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Revision 1

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ALLIANCE

Clean Energy for a Secure Future

Underground Injection Control Permit Applications for FutureGen 2.0 Morgan County Class VI UIC Wells 1, 2, 3, and 4

SUPPORTING DOCUMENTATION

March 2013

(Revised May 2013 in accordance with the U.S. Environmental Protection Agency's Completeness Review)

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Contact Information:
FutureGen Industrial Alliance, Inc.
73 Central Park Plaza East
Jacksonville, IL 62650
Telephone: 217/243-8215
Email: info@FutureGenAlliance.org
Homepage: www.FutureGenAlliance.org

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Prepared by
FutureGen Industrial Alliance, Inc.
73 Central Park Plaza East
Jacksonville, IL 62650

Prepared for
U.S. Environmental Protection Agency, Region 5
77 West Jackson Boulevard
Chicago, IL 60604

March 2013
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Summary

The FutureGen Industrial Alliance (Alliance) prepared this supporting documentation for its Underground Injection Control (UIC) Class VI permit applications for the construction and operation of four injection wells in Morgan County, Illinois, for the injection of carbon dioxide (CO_2). The Alliance is a non-profit membership organization created to benefit the public interest and the interests of science through research, development, and demonstration of near-zero emissions coal technology. It is partnering with the U.S. Department of Energy (DOE) on the FutureGen 2.0 Project.

The Alliance proposes to construct and operate four wells for the injection of CO_2. Permit applications have been prepared for each of the proposed injection wells, with the supporting documentation for each of the wells collectively provided within this document. This supporting documentation was prepared in accordance with the U.S. Environmental Protection Agency's (EPA's) *UIC Control Program for Carbon Dioxide Geologic Sequestration Wells* (The Geological Sequestration [GS] Rule, codified in Title 40 of the Code of Federal Regulations [40 CFR 146.81 et seq.]). The applications and supporting documentation are based on currently available data, including regional data and site-specific data derived from a stratigraphic well drilled by the Alliance in late 2011 near the site of the proposed injection wells.

The proposed Morgan County CO_2 storage site is 11 mi (18 km) northeast of the City of Jacksonville (see Figure S.1), and is located under agricultural land. The Alliance plans to inject approximately 1.1 million metric tons (MMT) of CO_2 annually into the Mount Simon Sandstone over 20 years, for a total of 22 MMT. The CO_2 for injection will be captured from the nearby Meredosia, Illinois, coal-fueled power plant, which will be repowered with oxy-combustion and carbon capture technology. The CO_2 will be captured from the power plant and then piped underground approximately 30 mi to the storage site for injection and permanent storage. Figure S.2 is a schematic of the FutureGen 2.0 Project showing the integration of the repowered oxy-combustion power plant, transport of CO_2 by buried pipeline, and injection of CO_2 for permanent storage.

Figure S.3 shows the stratigraphy at the Morgan County CO_2 storage site. The four injection wells will be directionally drilled from a single well pad and completed within a permeable layer of the Cambrian-aged Mount Simon Sandstone approximately 4,000 ft below ground surface (bgs) (the "injection zone"). The Alliance proposes this injection zone because it is of sufficient depth, thickness, porosity, and permeability to contain the proposed 22 MMT of CO_2. This proposed injection zone has demonstrated reservoir capacity in natural-gas storage facilities elsewhere in the Illinois Basin and contains a hypersaline aquifer that is in excess of recommended Safe Drinking Water Act standards and is not considered to be of beneficial use.

The injection zone is overlain by the Eau Claire Formation, a thick regional layer of predominantly sandstone that is of sufficient thickness, lateral continuity, and has low enough permeabilities to serve as the primary confining zone or caprock. No faults or fractures were identified based on geophysical well logs of the stratigraphic well and seismic analysis of the site. The Eau Claire Formation is a carbonate and shale unit that has been proven to be an effective confining zone at 38 natural-gas storage reservoirs in Illinois. The Morgan County CO_2 storage site affords a secondary confining zone – the Franconia Formation – for additional protection of underground sources of drinking water (USDWs).

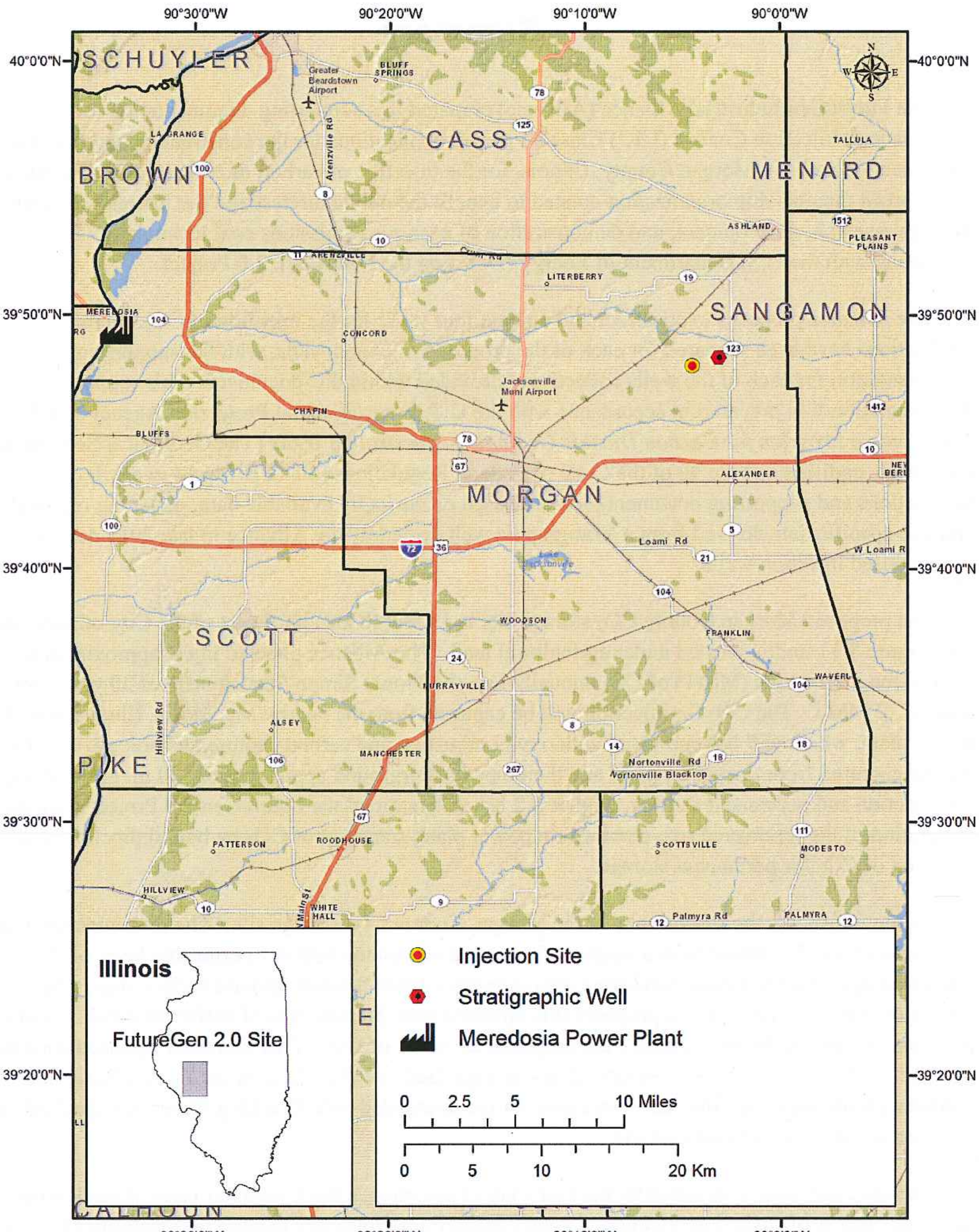

Figure S.1. Illinois Map Showing Morgan County and the Location of the Injection Well Pad

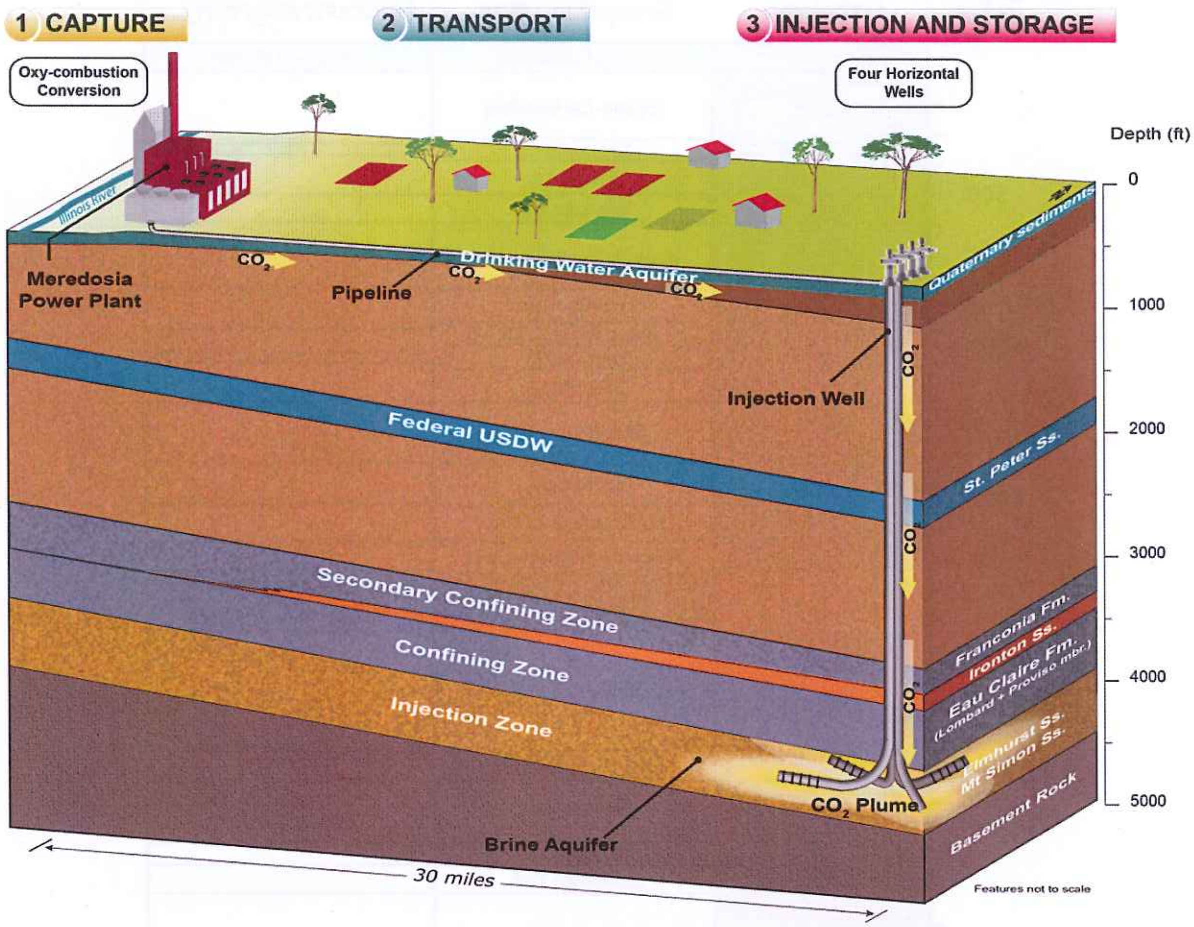

Figure S.2. Graphical Overview of the Conceptual Design of the CO_2 Storage Site

At the proposed Morgan County site, all known water-supply wells are completed in the surficial sediments (<150 ft bgs). For the purpose of the permit applications and supporting documentation, the deeper St. Peter Sandstone is considered the lowermost USDW based on a water sample collected at the stratigraphic well that was 3,700 ppm of total dissolved solids, and below the federal regulatory upper limit of 10,000 ppm for drinking water aquifers. While recognized as a federal USDW, the St. Peter Sandstone is not recognized by the State of Illinois as a suitable source for potable water at the Morgan County storage site.

The supporting documentation that accompanies the Alliance's UIC permit applications demonstrates that the injection zone is of sufficient capacity and the confining zone is of sufficient thickness and integrity for the site to permanently store the CO_2 in a manner that is protective of USDWs. The application is based on regional and site-specific data derived from the stratigraphic well that was specifically drilled in support of this UIC application in late 2011 near the site of the proposed injection wells. These data were used as input to a numerical model that was used to delineate the Area of Review (AoR) and to optimize the storage site design.

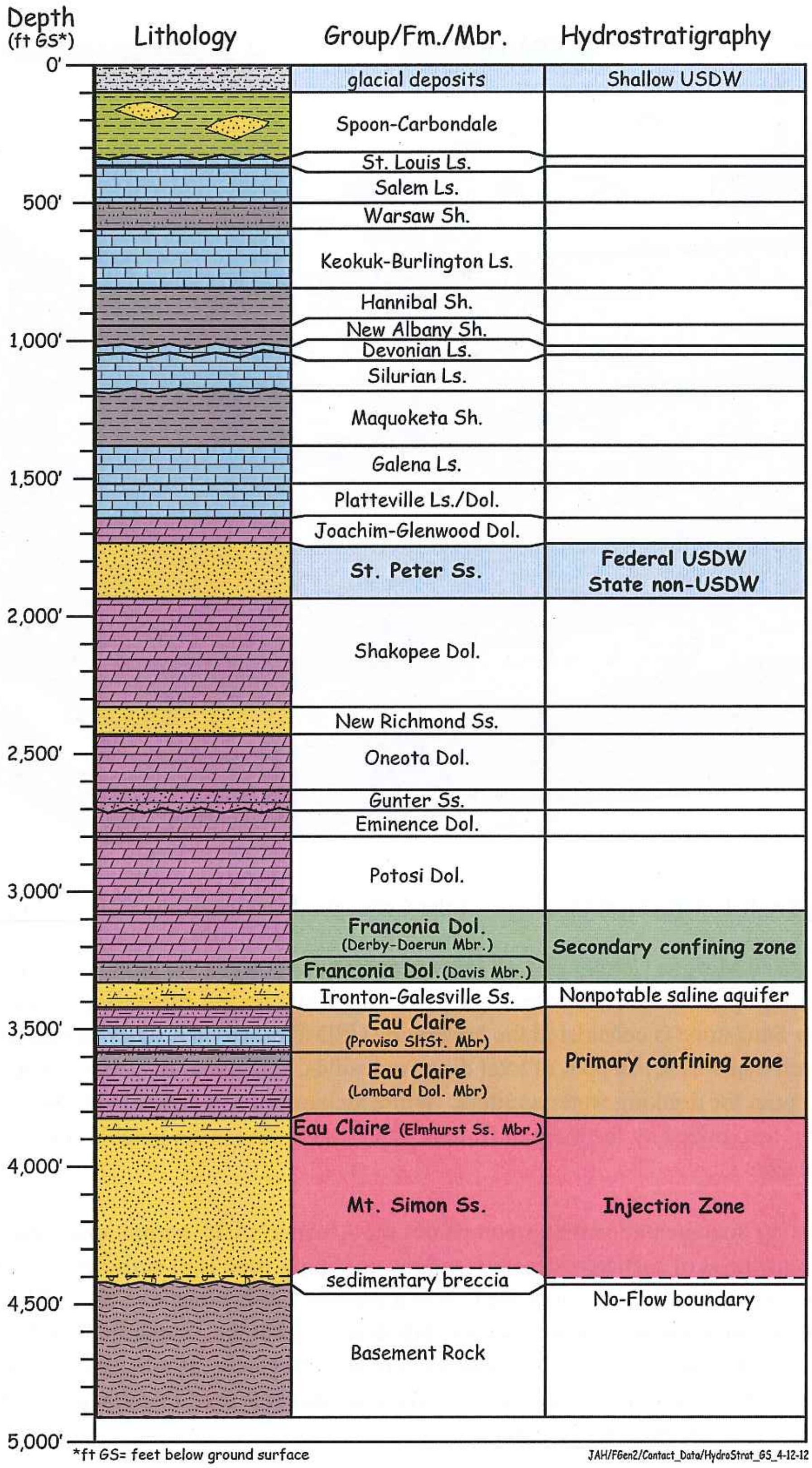

Figure S.3. Stratigraphy and Proposed Injection and Confining Zones at the Morgan County CO_2 Storage Site

Area of Review

The Alliance has defined the AoR (the region encompassing the CO_2 storage site where particular attention must be paid to USDW protection) as the projected lateral and vertical migration of the CO_2 plume from the start of injection until the lateral spread of the plume ends (approximately 5 years after injection stops). To identify this plume area, the Alliance used the STOMP-CO_2 simulator to model the coupled hydrologic, chemical, thermal processes, and chemical interactions with aqueous fluids and rock minerals. The plume is identified as the volume in which 99 percent of the mass resides. This volume is determined from the numerical model and the resulting map area is displayed in Figure S.4.

