clay City Anticline, a long, sinuous, southward-plunging anticlinal nose with numerous small areas of closure. The Clay City Anticline hosts numerous oil pools (known collectively as Clay City Consolidated Oil Field) in several reservoirs and has produced over 360 million barrels of oil.

Noble Oil Field has undergone characterization research for two current DOE projects focused on the potential of Residual Oil Zones (ROZ) in the Illinois basin. The Cypress Sandstone, Illinois's most prolific oil producing formation and a potential saline carbon storage target, was characterized in detail to determine the presence and extent of a brownfield ROZ (DE-FE0024431). In Noble Field, the Cypress Sandstone is characterized by a thick (100 ft, 30 m) Cypress Sandstone with significant thinning of the sandstone on both the south and west side of the field (Figure *23*).

Building on Cypress characterization work, DE-FE0031700 will use Noble Field as a field laboratory site to validate the Cypress ROZ and provide valuable information about the potential of the field for stacked CO_2-EOR and associated storage. Part of the study includes the drilling of a new well, collection of core samples, and the acquisition of modern suite of wireline logs (including sonic). To compliment the project, seismic reflection data has been acquired approximately one mile from the proposed drill site. Velocity information collected from the wireline logs will be correlated with the seismic data to validate the usage of seismic reflection to advance Cypress mapping efforts and further characterize the sequestration potential of the area.

In addition, the seismic data has enabled greater characterize of the deeper strata such as the Precambrian basement and the Mt. Simon Sandstone storage reservoir in this part of the East Sub-Basin study area. The approximate Precambrian surface below Noble Field Area appears to be heavily faulted and may also be a Precambrian paleotopographic high (Figure 24). There is onlap of the overlying reflectors across the Precambrian surface. The final interpretation will be completed after drilling of a nearby well and will then be integrated into the regional structural analysis of the Illinois Basin.

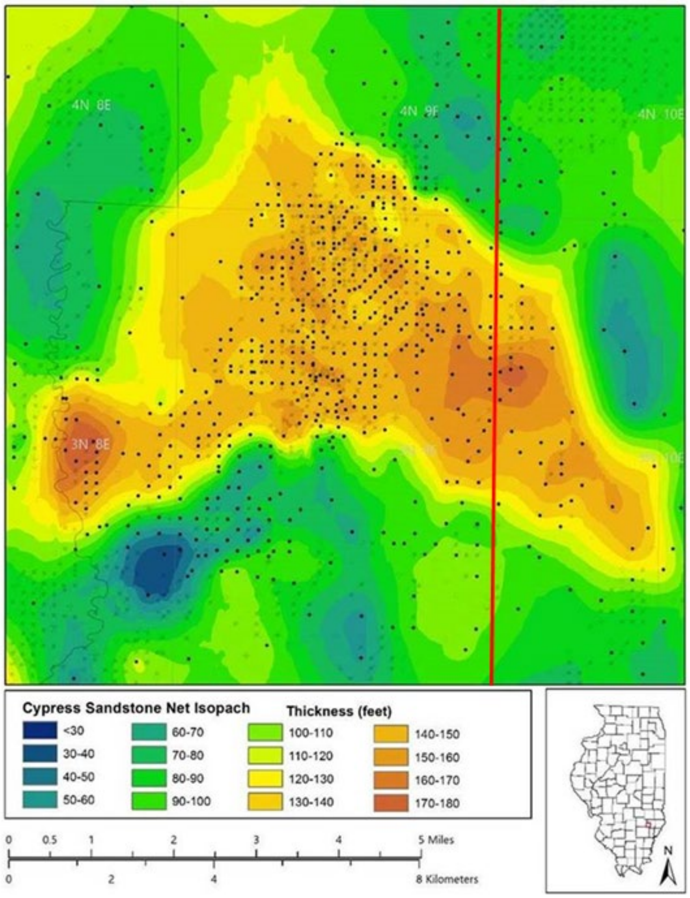

Figure 23. Thickness of the Cypress Sandstone in Noble Field. Location of 2D seismic reflection shown as the red line across the Noble Field.

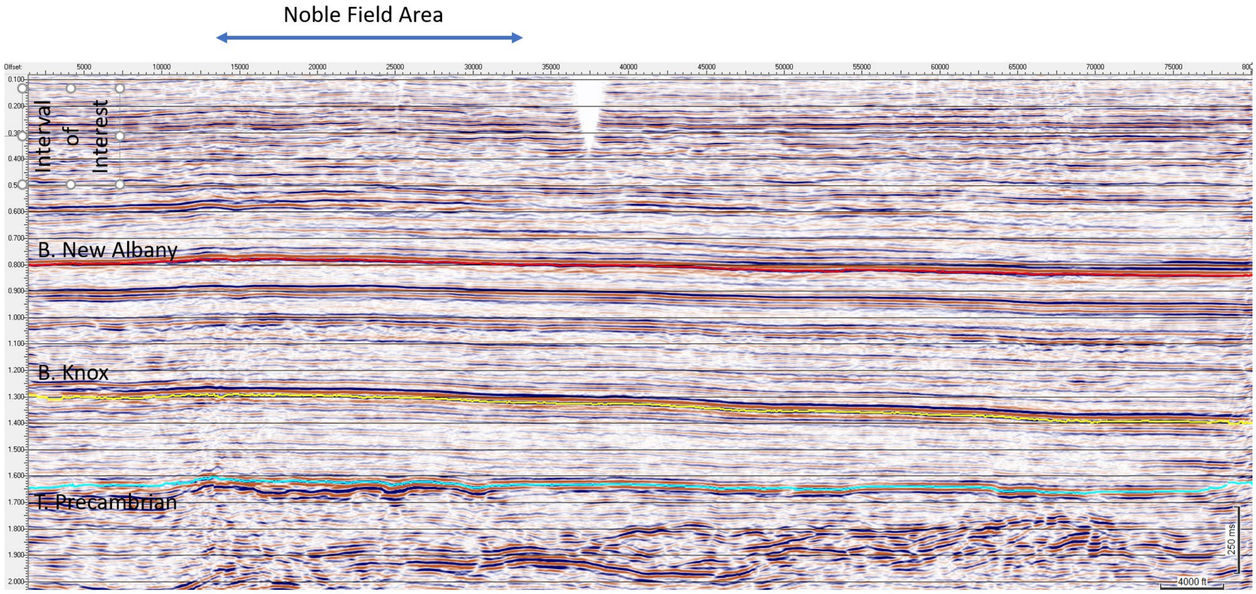

Figure 24. Seismic reflection across the Noble Field Areas (overlies the Clay City Anticline). The Base of Knox reflector shows a broad anticlinal feature in the Noble Field Area. The Top of Precambrian is structurally complex and needs further analysis and integration with other regional seismic reflection profiles. The vertical scale is in seconds.

Regional Deep Saline Storage Landscape

The stratigraphic cross section (Figure 25) displays variability of the potential reservoir and overlying sealing strata as well as the lack of penetrations into or through the full thickness of Mt. Simon interval. The Lower Mt. Simon reservoir has been successfully used to store CO_2 at the US DOE funded IBDP and IL-ICCS study areas; a major focus has been on the characterization of the Lower Mt. Simon. Lower Mt Simon well logs and regional trends indicate porosity and permeability are 16.3% and 11.1 mD (Mehnert et al., 2014). The high porosity, highly arkosic interval, considered the best potential reservoir for carbon storage, has been identified near the base of the lower Mt. Simon. Because of the sparsity of wells in the Illinois Basin that penetrate this reservoir, the lateral extent of this lower reservoir is not well known. The Hinton #7 well, has 215 feet (66 m) of excellent quality reservoir in the arkose zone with porosity and

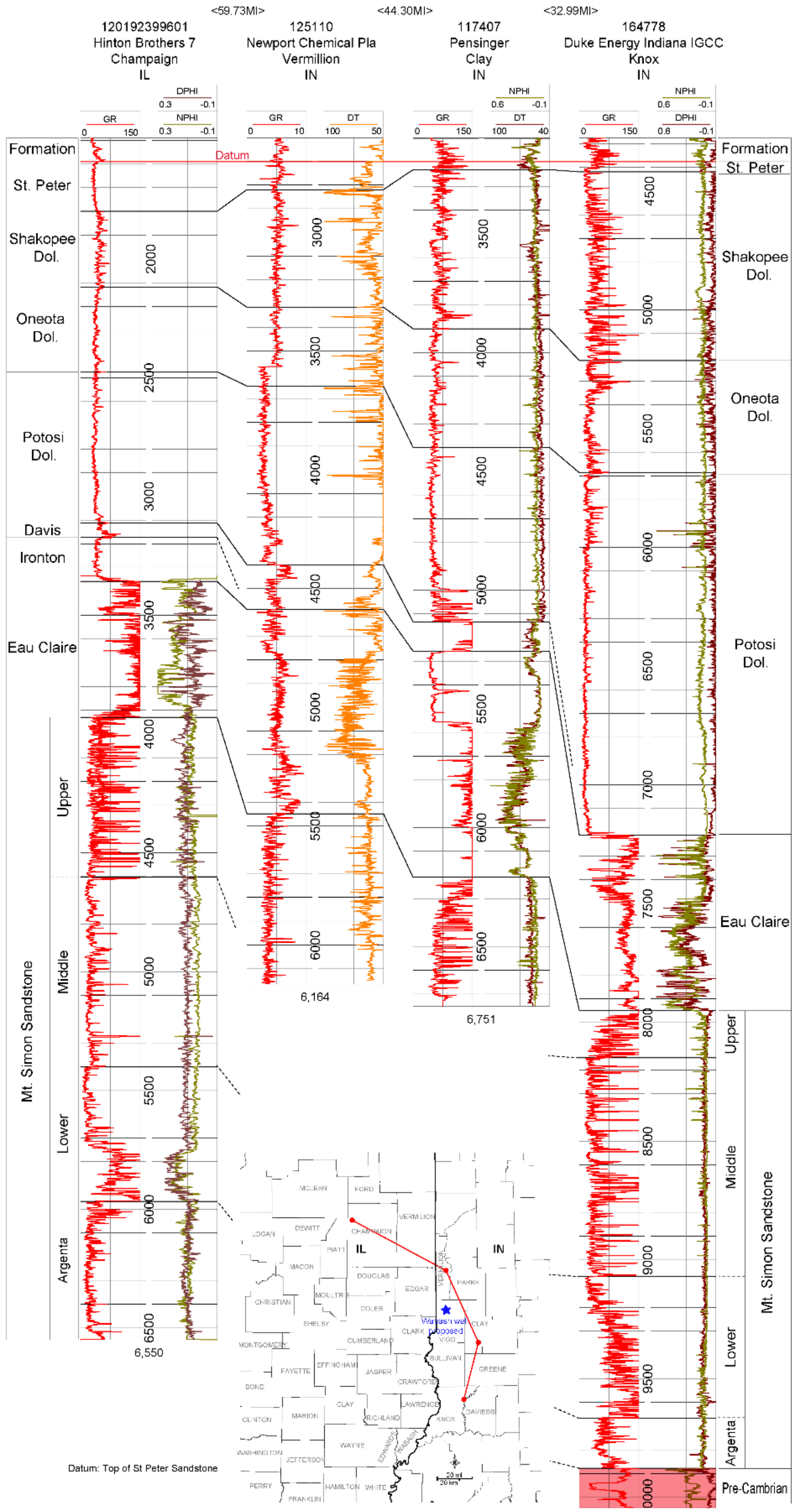

Figure 25. Structural cross section using deep wells near the proposed drill site; datum: Top of St. Peter Sandstone.

permeability values up to 25% and 600 mD. Although the Duke Energy Indiana IGCC well, Knox Co., IN, penetrates through the entire Mt. Simon storage complex, core measured porosity and permeability data are not available below the Middle Mt. Simon. Drilling in Vermillion Co., IN or Clay Co., IN has not penetrated such a high porosity zone, but these wells may lack the depth of penetration needed. A geological characterization borehole must be completed in order to determine the potential reservoir quality, heterogeneity, and capability for long-term and large-scale storage at the WVR facility.

Reservoir Simulation

Geocellular Model

A preliminary assessment of the proposed Wabash Valley Resources area was completed evaluating simulated injection of an injection simulation of 50 million tonnes of CO_2 into the Mt. Simon Sandstone unit and predicting the injected CO_2 plume lateral extent. To carry out the evaluation in the proposed East Sub-Basin area (i.e. Wabash Valley Resources facility), a preliminary static geocellular model of the Mt. Simon Sandstone was built using constrained structural surfaces (i.e. for storage unit and its subunits) and available geophysical log data from wells that penetrate the Mt. Simon Sandstone unit. The primary wells used as the basis for the model included the Newport Chemical Plant WD-1 well (Newport 1), and the Hinton Brothers #7 well (Hinton #7). Each well is discussed in more detail in the previous section on data availability. Available log suites include neutron, density and sonic porosity as well as core plug analysis data were compiled. Given the observed Mt Simon heterogeneity, it is uncertain how representative the wells are of the geology of the proposed location, however, based on regional mapping, there is a strong possibility that all three units of The Mt. Simon (Upper, Middle and Lower) exists at the location. Additionally, well data from the previous pilot work in Decatur, Illinois (Decatur) was supplemented to the analysis.

A grid that covers a surface area of 16 x 16.1 km (10 x 10 mi) was created with 264 cells in the X direction and 265 cells in the Y direction and spacing of 61 m x 61 m (200 ft x 200ft). Surfaces for the tops of the Upper, Middle and Lower units of the Mt Simon were based on from regional and local mapping. The lower zone was further divided into a fourth zone, referred to as Arkosic, the high permeability and porosity Lower Mt. Simon that has been identified in the Hinton #7 and is the main injection target at the Decatur project. The Upper Mt Simon was 96.0 m (315 ft) thick, the Middle Mt Simon zone was 330.7 m (1085 ft) thick, the Lower Mt Simon zone was 63.7 m (209 ft) thick, and the Arkosic zone was 61.0 m (200 ft) thick. The model was discretized vertically into 70 layers with the thickness of each proportionally determined between the zones.

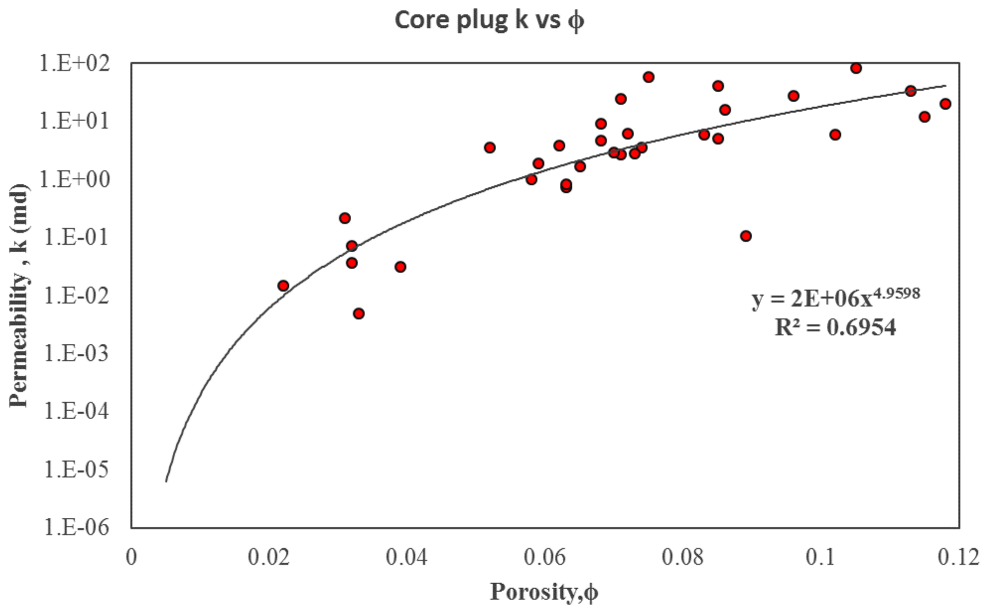

Figure 26. Cross-plot of porosity and permeability results from core plug testing from the Newport well used for the Upper and Middle Mt. Simon model zones.

Separate zones in the model were created since the units consistently display noticeable distributions in petrophysical properties. In the Upper and Middle Mt. Simon, porosity was modeled using the Newport 1 data through geostatistical methods and the permeability transformed using regression model based on cross-plotting core data (Figure 26). The Lower and Arkosic was based on analysis of the petrophysical properties from Hinton #7 and Decatur project. At Decatur, a single regression model of permeability and porosity was found insufficient and thus the core analysis data was divided into five different separate models (Figure 27).

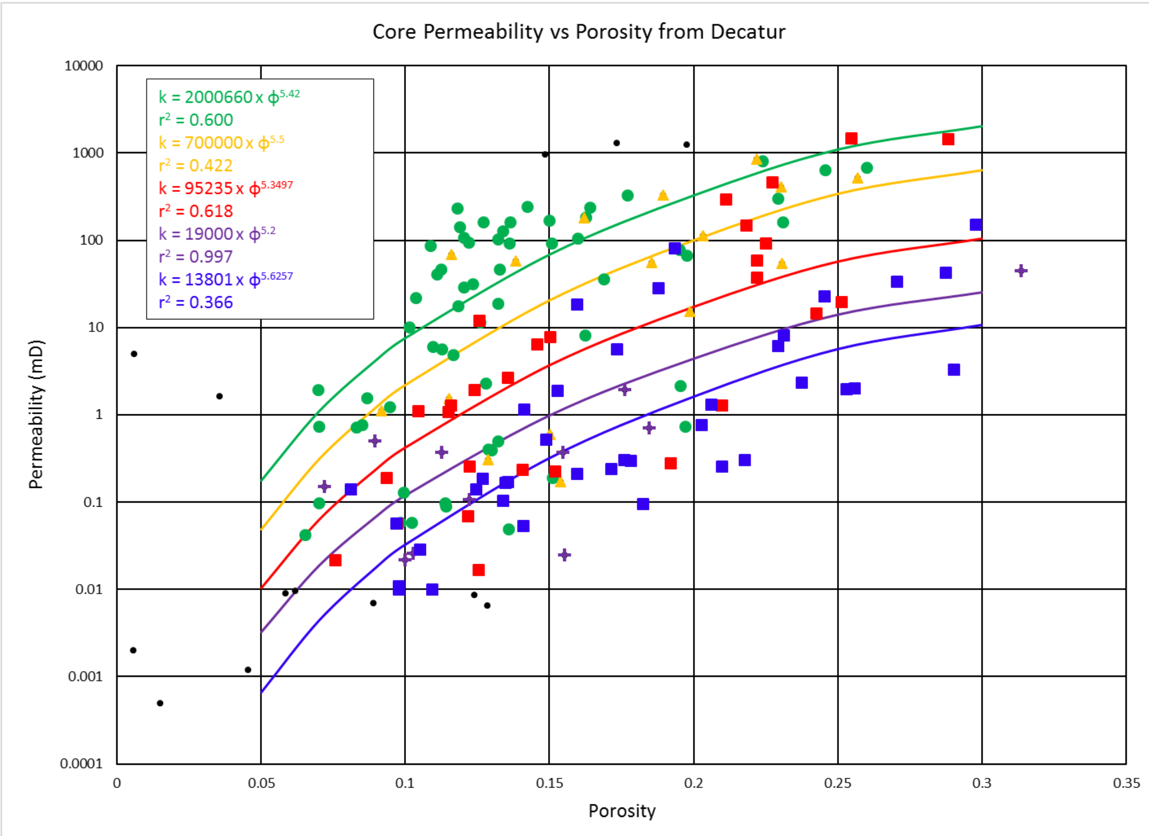

Figure 27. Cross-plot of porosity and permeability results from core plug testing from the Decatur project used for the Lower Mt. Simon and Arkosic model zones. Points and fitted curves are colorized by which facies each was assigned. Equations for each regression model and associated r2 values are also shown and colorized according to match the corresponding facies.

Five separate facies were created in the model to represent these different porosity-permeability relationships and randomly distribute in the two zones based on proportions observed at the Decatur project and Hinton #7. Porosity was distributed randomly within each facies based on distributions from the two wells and the different transforms were used to calculate permeability (Figure 28 and Figure 29). Table 9 contains model dimensions and the resulting statistics of permeability and porosity of the different zones and Table 10 contains statistics of model volumetrics.

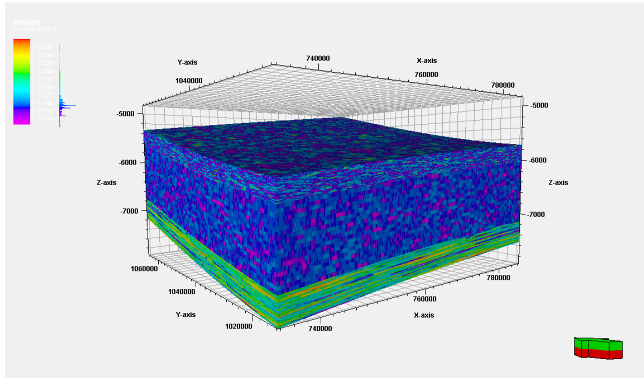

Figure 28. Distribution of porosity in final model as viewed from the south west looking north east.

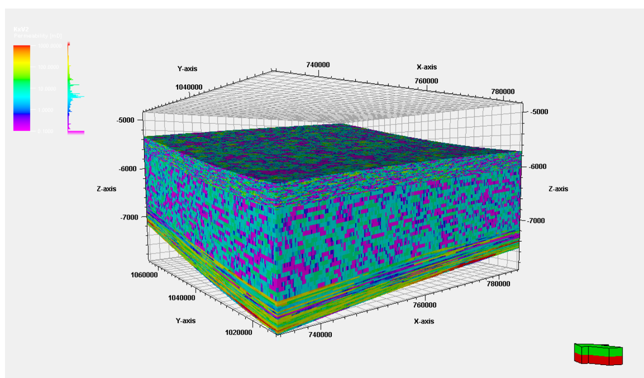

Figure 29. Distribution of permeability in final model as viewed from the south west looking north east.

The complete static earth model is the foundation of the simulated fluid flow modeling performed to determine the suitability of Mt. Simon Sandstone for storing 50 million tonnes of CO_2 at this location and predict the lateral CO_2 plume extent. After discussion with project geologists, the current geocellular model is seen as a reasonable possible reservoir architecture and represents a middle ground in terms of reservoir quality. The Mt. Simon sandstone storage complex is regionally extensive, hence calculated bulk, net and pore volumes in Table 10 is constrained by the model dimension.

Table 9. Model summary

Model size	52800 x 53000 x 3109.76 ft^3			
Cell number (x, y, z)	264 x 265 x 70			
Cell Dimension	61.0 m x 61.0 m (200 ft x200 ft)			
Total number of cells	4897200			
Total number of zones	4+			
Total number of layers	70			
Formation Units	Upper Mt. Simon (Secondary storage unit), Middle Mt. Simon (Baffle/Seal unit), Lower Mt. Simon (Primary storage unit), Arkosic Zone (Primary storage unit)			
Model (top, bottom)	Upper Mt. Simon, Precambrian basement			
Porosity Statistics	Unit	Min	Max	Mean
	Upper Mt. Simon	0.0403	0.2164	0.0928
	Middle Mt. Simon	0	0.1047	0.0839
	Lower Mt. Simon	0.0306	0.2799	0.1663
	Arkosic	0.030	0.280	0.1619
Permeability (Kx) Statistics	Units	Min (mD)	Max(mD)	Mean (mD)
	Upper Mt. Simon	0	112.3	8.814
	Middle Mt. Simon	8.11E-09	14.8645	4.2096
	Lower Mt. Simon	0.0001	1948.3	40.54
	Arkosic	0.0016	2017.05	134.9

Table 10. Bulk, net and pore volume for constructed model assuming net-to-gross ratio of 0.6, 0.8 and 1.

		Net to gross					
		0.6		0.8		1	
Zones	**Bulk Vol 10^6 m^3 (× 10^9 ft^3)**	**Net Vol 10^6 m^3 (× 10^9 ft^3)**	**Pore Vol 10^6 m^3 (× 10^9 ft^3)**	**Net Vol 10^6 m^3 (× 10^9 ft^3)**	**Pore Vol 10^6 m^3 (× 10^9 ft^3)**	**Net Vol 10^6 m^3 (× 10^9 ft^3)**	**Pore Vol 10^6 m^3 (× 10^9 ft^3)**
Upper Mt. Simon	25100 (886)	15000 (531)	249 (8.78)	20000 (708)	331 (11.7)	25100 (886)	413 (14.6)
Middle Mt. Simon	86800 (3060)	52100 (1840)	778 (27.5)	69400 (2450)	1040 (36.6)	86800 (3060)	1300 (45.8)
Lower Mt. Simon	16600 (586)	9970 (352)	295 (10.4)	13300 (469)	394 (13.9)	16600 (586)	493 (17.4)
Arkosic	15900 (560)	9510 (336)	274 (9.68)	12700 (448)	365 (12.9)	15900 (560)	456 (16.1)
Total	144000 (5100)	86600 (3060)	1600 (56.4)	115000 (4080)	2130 (75.2)	144000 (5100)	2660 (93.9)

Fate and Transport of Injected CO_2

Landmark's, NEXUS (Desktop version 5000.4.12) compositional simulator was used to perform reservoir simulations. Simulation results will be used to make preliminary assessment of CO_2 storage resource and associated changes in pressure within the Mt. Simon formation at the proposed East Sub-Basin site at WVR facility.

Three relative permeability curves were generated for the Mt Simon representing various quality of rocks (Figure 30): 1) High quality with permeability greater than 100 md, 2) intermediate quality with permeability between 1 md and 100 md, and 3) low quality with permeability lower than 1 mD. The curve for high quality rock was based on lab measurements of samples from lower Mt. Simon in Decatur conducted by Schlumberger Reservoir Laboratories, Houston, Texas, in 2015 (unpublished report). The other two curves were generated based on general knowledge from the literature using the Brooks-Corey function (Krevor et al., 2012; Lahann et al., 2014). The initial reservoir temperature and pressure was 122.6 °F and 2179 psia at 4843 ft. The initial pressure estimated is a based on an assumption of an average hydrostatic gradient of about 0.45 psi/ft, which is equivalent to field measurements at the Decatur storage site. The Mt. Simon at Wabash Valley Resources is assumed an infinite-acting aquifer.

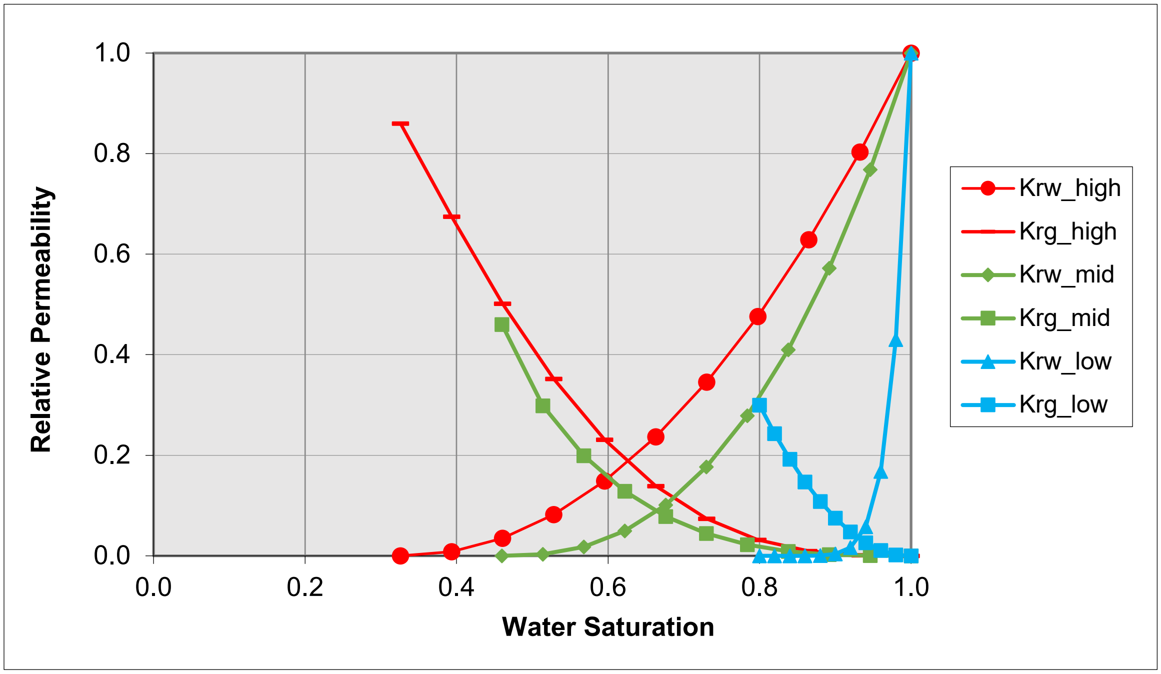

Figure 30. CO_2 and brine relative permeability curves used in the reservoir model.

A radial Carter-Tracy analytical function (Carter and Tracy, 1960) surrounding the reservoir model, was used to represent infinite-acting aquifer in simulations. The analytical aquifer function was assigned or attached only to peripheral boundary grid cells. A combination of the model and the analytical aquifer function represent are assumed to represent an aquifer with infinite lateral extent.

Numerous reservoir simulations were performed to evaluate the feasibility of injecting 50 million tonnes of CO_2 into the Mt. Simon at WVR. The maximum injection pressure gradient was constrained at 0.64 psi/ft for all simulations. This is equivalent to 90% of the estimated fracturing gradient (0.71 psi/ft) of the Mt. Simon formation at the Decatur site. Maintaining a maximum pressure gradient at 0.64 psi/ft prevents formation fracturing during injection.

Based on information for the WVR facility, its CO_2 capture capacity ranges between 120 and 179 metric tons per hour. The estimated operating time of this plant is about 7200 hours per year i.e. 82% of a year (9.84 months). Assuming all the capture CO_2 will be injected into the subsurface, between 0.86 and 1.29 million tonnes of CO_2 can be stored in 82% of a year. If the plant operates continuously the annual CO_2

injection would range between 1.05 and 1.57 million tonnes per year. Reservoir simulations were performed based a maximum CO_2 capture capacity of 1.57 million tonnes per year.

A detailed evaluation of the static reservoir model indicate that the Lower Mt. Simon has the highest permeability compared to middle and upper Mt. Simon. The bottom section (about 93 ft) of the Lower Mt. Simon has the highest permeability (Figure 31, top). As a result, three simulation scenarios were performed to evaluate sensitivity of well injectivity, and pressure change to the perforated interval. The simulations differ the perforated interval through which CO_2 is injection, i.e., 93 ft (Case 1), 160 ft (Case 2), and 200 ft (Case 3).