Also shown in Figure S.4 is a larger 25-mi^2 (65-km^2) area that represents an expanded survey area used to identify the existence of any confining zone penetrations (i.e., existing wells that may penetrate the caprock). Although numerous wells are located within the expanded survey area that includes the AoR, none other than the Alliance's stratigraphic well penetrates the injection zone, the confining zone, or the secondary confining zone. Within the AoR itself, there are three other existing deep wells, none of which penetrates beyond the Maquoketa Shale (see Figure S.3). Because no wells within the AoR could serve as conduits for the movement of fluids from the injection zone into USDWs, no corrective actions on existing wells will need to be taken.

Surface bodies of water and other pertinent surface features (including structures intended for human occupancy), administrative boundaries, and roads within the AoR and the expanded survey area are shown in Figure S.4. There are no subsurface cleanup sites, mines, quarries, or Tribal lands within this area.

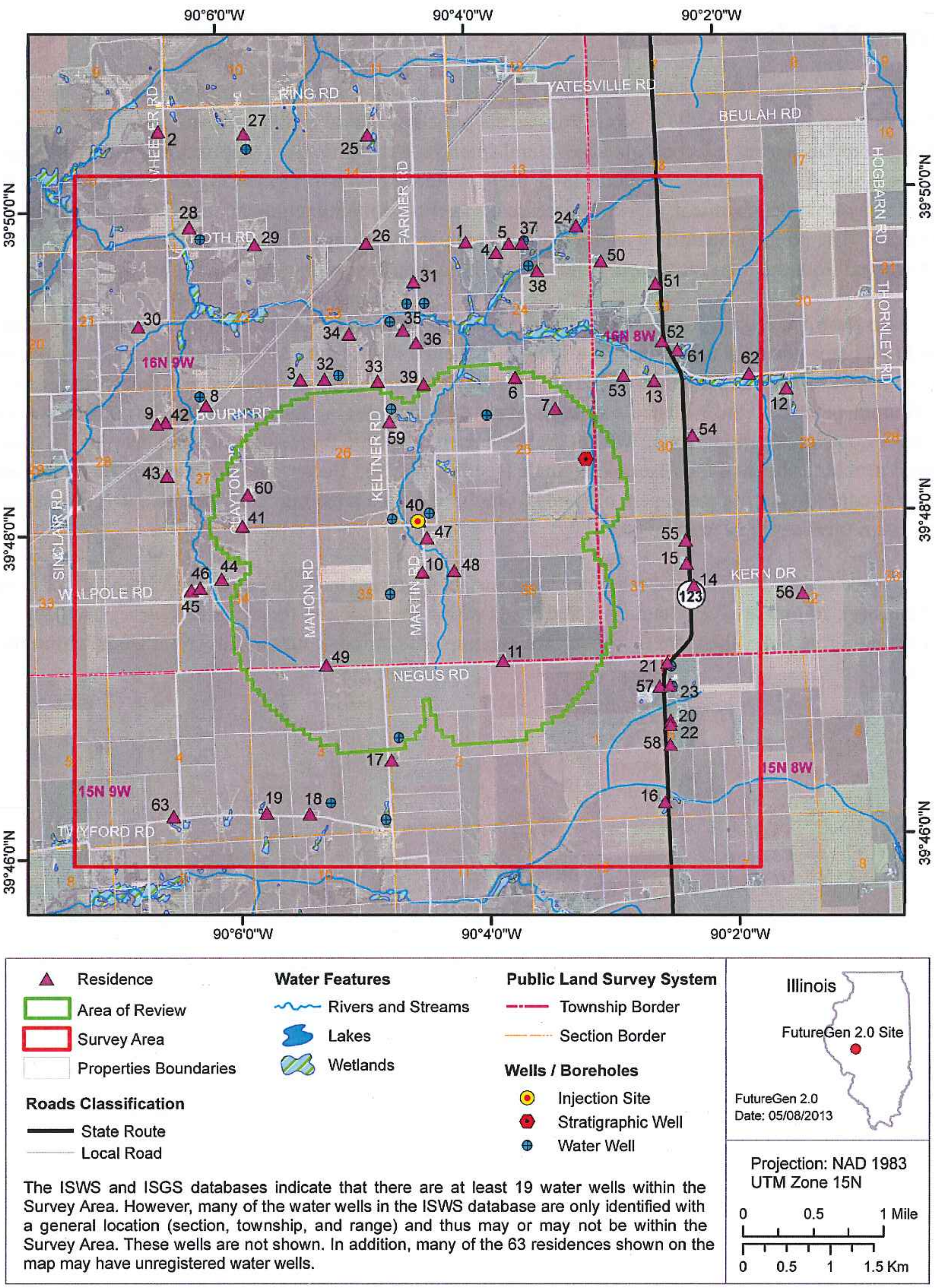

Figure S.4. Map of Residences, Water Wells, and Surface Water Features Within the Delineated AoR and Survey Area

Construction and Operations Plan

At the Meredosia Power Plant, the captured CO_2 will be purified (at least 97 percent purity), dehydrated, and compressed to 2,100 psig before entering the CO_2 pipeline. At these conditions, the CO_2 will be in a dense fluid phase, non-corrosive and non-flammable. The CO_2 pressure will decrease as the CO_2 travels the length of the pipeline to the CO_2 storage site. At the injection wellhead, the pressure is estimated to between 1,100 and 1,900 psi. The approximately 30-mile (48-km) pipeline will be 10 to 12 in. (25 to 30 cm) in diameter and have a design flow rate of 1.1 MMT/yr (57.3 mmscf/d).

The storage site design was optimized for receiving the CO_2 at a rate of 1.1 MMT/yr. The four horizontal injection well design affords a number of advantages over the more common vertical injection well design. The horizontal wells will minimize the required injection pressures, which for this design will be less than 450 psi above the natural formation pressures. This provides additional protection of the confining layer and eliminates the need for some surface infrastructure such as booster pumps. The "thin" CO_2 plume that results from horizontal wells will also stabilize faster than if the CO_2 were to be injected over a longer vertical interval.

The injection wells will be built with a protection system that will control the injection of the CO_2 and provide a means to safely halt CO_2 injection in the event of an injection well or equipment failure. The injection process will be monitored by an integrated system of equipment and instrumentation that will be capable of detecting whether injection conditions are out of acceptable limits and responding by either adjusting conditions or halting injection. The system is designed to operate automatically with manual overrides.

Testing and Monitoring Plan

An extensive monitoring, verification, and accounting system will be implemented to verify that injected CO_2 is effectively contained within the injection zone. The objectives of the monitoring program are to track the lateral extent of CO_2 within the injection zone, characterize any geochemical or geomechanical changes that occur within the injection and confining zones that may affect containment, and to track the areal extent of the injected CO_2 through indirect monitoring techniques such as geophysical and surveillance methods. The monitoring network, shown in Figure S.5, will be designed to account for and verify the location of all CO_2 injected into the ground. It will include three monitoring wells in the injection zone and a monitoring well above the confining zone to verify CO_2 has not migrated into that zone. In addition, a groundwater monitoring well will be completed in the St. Peter Formation to be protective of this lowermost federal USDW. Monitoring of the site will continue for 50 years after injection has ceased.

A *vertical well* is drilled from the ground surface to a specified completion depth in a straight line.

A *horizontal well* is drilled from the ground surface to a specified depth and then curved to proceed in a horizontal direction. The curved section is referred to as a lateral.

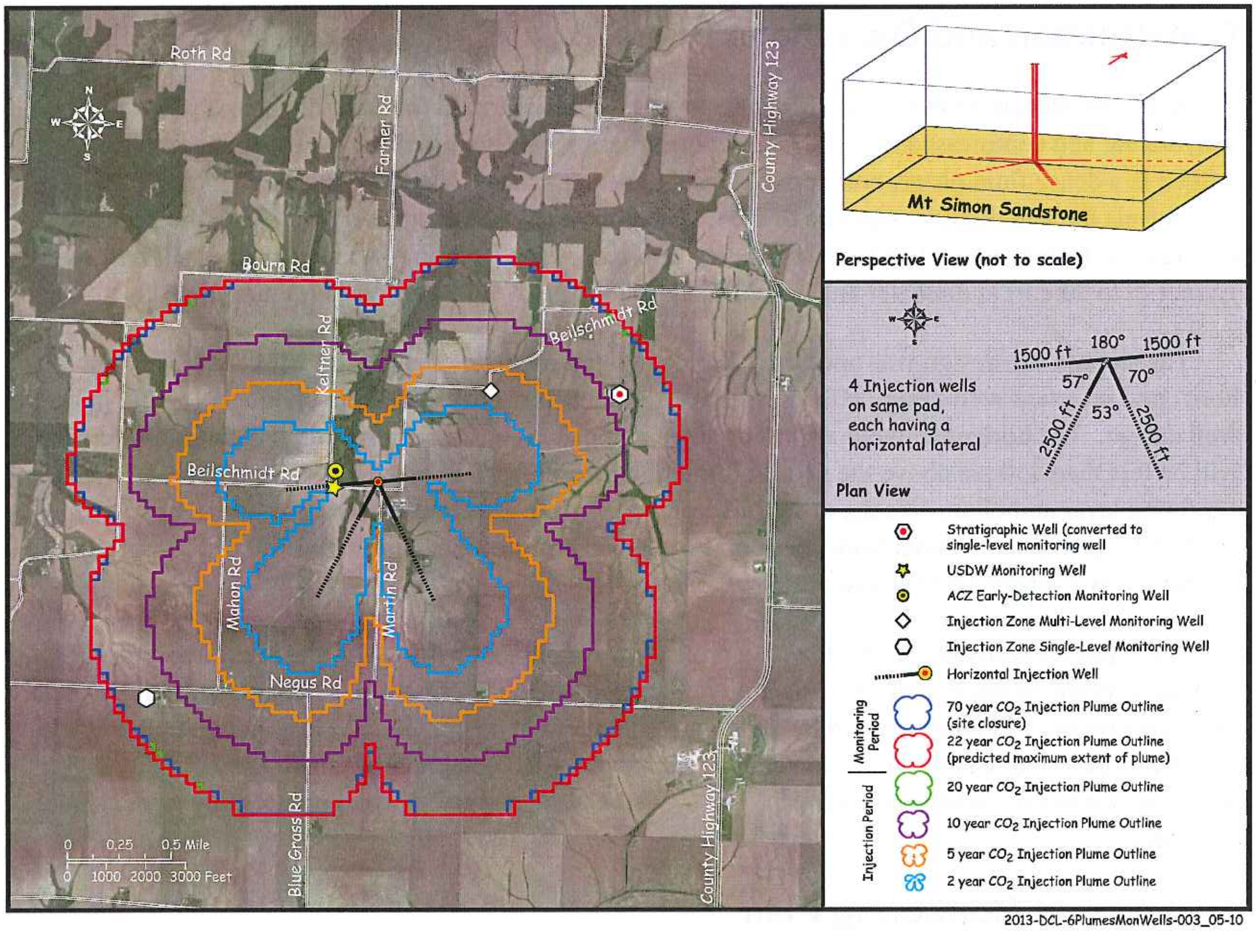

Figure S.5. Nominal Well Network Layout

Injection Well Plugging Plan

After injection ceases, the injection wells will be plugged with cement to ensure that they do not provide a conduit from the injection zone to a USDW or the ground surface. Post-injection monitoring will include a combination of groundwater monitoring, storage zone pressure monitoring, and geophysical monitoring of the Morgan County CO_2 storage site. The monitoring locations, methods, and schedule will be designed to show the position of the CO_2 plume and demonstrate that USDWs are not being endangered.

Post-Injection Site Care and Site Closure Plan

Post-injection monitoring will include a combination of groundwater monitoring, storage zone pressure monitoring, and geophysical monitoring of the Morgan County CO_2 storage site. The monitoring locations, methods, and schedule are designed to show the position of the CO_2 plume and demonstrate that USDWs are not being endangered.

After the active injection phase, the surface infrastructure will be reduced and the remaining areas reclaimed and returned to their pre-development condition. All unneeded gravel pads, access roads, and surface facilities will be removed, and the land will be reclaimed for agricultural or other pre-development uses.

Site closure will occur at the end of the post-injection site care period. Site closure activities will include decommissioning remaining surface equipment, plugging monitoring wells, restoring the site, and preparing and submitting site closure reports. All remaining surface facilities will be removed, including buildings, access roads and parking areas, sidewalks, underground electric and telecommunication facilities, and fencing. The land will be reclaimed for agricultural or other pre-development uses.

Emergency and Remedial Response Plan

The Alliance will develop a comprehensive Emergency and Remedial Response Plan for its Morgan County CO_2 storage site, indicating what actions would be necessary in the unlikely event of an emergency at the site. The plan will ensure that site operators know which entities and individuals are to be notified and what actions need to be taken to expeditiously mitigate any emergency situation and protect human health and safety and the environment, including USDWs. If an adverse event occurred, a variety of emergency or remedial responses would be deployed depending on the circumstances (e.g., the location, type, and volume of a release) to protect USDWs.

The entire CO_2 storage project is focused on retention of the CO_2 in the injection zone.

Financial Responsibility Plan

The Alliance has developed a plan to maintain financial responsibility for the construction, operation, closure, and monitoring of the proposed injection wells and to undertake any emergency or remedial actions that may be necessary. To ensure that sufficient funds will be available, the Alliance has obtained an estimate of the cost of hiring a third party to undertake any necessary actions to protect USDWs within the AoR. Funding for performing any needed corrective actions will be deposited in a CO_2 Storage Trust Fund that will be available during all phases of the project. The Alliance will also obtain a third-party insurance policy that would be available for conducting any emergency or remedial response actions.

Conclusion

The Alliance prepared its Class VI UIC permit applications and supporting documentation to demonstrate that 1) the proposed Morgan County CO_2 storage site comprises an injection zone of sufficient areal extent, thickness, porosity, and permeability to receive up to 22 MMT of CO_2 over 20 years; and 2) the confining zone and secondary confining zone are free of faults and fractures and are of sufficient areal extent and integrity to contain the injected CO_2, allowing the injection of CO_2 at the proposed pressures and volumes without initiating or propagating fractures in the confining zones. These findings are supported by the results of the drilling of a stratigraphic well that provided site-specific geologic data as well as available regional data from sources such as the Illinois State Geological Survey.

The Alliance has developed comprehensive construction and operations, testing and monitoring, injection well plugging, and post-injection site care and site closure plans, as well as an emergency and remedial response plan, to protect USDWs. To ensure that sufficient funds are available to undertake these actions, the Alliance has also developed a financial responsibility plan.

The Alliance is confident that its permit applications and supporting documentation demonstrate compliance with EPA's GS Rule. Table S.1 provides a crosswalk between the regulatory requirements in that rule and the organization of the Alliance's supporting documentation.

Table S.1. Crosswalk Between Applicable Regulatory Provisions in the GS Rule and the Alliance UIC Permit Application Supporting Documentation

GS Rule – Regulatory Requirements	Alliance UIC Permit Application
40 CFR 146.82, Required Class VI permit information	Chapter 1, Introduction Chapter 2, Conceptual Model of the Site Based on Geology and Hydrology
40 CFR 146.83, Minimum criteria for siting	Chapter 2, Conceptual Model of the Site Based on Geology and Hydrology
40 CFR 146.84, Area of review and corrective action	Chapter 3, Area of Review and Corrective Action Plan
40 CFR 146.85, Financial responsibility	Chapter 9, Financial Responsibility
40 CFR 146.86, Injection well construction requirements	Chapter 4, Construction and Operations Plan
40 CFR 146.87, Logging, sampling, and testing prior to injection well operation	Chapter 4, Construction and Operations Plan
40 CFR 146.88, Injection well operating requirements	Chapter 4, Construction and Operations Plan
40 CFR 146.89, Mechanical integrity	Chapter 5, Testing and Monitoring Plan
40 CFR 146.90, Testing and monitoring requirements	Chapter 5, Testing and Monitoring Plan
40 CFR 146.91, Reporting requirements	throughout
40 CFR 146.92, Injection well plugging	Chapter 6, Injection Well-Plugging Plan
40 CFR 146.93, Post-injection site care and site closure	Chapter 7, Post-Injection Site Care and Site Closure Plan
40 CFR 146.94, Emergency and remedial response	Chapter 8, Emergency and Remedial Response Plan
40 CFR 146.95, Class VI injection depth waiver requirements	Not applicable

Acronyms and Abbreviations

°C	degrees Celsius (or Centigrade)
°F	degree(s) Fahrenheit
2D	two-dimensional
3C	three-component
3D	three-dimensional
ac	acre(s)
ACZ	Above Confining Zone
ADM	Archer Daniels Midland
AFL	Annular Flow Log
AIC	Akaike information criterion
Al	aluminum
Alliance	FutureGen Industrial Alliance, Inc.
AoR	Area of Review
API	American Petroleum Institute
APT	annular pressure test
As	arsenic
ASTM	American Society for Testing and Materials
ASU	air separation unit
B	boron
bbl	barrel(s)
bgs	below ground surface
bkb	below the kelly bushing
BTC	buttress thread coupling
C	carbon
Ca	calcium
CAA	Clean Air Act
CAAPP	Clean Air Act Permit Program
$CaCl_2$	calcium chloride
CBL	cement bond log
CCS	carbon capture and storage
Cd	cadmium
CFR	Code of Federal Regulations

CH_4	methane
Cl	chlorine
cm	centimeter(s)
cm/sec	centimeter(s) per second
CMR	compensated magnetic resonance
CO	carbon monoxide
CO_2	carbon dioxide
cP	centipoise
CPU	compression unit
Cr	chromium
CRDS	cavity ring-down laser spectroscopy
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWA	Clean Water Act
d	day(s)
DCS	Distributed Control System
DIC	dissolved inorganic carbon
DIS	discriminator
DO	dissolved oxygen
DOE	U.S. Department of Energy
Dol	dolomite
DST	drill-stem test
DTS	distributed temperature sensing
ECD	electron capture detector
EIS	environmental impact statement
ELAN	Elemental Analysis
EPA	U.S. Environmental Protection Agency
ERT	electrical resistivity tomography
ESP	electrostatic precipitator or electric submersible pump
EUE	external upset end
F	fluorine
FBP	Formation Break-Down Pressure
FCP	fracture closure pressure
Fe	iron
FEED	Front-End Engineering Design
FG1	FutureGen stratigraphic well

FGD	flue-gas desulphurization
FIT	Formation Integrity Test
FL	Flux Leakage
FPP	fracture propagation pressure
FR	Federal Register
ft	foot(feet)
ft/min	foot(feet) per minute
ft^3	cubic foot(feet)
FTS	Flow-Through Sampler
$\mu g/m^3$	microgram(s) per cubic meter
G	ground acceleration
g	gram(s)
g/cc	gram(s) per cubic centimeter
g/cm^3	gram(s) per cubic centimeter
gal	gallon(s)
GAP	U.S. Geological Survey Gap Analysis Program
GIE	Gulf Interstate Engineering
gpd	gallon(s) per day
gpm	gallon(s) per minute
GPS	global positioning systems
GR	gamma ray survey log
GS	geological sequestration
H_2S	hydrogen sulfide
ha	hectare(s)
HCl	hydrochloric (acid)
HCO_3	bicarbonate
HDPE	high-density polyethylene
Hg	mercury
HMI	Human Machine Interface
hp	horse power
hr	hour(s)
I.D.	inner diameter
ICL	imaging caliper tool
ICP	inductively coupled plasma
ID	identification

IDNR	Illinois Department of Natural Resources
IEPA	Illinois Environmental Protection Agency
ILCS	Illinois Compiled Statutes
ILOIL	Illinois Oil and Gas Resources (Internet Map Service)
in.	inch(es)
InSAR	Interferometric Synthetic Aperture Radar
INW	Instrumentation Northwest
IRMS	isotope ratio mass spectrometry
ISGS	Illinois State Geological Survey
ISIP	Instantaneous Shut-In Pressure
ISWS	Illinois State Water Survey
K	potassium (or thousand)
KB	kelly bushing
KCl	potassium chloride
kg/m^3	kilogram(s) per cubic meter
Kh	horizontal permeability; permeability parallel to sedimentary layering
km	kilometer(s)
ksi	kilopound(s) per square inch
k-s-p	permeability-saturation-capillary pressure
Kv	vertical permeability; permeability perpendicular to sedimentary layering
kW	kilowatt(s)
L	liter(s)
lb	pound(s)
lbm	pound-mass
LC/MS	liquid chromatography/mass spectrometry
LOP	Leak-Off Pressure
Ls	limestone
LT	Limit Test
LTC	long thread coupling
µMHOS/cm	micromho(s) per centimeter
mBq	millibequerel(s)
Mbr	geologic member (unit)
MD	measured depth
mD	millidarcy(ies)
mD-ft	millidarcy foot(feet)

MDNR	Missouri Department of Natural Resources
MDT	Modular Formation Dynamics Tester
MESPOP	maximum extent of the separate-phase plume or pressure
Mg	magnesium
mg	milligram(s)
mg/kg	milligram(s) per kilogram
mg/m^3	milligram(s) per cubic meter
Mgd	million gallons per day
mi	mile(s)
mi^2	square mile(s)
MICP	mercury injection capillary pressure
mGal	milliGal(s)
min	minute(s)
MIP	maximum injection pressure
MIT	mechanical integrity test(ing) or Massachusetts Institute of Technology
mmscf	million standard cubic (foot)feet
mmscfd	million standard cubic (foot)feet per day
MMT	million metric ton(s)
MMT/yr	million metric ton(s) per year
MMTA	million metric tons per annum
Mn	manganese
MPa	megapascal(s)
mph	mile(s) per hour
ms	millisecond(s)
MS	microseismic or mass spectrometry
MSL	mean sea level
MT	magnetotelluric or metric ton(nes)
MTC	metal to metal seal
mV	millivolt(s)
MVA	Monitoring, Verification, and Accounting
MW(e)	megawatt electric
N	nitrogen
N^2	nitrogen
NA	not applicable
Na	sodium
NACE	National Association of Corrosion Engineers
NaCl	sodium chloride

NAD	North American Datum
$NaAlCO_3(OH)_2$)	dawsonite
NEPA	National Environmental Policy Act of 1969, as amended
NETL	National Environmental Technology Laboratory
Ni	nickel
NO_2	nitrogen oxide
NOG	naturally occurring gas
NO_x	nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NPT	National Pipe Threads
O_2	oxygen
O.D.	outside diameter
OES	optical emission spectrometry
OG	(IDNR's) Division of Oil and Gas
OGW	oil and gas well
OPID	Operator Identification Number
P	phosphorus
Pb	lead
PBTD	plugged-back depth
PDC	polycrystalline diamond compact drilling bit
PDCB	perfluorodimethylcyclobutane
PDCH	perfluoro-1,2-dimethylcyclohexane
PEB	plain-end and beveled
PETE	polyethylene terephthalate
PFBA	pentafluorobenzoic acid
PFT	referred to as perfluorinated tracers
PIGN	Gamma-Neutron Porosity (Schlumberger ELAN porosity log/survey)
PHIT	Total Porosity (Schlumberger ELAN porosity log/survey)
PIGE	Effective Porosity (Schlumberger ELAN porosity log/survey)
PLC	programmable logic controller
PLL	Pollution Legal Liability
PM	particulate matter
PM_{10}	particulate matter with an aerodynamic diameter of less than 10 microns
$PM_{2.5}$	particulate matter with an aerodynamic diameter of less than 2.5 microns
PNNL	Pacific Northwest National Laboratory
PNWD	(Battelle–) Pacific Northwest Division
ppb	parts per billion

ppbv	parts per billion on a volumetric basis
ppg	pound(s) per gallon
ppm	parts per million
pptv	parts per trillion on a volumetric basis
psi	pounds per square inch
psia	pounds per square inch, absolute
psig	pound-force per square inch gauge (or pounds per square inch gauge)
PTCH	perfluorotrimethylcyclohexane
PVC	polyvinyl chloride
QA	Quality Assurance
QMC	quasi Monte Carlo
RAT	radioactive tracer
RCI	(Tool and Baker's) Reservoir Characterization Instrument
RCRA	Resource Conservation and Recovery Act
RH	relative humidity
Rn	radon
RTU	remote terminal unit
Rwa	water resistivity
µS/cm	microsiemen(s) per centimeter
s	second(s)
S	sulfur
SAR	synthetic aperture radars
Sb	antimony
SBT	segmented bond tool
$scCO_2$	supercritical carbon dioxide
SCMT	slim cement mapping tool
SDWA	Safe Drinking Water Act
Se	selenium
sec	second(s)
SEM	scanning electron microscopy
SEM/EDX	scanning electron microscopy with energy dispersive x-ray (analysis)
SF_6	sulfur hexafluoride
SG	shallow gas (collector)
Sh	shale
SIC	Standard Industrial Classification

SltSt	siltstone
SO_x	sulfur oxides
SpC	specific conductance
Sr	strontium
Ss	sandstone
STOMP	Subsurface Transport Over Multiple Phases
STP	standard temperature and pressure
SWC	side-wall core
SWPPP	Storm Water Pollution Prevention Plan
TD	total depth
TDAS	Tubular Design and Analysis System
TDS	total dissolved solids
THPO	Tribal Historic Preservation Office
Tl	thallium
TOC	total organic carbon
TVD	total vertical depth
UCI	Ultrasonic Casing Imager
UIC	Underground Injection Control
USDW	underground sources of drinking water
USI	ultrasonic Imager
UTM	Universal Transverse Mercator
V	vanadium
VdB	vibration decibel(s)
VDL	variable-density log
VIM	vertically integrated mass
VIMPA	vertically integrated mass per unit area
VSP	vertical seismic profile(ing)
W	watt(s)
WAPMMS	well annular pressure maintenance and monitoring system
WGNHS	Wisconsin Geological and Natural History Survey
WS-CRDS	wavelength-scanned cavity ring-down spectroscopy
XRD	x-ray diffraction
X-Z	cross-section

yd^3	cubic yard(s)
yr	year(s)
Zn	zinc

Contents

Figures

Tables

1.0 Introduction

The FutureGen Industrial Alliance, Inc. (Alliance) prepared this documentation to support its Underground Injection Control (UIC) Class VI permit applications to the U.S. Environmental Protection Agency (EPA), Region 5, for the construction and operation of four wells for the injection of carbon dioxide (CO_2) in Morgan County, Illinois. The four injection wells will be drilled from a single well pad. Figure 1.1 shows the location of the proposed injection wells. This supporting documentation was prepared in accordance with the UIC Control Program for Carbon Dioxide Geologic Sequestration Wells (The GS [Geological Sequestration] Rule, published on December 10, 2010 [75 FR 77230] and codified in Title 40 of the Code of Federal Regulations [40 CFR 146.81 et seq.].[1]

The Alliance has prepared separate application forms (EPA Forms 7520-6 and 7520-14) for each proposed injection well (referred to as Morgan County Class VI UIC Wells 1, 2, 3, and 4). Because the four injection wells will be similarly constructed and drilled from a single well pad, the CO_2 injected through the four wells will form one co-mingled CO_2 plume. Therefore, this supporting documentation applies to all four proposed injection wells.[2] The applications and supporting documentation are based on currently available data, including regional data and site-specific data derived from a stratigraphic well drilled by the Alliance in late 2011 near the site of the proposed injection wells.

A project overview, administrative information required by 40 CFR 144.31(e)(1) through (6), and a description of the remaining chapters of this supporting documentation are presented in the following sections. Appendix A contains a table listing where each regulatory requirement in the GS Rule, including the minimum criteria for siting, is addressed.

1.1 Project Overview

This section provides a description of the Alliance, the FutureGen 2.0 Project, and the Alliance's proposed CO_2 storage system.

1.1.1 FutureGen Alliance

The Alliance is a non-profit corporation created to benefit the public interest and the interests of science through research, development, and demonstration of near-zero emissions coal technology. It is partnering with the U.S. Department of Energy (DOE) on the FutureGen 2.0 Project. Members of the Alliance include some of the largest coal producers, coal users, and coal equipment suppliers in the world. The active role of industry in this project ensures that the public and private sector share the cost and risk of developing the advanced technologies necessary to commercialize the FutureGen 2.0 concept.

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[1] The injection well permit applications and this supporting documentation were prepared at the Alliance's direction by Battelle's Pacific Northwest Division.

[2] Throughout this supporting documentation, the Alliance uses the future tense to refer to the actions the Alliance intends to undertake with respect to its proposed injection wells. The Alliance recognizes that such actions can only be undertaken after the issuance of UIC permits by the EPA.

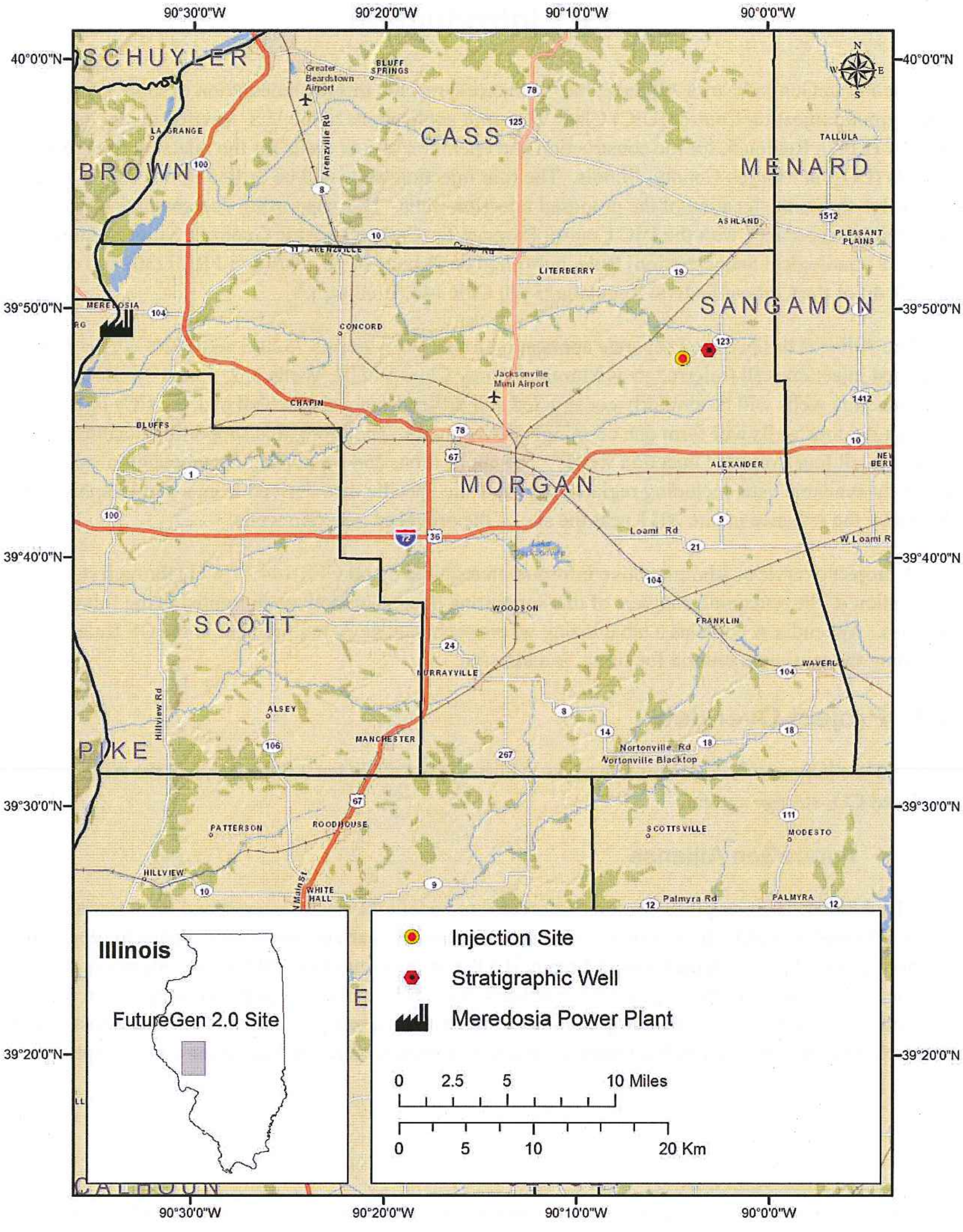

Figure 1.1. Map Showing Morgan County and the Location of the Injection Wells

1.1.2 The FutureGen 2.0 Project

DOE Cost-Share Phases

- *Phase I*: Project Definition
- *Phase II*: Design and Permitting
- *Phase III*: Construction, and Commissioning
- *Phase IV*: Operations

In September 2010, the Alliance signed a Cooperative Agreement (DE-FE0001882) with DOE to develop FutureGen 2.0, a commercial-scale oxy-combustion repowering project that will use carbon capture and storage (CCS) technology. The FutureGen 2.0 Project is a public-private partnership, with costs shared by DOE and the other project partners. The project has been awarded $1 billion in American Recovery and Reinvestment Act funding through the DOE Office of Fossil Energy.