Two additional simulations, namely Case 4 and Case 5, in which the daily injection rates were not constrained to the CO_2 capture capacity of the WVR facility at Terre Haute, Indiana. About 93 ft and 409 ft of the bottommost or deepest section of the lower Mt. Simon were modeled as the perforated intervals in Case 3 and Case 4 simulations.

Figure 311 (bottom) shows a cross-section of CO_2 saturation distribution which preferential migrates up dip. Pressure buildup during injection could be as high as 434 psi but would dissipate during post-injection period.

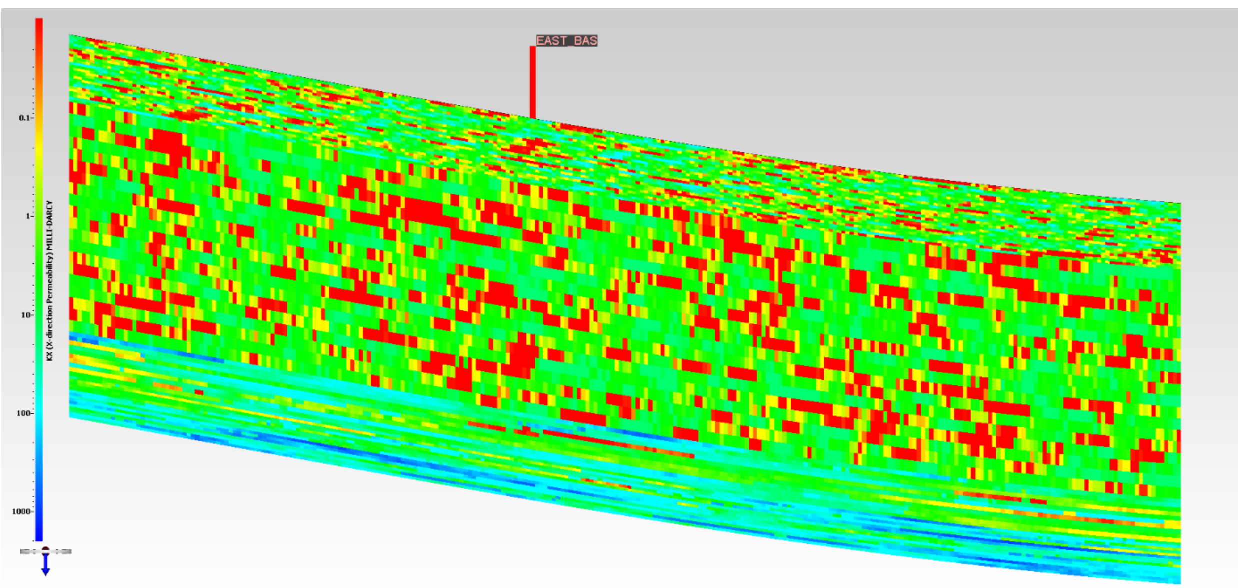

Figure 31. Horizontal permeability distribution (top) and CO_2 saturation distribution using a (bottom). Hot colors indicate low permeability or CO_2 saturation. Cooler colors indicate high permeability or CO_2 saturation.

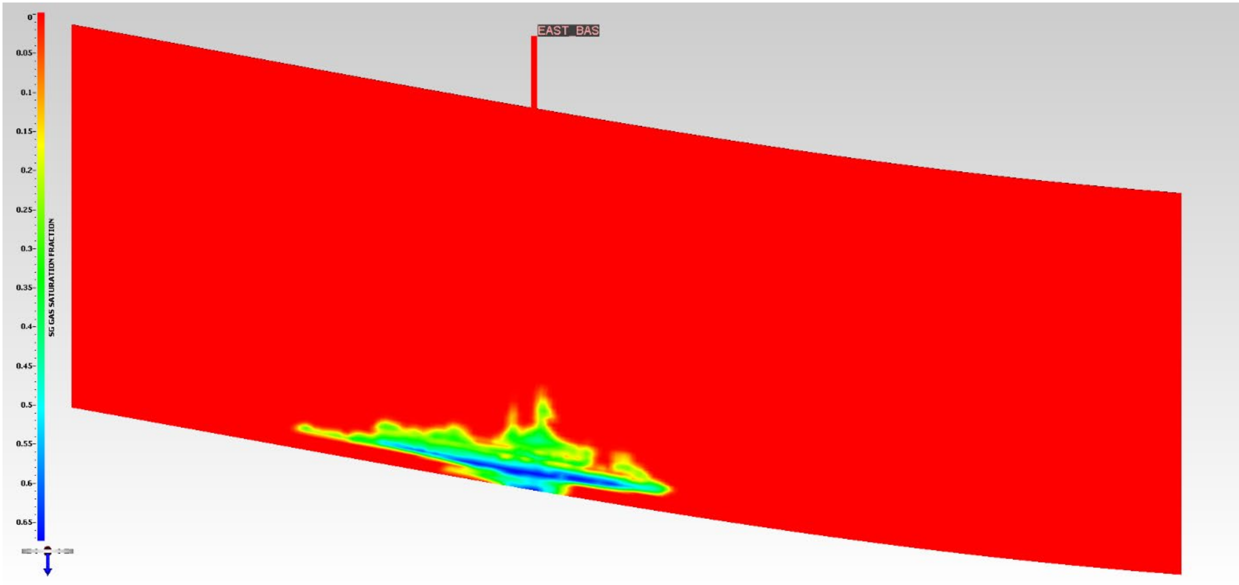

Figure 32. Horizontal permeability distribution (top) and CO_2 saturation distribution using a (bottom). Hot colors indicate low permeability or CO_2 saturation. Cooler colors indicate high permeability or CO_2 saturation.

Simulation results suggest that it would take about 32.1 years to inject 50 million tonnes of CO_2 via the 93 ft perforated interval (Case 1). Simulation results also predict that 50 million tonnes of CO_2 can be injected via 160 ft (Case 2) and 200 ft (Case 3) perforated intervals in the Lower Mt. Simon after about 32 years for both cases. However, when injection rate is unconstrained it could take about 30.3 years and 26.9 years to inject 50 million tonnes of CO_2 via the 93 ft (Case 4) and 409 ft (Case 5) perforated intervals, respectively.

Results presented in Table 11 suggest that the maximum pressure change (Δp_{max}) due to CO_2 injection within a margin of error of ±1 psi in the 93 ft (Case 1), 160 ft (Case 2), and 200 ft (Case 3) perforated interval simulations are similar. This is because CO_2 injection rate was constrained at a maximum value (q_{max}) 80,997 Mscf/d in these simulation cases. In a scenario where the injection rate is unconstrained, as is in Case 4 and Case 5, Δp_{max} and q_{max} increase with the product of thickness (H) and permeability (k) of the perforated interval, i.e. kH (Table 11).

Results also indicate that the maximum CO_2 injection rate increases with perforated interval.

Table 11. Plume extents of different simulated scenarios.

Simulatio n case	Rate constraint	Perforated interval		Δp_{max} (psi)	q_{max} (Mscf/d)	Plume extent (ft)	
		H (ft)	kH (mD. ft)			Equiv. Radius	Frailey 2014
Case 1	Yes	93	2,392	434	80,997	12,799	
Case 2	Yes	160	1,959	433	80,997	12,893	
Case 3	Yes	200	1,799	435	80,997	12,943	
Case 4	No	93	2,392	489	89,253	13,359	
Case 5	No	409	1,419	565	100,000	12,943	

Frailey 2013 discusses plume size correlations developed using a right circular cylinder with storage efficiency values derived from Monte Carlo simulation for the purpose of producing a reliable estimate of plume size at the end of an injection period during the site screening process.

An example from Frailey 2013, evaluates a source with annual emissions of 1 M tonnes/year looking to inject for 30 years, or an ultimate storage mass of 30 M tonnes, and the site has a geologic formation with a net thickness of 91.4 m (300 ft) with an effective porosity of 10%, the unit storage mass is:

$$\frac{30\text{Mtonnes}}{91.4\text{m}/0.1} = \frac{3.28\text{Mtonnes/m}}{1.0\text{Mtonnes/ft}}$$

Using a value of 3.28 M tonnes/m (1.0 M tonnes/ft) on the *x*-axis of Figure 32, the plume radius corresponding to the P_{50} storage efficiency radius is about 4450 m (14,600 ft); P_{90} storage efficiency radius is 2789 m (9150 ft), and P_{10} storage efficiency radius is 4907 m (16,100 ft).

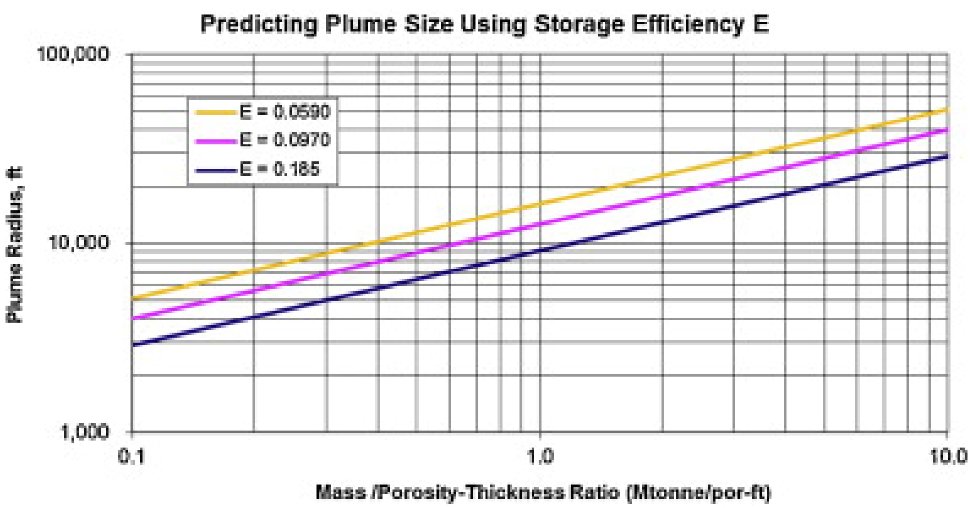

Figure 33. **Plume size radius (feet) correlation using cumulative mass injection (M tonnes), effective porosity (fraction) and net thickness (feet) (1 ft = 0.3048 m).**

Predicting Plume Size Using Storage Efficiency E

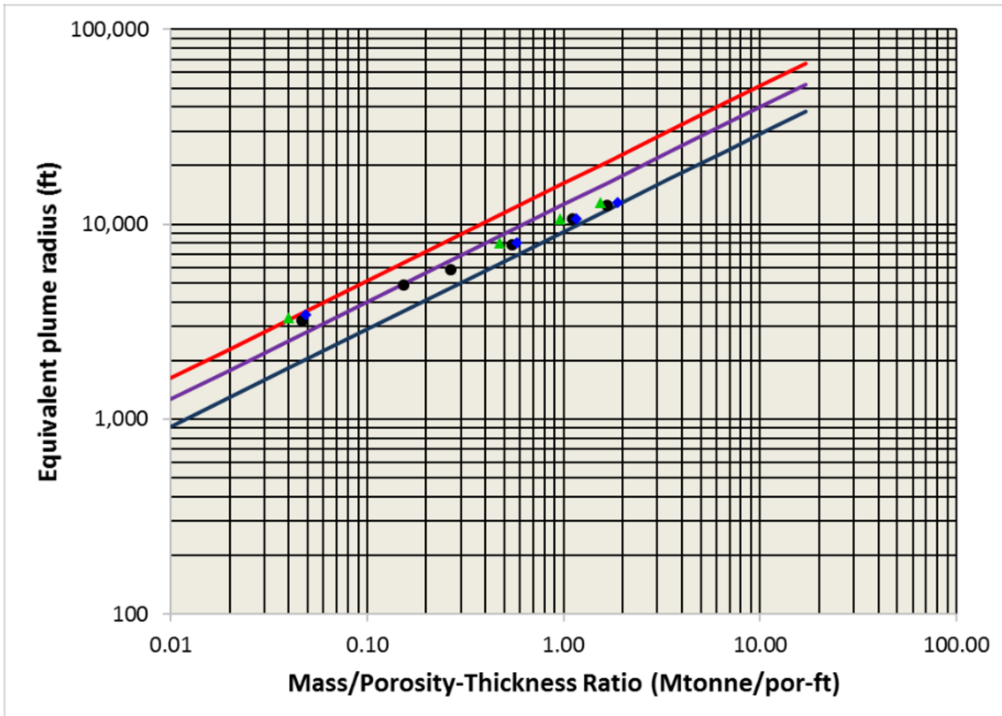

Figure 34. Comparison of simulation predictions to plume size correlation developed by Frailey, 2013. Plume size radius (feet) correlation using the cumulative mass injection (M tonnes), effective porosity (fraction) and net thickness (feet) (1 ft = 0.3048 m).

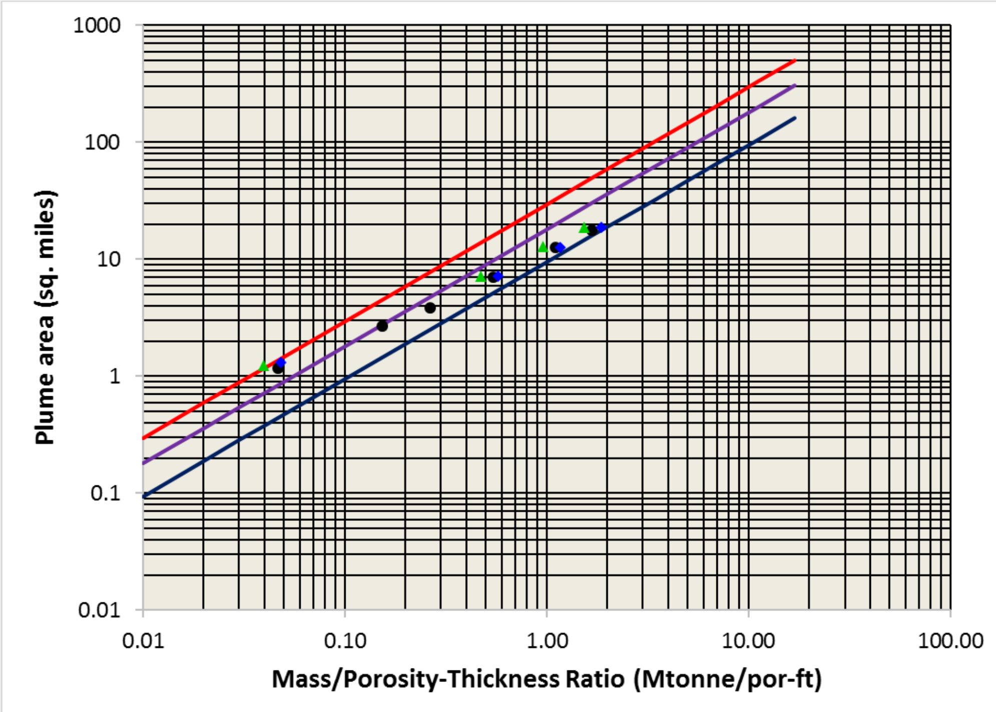

Figure 35. Comparison of simulation predictions to plume size correlation developed by Frailey, 2013. Plume size area (square miles) correlation using cumulative mass injection (M tonnes), effective porosity (fraction) and net thickness (feet) (1 mile = 1.609 km; 1 ft = 0.3048 m).

The predicted CO_2 plume size for the 93 ft perforated interval simulation case reasonable matches the Frailey 2013 CO_2 plume size correlations (Figure 33, Figure 34,).