Pursuant to the Cooperative Agreement, the Alliance is working with Ameren Energy Resources (Ameren), Babcock & Wilcox Company, and Air Liquide Process and Construction, Inc. to develop a near-zero emission, coal-fueled power plant. The Alliance plans to acquire a portion of Ameren's existing Meredosia Power Plant in Meredosia, Illinois, and repower one of its units with oxy-combustion and carbon capture technology. An oxy-combustion system combusts coal in the presence of a mixture of oxygen and CO_2. The heat produced by the combustion process is used to make steam. The steam is used to generate electricity. A byproduct of the oxy-combustion process is an emission stream that has a high concentration of CO_2 that can be captured and passed through a CO_2 purification and compression unit. In combination, these processes result in the capture of at least 90 percent of the power plant's CO_2 emissions and reduction of other conventional emissions to near-zero levels.

The captured CO_2 will be transported from the power plant through an underground pipeline to four injection wells (on a single well pad) drilled into the Mount Simon Sandstone—sandstone that underlies central Illinois—so that the CO_2 can be sequestered within that injection zone, which would serve as a permanent underground CO_2 storage reservoir. The Alliance plans to inject approximately 1.1 MMT of CO_2 annually into the Mount Simon Sandstone where it will be permanently stored. A total of 22 MMT will be injected over 20 years, using four horizontal injection wells. Visitor, research, and training facilities will be located in nearby Jacksonville, Illinois.

In accordance with the National Environmental Policy Act of 1969, as amended, DOE is preparing an environmental impact statement (EIS) to assess the potential environmental impacts of the FutureGen 2.0 Project. DOE issued its Notice of Intent to prepare the EIS in May 2011 (76 FR 29728), and held scoping meetings in the area in June 2011. A draft EIS is expected to be released in spring 2013; additional public hearings will be held at that time.

1.1.3 Proposed CO_2 Storage System

The CCS component of the FutureGen 2.0 Project is a GS demonstration project intended to prove the effectiveness of the GS conceptual design and related CCS technologies. The primary objective is to site, design, construct, and operate a CO_2 pipeline and underground CO_2 storage reservoir with sufficient capacity to accept, transport, and sequester at least 1.1 MMT of CO_2 annually in a deep saline geologic formation.

The proposed CO_2 storage site includes the surface facilities, injection wells, monitoring wells, access roads, and an underground CO_2 injection zone. The surface facilities, wells, and access roads are expected to require no more than 25 surface acres. The area of CO_2 storage is cloverleaf-shaped and is located on the western margin of the Illinois Basin, an elongated structural basin that is centered in and underlying most of the state of Illinois (see Chapter 2.0, Figure 2.2). The storage site is approximately 6 mi (10 km) north of the unincorporated town of Alexander, 6 mi (10 km) southwest of Ashland, and 11 mi (18 km) northeast of the City of Jacksonville (see Figure 1.2), and is currently agricultural land.

The conceptual design of the CO_2 storage site includes four horizontal injection wells; surface facilities; the subsurface CO_2 injection zone; and monitoring, verification, and accounting systems (including monitoring wells). Figure 1.3 provides a graphical overview of the conceptual design.

1.1.3.1 Stratigraphic Well

In 2011, the Alliance drilled a stratigraphic well (sometimes referred to as the project's "characterization well" and numerically identified in some figures as "FGA #1") near the location of the proposed injection wells to generate site-specific information about geologic, hydrogeologic, and biogeochemical conditions. Figure 1.2 shows the relative locations of the well pad for the four proposed injection wells and the stratigraphic well. The stratigraphic well provided the detailed hydrologic data with which to characterize the below ground surface environment as part of assessing site feasibility and designing the CO_2 storage site. By further revealing the geologic characteristics (injectivity, porosivity, etc.) of the proposed injection zone, this well has enabled the project to move from a generalized understanding of the geology of the region to an understanding of the site-specific geology of the proposed injection zone. This supporting documentation reflects the stratigraphic well data and analysis. Once injection begins, the Alliance plans to use the stratigraphic well as one of its monitoring wells, as described more fully in Chapter 5.0, Testing and Monitoring Plan.

1.1.3.2 CO_2 Stream

The Morgan County CO_2 storage site is expected to receive approximately 1.1 MMT of CO_2 annually from the oxy-combustion power plant. The emissions stream from the power plant will be captured at the plant, purified, dehydrated, and compressed to 2,100 psig before the CO_2 is placed into the pipeline for transport to the injection wells. At these conditions, the CO_2 will be in a dense fluid phase, non-corrosive, and non-flammable. Transporting CO_2 as a dense fluid is preferred because it requires smaller diameter pipelines and the CO_2 can be pumped without the need for complex and additional compression equipment along the pipeline route. The estimated length of the pipeline to the UIC injection well site is approximately 30 mi (48 km).

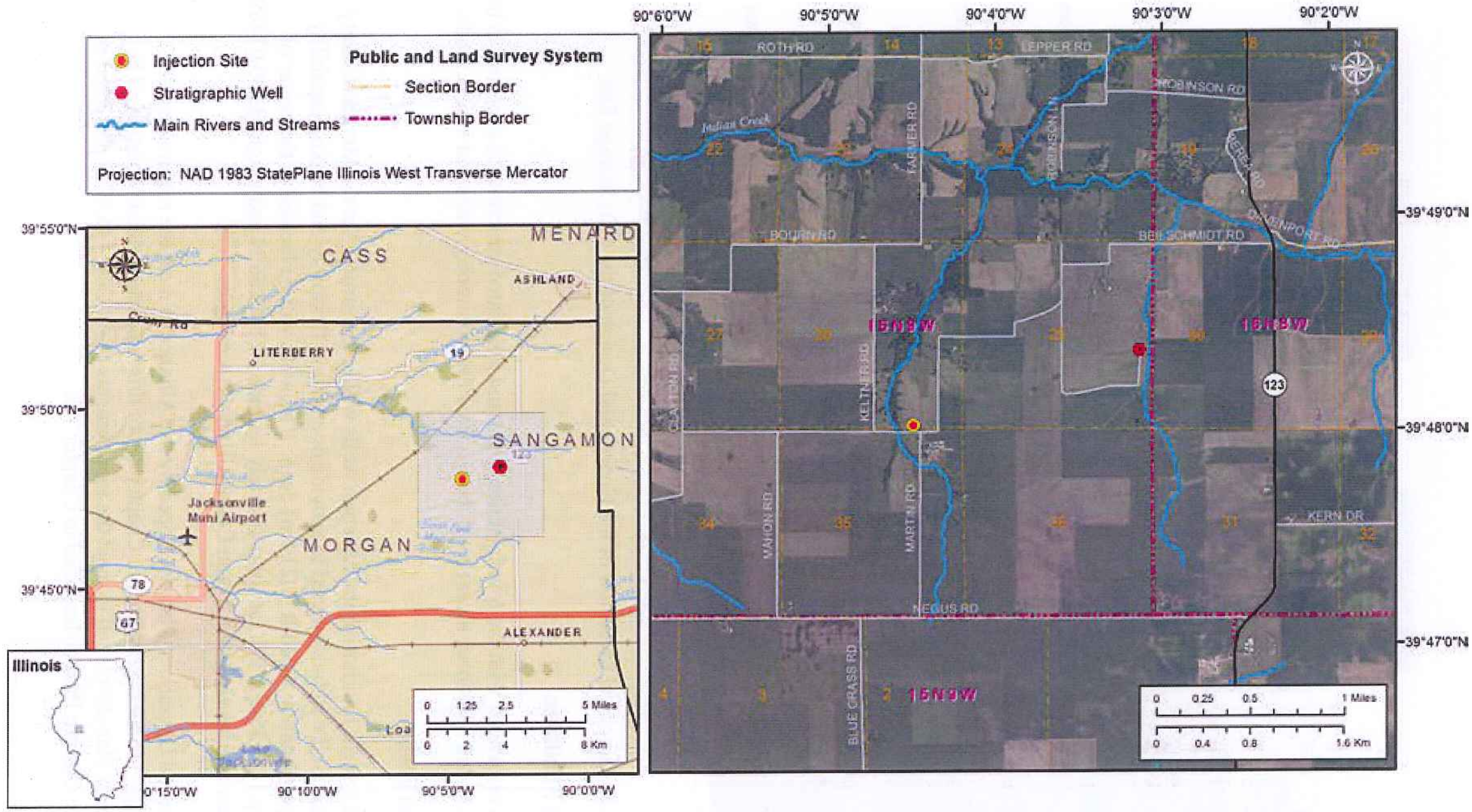

Figure 1.2. Location Maps of the Stratigraphic Well and the Proposed Storage Site's Injection Wells

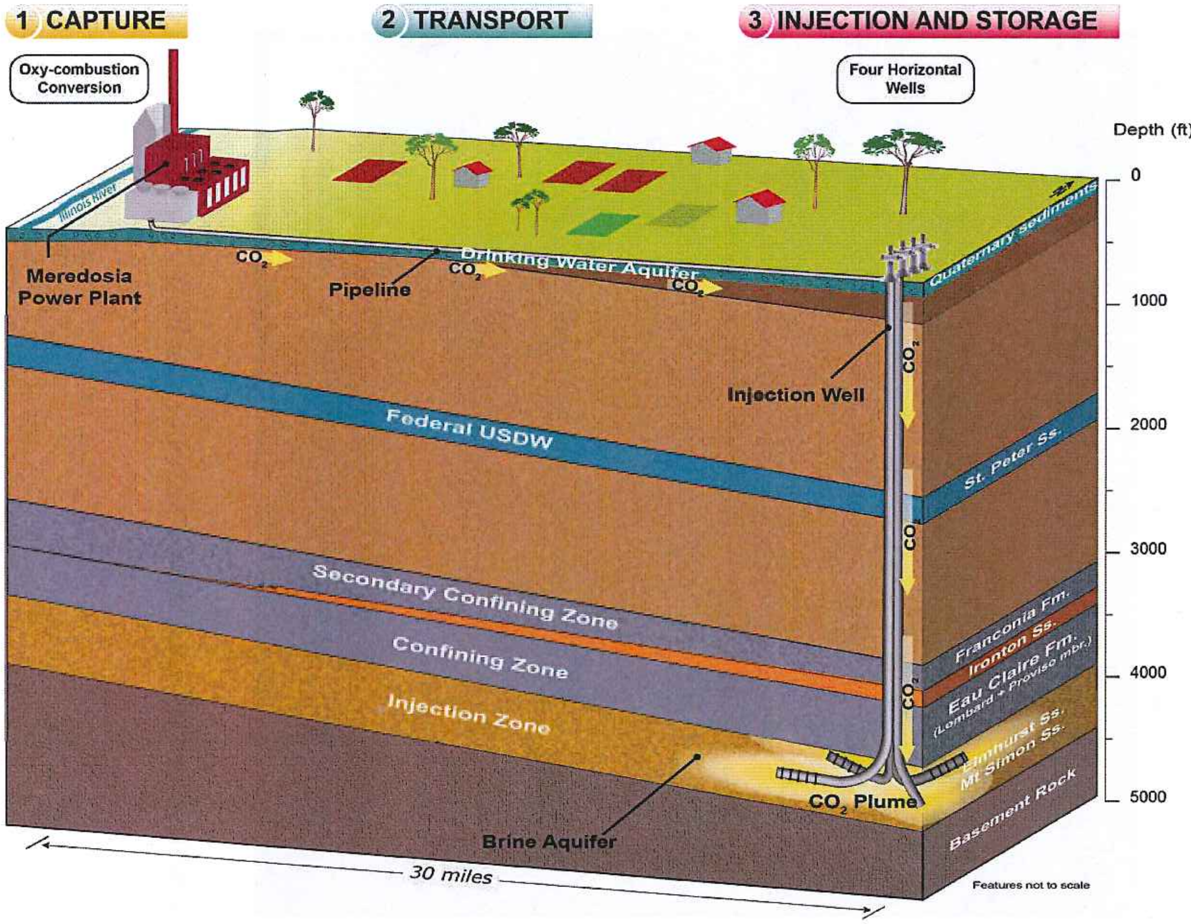

Figure 1.3. Graphical Overview of the Conceptual Design of the CO_2 Storage Site

1.1.3.3 Surface Facilities

The surface area associated with the four injection wells and associated structures is expected to be less than 10 acres. Limited additional acreage will be required for monitoring wells and access roads.

1.1.3.4 Injection Wells

Once permits are issued, four horizontal injection wells will be constructed at the Morgan County CO_2 storage site. Each well will be designed to provide operational flexibility and backup capability. The wells will be approximately 4,000 ft (1,219 m) deep. The wells will be located in the center of Section 26, Township 16N, Range 9W, at approximately latitude 39.800266°N and longitude 90.07469°W (subject to final review and survey), in Morgan County, Illinois (see Figure 1.2).

The Construction and Operations Plan developed by the Alliance to meet the requirements of 40 CFR 146.86 through 146.89 is presented in Chapter 4.0 of this supporting documentation. The Injection Well-Plugging Plan developed to meet the requirements of 40 CFR 146.92 is presented in Chapter 6.0. The Site Closure Plan is described in Chapter 7.0.

1.1.3.5 Injection and Confining Zones

The Alliance proposes to inject CO_2 into the Mount Simon Sandstone and Elmhurst Sandstone member of the Eau Claire Formation (see Figure 1.3). The Alliance proposes this injection zone because of its depth, thickness, porosity, and permeability. The top of the Elmhurst Sandstone member is approximately 3,900 ft (1,190 m) bgs and the injection zone is approximately 565 ft (172 m) thick in the target location. The proposed injection zone consists of quartz sandstone, and it has demonstrated reservoir capacity in natural-gas storage facilities elsewhere in the Illinois Basin. The injection zone contains a hypersaline aquifer with a temperature of approximately 103°F (39.4°C) and total dissolved solids of approximately 40,000 mg/L—well in excess of recommended Safe Drinking Water Act standards.

The injection zone is overlain by the Eau Claire Formation, a thick regional confining zone with low permeability above the Elmhurst Sandstone member. The Franconia Dolomite and Davis member serves as a secondary confining zone for additional protection of underground sources of drinking water.

The geologic setting, along with detailed information about the Morgan County CO_2 storage site, is presented in Chapter 2.0.

1.1.3.6 Monitoring Program

An extensive monitoring, verification, and accounting system will be installed to verify that injected CO_2 is effectively contained within the injection zone. The monitoring network will be designed to account for and verify the location of all CO_2 injected into the ground. It will include monitoring wells in the injection zone, immediately above the primary confining zone, and in the lowermost USDW aquifer. The objectives of the monitoring program are to track the lateral extent of CO_2 within the injection zone, characterize any geochemical or geomechanical changes that occur within the injection and confining zones that may affect containment, and track the extent of the injected CO_2 using direct and indirect monitoring methods. The monitoring program is designed to verify CO_2 retention in the injection zone. In the unlikely event of unintended migration, the monitoring program is intended to detect and quantify the migration through the confining zones, assess the potential to adversely affect underground sources of drinking water, and guide remedial actions.