Stratigraphic test well and 2D seismic reflection profiles

The Wabash CarbonSAFE project intends to drill and acquire wireline logs for a stratigraphic test well at the Wabash Valley Resources (WVR) facility to approximately 8,300 feet (2530 m) deep, to determine the feasibility for the geologic sequestration of 45 metric tons (50 million tons) or more of injected CO_2. The characterization plan will include retrieving whole core samples for description, testing, and analysis. The primary characterization target for this project is the Mt. Simon Sandstone; we intend to drill completely through the Mt. Simon in order to obtain samples of the underlying Precambrian basement rocks. Whole core samples will be collected in the arkosic Lower Mt. Simon and an interval of the Upper Mt Simon into the overlying Eau Claire Shale. To supplement the coring program, sidewall cores will be collected at select depths, including the Precambrian. Final coring intervals will be determined with the refinement of the Wabash CarbonSAFE drilling and sampling procedures. Similarly, the well testing program has yet to be finalized, but may include a vertical seismic profile (VSP), fluid sampling, step rate tests, and/or pressure fall-off testing.

Approximately 20 miles (32 km) of 2D seismic reflection data have been acquired in the vicinity of the WVR plant site (in two acquisition lines, each approximately ten miles [16 km] in length). The data acquisition was primarily on existing roadways across part of Vigo County, Indiana, and Edgar County, Illinois. Results from the 2D seismic reflection processing and stratigraphic well logging, sampling, and testing will be used to update conceptual geologic models and will be integrated into static geologic and dynamic reservoir models to fully characterize the geology of the WVR site.

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Appendix

Site Assessment Summary: Abbott Power Plant					
Risk Element Likelihood					
Very Unlikely	**1**	**<1% chance during the project**			
Unlikely	**2**	**3% chance**			
Possible	**3**	**10% chance**			
Likely	**4**	**30% chance**			
Very Likely	**5**	**>= 90% chance during the project**			
Impact Severity					
Light	**-1**				
Serious	**-2**				
Major	**-3**				
Catastrophic	**-4**				
Multi- Catastrophic	**-5**				
Description of Characteristics	**Recommended**	**Site Evaluation**	**Likelihood**	**Severity**	**Importance**
Reservoir Analysis					
Distance to suitable geologic formation	Site must be located within 50 miles (80 km) of a suitable geological storage area	The Mt. Simon Sandstone is the primary sequestration reservoir at the Abbott Power Plant site. The nearest deep well is the Hinton #7, located in the Manlove Natural Gas Storage Field, Champaign Co., Illinois, approximately 14 miles (23 km) from Abbott Power Plant. In the Hinton #7 well the Mt. Simon Sandstone surface was encountered at approximately 4000 feet (1219 m) deep.	2	-5	-5
Reservoir Thickness	Location must have reservoir with 20 feet (6m) or greater of <10% porosity	Regional thickness (Figure 5) map of the Mt Simon Sandstone indicate estimated thickness between 2,250 to 2,500 feet (686 to 762 m) thick at the Abbott Power Plant facility. The Hinton #7 well has 215 feet (66 m) of excellent quality reservoir in the Lower Mt, Simon arkose zone with porosity and permeability values up to 25% and 600 mD. Due to the fact of limited regional data for the Lower Mt. Simon deeper well data is still needed.	2	-3	-3
Injection Rate Capacity	The proposed geologic formation for sequestration must support a CO_2 injection rate of 1 million metric tons of CO_2 per year for up to 30 years.	From the Hinton well the upper Mt. Simon should have an average permeability of 150 mD and lower Mt. Simon has zones may be over 1 Darcy.	2	-3	

Depth and capacity of Saline Formation (if Saline Formation is the preferred sequestration option)	If a deep saline formation is the sequestration target, the formation must have in-situ hydrostatic pressure and temperature conditions above the CO_2 supercritical point (31° C at 73 atm). The deep saline formation must have sufficient storage capacity for the planned life of the plant (30 years) under these conditions.	Regional structure (Figure 6) map of the Mt. Simon Sandstone indicate estimated depth around 4,000 feet (1219 m). In the Hinton #7 well, the Mt. Simon Sandstone is at a drill confirmed depth of approximately 4,000 feet (1219 m).	2	-4	-4
Availability of secondary reservoirs	Not required	Regional thickness map for the St. Peter Sandstone (Figure 8) is estimated to between 200 to 250 feet thick (61 to 76 m). Abbott Power Plant has suitable porosity and permeability for storage, but it is a freshwater aquifer with dissolved solids of under 10,000 mg/L.	2	-1	-1
Proximity to Oil Fields	If CO_2 enhanced oil recovery (EOR) reservoirs are the target, then the site must be 50 miles (80 km) or closer to oil fields that are deep enough for miscible EOR methods.	No oil fields for EOR are available	2	-1	-1
Seismic Risk	Must not be in an area of high seismic hazard (per USGS).	There is a 2% probability that the Peak Ground Acceleration due to seismic activity will exceed 8% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second).	1		
Seal Analysis					
Relation of Primary Seal to Active or Transmissive Faults	The primary seal must not be intersected by any known historically active or hydraulically transmissive faults. The proposed seal must have a low differential in-situ caprock or target formation stress and high mechanical seal strength relative to injection pressure	The mapped northern extent of the Tuscola Anticline (Figure 18) is approximately 10 miles (16 km) south of the site. The Tuscola Anticline underwent major uplift in the very late Mississippian and early Pennsylvanian Periods (Nelson 1995). Recommended that new 2D seismic reflection data be acquired if storage pursued.	2	-4	-5
Primary Seal	The primary seal must have sufficient thickness (greater than 20 feet or 6 m), be regionally extensive, and be continuous over the entire projected CO_2 plume boundary after injection of 50 MMT of CO_2. It must have sufficiently low vertical permeability and have sufficiently high capillary entry pressure to provide a barrier to migration of CO_2 out of the target formation.	Regional thickness map for the Eau Claire Shale (Figure 11) is estimated to between 500 to 750 feet (152 to 229 m) thick. The Eau Claire Formation is over 475 feet (145 m) thick 14 miles (23 km) north at The Manlove Gas Storage Field safely stored natural gas for over 60 years. The Eau Claire Formation at the Abbott Power Plant should be of similar thickness and rock properties to that found at the Manlove Gas Storage Field.	2	-5	-5

Secondary Seal	Not required but preferred. Secondary seal should overlie the primary caprock seal, be largely continuous, be greater than 10 feet (3 m) thick throughout and cover at least 75 percent of the projected plume after injection of 50 MMT CO_2.	Regional thickness map of the Maquoketa Shale (Figure 12) indicates thickness range between 200 to 300 feet (61 to 91 m). The Maquoketa Shale is around 200 feet (61 m) thick at this location.	2	-2	-2
Tertiary Seal	Not required	The New Albany Shale (a regional shale in southern Illinois) is less than 100 feet (30 m) thick.			
Gas Storage	Gas storage reservoirs cannot be within the estimated CO_2 plume radius.	The Manlove Gas Storage Field (Table 4), approximately 14 miles (23 km) to the northwest of the Abbott facility, injects into the Upper Mt. Simon Sandstone.	2	-3	-5
Seismic data availability?	Is there any seismic reflection data available at this site? This is not a requirement, but it reduces subsurface uncertainty.	Seismic reflection data exists 14 miles (23 km) to the north at Manlove Gas Storage Field, a 25 mile N-S profile approximately 10 miles (16 km)to the west, and a 25 mile (40 km) E-W profile approximately 10 miles (16 km) to the south. Recommended that new 2D seismic reflection data be acquired.			
Reservoir salinity	Injection reservoir must be over 10,000 mg/L	Mt. Simon reservoir has a salinity of over 100,000 mg/L (Figure 4) at Manlove Gas Storage Field (14 miles [23 km] to the north); the proposed site should have similar salinity values.	1	-2	-2
Boreholes penetrating injection reservoir	Abandoned boreholes penetrating the reservoir interval may allow leakage into shallower horizons	None within 14 miles (23 km).	1	-2	-2
Seal becomes target for unconventional petroleum production	Identify a potential scenario where primary seal becomes a target for shale gas production, and operators object to CCS injection	The Eau Claire Formation is not organic rich and the Maquoketa Shale (secondary seal) is unlikely to be an unconventional petroleum target in this area	2	-2	-4
Legal/regulatory permitting issues	Permitting time and requirements cause economic delays		3	-3	-5
Near Surface Impacts					
Sensitive features above sequestration area	The land above the proposed sequestration formation must not intersect large dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features.	No known sensitive surface features or protected biological species. The Abbott Power Plant is within 2 miles (3 km) of eastern mapped boundary of the Mahomet Aquifer. This aquifer is defined by the federal government as a sole source aquifer (SSA).	2	-3	-5
Sequestration impacts on drinking water	Proposed target formation for CO_2 sequestration must not be an underground source of drinking water	The Abbott Power Plant is within 2 miles of eastern mapped boundary of the Mahomet Aquifer (Figure 20). This aquifer is defined by the federal government as a sole source aquifer (SSA). Illinois State Water Survey Illinois Groundwater Resources Maps identify the unconsolidated/surficial deposits	2	-5	-5

		above bedrock at the site are between 200 to 300 feet (61 to 91 m) thick with major sand and gravel aquifer identified in the unconsolidated material. Additionally, maps included bedrock aquifers in the Pennsylvanian and Devonian Shallow Bedrock Aquifers (within 500 feet [152 m] depth).			
Access to sequestration area for CO_2 leakage monitoring	There must be sufficient access to the land surface above the proposed sequestration area to implement a CO_2 leakage monitoring program.	Area is flat lying and appears to have no issues with access.	1	-3	-3
Mineral Rights in the CO_2 sequestration area	The proposed CO_2 sequestration area must be located where the project can obtain, purchase, or get a waiver of subsurface mineral rights. (unless recovery of coal-bed methane or oil is a part of the sequestration process).	Needs to be addressed by Abbott Power Plant.			

Site Assessment Summary: Archer Daniels Midland (ADM), Decatur, IL					
Risk Element Likelihood					
Very Unlikely	**1**	**<1% chance during the project**			
Unlikely	**2**	**3% chance**			
Possible	**3**	**10% chance**			
Likely	**4**	**30% chance**			
Very Likely	**5**	**>= 90% chance during the project**			
Impact Severity					
Light	**-1**				
Serious	**-2**				
Major	**-3**				
Catastrophic	**-4**				
Multi- Catastrophic	**-5**				
Description of Characteristics	**Recommended**	**Site Evaluation**	**Likelihood**	**Severity**	**Importance**
Reservoir Analysis					
Distance to suitable geologic formation	Site must be located within 50 miles (80 km) of a suitable geological storage area	The Mt. Simon Sandstone is the primary sequestration reservoir at the Archer Daniels Midland (ADM) site. There are 4 deep wells within a 2-mile (3 km) radius supporting the injection projects at ADM facility. These boreholes penetrated through the Mt. Simon	1	-5	-5

		Sandstone into the underlying granitic bedrock.			
Reservoir Thickness	Location must have reservoir with 20 feet (6 m) or greater of <10% porosity	Regional thickness (Figure 5) map of the Mt Simon Sandstone indicate estimated thickness between 1,500 to 1,750 feet (457 to 533 m) thick at the ADM facility. The Mt Simon Sandstone is drill hole confirmed to be approximately 1500 feet (457 m) thick at the borehole locations.	1	-3	-3
Injection Rate Capacity	The proposed geologic formation for sequestration must support a CO_2 injection rate of 1 million metric tons of CO_2 per year for up to 30 years.	Successful large-scale demonstration project (1 million metric tons (1102311 tons) over three years at a rate of 1,000 metric tons (1102 tons) per day) completed and ongoing industrial-scale demonstration injection project (up to 5 million metric tons over approximately three years at a rate of 3,000 tons [2721 metric tons] per day) within 2 mile (3 km) radius at the ADM facility. The Lower Mt. Simon Sandstone has an average porosity of 22% and permeability of 200 mD, with greater than 10% porosity over most of its thickness. Individual beds can have porosity as high as 28% and permeability over 1,000 mD.	1	-3	
Depth and capacity of Saline Formation (if Saline Formation is the preferred sequestration option)	If a deep saline formation is the sequestration target, the formation must have in-situ hydrostatic pressure and temperature conditions above the CO_2 supercritical point (31° C at 73 atm). The deep saline formation must have sufficient storage capacity for the planned life of the plant (30 years) under these conditions.	Regional structure (Figure 6) map of the Mt. Simon Sandstone indicate estimated depth around 5,000 feet (1524 m). Top of Mt. Simon is approximately 5,550 feet (1692 m) drill hole confirmed at the site. Reservoir temperature is 122°F, and the reservoir is 100% saturated with formation salinity of 200,000 ppm.	1	-4	-4
Availability of secondary reservoirs	Not required	Regional thickness map for the St. Peter Sandstone (Figure 8) estimated to between 150 to 200 feet (46 to 61 m) thick. At the ADM site, the St. Peter is approximately 225 feet (69 m) thick with porous and permeability favorable for injection.	1	-1	-1
Proximity to Oil Fields	If CO_2 enhanced oil recovery (EOR) reservoirs are the target, then the site must be 50 miles (80 km) or closer to oil fields that are deep enough for miscible EOR methods.	Oil fields within the 50-mile (80 km) surrounding area are predominantly near-miscible. The potential may exist for stacked CO_2-EOR and saline storage.	2	-1	-1
Seismic Risk	Must not be in an area of high seismic hazard (per USGS).	There is a 2% probability that the Peak Ground Acceleration due to seismic activity will exceed 9% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second).	1		
Seal Analysis					

Relation of Primary Seal to Active or Transmissive Faults	The primary seal must not be intersected by any known historically active or hydraulically transmissive faults. The proposed seal must have a low differential in-situ caprock or target formation stress and high mechanical seal strength relative to injection pressure	Regional mapping, and 2D seismic data analysis in the vicinity of the ADM facility does not indicate the presence of faulting (Figure 18). Recent 2D seismic reflection data near the proposed site does not show any resolvable faults. There are no known regional faults or fractures mapped within a 25-mile (40 km) radius of the proposed site.	1	-4	-5
Primary Seal	The primary seal must have sufficient thickness (greater than 20 feet or 6 m), be regionally extensive, and be continuous over the entire projected CO_2 plume boundary after injection of 50 MMT of CO_2. It must have sufficiently low vertical permeability and have sufficiently high capillary entry pressure to provide a barrier to migration of CO_2 out of the target formation.	The Eau Claire Formation (Figure 11) is about 500 ft thick at the site. It consists of shale, tight siltstones and limestone with lowermost 200 ft shale (61 m). The Eau Claire Formation average core measured horizontal permeability is 0.000344 mD. The median permeability of the Eau Claire samples tested is 0.000026 mD and median porosity is 4.7%.	1	-5	-5
Secondary Seal	Not required but preferred. Secondary seal should overlie the primary caprock seal, be largely continuous, be greater than 10 feet (3 m) thick throughout and cover at least 75 percent of the projected plume after injection of 50 MMT CO_2.	Regional thickness map of the Maquoketa Shale (Figure 12) indicates thickness range between 200 to 300 feet (61 to 91 m). The Maquoketa Shale is over 200 feet (61 m) thick at this location.	1	-2	-2
Tertiary Seal	Not required	The New Albany Shale is approximately 125 feet (38 m) thick at this location.			
Gas Storage	Gas storage reservoirs cannot be within the estimated CO_2 plume radius.	Lincoln Gas Storage Field (Table 4), approximately 30 miles [30 km] away in Logan Co., IL., injects into the Silurian which occurs less than 1,500 feet (457 m) deep. The Manlove Gas Storage Field (Table 4), approximately 40 miles (64 km) northeast in Champaign, Co., IL., injects into the Upper Mt. Simon	2	-3	-5
Seismic data availability?	Is there any seismic reflection data available at this site? This is not a requirement, but it reduces subsurface uncertainty.	There is over 80 miles (129 km) of recent 2D seismic reflection data near the site. One E-W profile extends over a 50-mile (80 km) distance in northern Sangamon Co. through central Macon Co. ending northeast of the Archer Daniels Midland Facility in Decatur and the second E-W profile extends due east of the CWLP facility through Christian Co. ending in Macon Co.			
Reservoir salinity	Injection reservoir must be over 10,000 mg/L	Mt. Simon reservoir has a salinity of over 200,000 mg/L at the site (Figure 4).	1	-2	-2
Boreholes penetrating injection reservoir	Abandoned boreholes penetrating the reservoir interval may allow leakage into shallower horizons	Wells penetrating the injection reservoir are not abandoned.	1	-2	-2

Seal becomes target for unconventional petroleum production	Identify a potential scenario where primary seal becomes a target for shale gas production, and operators object to CCS injection	The Eau Claire Formation is not organic rich and the Maquoketa Shale (secondary seal) is unlikely to be an unconventional petroleum target in this area	2	-2	-4
Legal/regulatory permitting issues	Permitting time and requirements cause economic delays		3	-3	-5
Near Surface Impacts					
Sensitive features above sequestration area	The land above the proposed sequestration formation must not intersect large dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features.	No known sensitive surface features or protected biological species. The ADM facility is immediately adjacent to Lake Decatur, a 2,800-acre (11 km^2) reservoir which serves primarily as a water source for commercial and industrial purposes. The ADM facility is within 10 miles (16 km) of southern mapped boundary of the Mahomet Aquifer (Figure 20). This aquifer is defined by the federal government as a sole source aquifer (SSA).	1	-3	-5
Sequestration impacts on drinking water	Proposed target formation for CO_2 sequestration must not be an underground source of drinking water	The ADM facility is within 10 miles (16 km) of southern mapped boundary of the Mahomet Aquifer. Illinois State Water Survey Illinois Groundwater Resources Maps identify the unconsolidated/surficial deposits above bedrock at the site between 100 to 200 feet (30 to 61 m) thick. Aquifer potential exists within unconsolidated material with the major sand and gravel aquifers present at the site. No bedrock aquifer systems are mapped in the area.	1	-5	-5
Access to sequestration area for CO_2 leakage monitoring	There must be sufficient access to the land surface above the proposed sequestration area to implement a CO_2 leakage monitoring program.	Area is flat lying and appears to have no issues with access.	1	-3	-3
Mineral Rights in the CO_2 sequestration area	The proposed CO_2 sequestration area must be located where the project can obtain, purchase, or get a waiver of subsurface mineral rights. (unless recovery of coal-bed methane or oil is a part of the sequestration process).	Needs to be addressed by ADM.			

Site Assessment Summary: City, Water, Light and Power (CWLP)		
Risk Element Likelihood		
Very Unlikely	**1**	**<1% chance during the project**
Unlikely	**2**	**3% chance**
Possible	**3**	**10% chance**
Likely	**4**	**30% chance**

Very Likely	**5**	**>= 90% chance during the project**			
Impact Severity					
Light	**-1**				
Serious	**-2**				
Major	**-3**				
Catastrophic	**-4**				
Multi- Catastrophic	**-5**				
Description of Characteristics	**Recommended**	**Site Evaluation**	**Likelihood**	**Severity**	**Importance**
Reservoir Analysis					
Distance to suitable geologic formation	Site must be located within 50 miles (80 km) of a suitable geological storage area	The Mt. Simon Sandstone is the primary sequestration reservoir at the City, Water, Light, and Power (CWLP) site. The McMillen #2, approximately 24 miles (39 km) to the east, is the stratigraphic hole drilled in support of the CarbonSAFE Macon project. The Mt. Simon Sandstone upper contact has been confirmed at 5135 feet (1565 m) depth. Two wells within 25 miles (40 km) of the CWLP facility in Morgan Co., penetrate the upper Mt. Simon Sandstone at a depth of approximately 4,100 feet (1250 m).	2	-5	-5
Reservoir Thickness	Location must have reservoir with 20 feet (6 m) or greater of <10% porosity	Regional thickness (Figure 5) map of the Mt Simon Sandstone indicate estimated thickness over 1,000 feet (305 m) thick at the CWLP site. The McMillen #2, approximately 24 miles (39 km) to the east, penetrated through the Mt. Simon Sandstone, which is approximately 1200 feet (366 m) thick, into the underlying granitic bedrock. There are 4 deep wells within a 2-mile (3-km) radius supporting the injection projects at Archer Daniels Midland facility in Decatur, IL (approximately 30 miles from the Cronus site). These boreholes penetrated through the Mt. Simon Sandstone, which is approximately 1500 feet (457 m) thick, into the underlying granitic bedrock.	2	-3	-3
Injection Rate Capacity	The proposed geologic formation for sequestration must support a CO_2 injection rate of 1 million metric tons of CO_2 per year for up to 30 years.	Successful large-scale demonstration project (1 million metric tons (1102311 tons) over three years at a rate of 1,000 metric tons (1102 tons) per day) completed and ongoing industrial-scale demonstration injection project (up to 5 million metric tons over approximately three years at a rate of 3,000 tons [2721 metric tons] per day) within 2 mile (3 km) radius at the ADM facility. Due	2	-3	

		to the fact of limited regional data for the Lower Mt. Simon deeper well data is still needed.			
Depth and capacity of Saline Formation (if Saline Formation is the preferred sequestration option)	If a deep saline formation is the sequestration target, the formation must have in-situ hydrostatic pressure and temperature conditions above the CO_2 supercritical point (31° C at 73 atm). The deep saline formation must have sufficient storage capacity for the planned life of the plant (30 years) under these conditions.	Regional structure (Figure 6) map of the Mt. Simon Sandstone indicate estimated depth around 4,000 feet (1219 m). Several wells within 25 miles (40 km) of the CWLP facility in Morgan Co., penetrate the upper Mt. Simon Sandstone at a depth of approximately 4,000 feet (1219 m).	2	-4	-4
Availability of secondary reservoirs	Not required	Regional thickness map for the St. Peter Sandstone (Figure 8) estimated to between 200 to 250 feet (61 to 76 m) thick. Well data confirms average thickness around 200 feet (61 m) around the CWLP area but thickness ranges vary across Sangamon County.	2	-1	-1
Proximity to Oil Fields	If CO_2 enhanced oil recovery (EOR) reservoirs are the target, then the site must be 50 miles (80 km) or closer to oil fields that are deep enough for miscible EOR methods.	Oil fields within the 50-mile (80 km) surrounding area are predominantly near-miscible. The potential may exist for stacked CO_2-EOR and saline storage.	2	-1	-1
Seismic Risk	Must not be in an area of high seismic hazard (per USGS).	There is a 2% probability that the Peak Ground Acceleration due to seismic activity will exceed 9% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second).	1		
Seal Analysis					
Relation of Primary Seal to Active or Transmissive Faults	The primary seal must not be intersected by any known historically active or hydraulically transmissive faults. The proposed seal must have a low differential in-situ caprock or target formation stress and high mechanical seal strength relative to injection pressure	Regional mapping, and 2D seismic data analysis in the vicinity of the CWLP site does not indicate the presence of faulting (Figure 18). Recent 2D seismic reflection data near the proposed site does not show any resolvable faults. There are no known regional faults or fractures mapped within a 25-mile (40 km) radius of the proposed site.	2	-4	-5
Primary Seal	The primary seal must have sufficient thickness (greater than 20 feet or 6 m), be regionally extensive, and be continuous over the entire projected CO_2 plume boundary after injection of 50 MMT of CO_2. It must have sufficiently low vertical permeability and have sufficiently high capillary entry pressure to provide a barrier to migration of CO_2 out of the target formation.	Regional thickness map for the Eau Claire Shale (Figure 11) is estimated to between 250 to 500 feet (76 to 152 m) thick. Available well data confirmed Eau Claire Shale thickness about 500 ft (152 m) thick around the CWLP site.	2	-5	-5

Secondary Seal	Not required but preferred. Secondary seal should overlie the primary caprock seal, be largely continuous, be greater than 10 feet (3 m) thick throughout and cover at least 75 percent of the projected plume after injection of 50 MMT CO_2.	Regional thickness map of the Maquoketa Shale (Figure 12) indicates thickness range between 200 to 300 feet (61 to 91 m). The Maquoketa Shale is over 200 feet (61 m) thick at this location.	2	-2	-2
Tertiary Seal	Not required	The New Albany Shale is approximately 200 feet (61 m) thick at this location.			
Gas Storage	Gas storage reservoirs cannot be within the estimated CO_2 plume radius.	Lincoln Gas Storage Field (Table 4) is approximately 20 miles [32 km] away in Logan Co., IL. injects into the Silurian which occurs less than 1,500 feet (458 m) deep. Waverly Gas Storage Field (Table 4) is approximately 25 miles [40 km] away) in Morgan Co., IL., injects into the Ordovician St Peter Sandstone in excess of 1,750 feet (533 m) deep.	2	-3	-5
Seismic data availability?	Is there any seismic reflection data available at this site? This is not a requirement, but it reduces subsurface uncertainty.	There is over 80 miles (129 km) of recent 2D seismic reflection data near the site. One E-W profile extends over a 50-mile (80 km) distance in northern Sangamon Co. through central Macon Co. ending northeast of the Archer Daniels Midland Facility in Decatur while the second E-W profile extends due east of the CWLP facility through Christian Co. ending in Macon Co.			
Reservoir salinity	Injection reservoir must be over 10,000 mg/L	Mt. Simon reservoir has a salinity range between 75,000 to 100,000 mg/L at the site (Figure 4).	1	-2	-2
Boreholes penetrating injection reservoir	Abandoned boreholes penetrating the reservoir interval may allow leakage into shallower horizons	None within 24 miles (39 km).	1	-2	-2
Seal becomes target for unconventional petroleum production	Identify a potential scenario where primary seal becomes a target for shale gas production, and operators object to CCS injection	The Eau Claire Formation is not organic rich and the Maquoketa Shale (secondary seal) is unlikely to be an unconventional petroleum target in this area	2	-2	-4
Legal/regulatory permitting issues	Permitting time and requirements cause economic delays		3	-3	-5
Near Surface Impacts					
Sensitive features above sequestration area	The land above the proposed sequestration formation must not intersect large dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features.	No known sensitive surface features or protected biological species. CWLP owns and manages Lake Springfield (approximately 5 miles [8 km] southeast of the facility), a 4200-acre (17 km^2) reservoir with primary purpose to serve as the source of drinking water for the city of Springfield and several nearby communities. CWLP facility is within 25 miles (40 km) of	2	-3	-5

		southern mapped boundary of the Mahomet Aquifer (Figure 20). This aquifer is defined by the federal government as a sole source aquifer (SSA).			
Sequestration impacts on drinking water	Proposed target formation for CO_2 sequestration must not be an underground source of drinking water	The CWLP facility is within 25 miles (40 km) of southern mapped boundary of the Mahomet Aquifer. Illinois State Water Survey Illinois Groundwater Resources Maps identify the unconsolidated/surficial deposits above bedrock at the site are up to 50 feet (15 m) thick. Aquifer potential exists within unconsolidated material with the major sand and gravel aquifer identified east of the site within 5 miles (8 km). No bedrock aquifer systems are mapped in the area.	2	-5	-5
Access to sequestration area for CO_2 leakage monitoring	There must be sufficient access to the land surface above the proposed sequestration area to implement a CO_2 leakage monitoring program.	Area is flat lying and appears to have no issues with access.	1	-3	-3
Mineral Rights in the CO_2 sequestration area	The proposed CO_2 sequestration area must be located where the project can obtain, purchase, or get a waiver of subsurface mineral rights. (unless recovery of coal-bed methane or oil is a part of the sequestration process).	Needs to be addressed by CWLP.			

Site Assessment Summary: Cronus Fertilizer Plant					
Risk Element Likelihood					
Very Unlikely	**1**	**<1% chance during the project**			
Unlikely	**2**	**3% chance**			
Possible	**3**	**10% chance**			
Likely	**4**	**30% chance**			
Very Likely	**5**	**>= 90% chance during the project**			
Impact Severity					
Light	**-1**				
Serious	**-2**				
Major	**-3**				
Catastrophic	**-4**				
Multi- Catastrophic	**-5**				
Description of Characteristics	**Recommended**	**Site Evaluation**	**Likelihood**	**Severity**	**Importance**
Reservoir Analysis					

Distance to suitable geologic formation	Site must be located within 50 miles (80 km) of a suitable geological storage area	The Mt. Simon Sandstone is the primary sequestration reservoir at the Cronus Fertilizer site. Wells that penetrate the surface of the Mt. Simon, less than 10 miles (16 km) away from the site, are classified gas storage wells at The Tuscola Gas Storage Field and waste disposal wells for Cabot and U.S Industrial Chemical projects have drill confirmed depth of approximately 4,000 feet (1219 m).	2	-5	-5
Reservoir Thickness	Location must have reservoir with 20 feet (6 m) or greater of <10% porosity	Regional thickness (Figure 5) map of the Mt Simon Sandstone indicate estimated thickness over 2,000 feet (610 m) thick at the Cronus Fertilizer site. There are 4 deep wells within a 2-mile radius supporting the injection projects at Archer Daniels Midland facility in Decatur, IL (approximately 30 miles [48 km] from the Cronus site). These boreholes penetrated through the Mt. Simon Sandstone (approximately 1500 feet [457 m] thick) into the underlying granitic bedrock. Due to the fact of limited regional data for the Lower Mt. Simon deeper well data is still needed.	2	-3	-3
Injection Rate Capacity	The proposed geologic formation for sequestration must support a CO_2 injection rate of 1 million metric tons of CO_2 per year for up to 30 years.	Successful large-scale demonstration project (1 million metric tons (1102311 tons) over three years at a rate of 1,000 metric tons (1102 tons) per day) completed and ongoing industrial-scale demonstration injection project (up to 5 million metric tons over approximately three years at a rate of 3,000 tons [2721 metric tons] per day) within 2 mile (3 km) radius at the ADM facility.	2	-3	
Depth and capacity of Saline Formation (if Saline Formation is the preferred sequestration option)	If a deep saline formation is the sequestration target, the formation must have in-situ hydrostatic pressure and temperature conditions above the CO_2 supercritical point (31° C at 73 atm). The deep saline formation must have sufficient storage capacity for the planned life of the plant (30 years) under these conditions.	Regional structure (Figure 6) map of the Mt. Simon Sandstone indicate estimated depth around 4,000 feet (1219 m). Wells that penetrate the surface of the Mt Simon, less than 10 miles (16 km) away from the site, are classified gas storage wells at The Tuscola Gas Storage Field and waste disposal wells for Cabot and U.S Industrial Chemical projects have drill confirmed depth of approximately 4,000 feet (1219 m).	2	-4	-4
Availability of secondary reservoirs	Not required	Regional thickness map for the St. Peter Sandstone (Figure 8) estimated to between 150 to 200 feet (46 to 61 m) thick. Well data around the proposed Cronus Fertilizer site confirms regional thickness range.	2	-1	-1