The Testing and Monitoring Plan developed by the Alliance to meet the requirements of 40 CFR 146.90 is presented in Chapter 5.0 of this supporting documentation. Post-injection site care monitoring is described in Chapter 7.0.

1.2 Required Administrative Information

Table 1.1 provides the administrative information for the Class VI injection well permit applications as required by 40 CFR 144.31(e)(1 through 6).

Table 1.2 lists the permits or construction approvals received or applied for under specific programs listed in 40 CFR 144.31(e)(6). It also includes other relevant state environment permits and permits required for modifications at the Meredosia Power Plant.

Table 1.1. General Class VI Waste Injection Well Permits Application Information

Injection Well Information	
Well Name and Number	Morgan County Class VI UIC Wells 1, 2, 3, and 4
County	Morgan County, Illinois
Section–Township–Range	26–16N–9W
Latitude and Longitude	39.800266°N and 90.07469°W
Applicant Information	
Name	FutureGen Industrial Alliance, Inc.
Address and Phone Number	Washington D.C. Office 1101 Pennsylvania Ave., Sixth Floor Washington, D.C. 20004 Phone: (202) 280-6019 Morgan County Office 73 Central Park Plaza East Jacksonville, IL 62650 Phone: (217) 243-8215
Ownership Status	Non-stock, non-profit corporation
Status as Federal, State, Private, Public, Or Other Entity	Private entity
Related Standard Industrial Classification (SIC) Codes	
The GS Rule asks for the identification of up to four SIC codes that best reflect the principal products or services provided by the facility. The SIC system is a U.S. government system for classifying industries by a four-digit code. A SIC code has not been established for geologic sequestration of CO_2. SIC Code 4922 is Natural Gas Transmission, and includes natural-gas storage (OSHA 2012b, a). Natural-gas storage is similar to CO_2 storage.	
Federal Government Jurisdiction or Protection	
The injection wells and the storage site are not located on Indian land, as there are no federally recognized Native American tribes located within the State of Illinois.	

Table 1.2. Permits Required for the FutureGen 2.0 Project

Program	Permits	Status
(i) Hazardous Waste Management program under RCRA	Not required	Not applicable
(ii) UIC program under SDWA	(UIC) Class VI Permit Morgan County FutureGen UIC Well 1	Permit Submitted to EPA Region 5
	(UIC) Class VI Permit Morgan County FutureGen UIC Well 2	Permit Submitted to EPA Region 5
	UIC) Class VI Permit Morgan County FutureGen UIC Well 3	Permit Submitted to EPA Region 5
	(UIC) Class VI Permit Morgan County FutureGen UIC Well 4	Permit Submitted to EPA Region 5
(iii) NPDES program under CWA	Required for stratigraphic well, power plant, pipeline, and injection/monitoring wells	Stratigraphic well construction performed under General NPDES Permit No. ILR10 (issued August 11, 2008, expires July 31, 2013). SWPPP prepared May 4, 2011; Ameren Energy Resources, with the Alliance, submitted an NPDES modification application to IEPA on May 10, 2012 for power plant modifications

Table 1.2. (contd)

Program	Permits	Status
(iv) Prevention of Significant Deterioration (PSD) program under the CAA	Not required	Ameren Energy Resources, with the Alliance, submitted a Construction Permit Application for a Proposed Project at a CAAPP Source to IEPA on February 8, 2012 for power plant modifications. Due to netting, PSD not required
(v) Nonattainment program under the CAA	Not required	Not applicable. Area is in attainment for all criteria pollutants
(vi) National Emission Standards for Hazardous Pollutants (NESHAPS) preconstruction approval under the CAA	Not required	Not applicable
(vii) Ocean dumping permits under the Marine Protection Research and Sanctuaries Act	Not required	Not applicable
(viii) Dredge and fill permits under section 404 of CWA	May be required for power plant and pipeline; well pads will not affect wetlands	Wetlands areas are being avoided at the power plant site and injection/monitoring well pad locations; pipeline route not yet finalized
(ix) Other relevant environmental permits, including state permits		
Drilling Permit	Required for stratigraphic well and injection/monitoring wells	OG-7 permit application for stratigraphic well was delivered to the IDNR on June 28, 2011
Illinois Endangered Species Protection Act (520 ILCS 10; ILCS 2012a)	Incidental take permit may be required for the power plant and pipeline	Consultations with IDNR are ongoing
Illinois' Private Sewage Disposal Licensing Act (225 ILCS 225; ILCS 2012b)	Applicability being determined	

CAA = Clean Air Act; CAAPP = Clean Air Act Permit Program; CWA = Clean Water Act; IDNR = Illinois Department of Natural Resources; IEPA = Illinois Environmental Protection Agency; ILCS = Illinois Compiled Statutes; NPDES = National Pollution Discharge Elimination System; OG = (IDNR) Division of Oil and Gas; RCRA = Resource Conservation and Recovery Act; SDWA = Safe Drinking Water Act; SWPPP = Storm Water Pollution Prevention Plan.

1.3 Supporting Documentation Contents and Organization

The following chapters address proposed injection well activities and responsibilities from the geologic setting and development of the Area of Review (AoR) through post-injection site care and site closure, including emergency and remedial actions and financial responsibility, as described in Table 1.3. Table 1.4 summarizes where the applicable regulatory provisions in the GS Rule are addressed within the supporting documentation.

Table 1.3. Summary of UIC Permit Applications Supporting Documentation

Chapter	Title	Purpose
1	Introduction	This chapter provides an overview of the Alliance and the FutureGen 2.0 Project, a description of the Alliance's proposed CO_2 storage system, and administrative information.
2	Conceptual Model of the Site Based on Geology and Hydrology	This chapter provides information about the geology, hydrology, and biogeochemistry of the Morgan County site. This information is used collectively to develop a conceptual model of the site, which will guide the numerical simulations, design, and monitoring of the site. A set of input parameters is presented that will form the basis for the numerical model of the injection and confining zones used to develop the AoR. The conceptual model is based on regional geology, hydrology, and site-specific information from the stratigraphic well.
3	Area of Review and Corrective Action Plan	This chapter describes the AoR and specifies the corrective actions that will be taken to address features that compromise the integrity of the confining zone above the injection zone targeted for CO_2 storage.
4	Construction and Operations Plan	This chapter describes the injection well design, construction methods, and materials, as well as the proposed conduct of injection operations.
5	Testing and Monitoring Plan	This chapter describes the plan for testing the injection wells during and after construction and the requirements for monitoring the injection zone, performance of the confining zone, and other media to ensure the protection of underground sources of drinking water.
6	Injection Well-Plugging Plan	This chapter describes planned methods for plugging the injection wells after the period of injection is complete.
7	Post-Injection Site Care and Site Closure Plan	This chapter describes the plan for closure of the CO_2 storage site after the injection period and activities related to long-term site care.
8	Emergency and Remedial Response Plan	This chapter describes the actions that may be required if injection activities cause endangerment to underground sources of drinking water, including notification procedures and identification of emergency contacts.
9	Financial Responsibility	This chapter describes the instruments the Alliance will use to demonstrate and maintain financial responsibility for the operation and closure of the CO_2 storage site in a manner that will protect underground sources of drinking water.

Table 1.4. Crosswalk Between Applicable Regulatory Provisions in the GS Rule and the Alliance UIC Permit Application Supporting Documentation

GS Rule – Regulatory Requirements	Alliance UIC Permit Application Supporting Documentation
40 CFR 146.82, Required Class VI permit information	Chapter 1, Introduction Chapter 2, Conceptual Model of the Site Based on Geology and Hydrology
40 CFR 146.83, Minimum criteria for siting	Chapter 2, Conceptual Model of the Site Based on Geology and Hydrology
40 CFR 146.84, Area of review and corrective action	Chapter 3, Area of Review and Corrective Action Plan
40 CFR 146.85, Financial responsibility	Chapter 9, Financial Responsibility
40 CFR 146.86, Injection well construction requirements	Chapter 4, Construction and Operations Plan

Table 1.4. (contd)

GS Rule – Regulatory Requirements	Alliance UIC Permit Application Supporting Documentation
40 CFR 146.87, Logging, sampling, and testing prior to injection well operation	Chapter 4, Construction and Operations Plan
40 CFR 146.88, Injection well operating requirements	Chapter 4, Construction and Operations Plan
40 CFR 146.89, Mechanical integrity	Chapter 5, Testing and Monitoring Plan
40 CFR 146.90, Testing and monitoring requirements	Chapter 5, Testing and Monitoring Plan
40 CFR 146.91, Reporting requirements	throughout
40 CFR 146.92, Injection well plugging	Chapter 6, Injection Well-Plugging Plan
40 CFR 146.93, Post-injection site care and site closure	Chapter 7, Post-Injection Site Care and Site Closure Plan
40 CFR 146.94, Emergency and remedial response	Chapter 8, Emergency and Remedial Response Plan
40 CFR 146.95, Class VI injection depth waiver requirements	Not applicable

Appendixes contain supplemental information, as follows:

Appendix A – Requirements Matrices

Appendix B – Known Wells Within the Survey Area

Appendix C – Third-Party Cost Estimate

Appendix D – Memorandum Regarding Insurance Coverage

1.4 References

40 CFR 144.31. Code of Federal Regulations, Title 40, *Protection of the Environment*, Part 144 "Underground Injection Control Program," Section 31, "Application for a Permit; Authorization by Permit."

40 CFR 146. Code of Federal Regulations, Title 40, *Protection of Environment*, Part 146, "Underground Injection Control Program: Criteria and Standards."

75 FR 77230. December 10, 2010. "Federal Requirements Under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO_2) Geologic Sequestration (GS) Wells." *Federal Register.* U.S. Environmental Protection Agency.

76 FR 29728. May 23, 2011. "Notice of Intent to Prepare an Environmental Impact Statement and Notice of Potential Floodplain and Wetlands Involvement for the FutureGen 2.0 Program." *Federal Register.* U.S. Department of Energy.

American Recovery and Reinvestment Act of 2009 (ARRA). Public Law 111-5.

Clean Air Act (CAA). 42 U.S.C. § 7401 et seq.

Clean Water Act (CWA)/Federal Water Pollution Control Act. 33 U.S.C. § 1344 et seq.

ILCS (Illinois Compiled Statutes). 2012a. *Illinois Endangered Species Protection Act.* Available online at http://www.ilga.gov/legislation/ilcs/ilcs3.asp?ActID=1730&ChapterID=43

ILCS (Illinois Compiled Statutes). 2012b. *Private Sewage Disposal Licensing Act.* Available online at http://www.ilga.gov/legislation/ilcs/ilcs3.asp?ActID=1337&ChapterID=24

Marine Protection, Research, and Sanctuaries Act (MPRSA) of 1972, as amended. 16 U.S.C. § 1431 et seq. and 33 USC § 1401 et seq. (1988)

National Environmental Policy Act of 1969, as amended (NEPA). 42 U.S.C. § 4321 et seq.

OSHA (Occupational Health and Safety Administration). 2012a. *Standard Industrial Code 2813; Industrial Gases.* Occupational Safety and Health Administration, Washington D.C. Accessed on 8/30/12 at http://www.osha.gov/pls/imis/sic_manual.display?id=600&tab=description.

OSHA (Occupational Health and Safety Administration). 2012b. *Standard Industrial Code 4619; Pipelines, Not Elsewhere Included.* Occupational Safety and Health Administration, Washington D.C. Accessed on 8/30/12 at http://www.osha.gov/pls/imis/sic_manual.display?id=929&tab=description.

Resource Conservation and Recovery Act of (RCRA). 42 U.S.C. § 6901 et seq.

Safe Drinking Water Act of 1974, as amended. 42 U.S.C. 300f et seq.

2.0 Geology and Hydrology

The geologic and hydrogeologic properties described in this chapter are used to develop a conceptual model of the proposed CO_2 storage site in Morgan County, Illinois. The conceptual model is a fundamental part of this UIC Class VI Permit submitted by the Alliance for the construction and operation of up to four CO_2 injection wells. This chapter provides both regional and local information about the injection zone (the geologic formation that will receive the CO_2) and the confining zones (the geologic formations that will act as a barrier to fluid migration). This information is provided to demonstrate that the proposed Morgan County CO_2 storage site is a suitable geologic system for CO_2 storage, and the confining zones have sufficient extent and integrity to contain the injected CO_2 and displaced formation fluids so as to ensure the protection of nearby underground sources of drinking water (USDWs). This chapter provides background information in support of the conceptual model, which is developed in detail in Chapter 3.0. The information in this chapter is also critical to the design, construction, and operation of the injection and monitoring wells and in the subsequent well plugging after the site has completed CO_2 injections.

The regional geology, including the regional continuity of the proposed injection and confining zones, is described in Section 2.1. A site-specific description of the geology at the Morgan County CO_2 storage site—derived from a stratigraphic well that was drilled near the proposed injection in support of this UIC application—is provided in Section 2.2. This information is supported by results from other nearby wells and the published literature, which together form the basis of the description of the geologic setting of the proposed Morgan County CO_2 storage site described in Section 2.3. Geomechanical data for the proposed injection and confining zones are presented in Section 2.4. The seismic history of the region is described in Section 2.5. Site groundwater is described in Section 2.6. A site evaluation of mineral resources is presented in Section 2.7. A discussion of the wells within the AoR and the one well (stratigraphic well) that penetrates the injection and confining zones follows in Section 2.8. The conclusion in Section 2.9 demonstrates that the proposed Morgan County CO_2 storage site meets the minimum criteria for siting specified in 40 CFR 146.83(a). Note that the detailed physical and chemical properties used as input parameters to the computational model are presented in Chapter 3.0. References for sources cited in the text are contained in the final section of this chapter.

2.1 Geology

The Alliance proposes to inject CO_2 into the Cambrian-age Mount Simon Sandstone and the lower Eau Claire Formation (Elmhurst Sandstone member), which combined make up the injection zone. The Mount Simon Sandstone is the thickest and most widespread potential CO_2 injection formation in Illinois (Leetaru and McBride 2009), and at the Morgan County site (Figure 2.1). The Elmhurst Sandstone, along with the Mount Simon, is an injection zone at a number of natural-gas storage sites in Illinois (Morse and Leetaru 2005). The confining zone for the proposed injection zone consists of the Lombard and Proviso members of the Eau Claire Formation that overlies the Mount Simon and Elmhurst sandstones. The Eau Claire is the most important regional confining zone in Illinois (Leetaru et al. 2005, 2009). The Davis member of the Franconia Formation forms a secondary confining zone above the Eau Claire Formation. Impermeable Precambrian-aged basement rocks underlie the Mount Simon Sandstone and form a no-flow boundary to the conceptual model.

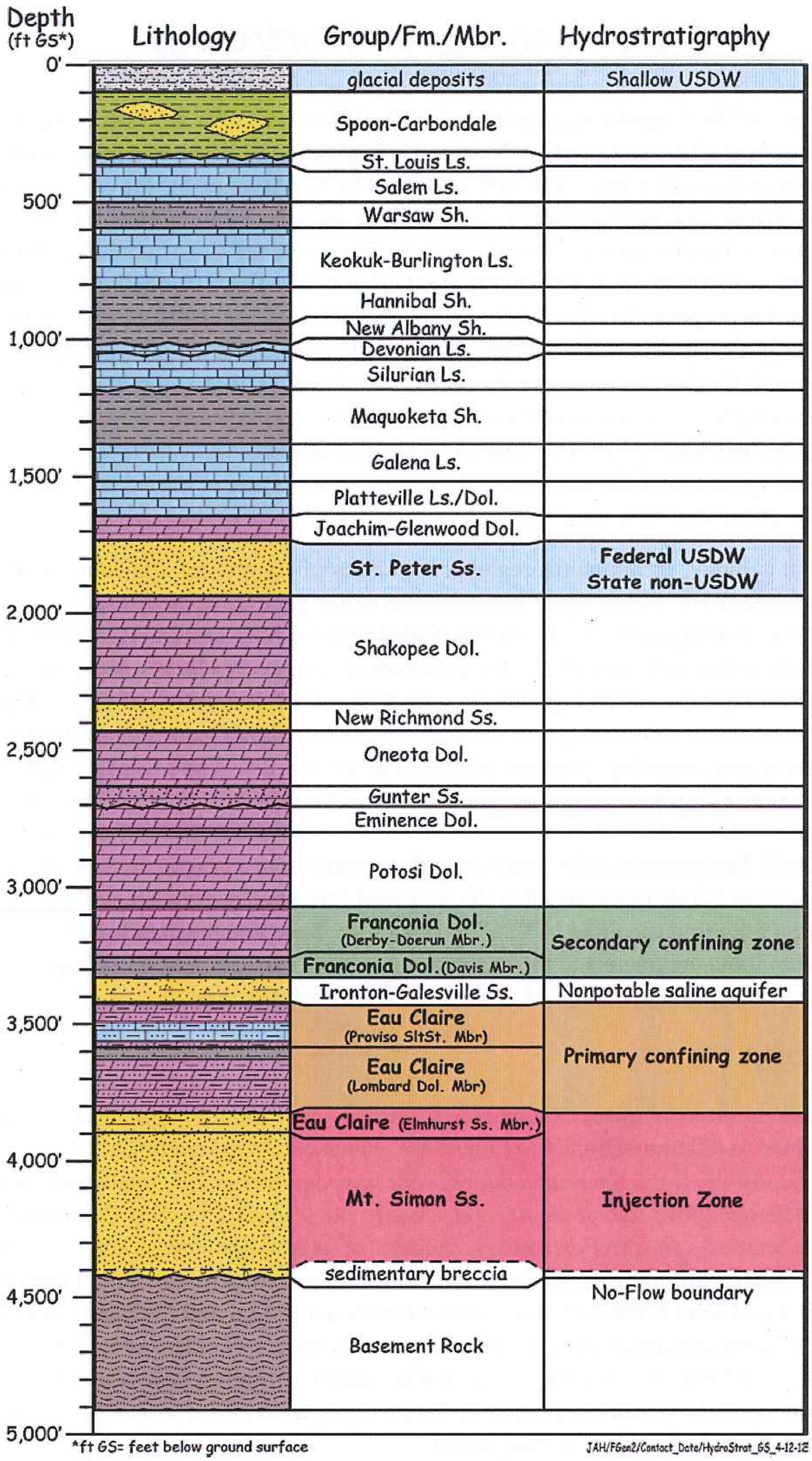

Figure 2.1. Stratigraphy and Proposed Injection and Confining Zones at the Morgan County CO_2 Storage Site

2.1.1 Regional Geology

The regional geology of Illinois is well known from wells and borings drilled in conjunction with hydrocarbon exploration, aquifer development and use, and coal and commercial mineral exploration. Related data are largely publicly available through the Illinois State Geological Survey (ISGS)[1] and the U.S. Geological Survey (USGS).[2] In addition, the DOE has sponsored a number of studies by the Midwest Geologic Sequestration Consortium[3] to evaluate subsurface strata in Illinois and adjacent states as possible targets for the containment of anthropogenic CO_2. This section describes the regional geology, including stratigraphy, structure, and seismicity.

The Mount Simon Sandstone in the Illinois Basin represents a regional target for safe injection of anthropogenic CO_2 (Leetaru et al. 2005). The Illinois Basin covers an area of about 110,000 mi^2 over Illinois and parts of Indiana and Kentucky (Figure 2.2). The Illinois Basin contains approximately 120,000 mi^3 of Cambrian to Pennsylvanian marine and terrestrial sedimentary rocks with a maximum thickness of about 15,000 ft (4,572 m) (Buschbach and Kolata 1991; Goetz et al. 1992; McBride and Kolata 1999). The basin structure across the proposed CO_2 storage site is shown in two regional cross sections in Figure 2.3 and Figure 2.4.

The thickest part of the Cambrian Mount Simon Sandstone is in northeast Illinois, where it exceeds a thickness of 2,600 ft (792 m). A post-Cambrian shift in basin subsidence gradually caused the center of the basin to migrate southeast. As a result, today the deepest part of the Illinois Basin lies in extreme southeastern Illinois. In that area, the top of the Precambrian basement is deeper than 14,000 ft (4,267 m), and the depth to the Mount Simon Sandstone is about 13,500 ft (4,114 m) (Willman et al. 1975). In west-central Illinois the Precambrian basement dips gently to the east-southeast (Figure 2.5).

[1] http://www.isgs.uiuc.edu/
[2] http://www.usgs.gov/
[3] http://sequestration.org/

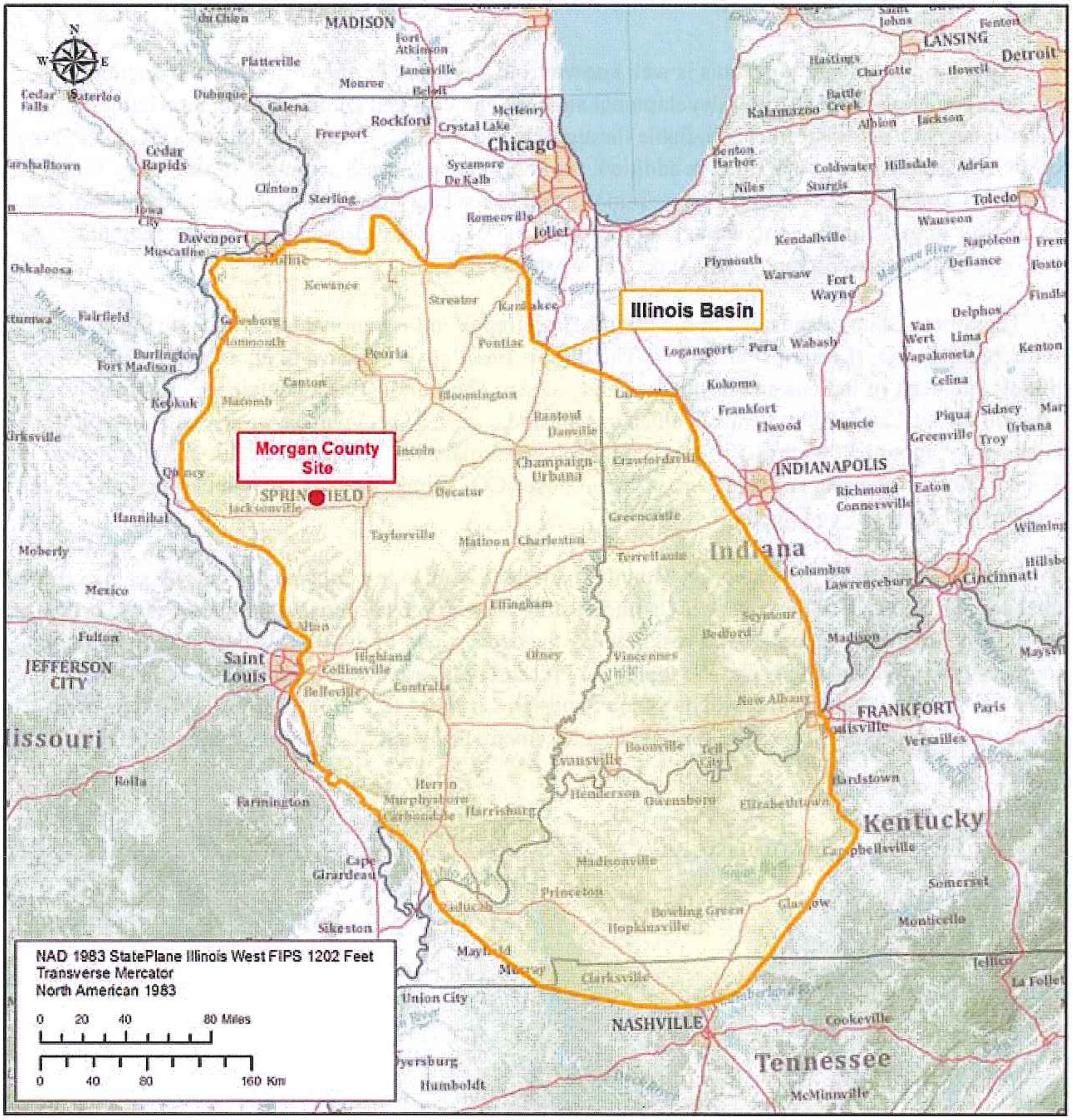

Figure 2.2. The Illinois Structural Basin Within the Midwestern United States (modified from Buschbach and Kolata 1991)

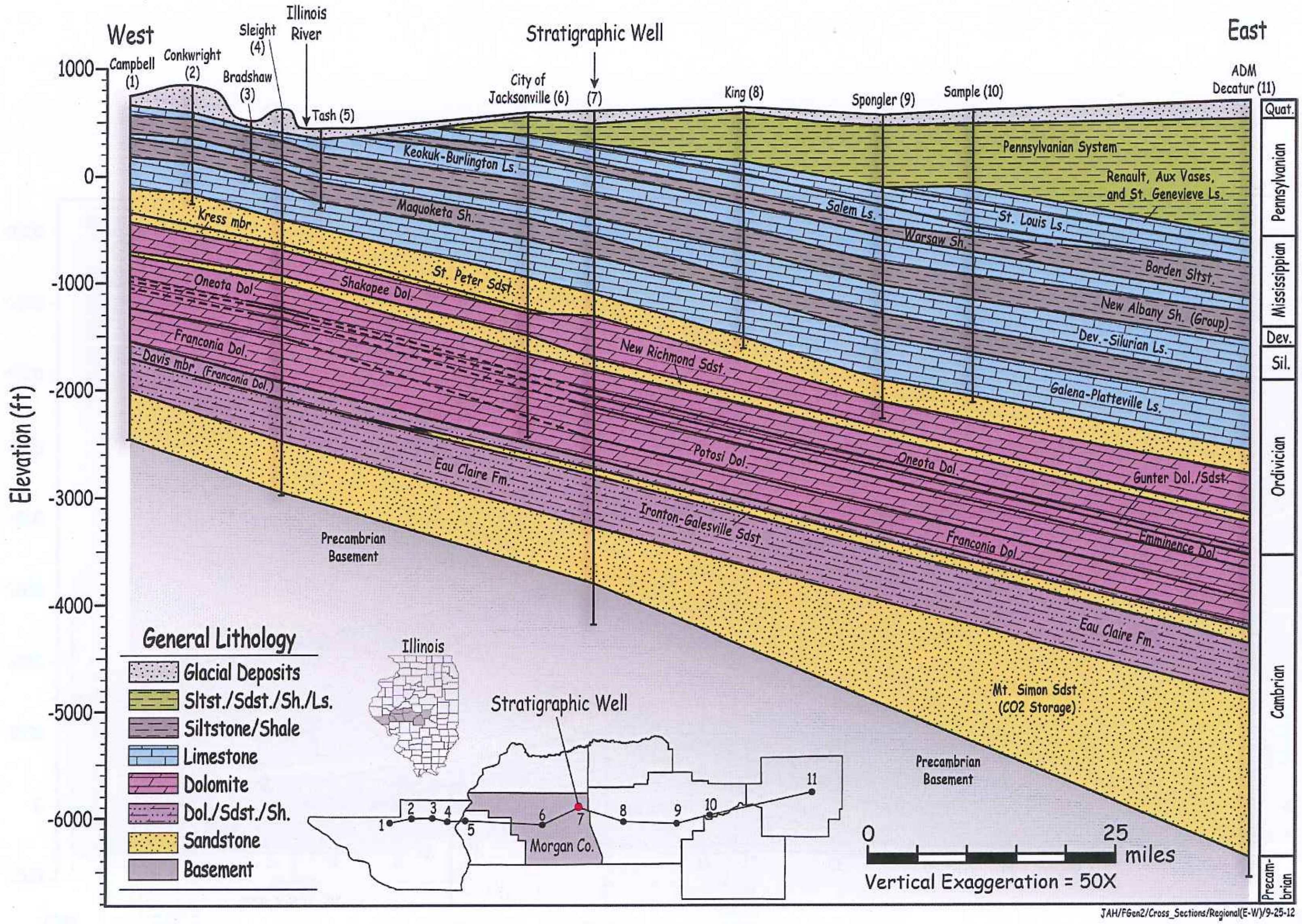

Figure 2.3. Regional East-West Cross Section Across the Western Half of Illinois (based in part on data from ISGS 2011)

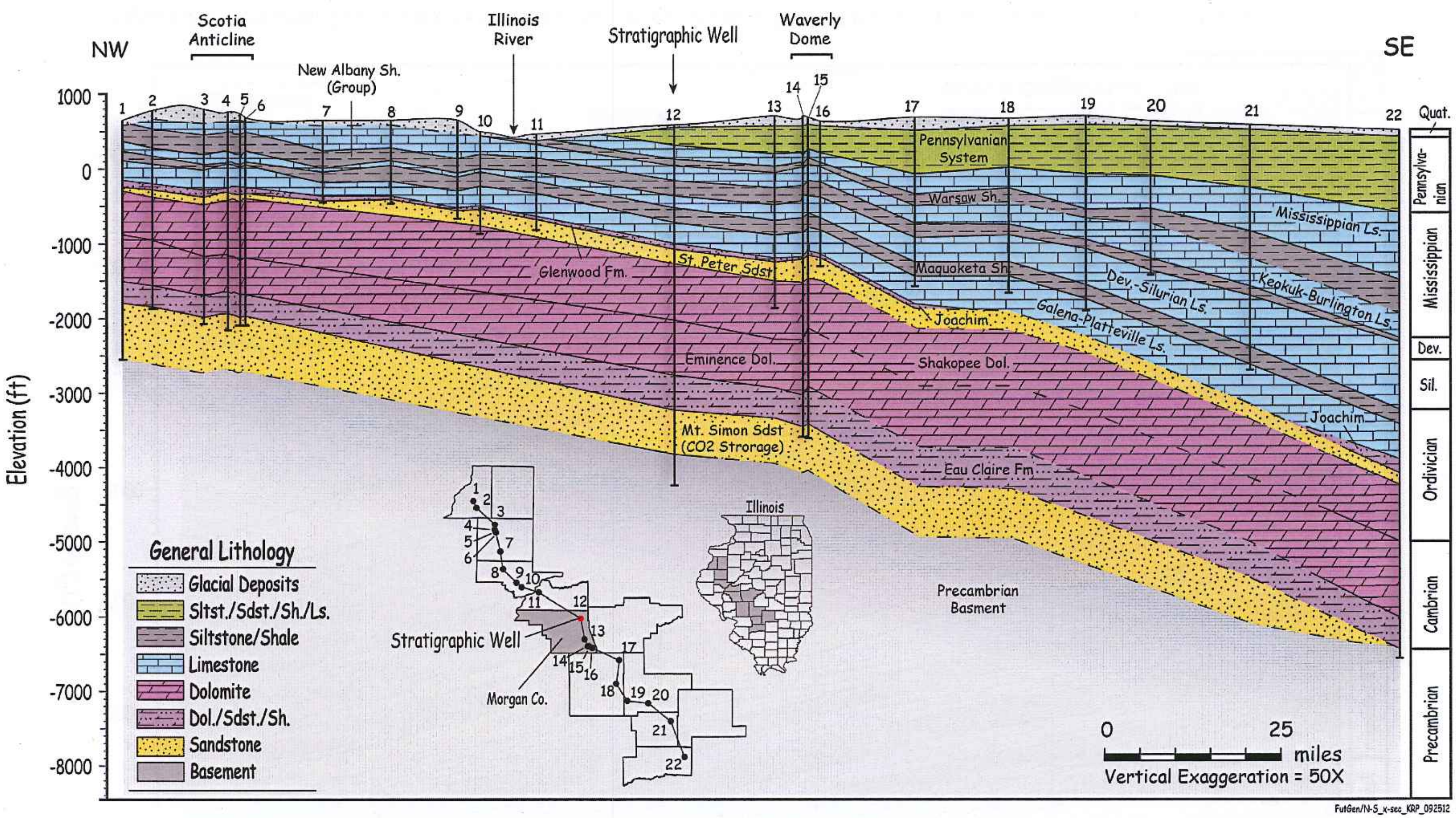

Figure 2.4. Regional North-South Cross Section (based in part on data from ISGS 2011a)