Proximity to Oil Fields	If CO_2 enhanced oil recovery (EOR) reservoirs are the target, then the site must be 50 miles (80 km) or closer to oil fields that are deep enough for miscible EOR methods.	Fields within the 50 miles (80 km) are identified immiscible to near-miscible with potential for miscible EOR in a reservoir or two in select fields.	2	-1	-1
Seismic Risk	Must not be in an area of high seismic hazard (per USGS).	There is a 2% probability that the Peak Ground Acceleration due to seismic activity will exceed 10% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second).	2		
Seal Analysis					
Relation of Primary Seal to Active or Transmissive Faults	The primary seal must not be intersected by any known historically active or hydraulically transmissive faults. The proposed seal must have a low differential in-situ caprock or target formation stress and high mechanical seal strength relative to injection pressure	The proposed Cronus site lies on the immediate western side of the Osman Monocline (Figure 18) with the larger Tuscola Anticline less than 10 miles (16 km) to the east and the Cooks Mills anticline less than 15 miles (24 km) to the south. Regional mapping efforts identify uplift began in the Pennsylvanian (Nelson 1995). This interpreted faulted interval needs to be verified by seismic reflection. More analysis needs to be completed.	2	-4	-5
Primary Seal	The primary seal must have sufficient thickness (greater than 20 feet or 6 m), be regionally extensive, and be continuous over the entire projected CO_2 plume boundary after injection of 50 MMT of CO_2. It must have sufficiently low vertical permeability and have sufficiently high capillary entry pressure to provide a barrier to migration of CO_2 out of the target formation.	Regional thickness map for the Eau Claire Shale (Figure 11) is estimated to between 500 to 750 feet (152 to 229 m) thick. The Eau Claire Formation is over 550 feet (168 m) thick less than 10 miles (16 km) away at The Tuscola Gas Storage Field.	2	-5	-5
Secondary Seal	Not required but preferred. Secondary seal should overlie the primary caprock seal, be largely continuous, be greater than 10 feet (3 m) thick throughout and cover at least 75 percent of the projected plume after injection of 50 MMT CO_2.	Regional thickness map of the Maquoketa Shale (Figure 12) indicates thickness range between 200 to 300 feet (61 to 91 m). The Maquoketa Shale is over 200 feet (61 m) thick at this location.	2	-2	-2
Tertiary Seal	Not required	The New Albany Shale (a regional shale in southern Illinois) typically up to 100 feet (30 m) thick in the region.			
Gas Storage	Gas storage reservoirs cannot be within the estimated CO_2 plume radius.	Cook Mills Consolidated Storage Field (Table 4), approximately 10 miles (16 km) away in Douglas and Coles Co., IL., injects into the Mississippian strata between 1,600 to 2,700 feet (488 to 823 m) is the nearest field. The Manlove Gas Storage Field, which injects into the Upper Mt. Simon, is 30 miles (48 km) to the north of the proposed Cronus Site.	2	-3	-5

Seismic data availability?	Is there any seismic reflection data available at this site? This is not a requirement, but it reduces subsurface uncertainty.	Nearest seismic reflection data are 25-mile (40 km) N-S profile approximately 5 miles (8 km) to west and 25-mile (40 km) E-W profile approximately 10 miles (16 km) to the north. Approximately 10 miles (16 km) away (southwest Champaign Co. into northwest Coles Co.), a cluster of 5 shorter profiles are available. Recommended that new 2D seismic reflection data be acquired.			
Reservoir salinity	Injection reservoir must be over 10,000 mg/L	Mt. Simon reservoir has a salinity (Figure 4) of over 100,000 mg/L at the proposed.	2	-2	-2
Boreholes penetrating injection reservoir	Abandoned boreholes penetrating the reservoir interval may allow leakage into shallower horizons	Wells that penetrate the upper Mt. Simon are within 10 miles (16 km). No wells penetrate the Lower Mt. Simon within 30 miles (48 km).	2	-2	-2
Seal becomes target for unconventional petroleum production	Identify a potential scenario where primary seal becomes a target for shale gas production, and operators object to CCS injection	The Eau Claire Formation is not organic rich and the Maquoketa Shale (secondary seal) is unlikely to be an unconventional petroleum target in this area	2	-2	-4
Legal/regulatory permitting issues	Permitting time and requirements cause economic delays		3	-3	-5
Near Surface Impacts					
Sensitive features above sequestration area	The land above the proposed sequestration formation must not intersect large dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features.	No known sensitive surface features or protected biological species. The proposed Cronus facility is within 15 miles (24 km) of southern mapped boundary of the Mahomet Aquifer (Figure 20). This aquifer is defined by the federal government as a sole source aquifer (SSA). The Cronus site is near multiple Class I disposal wells (Table 5).	2	-3	-5
Sequestration impacts on drinking water	Proposed target formation for CO_2 sequestration must not be an underground source of drinking water	The proposed Cronus facility is within 15 miles (24 km) of southern mapped boundary of the Mahomet Aquifer. Illinois State Water Survey Illinois Groundwater Resources Maps identify the unconsolidated/surficial deposits above bedrock at the site are generally between 100 to 200 feet (30 to 61 m) thick with areas reaching thickness of 300 feet (91 m). Aquifer potential exists within unconsolidated material with the major sand and gravel aquifer identified west of the site within 10 miles (16 km). Additionally, maps included bedrock aquifers in the Pennsylvanian and Devonian Shallow Bedrock Aquifers (within 500 feet [152 m] depth) within 5 miles (8 km) east of the site.	2	-5	-5

Access to sequestration area for CO_2 leakage monitoring	There must be sufficient access to the land surface above the proposed sequestration area to implement a CO_2 leakage monitoring program.	Area is flat lying and appears to have no issues with access.	1	-3	-3
Mineral Rights in the CO_2 sequestration area	The proposed CO_2 sequestration area must be located where the project can obtain, purchase, or get a waiver of subsurface mineral rights. (unless recovery of coal-bed methane or oil is a part of the sequestration process).	Needs to be addressed by Cronus Fertilizer.			

Site Assessment Summary: Edwardsport Integrated Gasification Combined Cycle (IGCC) Plant					
Risk Element Likelihood					
Very Unlikely	**1**	**<1% chance during the project**			
Unlikely	**2**	**3% chance**			
Possible	**3**	**10% chance**			
Likely	**4**	**30% chance**			
Very Likely	**5**	**>= 90% chance during the project**			
Impact Severity					
Light	**-1**				
Serious	**-2**				
Major	**-3**				
Catastrophic	**-4**				
Multi- Catastrophic	**-5**				
Description of Characteristics	**Recommended**	**Site Evaluation**	**Likelihood**	**Severity**	**Importance**
Reservoir Analysis					
Distance to suitable geologic formation	Site must be located within 50 miles (80 km) of a suitable geological storage area	The Mt. Simon Sandstone is the primary storage reservoir target at the Edwardsport IGCC Plant. The Duke Energy Indiana IGCC #1 well, located at this site in Knox, Co, IN, encountered the Mt. Simon surface at a depth of 7,950 feet (2423 m).	3	-5	-5
Reservoir Thickness	Location must have reservoir with 20 feet (6 m) or greater of <10% porosity	Regional thickness (Figure 5) map of the Mt Simon Sandstone indicate estimated thickness between 1750 to 2000 feet (533 to 610 m). In Duke Energy Indiana IGCC #1 the Mt Simon Sandstone is approximately 1,900 feet (579 m) thick. The Lower Mt. Simon, considered the best potential reservoir for carbon storage, is over 800 feet (244 m) thick.	3	-3	-3

Injection Rate Capacity	The proposed geologic formation for sequestration must support a CO_2 injection rate of 1 million metric tons of CO_2 per year for up to 30 years.	Drilling has confirmed the presence of the Mt. Simon Sandstone at this site. Well testing would be a required to determine injection capacity.	3	-3	
Depth and capacity of Saline Formation (if Saline Formation is the preferred sequestration option)	If a deep saline formation is the sequestration target, the formation must have in-situ hydrostatic pressure and temperature conditions above the CO_2 supercritical point (31° C at 73 atm). The deep saline formation must have sufficient storage capacity for the planned life of the plant (30 years) under these conditions.	Regional structure (Figure 6) map of the Mt Simon Sandstone indicate estimated depth between 7,000 to 8000 feet (2134 to 2438 m). The Duke Energy Indiana IGCC #1 well encountered the Mt. Simon surface at a depth of 7,950 feet (2423 m) at this site.	3	-4	-4
Availability of secondary reservoirs	Not required	Regional thickness map for the St. Peter Sandstone (Figure 8) estimated less than 50 feet (15 m) thick. At the Edwardsport IGCC site, the St. Peter is expected to be porous but too thin for injection.	3	-1	-1
Proximity to Oil Fields	If CO_2 enhanced oil recovery (CO_2-EOR) reservoirs are the target, then the site must be 50 miles (80 km) or closer to oil fields that are deep enough for miscible EOR methods.	The Edwardsport IGCC Plant is located east of the most significant oil producing region in the Illinois Basin. The potential exists for stacked CO_2-EOR and saline storage in many fields within a 50-mile (80 km) distance especially north, west, and south of the Edwardsport Power Station.	2	-1	-1
Seismic Risk	Must not be in an area of high seismic hazard (per USGS).	There is a 2% probability that the Peak Ground Acceleration due to seismic activity will exceed 21% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second).	2		
Seal Analysis					
Relation of Primary Seal to Active or Transmissive Faults	The primary seal must not be intersected by any known historically active or hydraulically transmissive faults. The proposed seal must have a low differential in-situ caprock or target formation stress and high mechanical seal strength relative to injection pressure	There are no known regional faults or fractures mapped within a 25-mile (40-km) radius of the proposed site (Figure 18).	2	-4	-5
Primary Seal	The primary seal must have sufficient thickness (greater than 20 feet or 6 m), be regionally extensive, and be continuous over the entire projected CO_2 plume boundary after injection of 50 MMT of CO_2. It must have sufficiently low vertical permeability and have sufficiently high capillary entry pressure to provide a barrier to migration of CO_2 out of the target formation.	Regional thickness map for the Eau Claire Shale (Figure 11) is estimated to between 750 to 1000 feet (229 to 305 m) thick. The Eau Claire Shale is drill hole confirmed to be approximately 750 feet (229 m) thick in the Duke Energy Indiana IGCC #1 well.	3	-5	-5

Secondary Seal	Not required but preferred. Secondary seal should overlie the primary caprock seal, be largely continuous, be greater than 10 feet (3 m) thick throughout and cover at least 75 percent of the projected plume after injection of 50 MMT CO_2.	Regional thickness map of the Maquoketa Shale (Figure 12) indicates thickness range between 200 to 300 feet (61 to 91 m). The Maquoketa Shale is over 250 feet (76 m) thick at this location.	3	-2	-2
Tertiary Seal	Not required	The New Albany Shale is estimated be approximately 150 feet (46 m) thick at this location.			
Gas Storage	Gas storage reservoirs cannot be within the estimated CO_2 plume radius.	Edwardsport IGCC Plant is within 20 miles (32 km) of 5 gas storage fields. Oaktown Gas Storage Field, (Table 4) approximately 14 miles (23 km) away in Knox Co., IN, with injection wells around 700 feet deep into the Pennsylvanian, Mineral City GSP (Table 4) and Simpson Chapel GSP (Table 4) in Greene Co., IN. (approximately 20 miles [32 km] away) injecting into the Silurian and Devonian with depths less than 1,700 feet (518 m), and Loogootee GSP (Table 4) in Daviess Co., IN. (approximately 20 miles [32 km] away) with wells not exceeding 600 feet (183 m) in the Mississippian.	2	-3	-5
Seismic data availability?	Is there any seismic reflection data available at this site? This is not a requirement, but it reduces subsurface uncertainty.	There is no known seismic reflection data available in the area.			
Reservoir salinity	Injection reservoir must be over 10,000 mg/L	Mt. Simon reservoir has a salinity of over 200,000 mg/L at the site (Figure 4).	1	-2	-2
Boreholes penetrating injection reservoir	Abandoned boreholes penetrating the reservoir interval may allow leakage into shallower horizons	Penetration through the Mt. Simon at the facility.	1	-2	-2
Seal becomes target for unconventional petroleum production	Identify a potential scenario where primary seal becomes a target for shale gas production, and operators object to CCS injection	The Eau Claire Formation is not organic rich and the Maquoketa Shale (secondary seal) is unlikely to be an unconventional petroleum target in this area	2	-2	-4
Legal/regulatory permitting issues	Permitting time and requirements cause economic delays	This must be addressed during the permitting of the well and is dependent on the regulatory agency.	3	-3	-5
Near Surface Impacts					
Sensitive features above sequestration area	The land above the proposed sequestration formation must not intersect large dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features.	No known sensitive surface features or protected biological species.	2	-3	-5

Sequestration impacts on drinking water	Proposed target formation for CO_2 sequestration must not be an underground source of drinking water	Unconsolidated/surficial deposits above bedrock at the site are estimated to be less than 100 feet (30 m) thick. Indiana DNR Aquifer Systems Maps denote the Pennsylvanian Carbondale Group as the predominant bedrock aquifer system in the area. The Edwardsport IGCC Plant is not located in a drinking water protection area, or above a sole source aquifer.	3	-5	-5
Access to sequestration area for CO_2 leakage monitoring	There must be sufficient access to the land surface above the proposed sequestration area to implement a CO_2 leakage monitoring program.	Area is flat lying and appears to have no issues with access	1	-3	-3
Mineral Rights in the CO_2 sequestration area	The proposed CO_2 sequestration area must be located where the project can obtain, purchase, or get a waiver of subsurface mineral rights. (unless recovery of coal-bed methane or oil is a part of the sequestration process).	Needs to be addressed by Edwardsport IGCC Plant and Duke Energy			

Site Assessment Summary: Gibson Station – Duke Energy					
Risk Element Likelihood					
Very Unlikely	**1**	**<1% chance during the project**			
Unlikely	**2**	**3% chance**			
Possible	**3**	**10% chance**			
Likely	**4**	**30% chance**			
Very Likely	**5**	**>= 90% chance during the project**			
Impact Severity					
Light	**-1**				
Serious	**-2**				
Major	**-3**				
Catastrophic	**-4**				
Multi- Catastrophic	**-5**				
Description of Characteristics	**Recommended**	**Site Evaluation**	**Likelihood**	**Severity**	**Importance**
Reservoir Analysis					
Distance to suitable geologic formation	Site must be located within 50 miles (80 km) of a suitable geological storage area	The Mt. Simon Sandstone is the primary storage reservoir target at the Gibson Station. The Duke-Gibson WDW #2 well, located at this site in Gibson, Co, IN, encountered the Mt. Simon surface at a depth of approximately 11,000 feet (3353 m).	3	-5	-5