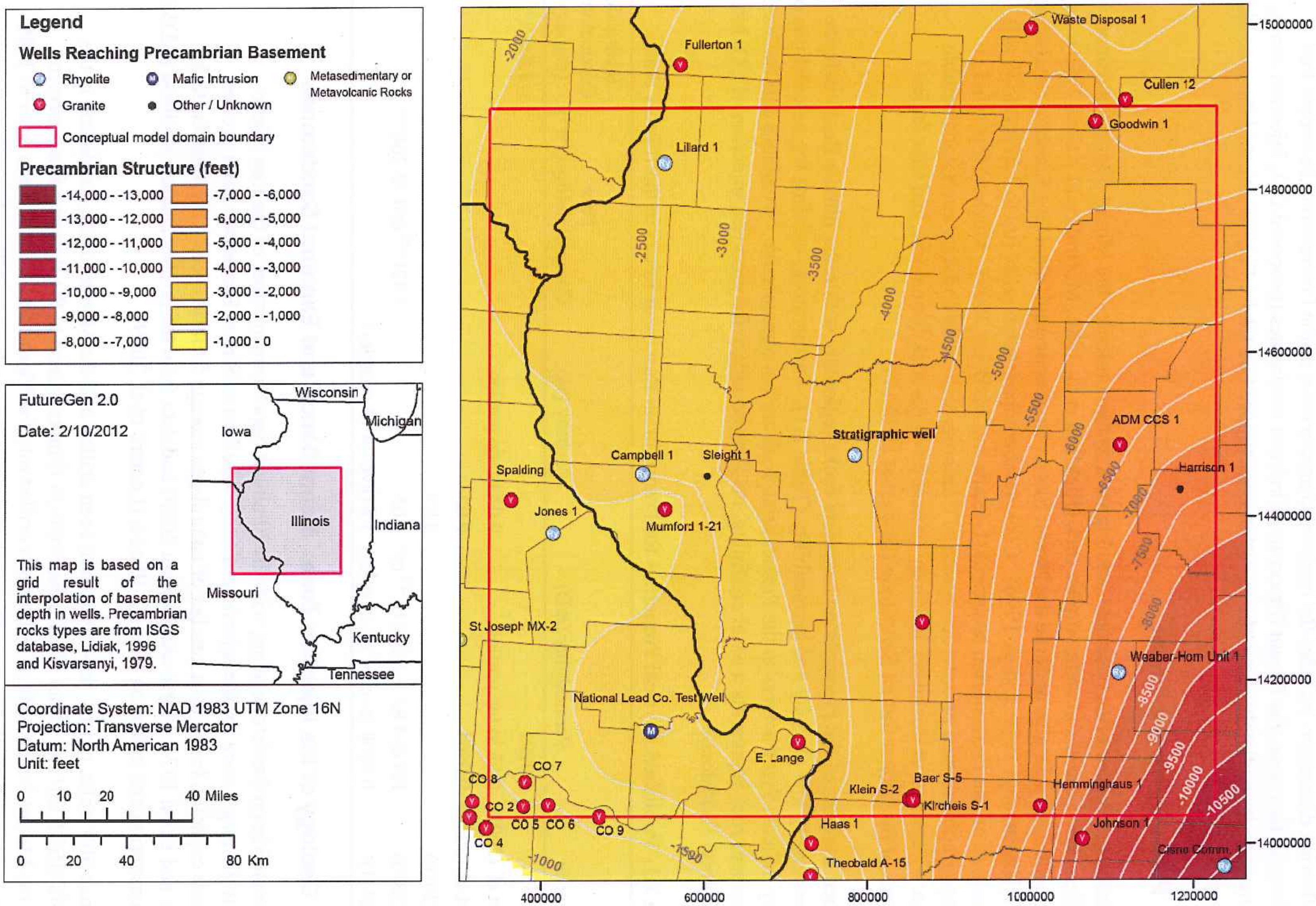

Figure 2.5. Structure and Lithology of the Precambrian Basement in Wells in Western Illinois and Portions of Iowa and Missouri. (Modified from Willman et al. 1975 with additional data from MDNR 2012; Precambrian lithology from Kisvarsanyi 1979 and Lidiak 1996.)

2.1.2 Major Stratigraphic Units

The following discussion includes the regional characteristics of the Precambrian basement that underlies the injection zone, the Mount Simon and Elmhurst sandstones (proposed CO_2 injection zone), the confining zone immediately above the injection zone (upper Eau Claire Formation), and the secondary confining zones.

2.1.2.1 Precambrian Basement

Regionally, the Precambrian basement (see Figure 2.5) that underlies the Mount Simon Sandstone includes silica-rich igneous and metamorphic rock (Bickford et al. 1986; McBride and Kolata 1999). Similar Precambrian rocks also underlie the Mount Simon Sandstone equivalent (the Lamotte Sandstone) in Missouri (Kisvarsanyi 1979; Lidiak 1996). Considerable topographic relief (up to 1,800 ft [549 m]) has been mapped on the Precambrian basement (Leetaru and McBride 2009). Much of this relief is erosional topography created prior to deposition of Cambrian sediments and may exert considerable influence on injection zone thickness, lithology (character of the rock formation), and lithofacies characteristics of the Mount Simon Sandstone (Bowen et al. 2011).

Published analyses of the Precambrian basement rocks regionally within the Illinois Basin indicate they have extremely low porosity and permeability (Table 2.1). Furthermore, wireline log calculations of permeability indicate that fractures in the Precambrian rock are not transmissive. Available data indicate that the basement rock represents a basal confining, no-flow boundary for proposed injection of CO_2 into the Mount Simon Sandstone.

Table 2.1. Published Physical Properties for Precambrian Basement Rocks in the Illinois Basin

Reference	Permeability (mD)	Porosity (%)	Pore Compressibility (Pa^{-1})	Hydraulic Conductivity (cm/sec)
EPA (2011)	0.0091			1.8×10^{-12}
Birkholzer et al. (2008)	0.03 in top portion	0.05 in top portion		
Birkholzer et al. (2008)	0.0001	0.05		
Zhou et al. (2010)		0.05		
Zhou et al. (2010)	Kh and Kv = $0.0001E^{-15}$ m^2	0.05	$7.42E^{-10}$ and $22.26E^{-10}$	
Sminchak (2011)	0.0008 (ave. of 13 samples)	1.8 (ave. of 13 samples)		

2.1.2.2 Geology of the Injection Zone: Mount Simon and Elmhurst Sandstones

The Mount Simon Sandstone along with the Elmhurst Sandstone member of the Eau Claire Formation is the target zone for the injection of CO_2. The Mount Simon Sandstone has a proven injection-zone capacity, based on a number of natural-gas storage facilities across the Illinois Basin (Buschbach and Bond 1974; Morse and Leetaru 2005) and data from the Archer Daniels Midland (ADM) carbon sequestration site in Macon County, Illinois (Leetaru et al. 2009).

More than 900 wells, mostly pre-1980, have been drilled into the Mount Simon Sandstone in the Illinois Basin (ISGS 2011a); about 50 of these wells in Illinois extend to the Precambrian basement underlying the Mount Simon. Most of the wells drilled into the Mount Simon Sandstone prior to 1980 lack well-log suites suitable for quantitative analysis of porosity and permeability. In north-central

Illinois where the Mount Simon Sandstone is used for natural-gas storage, some detailed analyses of porosity, permeability, and lithofacies connectivity are available, although most gas-storage wells only penetrate the upper part of the Mount Simon (Morse and Leetaru 2005).

The regional structural dip of the Mount Simon Sandstone in Morgan County is to the southeast as shown in Figure 2.6. The thickness of the Mount Simon ranges from less than 500 ft (152 m) in westernmost and southwestern Illinois to more than 2,500 ft (792 m) in the northeastern part of the state (Figure 2.7). The Mount Simon Sandstone thins or is not present over Precambrian structures and paleotopographic highs, such as the Ozark Dome in southeastern Missouri, and localized highs several tens of miles west and south of the proposed Morgan County CO_2 storage site (Figure 2.6 and Figure 2.9).

Regionally, the Mount Simon Sandstone varies in lithology from conglomerate to sandstone to shale. Bowen et al. (2011) recognized six dominant lithofacies in studying the Mount Simon Sandstone from 135 wells over a multi-state area (eastern Illinois, Indiana, northern Kentucky, and Tennessee). These lithofacies include cobble conglomerate, stratified gravel conglomerate, poorly sorted sandstone, well-sorted sandstone, interstratified sandstone and shale, and shale. Diagenetic clay minerals in the Mount Simon Sandstone most commonly include illite and kaolinite. Cements that can occlude porosity include iron oxide, authigenic clay, and quartz overgrowths (Bowen et al. 2011).

The ADM UIC Class 6 Application (EPA 2011) reported that in the ADM carbon capture and storage (CCS) well number 1 (ADM CCS#1 well), poorly sorted sandstone lithofacies, containing intervals of better-sorted finer and coarser sandstone, were the most common lithofacies in the Mount Simon Formation; some thin shale stringers were also present. An arkosic interval was selected as the injection target. The ADM CCS#1 well is closer to the center of the Cambrian Illinois Basin depocenter than is the proposed Morgan County CO_2 storage site. Lithologic variability is expected across the basin, especially in the lower part of the Mount Simon Sandstone, where lithologies can change due to paleotopography and depositional environment.

The Mount Simon Sandstone represents continental and shallow marine environments of deposition that reflect gentle basin subsidence and gradual transgressive marine encroachment over the deeply eroded Precambrian basement rocks (Leetaru et al. 2009). Terrestrial depositional environments such as alluvial fans, braided streams, eolian dunes, and wadi deposits are interpreted in the Mount Simon core from wells and outcrop in Missouri and Wisconsin (Houseknecht 2001; Hunt 2004; Wilkens et al. 2011). Transitional marine depositional environments represented in the Mount Simon Sandstone include barrier islands, deltas, and tidal inlets with shallow marine sands and coastal bars (Sargent and Lasemi 1993; Wilkens et al. 2011; Driese et al. 1981). The continental depositional lithofacies transition upward into marine facies of the Eau Claire Formation. This change is indicative (along with patterns of sediment thickening) of basin subsidence and sea-level rise during a major marine transgressive event (Kolata and Nimz 2010).

Included as part of the proposed injection zone is the Elmhurst Sandstone, the basal (lowest) member of the Eau Claire Formation (see Figure 2.1). The Elmhurst Sandstone consists of fine- to medium-grained, fossil-bearing, white, red, or gray sandstones with irregular interbedded gray shales and minor dolomite (Willman et al. 1975). Regionally, these sandstones are porous, permeable, and in hydrologic communication with the Mount Simon Sandstone (Buschbach and Bond 1974; Hanson 1960; Hunt 2004; Morse and Leetaru 2005).

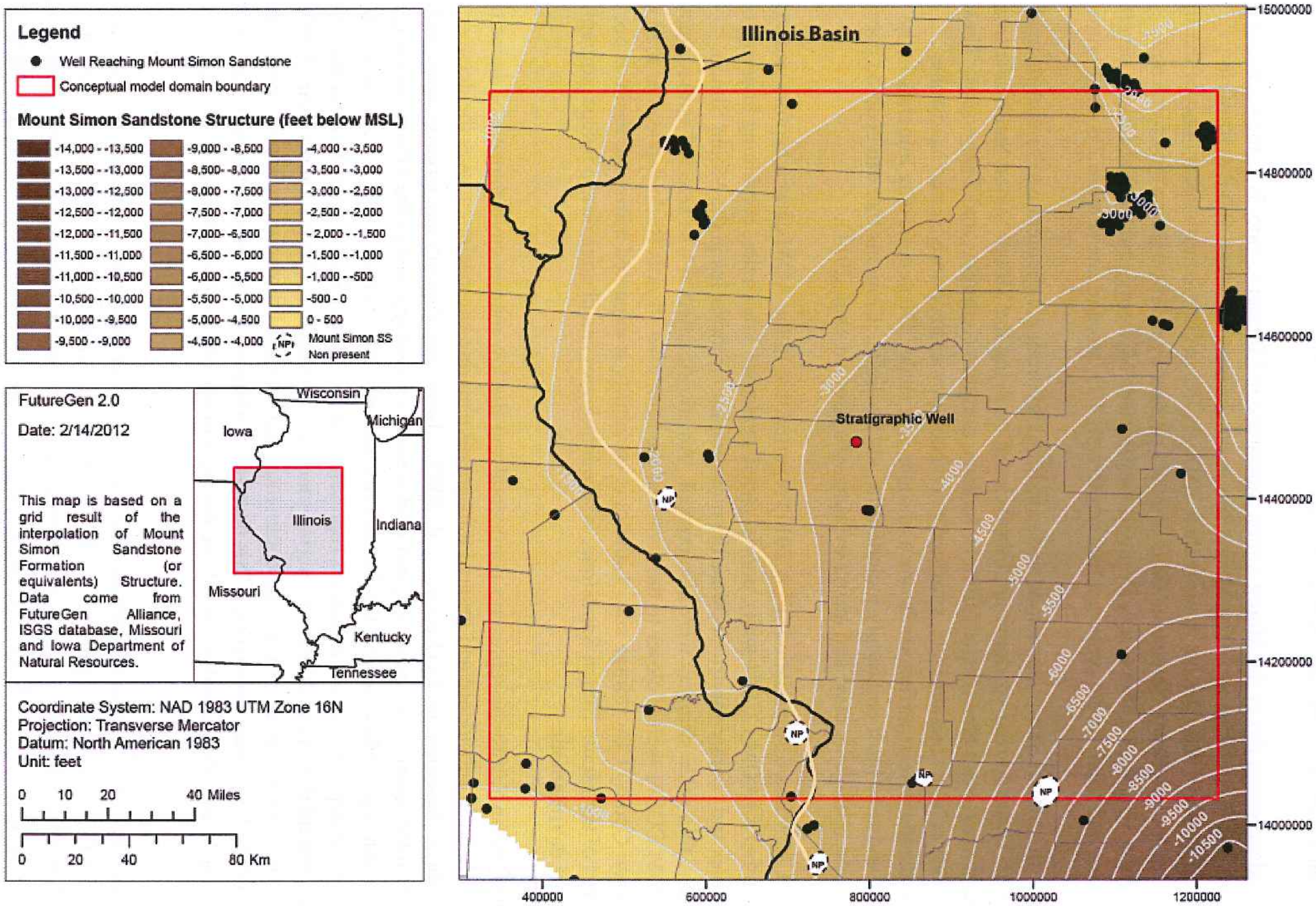

Figure 2.6. Structure on Top of the Mount Simon Sandstone in West-Central Illinois and Portions of Iowa and Missouri (based in part on data from ISGS 2011a, MDNR 2012, and IDNR 2012). White areas represent nondeposition of the Mount Simon Sandstone on Precambrian paleotopographic highs.