Reservoir Thickness	Location must have reservoir with 20 feet (6 m) or greater of <10% porosity	Regional thickness (Figure 5) map of the Mt Simon Sandstone indicate estimated thickness between 750 to 1000 feet (229 to 305 m). In Duke Energy WDW #2, approximately 670 feet (204 m) of the Mt Simon Sandstone was drilled without indication of breakthrough to the basement. Approximately 35 miles (56 km) west in Wayne Co., IL. Cisne Community #1 well recovered 364 feet (111 m) of Mt. Simon to a maximum depth of 11,514 feet (3509 m).	3	-3	-3
Injection Rate Capacity	The proposed geologic formation for sequestration must support a CO_2 injection rate of 1 million metric tons of CO_2 per year for up to 30 years.	There are no nearby wells that have penetrate the lower Mt. Simon Sandstone and the reservoir quality is unknown in this location. A stratigraphic test well is necessary to verify the characteristics of the Upper and Lower Mt. Simon Sandstone in the absence of nearby deep well data.	3	-3	
Depth and capacity of Saline Formation (if Saline Formation is the preferred sequestration option)	If a deep saline formation is the sequestration target, the formation must have in-situ hydrostatic pressure and temperature conditions above the CO_2 supercritical point (31^o C at 73 atm). The deep saline formation must have sufficient storage capacity for the planned life of the plant (30 years) under these conditions.	Regional structure (Figure 6) map of the Mt Simon Sandstone indicate estimated depth between 10,000 and 11,000 feet (3048 to 3353 m). Top of Mt. Simon was drill hole confirmed at the site at approximately 11,000 feet (3353 m) deep.	3	-4	-4
Availability of secondary reservoirs	Not required	Regional thickness map for the St. Peter Sandstone (Figure 8) estimated between thickness between 100 to 150 feet (30 to 46 m). At the Gibson Generating Station, the St. Peter is expected to be porous but is too thin (drill confirmed less than 150 feet [30 m]) for injection.	3	-1	-1
Proximity to Oil Fields	If CO_2 enhanced oil recovery (CO_2-EOR) reservoirs are the target, then the site must be 50 miles (80 km) or closer to oil fields that are deep enough for miscible EOR methods.	The Gibson Station is located east of the most significant oil producing region in the Illinois Basin. The potential exists for stacked CO_2-EOR and saline storage in many fields within a 50-mile (80-km) distance especially north, west, and south of the Edwardsport Power Station.	2	-1	-1
Seismic Risk	Must not be in an area of high seismic hazard (per USGS).	There is a 2% probability that the Peak Ground Acceleration due to seismic activity will exceed 38% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second).	2		
Seal Analysis					

Relation of Primary Seal to Active or Transmissive Faults	The primary seal must not be intersected by any known historically active or hydraulically transmissive faults. The proposed seal must have a low differential in-situ caprock or target formation stress and high mechanical seal strength relative to injection pressure	Gibson Station is less than 5 miles (8 km) east of the northern mapped extent of the Wabash Valley Fault System (north-northeast trended system extending across southeastern Illinois, southwestern Indiana, and into Kentucky [Figure 18]). The time of structural movement in the Wabash Valley Fault System cannot be defined more precisely than post-late Pennsylvanian, pre-Pleistocene most appear to die out within the Knox Group; only a few visibly offset the prominent basal Knox (Cambrian) reflector (Nelson 1995).	2	-4	-5
Primary Seal	The primary seal must have sufficient thickness (greater than 20 feet or 6 m), be regionally extensive, and be continuous over the entire projected CO_2 plume boundary after injection of 50 MMT of CO_2. It must have sufficiently low vertical permeability and have sufficiently high capillary entry pressure to provide a barrier to migration of CO_2 out of the target formation.	Regional thickness (Figure 11) map of the Eau Claire Shale indicates thickness range between 750 to 1,000 feet (229 to 305 m). The Eau Claire Shale is drill hole confirmed to be approximately 920 feet (280 m) thick in the Duke Energy WDW #2 well.	2	-5	-5
Secondary Seal	Not required but preferred. Secondary seal should overlie the primary caprock seal, be largely continuous, be greater than 10 feet (3 m) thick throughout and cover at least 75 percent of the projected plume after injection of 50 MMT CO_2.	Regional thickness map for the Maquoketa Shale (Figure 12) indicates thickness range between 300 to 400 feet (91 to 122 m) at this location. Drill hole confirmed thickness at Gibson Station record the thickness at approximately 300 feet (91 m).	2	-2	-2
Tertiary Seal	Not required	The New Albany Shale is estimated be less than 150 feet (46 m) thick at this location.			
Gas Storage	Gas storage reservoirs cannot be within the estimated CO_2 plume radius.	Giro East GSP (White River – Table 4), Monroe City GSP (Table 4), and Alford GSP (Table 4) are northeast within 30 miles (48 km) of the Gibson Station. Wells in these fields inject into the Pennsylvanian and Mississippian strata with maximum injection well depths less than 1500 feet (457 m).	2	-3	-5
Seismic data availability?	Is there any seismic reflection data available at this site? This is not a requirement, but it reduces subsurface uncertainty.	Approximately 10 miles (16 km) to the north is E-W regional seismic profile and approximately 30 miles (48 km) to the west is N-S regional seismic profile. Additionally, E-W seismic survey data exists 10 to 20 miles (16 to 32 km) east and south from the Gibson Station.			
Reservoir salinity	Injection reservoir must be over 10,000 mg/L	Mt. Simon reservoir has a salinity of over 200,000 mg/L at the site (Figure 4).	2	-2	-2

Boreholes penetrating injection reservoir	Abandoned boreholes penetrating the reservoir interval may allow leakage into shallower horizons	Penetration through the Mt. Simon at the facility.	2	-2	-2
Seal becomes target for unconventional petroleum production	Identify a potential scenario where primary seal becomes a target for shale gas production, and operators object to CCS injection	The Eau Claire Formation is not organic rich and the Maquoketa Shale (secondary seal) is unlikely to be an unconventional petroleum target in this area	2	-2	-4
Legal/regulatory permitting issues	Permitting time and requirements cause economic delays	This must be addressed during the permitting of the well and is dependent on the regulatory agency.	3	-3	-5
Near Surface Impacts					
Sensitive features above sequestration area	The land above the proposed sequestration formation must not intersect large dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features.	No protected biological species. Located immediately south of the power facility is Gibson Lake (Broad Pond), man-made lake measuring around 3,500 acres (14 km^2), which is used as cooling pond for the plant.	2	-3	-5
Sequestration impacts on drinking water	Proposed target formation for CO_2 sequestration must not be an underground source of drinking water	Unconsolidated/surficial deposits above bedrock at the site are estimated to be less than 100 feet (30 m) thick. Indiana DNR Aquifer Systems Maps denote the McLeansboro Group as the predominant bedrock aquifer system in the area. The Gibson Generating Station is not located in a drinking water protection area, or above a sole source aquifer.	3	-5	-5
Access to sequestration area for CO_2 leakage monitoring	There must be sufficient access to the land surface above the proposed sequestration area to implement a CO_2 leakage monitoring program.	Area is flat lying and appears to have no issues with access	2	-3	-3
Mineral Rights in the CO_2 sequestration area	The proposed CO_2 sequestration area must be located where the project can obtain, purchase, or get a waiver of subsurface mineral rights. (unless recovery of coal-bed methane or oil is a part of the sequestration process).	Needs to be addressed by Gibson Station – Duke Energy.			

Site Assessment Summary: Marathon Robinson Refinery		
Risk Element Likelihood		
Very Unlikely	**1**	**<1% chance during the project**
Unlikely	**2**	**3% chance**
Possible	**3**	**10% chance**
Likely	**4**	**30% chance**
Very Likely	**5**	**>= 90% chance during the project**
Impact Severity		

Light	**-1**				
Serious	**-2**				
Major	**-3**				
Catastrophic	**-4**				
Multi- Catastrophic	**-5**				
Description of Characteristics	**Recommended**	**Site Evaluation**	**Likelihood**	**Severity**	**Importance**
Reservoir Analysis					
Distance to suitable geologic formation	Site must be located within 50 miles (80 km) of a suitable geological storage area	The Mt. Simon Sandstone is the primary storage reservoir at the Robinson Refinery site. The nearest deep well is the Abe Reedy A-1 approximately 9 miles (14 km) away in Main Consolidated Oil Field, Crawford Co., IL. The surface of the Mt. Simon is drill confirmed at 8,162 feet (2488 m).	3	-5	-5
Reservoir Thickness	Location must have reservoir with 20 feet (6 m) or greater of <10% porosity	Regional thickness (Figure 5) map of the Mt Simon Sandstone indicate estimated thickness between 1,750 to 2,000 feet (533 to 610 m) thick at the Marathon Robinson Refinery facility. The nearest deep well penetrating the Lower Mt. Simon is the Duke Energy Indiana #1 IGCC, approximately 30 miles (48 km) away. In the Duke Energy well the Mt. Simon Sandstone is nearly 2,000 feet (610 m) thick with the Lower Mt. Simon over 800 feet (244 m) thick.	3	-3	-3
Injection Rate Capacity	The proposed geologic formation for sequestration must support a CO_2 injection rate of 1 million metric tons of CO_2 per year for up to 30 years.	Due to limited regional data for the Lower Mt. Simon deeper well data is needed.	3	-3	
Depth and capacity of Saline Formation (if Saline Formation is the preferred sequestration option)	If a deep saline formation is the sequestration target, the formation must have in-situ hydrostatic pressure and temperature conditions above the CO_2 supercritical point (31° C at 73 atm). The deep saline formation must have sufficient storage capacity for the planned life of the plant (30 years) under these conditions.	Regional structure (Figure 6) map of the Mt. Simon Sandstone indicate estimated depth between 7,000 to 8,000 feet (2134 to 2438 m). The surface of the Mt. Simon is drill hole confirmed at 8,162 feet (2488 m) in the Abe Reedy A-1 well approximately 9 miles (14 km) south in Main Consolidated Oil Field, Crawford Co., IL.	3	-4	-4
Availability of secondary reservoirs	Not required	Regional thickness map for the St. Peter Sandstone (Figure 8) estimated between 50 to 100 feet (15 to 30 m) thick. St. Peter Sandstone thickness is typically less than 100 feet (30 m) near the Robinson Refinery it can increase to 250 feet (76 m) thick in northern Crawford Co. into southern Clark Co., IL.	3	-1	-1

Proximity to Oil Fields	If CO_2 enhanced oil recovery (CO_2-EOR) reservoirs are the target, then the site must be 50 miles (80 km) or closer to oil fields that are deep enough for miscible EOR methods.	The Robinson Refinery is located the northern extent of the most significant oil producing region in the Illinois Basin. The potential exists for stacked CO_2-EOR and saline storage in fields within the 50-mile (80-km) search radius.	2	-1	-1
Seismic Risk	Must not be in an area of high seismic hazard (per USGS).	There is a 2% probability that the Peak Ground Acceleration due to seismic activity will about 23% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second).	2		
Seal Analysis					
Relation of Primary Seal to Active or Transmissive Faults	The primary seal must not be intersected by any known historically active or hydraulically transmissive faults. The proposed seal must have a low differential in-situ caprock or target formation stress and high mechanical seal strength relative to injection pressure	The Robinson Refinery is less than 5 miles (8 km) southwest of southern extent of the Marshall-Sidell Syncline (Figure 18), an elongated, north-trending depression between the La Salle Anticlinorium and the east flank of the Illinois Basin. Approximately 10 miles (16 km) west, the Edgar Monocline stretches about 60 miles (97 km) separating the La Salle Anticlinorium from the Marshall-Sidell Syncline to the east. The Edgar Monocline exhibits a pattern of relief increasing with depth, typical of La Salle Anticlinorium, reflecting the progressive growth of the structure during the late Mississippian and Pennsylvanian Periods (Nelson 1995).	3	-4	-5
Primary Seal	The primary seal must have sufficient thickness (greater than 20 feet or 6 m), be regionally extensive, and be continuous over the entire projected CO_2 plume boundary after injection of 50 MMT of CO_2. It must have sufficiently low vertical permeability and have sufficiently high capillary entry pressure to provide a barrier to migration of CO_2 out of the target formation.	Regional thickness map for the Eau Claire Shale (Figure 11) is estimated to between 750 to 1000 feet (228 to 305 m) thick. The Newport Chemical Plant #WD-1 well is (22 miles [35 km] to the north) has over 850 feet of Eau Claire Shale and has safely served as a disposal well that accepted millions of gallons of wastewater. Eau Claire Shale thickness data around the Robinson Refinery facility confirms anticipated thickness to the Newport Chemical Plant #WD-1.	3	-5	-5
Secondary Seal	Not required but preferred. Secondary seal should overlie the primary caprock seal, be largely continuous, be greater than 10 feet (3 m) thick throughout and cover at least 75 percent of the projected plume after injection of 50 MMT CO_2.	Regional thickness map of the Maquoketa Shale (Figure 12) indicates thickness range between 200 to 300 feet (61 to 91 m). The Maquoketa Shale is over 250 feet (76 m) thick at this location.	3	-2	-2
Tertiary Seal	Not required	The New Albany Shale is approximately 100 feet (30 m) thick in the area.			
Gas Storage	Gas storage reservoirs cannot be within the estimated CO_2 plume radius.	Oaktown Gas Storage Field (Table 4) is approximately 16.50 miles (26.50 km) to the	2	-3	-5

		southeast in Knox Co., IN. Injection wells in the field are less than 700 feet (213 m) deep into the Pennsylvanian with the deepest well in the field at 2,843 feet (867 m) into the Devonian.			
Seismic data availability?	Is there any seismic reflection data available at this site? This is not a requirement, but it reduces subsurface uncertainty.	There are regional seismic profiles to north, south, and west of the Robinson Refinery. A series of 5 to 10 mile (8 to 16 km) seismic lines have been collected south of the site in southwest Crawford County and central Lawrence County.			
Reservoir salinity	Injection reservoir must be over 10,000 mg/L	Mt. Simon reservoir has a salinity of over 200,000 mg/L at Newport Chemical Plant (22 miles [35 km] to the north); the Robinson Refinery site is expected to have Mt. Simon salinities values (Figure 4) similar to Newport chemistry data.	2	-2	-2
Boreholes penetrating injection reservoir	Abandoned boreholes penetrating the reservoir interval may allow leakage into shallower horizons	Well penetrations through the Mt. Simon approximately 9 miles.	2	-2	-2
Seal becomes target for unconventional petroleum production	Identify a potential scenario where primary seal becomes a target for shale gas production, and operators object to CCS injection	The Eau Claire Formation is not organic rich and the Maquoketa Shale (secondary seal) is unlikely to be an unconventional petroleum target in this area	2	-2	-4
Legal/regulatory permitting issues	Permitting time and requirements cause economic delays	This must be addressed during the permitting of the well and is dependent on the regulatory agency.	3	-3	-5
Near Surface Impacts					
Sensitive features above sequestration area	The land above the proposed sequestration formation must not intersect large dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features.	No protected biological species. Allen Lake (Allen Lake Dam) is a small reservoir located less than 2 miles (3 km) north of the Robinson Refinery facility.	2	-3	-5
Sequestration impacts on drinking water	Proposed target formation for CO_2 sequestration must not be an underground source of drinking water	Illinois State Water Survey Illinois Groundwater Resources Maps identify the unconsolidated/surficial deposits above bedrock at the site to be less than 25 feet (8 m) thick. Major sand and gravel aquifer potential exists less than 10 miles (16 km) west of the site within the thicker (over 50 feet [15 m]) unconsolidated material. No bedrock aquifer systems are mapped in the area.	2	-5	-5
Access to sequestration area for CO_2 leakage monitoring	There must be sufficient access to the land surface above the proposed sequestration area to implement a CO_2 leakage monitoring program.	Area is flat lying and appears to have no issues with access.	1	-3	-3

Mineral Rights in the CO_2 sequestration area	The proposed CO_2 sequestration area must be located where the project can obtain, purchase, or get a waiver of subsurface mineral rights. (unless recovery of coal-bed methane or oil is a part of the sequestration process).	Needs to be addressed by Marathon Robinson Refinery			

Site Assessment Summary: One Earth Energy LLC					
Risk Element Likelihood					
Very Unlikely	**1**	**<1% chance during the project**			
Unlikely	**2**	**3% chance**			
Possible	**3**	**10% chance**			
Likely	**4**	**30% chance**			
Very Likely	**5**	**>= 90% chance during the project**			
Impact Severity					
Light	**-1**				
Serious	**-2**				
Major	**-3**				
Catastrophic	**-4**				
Multi- Catastrophic	**-5**				
Description of Characteristics	**Recommended**	**Site Evaluation**	**Likelihood**	**Severity**	**Importance**
Reservoir Analysis					
Distance to suitable geologic formation	Site must be located within 50 miles (80 km) of a suitable geological storage area	The Mt. Simon Sandstone is the primary sequestration reservoir at the One Earth Energy (OEE) site. The nearest deep well is the Hinton #7, located in the Manlove Natural Gas Storage Field, Champaign Co., approximately 12 miles (19 km) from the OEE site. In the Hinton #7 well, the Mt. Simon Sandstone is at a drill confirmed depth of approximately 4,000 feet (1219 m).	1	-5	-5
Reservoir Thickness	Location must have reservoir with 20 feet (6 m) or greater of <10% porosity	Regional thickness (Figure 5) map of the Mt Simon Sandstone indicate estimated thickness over 2,500 feet (762 m) thick at the OEE facility. In the Hinton #7 the Mt Simon is over 2,600 feet (792 m) thick with 300 feet (91 m) of 10% of greater porosity lower Mt. Simon. Due to the fact of limited regional data for the Lower Mt. Simon deeper well data is still needed.	1	-3	-3

Injection Rate Capacity	The proposed geologic formation for sequestration must support a CO_2 injection rate of 1 million metric tons of CO_2 per year for up to 30 years.	From the Hinton well the upper Mt. Simon should have an average permeability of 150 mD and lower Mt. Simon has zones may be over 1 Darcy.	2	-3	
Depth and capacity of Saline Formation (if Saline Formation is the preferred sequestration option)	If a deep saline formation is the sequestration target, the formation must have in-situ hydrostatic pressure and temperature conditions above the CO_2 supercritical point (31° C at 73 atm). The deep saline formation must have sufficient storage capacity for the planned life of the plant (30 years) under these conditions.	Regional structure (Figure 6) map of the Mt Simon Sandstone indicate estimated depth around 4,000 feet (1219 m). In the Hinton #7 well, the Mt. Simon Sandstone is at a drill confirmed depth of approximately 4,000 feet (1219 m).	1	-4	-4
Availability of secondary reservoirs	Not required	Regional thickness map for the St. Peter Sandstone (Figure 8) is estimated to between 250 to 300 feet (76 to 91 m) thick. At the OEE location, the St. Peter has favorable porosity and permeability for storage, but it is a freshwater aquifer with dissolved solids of under 10,000 mg/L.	1	-1	-1
Proximity to Oil Fields	If CO_2 enhanced oil recovery (EOR) reservoirs are the target, then the site must be 50 miles (80 km) or closer to oil fields that are deep enough for miscible EOR methods.	No oil fields for EOR are available	2	-1	-1
Seismic Risk	Must not be in an area of high seismic hazard (per USGS).	There is a 2% probability that the Peak Ground Acceleration due to seismic activity will exceed 7% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second).	1		
Seal Analysis					
Relation of Primary Seal to Active or Transmissive Faults	The primary seal must not be intersected by any known historically active or hydraulically transmissive faults. The proposed seal must have a low differential in-situ caprock or target formation stress and high mechanical seal strength relative to injection pressure	The Osman Monocline is approximately 3 miles west of the site (Figure 18). Uplift began in the Pennsylvanian Period; Osman Monocline appears on maps of the top of the Galena (Trenton) Group (Ordovician) and base of the New Albany Group (Nelson 1995). This interpreted faulted interval needs to be verified by seismic reflection. More analysis needs to be completed.	2	-4	-5
Primary Seal	The primary seal must have sufficient thickness (greater than 20 feet or 6 m), be regionally extensive, and be continuous over the entire projected CO_2 plume boundary after injection of 50 MMT of CO_2. It must have sufficiently low vertical permeability and have sufficiently high capillary entry pressure to provide a barrier to migration of CO_2 out of the target formation.	Regional thickness map for the Eau Claire Shale (Figure 11) is estimated to between 500 to 750 feet (152 to 229 m) thick. The Eau Claire Formation is over 475 feet (145 m) thick 12 miles (19 km) south at The Manlove Gas Storage Field safely stored natural gas for over 60 years. The Eau Claire Formation at the OEE should be of similar thickness and rock properties to that found at the Manlove Gas Storage Field.	1	-5	-5

Secondary Seal	Not required but preferred. Secondary seal should overlie the primary caprock seal, be largely continuous, be greater than 10 feet (3 m) thick throughout and cover at least 75 percent of the projected plume after injection of 50 MMT CO_2.	Regional thickness map of the Maquoketa Shale (Figure 12) indicates thickness range between 100 to 200 feet (30 to 61 m). The Maquoketa Shale is approximately 200 feet (61 m) thick at this location.	1	-2	-2
Tertiary Seal	Not required	The New Albany Shale (a regional shale in southern Illinois) is not present at the proposed site.			
Gas Storage	Gas storage reservoirs cannot be within the estimated CO_2 plume radius.	The Manlove Gas Storage Field (Table 4), 12 miles (19 km) to the south of the OEE site, injects into the Upper Mt Simon Sandstone. Modeling of the plume needs to be completed.	1	-3	-5
Seismic data availability?	Is there any seismic reflection data available at this site? This is not a requirement, but it reduces subsurface uncertainty.	Nearest seismic reflection data is 12 miles (19 km) to the south at Manlove Gas Storage Field. Recommended that new 2D seismic reflection data be acquired.			
Reservoir salinity	Injection reservoir must be over 10,000 mg/L	Mt. Simon reservoir has a salinity of over 100,000 mg/L (Figure 4) at Manlove Gas Storage Field (12 miles [19 km] to the south); the proposed site should have similar salinity values.	1	-2	-2
Boreholes penetrating injection reservoir	Abandoned boreholes penetrating the reservoir interval may allow leakage into shallower horizons	None within 12 miles (19 km).	1	-2	-2
Seal becomes target for unconventional petroleum production	Identify a potential scenario where primary seal becomes a target for shale gas production, and operators object to CCS injection	The Eau Claire Formation is not organic rich and the Maquoketa Shale (secondary seal) is unlikely to be an unconventional petroleum target in this area	2	-2	-4
Legal/regulatory permitting issues	Permitting time and requirements cause economic delays		3	-3	-5
Near Surface Impacts					
Sensitive features above sequestration area	The land above the proposed sequestration formation must not intersect large dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features.	No known sensitive surface features or protected biological species. The proposed site is within 10 miles (16 km) of the limits of the Mahomet Valley aquifer (Figure 20). This aquifer is defined by the federal government as a sole source aquifer (SSA).	2	-3	-5
Sequestration impacts on drinking water	Proposed target formation for CO_2 sequestration must not be an underground source of drinking water	The proposed site is within 10 miles (16 km) of the limits of the Mahomet Valley aquifer (Figure 20). The OEE site location is within a watershed area adjacent to the Mahomet SSA, and the site is within the Mahomet SSA Project Review area. Illinois State Water Survey Illinois Groundwater Resources Maps identify the unconsolidated/surficial deposits	2	-5	-5

		above bedrock at the site are between 100 to 200 feet (30 to 61 m) thick with aquifer potential within the unconsolidated. Additionally, maps included bedrock aquifers in the Pennsylvanian, Silurian, and Devonian Shallow Bedrock Aquifers (within 500 feet [152 m] depth) and Cambrian-Ordovician Sandstone Aquifers (over 500 feet [152 m] depth).			
Access to sequestration area for CO_2 leakage monitoring	There must be sufficient access to the land surface above the proposed sequestration area to implement a CO_2 leakage monitoring program.	Area is flat lying and appears to have no issues with access.	1	-3	-3
Mineral Rights in the CO_2 sequestration area	The proposed CO_2 sequestration area must be located where the project can obtain, purchase, or get a waiver of subsurface mineral rights. (unless recovery of coal-bed methane or oil is a part of the sequestration process).	Needs to be addressed by One Earth Energy.			

Site Assessment Summary: Prairie State Generating Company					
Risk Element Likelihood					
Very Unlikely	**1**	**<1% chance during the project**			
Unlikely	**2**	**3% chance**			
Possible	**3**	**10% chance**			
Likely	**4**	**30% chance**			
Very Likely	**5**	**>= 90% chance during the project**			
Impact Severity					
Light	**-1**				
Serious	**-2**				
Major	**-3**				
Catastrophic	**-4**				
Multi- Catastrophic	**-5**				
Description of Characteristics	**Recommended**	**Site Evaluation**	**Likelihood**	**Severity**	**Importance**
Reservoir Analysis					
Distance to suitable geologic formation	Site must be located within 50 miles (80 km) of a suitable geological storage area	The St Peter Sandstone is the primary storage reservoir at Prairie State Generating Company site. The nearest deep well that penetrated through the St. Peter Sandstone is the Shaglee Unit #1 approximately 12 miles (19 km) away in Perry Co, IL. The top of the	2	-5	-5

		St. Peter is approximately 4100 feet (1250 m) deep in the Shaglee Unit #1 well.			
Reservoir Thickness	Location must have reservoir with 20 feet (6 m) or greater of <10% porosity	Regional thickness map for the St. Peter Sandstone (Figure 8) estimated between thickness between 150 to 200 feet (46 to 61 m). In the Shaglee Unit #1 well, the St Peter Sandstone is approximately 150 feet (46 m) thick. Wells within a 25-mile (40-km) search radius have confirmed thickness ranges reflected in regional maps.	2	-3	-3
Injection Rate Capacity	The proposed geologic formation for sequestration must support a CO_2 injection rate of 1 million metric tons of CO_2 per year for up to 30 years.	Drilling has confirmed the presence of the St Peter Sandstone at this site. Well testing would be a required to determine injection capacity.	2	-3	
Depth and capacity of Saline Formation (if Saline Formation is the preferred sequestration option)	If a deep saline formation is the sequestration target, the formation must have in-situ hydrostatic pressure and temperature conditions above the CO_2 supercritical point (31° C at 73 atm). The deep saline formation must have sufficient storage capacity for the planned life of the plant (30 years) under these conditions.	The St. Peter Sandstone upper contact is typically between 3,000 to 4,500 feet (914 to 1372 m) in depth in the area. St Peter thickness and depth can change in a very short distance in this area.	2	-4	-4
Availability of secondary reservoirs	Not required				
Proximity to Oil Fields	If CO_2 enhanced oil recovery (CO_2-EOR) reservoirs are the target, then the site must be 50 miles (80 km) or closer to oil fields that are deep enough for miscible EOR methods.	Prairie State Generating Company is located west of the most significant oil producing region in the Illinois Basin. The potential exists for stacked CO_2-EOR and saline storage within a 50-mile (80 km) distance north and east of the site.	2	-1	-1
Seismic Risk	Must not be in an area of high seismic hazard (per USGS).	There is a 2% probability that the Peak Ground Acceleration due to seismic activity will exceed 31% G within 50 years (USGS, 2014; based on 2014 long-term model; 760 meters/second).	2		
Seal Analysis					
Relation of Primary Seal to Active or Transmissive Faults	The primary seal must not be intersected by any known historically active or hydraulically transmissive faults. The proposed seal must have a low differential in-situ caprock or target formation stress and high mechanical seal strength relative to injection pressure	The Elkton Anticline (Figure 18) is approximately twenty miles to the east of the Prairie State Generating Company site. The Elkton Anticline is a north-trending structural high about 6.5 miles (10.5 km) long and 1.5 miles (2.5 km) wide (Nelson 1995). This interpreted faulted interval would need to be verified by seismic reflection if storage were considered.	2	-4	-5

Primary Seal	The primary seal must have sufficient thickness (greater than 20 feet or 6 m), be regionally extensive, and be continuous over the entire projected CO_2 plume boundary after injection of 50 MMT of CO_2. It must have sufficiently low vertical permeability and have sufficiently high capillary entry pressure to provide a barrier to migration of CO_2 out of the target formation.	Regional thickness map of the Maquoketa Shale (Figure 12) indicates thickness range between 100 to 200 feet (30 to 61 m). Surrounding drill hole data indicates formation thickness between 150 to 200 feet (46 to 61 m).	2	-5	-5
Secondary Seal	Not required but preferred. Secondary seal should overlie the primary caprock seal, be largely continuous, be greater than 10 feet (3 m) thick throughout and cover at least 75 percent of the projected plume after injection of 50 MMT CO_2.	The New Albany Shale is estimated to be less 100 feet (30 m) thick at this location.	2	-2	-2
Tertiary Seal	Not required				
Gas Storage	Gas storage reservoirs cannot be within the estimated CO_2 plume radius.	Tilden Gas Storage Field (Table 4), St. Clair, Co. is about 2 miles (3 km) to the southwest of the Prairie State Energy Campus site. Tilden Gas Storage Field injects into the Mississippian Cypress Formation with a basal depth less than 900 feet (274 m).	2	-3	-5
Seismic data availability?	Is there any seismic reflection data available at this site? This is not a requirement, but it reduces subsurface uncertainty.	There are over 30 (north-south and east-west) existing 2D seismic reflection profiles collected in central to east central Washington Co., IL.			
Reservoir salinity	Injection reservoir must be over 10,000 mg/L	St. Peter Sandstone salinity is expected to be more than 10,000 mg/l at the Prairie State Energy Campus.	2	-2	-2
Boreholes penetrating injection reservoir	Abandoned boreholes penetrating the reservoir interval may allow leakage into shallower horizons	Penetrations into the St. Peter Sandstone within 20 miles (32 km) of the facility.	2	-2	-2
Seal becomes target for unconventional petroleum production	Identify a potential scenario where primary seal becomes a target for shale gas production, and operators object to CCS injection	The Maquoketa Shale is unlikely to be an unconventional petroleum target in this area	2	-2	-4
Legal/regulatory permitting issues	Permitting time and requirements cause economic delays	This must be addressed during the permitting of the well and is dependent on the regulatory agency.	3	-3	-5
Near Surface Impacts					
Sensitive features above sequestration area	The land above the proposed sequestration formation must not intersect large dams, water reservoirs, hazardous materials storage facilities, Class 1 injection wells, or other sensitive features.	No known sensitive surface features or protected biological species.	2	-3	-5

Sequestration impacts on drinking water	Proposed target formation for CO_2 sequestration must not be an underground source of drinking water	Illinois State Water Survey Illinois Groundwater Resources Maps identify the unconsolidated/surficial deposits above bedrock at the site approximately 50 feet (15 m) thick. Prairie State Generating Company is east within 5 miles (8 km) of the mapped extent of the Kaskaskia River Alluvial Aquifer. No bedrock aquifer systems are mapped in the area. The Prairie State Generating Company site is not located in a drinking water protection area, or above a sole source aquifer.	3	-5	-5
Access to sequestration area for CO_2 leakage monitoring	There must be sufficient access to the land surface above the proposed sequestration area to implement a CO_2 leakage monitoring program.	Area is flat lying and appears to have no issues with access.	1	-3	-3
Mineral Rights in the CO_2 sequestration area	The proposed CO_2 sequestration area must be located where the project can obtain, purchase, or get a waiver of subsurface mineral rights. (unless recovery of coal-bed methane or oil is a part of the sequestration process).	Needs to be addressed by Prairie State Generating Company.			