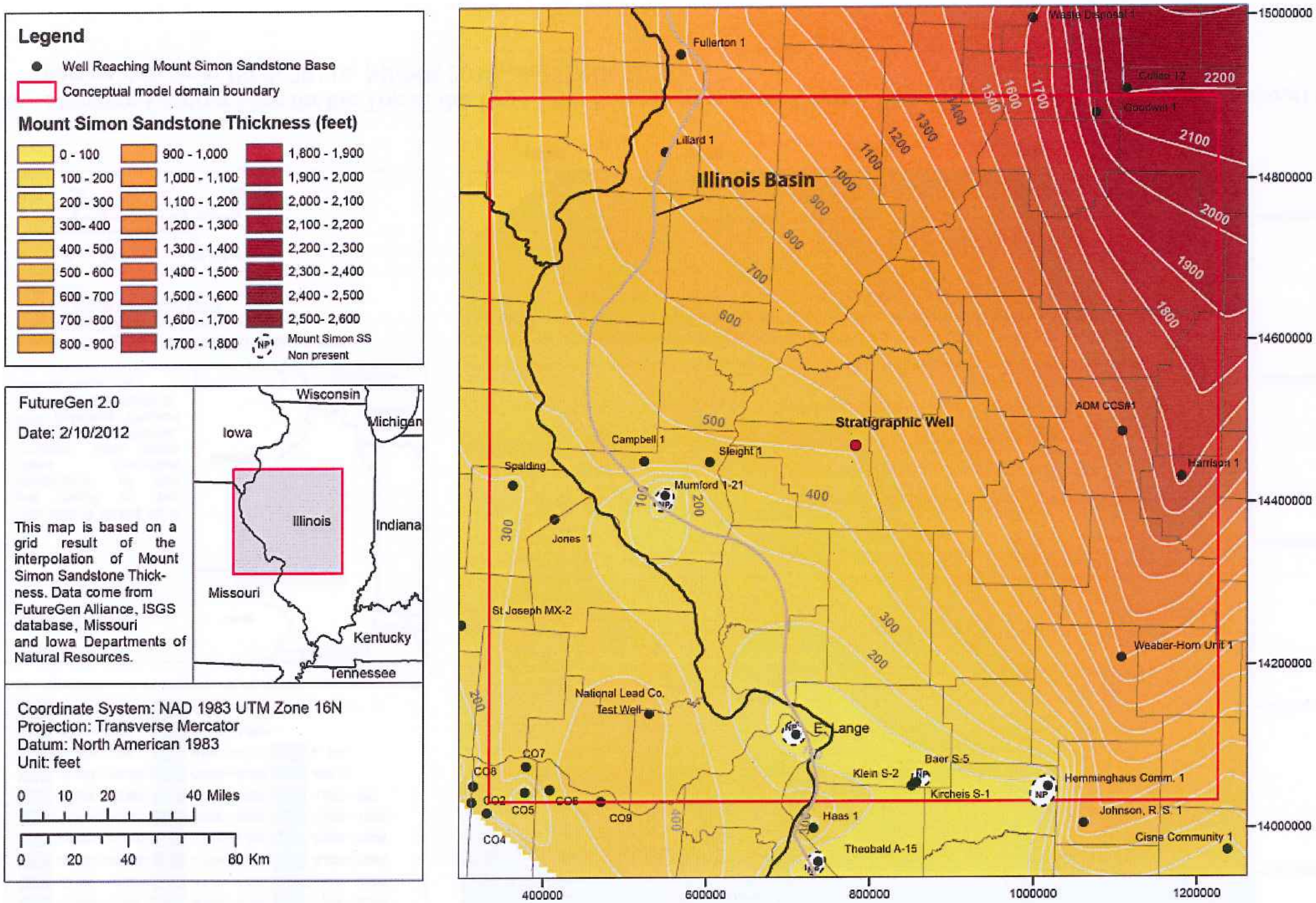

Figure 2.7. Thickness of the Mount Simon Sandstone in West-Central Illinois and Portions of Iowa and Missouri. The Mount Simon is thin or absent across localized Precambrian highs west and south of Morgan County. (Based in part on data from ISGS 2011a, MDNR 2012, and IDNR 2012)

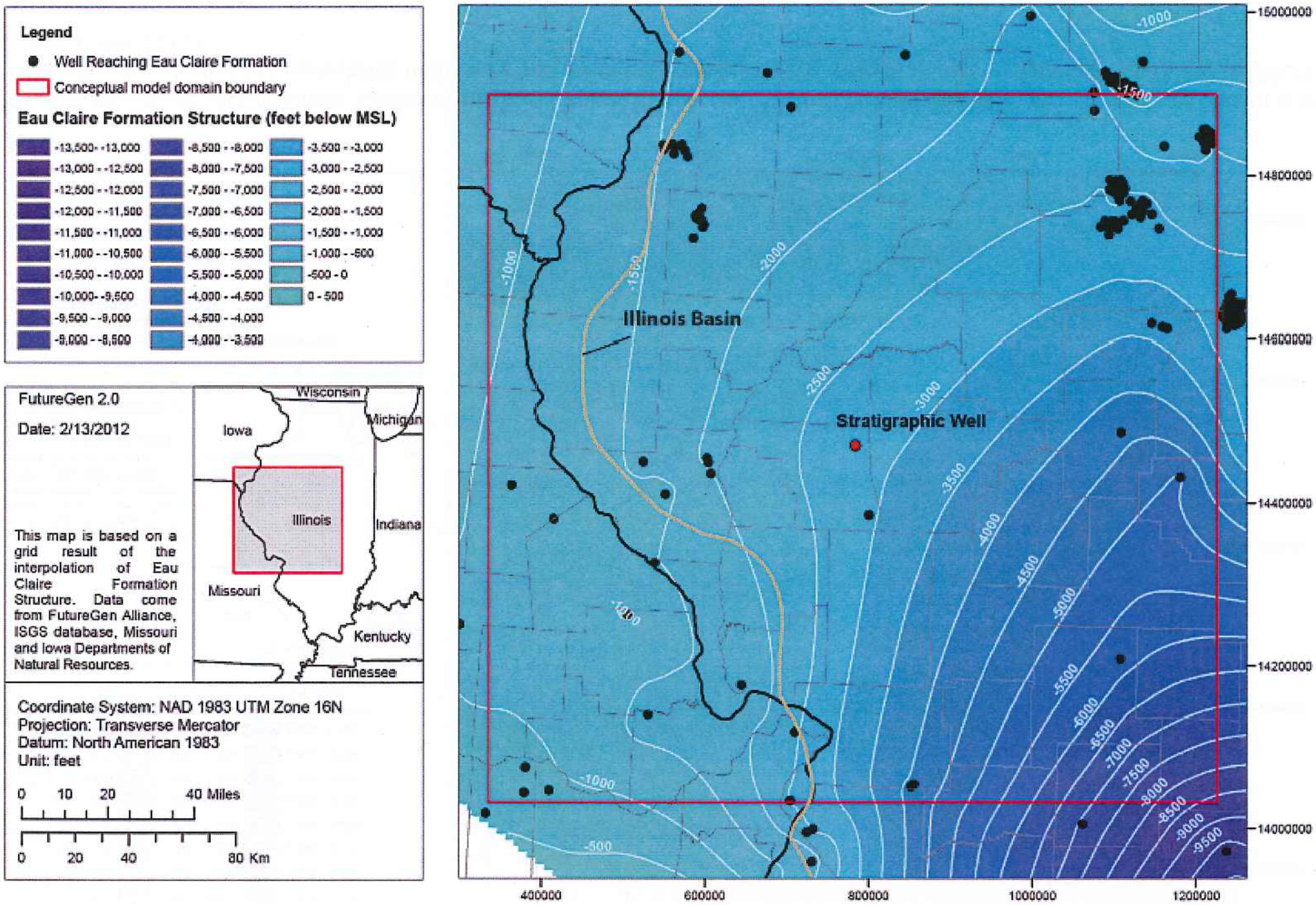

Figure 2.8. Structure-Contour Map for the Top of the Eau Claire Formation in West-Central Illinois and Portions of Iowa and Missouri (based in part on data from ISGS 2011a, MDNR 2012, and IDNR 2012)

2.1.2.3 Geology of the Confining Zone: Eau Claire Formation

The Eau Claire Formation is a widespread, heterolithic carbonate and fine siliciclastic unit present across west-central Illinois (Figure 2.8) and parts of seven adjoining states (Sminchak 2011). The low-permeability Lombard and Proviso members of the Eau Claire form an effective confining layer at 38 natural-gas storage reservoirs in Illinois (Buschbach and Bond 1974; Morse and Leetaru 2005). The confining members of Eau Claire overlie the Elmurst Sandstone member (see Figure 2.1).

Regionally, the Lombard member of the Eau Claire Formation consists of glauconitic and sandy dolomite interbedded with mudstones and shale; the shale content increases to the south and sand content increases to the west and north (Willman et al. 1975). The Lombard member is overlain by the Proviso member, which is characterized by limestone, dolomite, sandy siltstone, and shale beds. The Lombard and Proviso members are continuous and extend across several buried Precambrian highs in the region.

In addition to the Eau Claire Formation, the widespread, low-permeability Franconia Dolomite Formation (Figure 2.1) (Kolata and Nimz 2010) may be considered a secondary confining zone for the containment of scCO_2 within the region (see Figure 2.1).

2.1.3 Site Geology

The proposed storage site is located approximately 11 mi (18 km) northeast of the City of Jacksonville, 6 mi (9.7 km) north of the unincorporated village of Alexander, and 6 mi (9.7 km) southwest of Ashland (see Figure 2.2). To support the evaluation of the Morgan County site as a potential carbon storage site a deep stratigraphic well (Figure 2.9) was drilled and extensively characterized. The stratigraphic well, located at longitude 90.0528W, latitude 39.8067N, is approximately 1 mi (1.6 km) east of the planned storage site. The results and interpretations of the data from the stratigraphic well are presented in this supporting documentation and used to support the following discussions of site-specific geology and hydrology at the proposed Morgan County CO_2 storage site.

The stratigraphic well reached a total depth of 4,826 ft (1,471 m) bgs within the Precambrian basement. The well penetrated 479 ft (146 m) of the Eau Claire Formation and 512 ft (156 m) of the Mount Simon Sandstone. Contact picks in the stratigraphic well (Figure 2.9) are based on correlations with wells in the ISGS database as well as comparison of the well cuttings with lithologies in drillers logs and published descriptions.

The stratigraphic well was extensively characterized, sampled, and geophysically logged during drilling. These resulting data, together with the regional data, form the basis for developing a conceptual model. Intervals where wireline geophysical logs and rotary side-wall drill cores were acquired are listed in Table 2.2. A total of 177 ft of whole core were collected from the lower Eau Claire-upper Mount Simon Sandstone (Table 2.3) and 34 ft were collected from lower Mount Simon Sandstone-Precambrian basement interval. In addition to whole drill core, a total of 130 side-wall core plugs were obtained from the combined interval of the Eau Claire Formation, Mount Simon Sandstone, and the Precambrian basement. Depths for the primary hydrogeologic units relevant to injection of CO_2 and protection of USDWs are listed in Table 2.4. Slabbed cores from the Lombard and Elmhurst members and the Mount Simon Sandstone are shown in Figure 2.10.

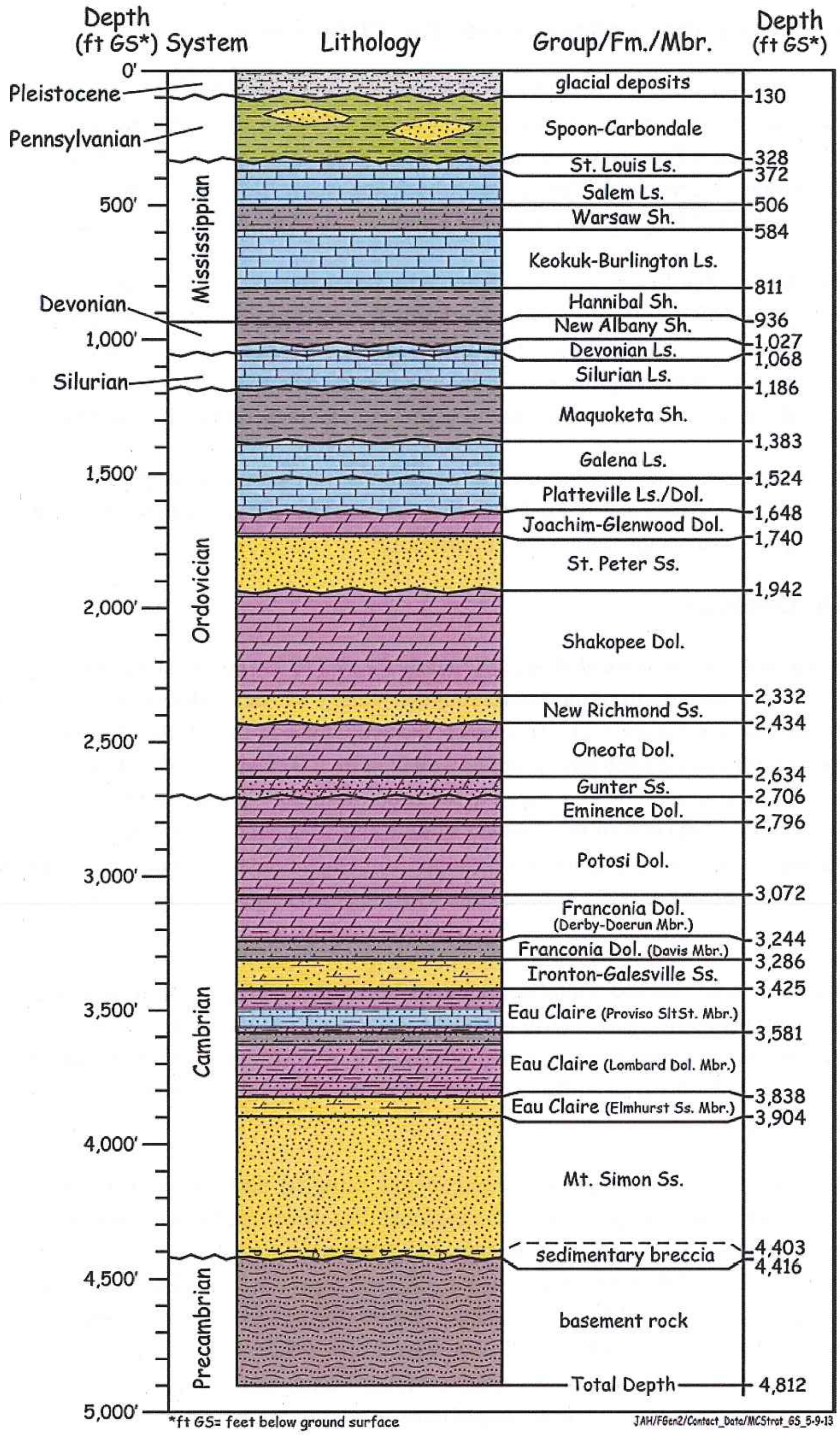

Figure 2.9. Stratigraphic Column for the Recently Drilled Stratigraphic Well at the Proposed Morgan County CO_2 Storage Site. Wavy lines represent major unconformities reported for the Morgan County area by Willman et al. (1975).

Table 2.2. Intervals of Geophysical Wireline Characterization Logs and Side-Wall Cores Collected in the Stratigraphic Well

Log Type	Run #	Log Interval Top (ft bgs)	Log Interval Bottom (ft bgs)
Triple Combo	1	31	2,036
Resistivity	1	31	2,036
Triple Combo (Gamma, Neutron, Density) plus Photoelectric Cross-Section Log	2	553	4,015
Sonic Dipole	2	566	3,962
Resistivity Image	2	564	4,013
Spectral Gamma Ray	2	372	3,978
Elemental Capture Log	2	91	4,014
Rotary Side-Wall Cores	2	Top Sample 684	Bottom Sample 3,968
Triple Combo (Gamma, Neutron, Density) plus Photoelectric Cross-Section Log	3	3,932	4,806
Sonic Dipole	3	3,932	4,806
Resistivity Image	3	3,966	4,810
Ultrasonic Image	3	3,922	4,886
Spectral Gamma Ray	3	3,932	4,806
Elemental Capture Log	3	81	4,024
Nuclear Magnetic Resonance	3	3,932	4,806
Rotary Side-Wall Cores	3	Top Sample 4,020	Bottom Sample 4,782

Table 2.3. Whole-Core Intervals Collected from the Stratigraphic Well

Core Run #	Core Diameter (in.)	Interval Top (ft bgs)	Interval Bottom (ft bgs)	Number of Feet Cored/ Recovered	Stratigraphic Unit
1	3.5	3,758	3,868	110/107.8	Eau Claire Lombard and Elmhurst members
2	3.5	3,868	3,908	40/30.0	Eau Claire Elmhurst member
3	3.5	3,910	3,943	33/33.0	Upper Mount Simon Sandstone
4	4.5	4,486	4,420	34/25.9	Lower Mount Simon Sandstone and Precambrian basement
5	4.5	4,420	4,428	8/8.5	Precambrian basement

Table 2.4. Hydrogeology of the Injection and Confining Zones Within the Stratigraphic Well

Stratigraphic Unit	Hydrostratigraphic Unit	Top Depth (ft bgs)	Thickness (ft)
Eau Claire (Proviso member)	Eau Claire Siltstone (Confining zone)	3,425	156
Eau Claire (Lombard member)	Eau Claire Dolomite (Confining zone)	3,581	257
Eau Claire (Elmhurst member)	Eau Claire Sandstone (Injection zone)	3,838	66
Mount Simon Sandstone	Mount Simon Sandstone (Injection zone)	3,904	512
Precambrian basement	(Lower No-Flow Boundary)	4,416	>400

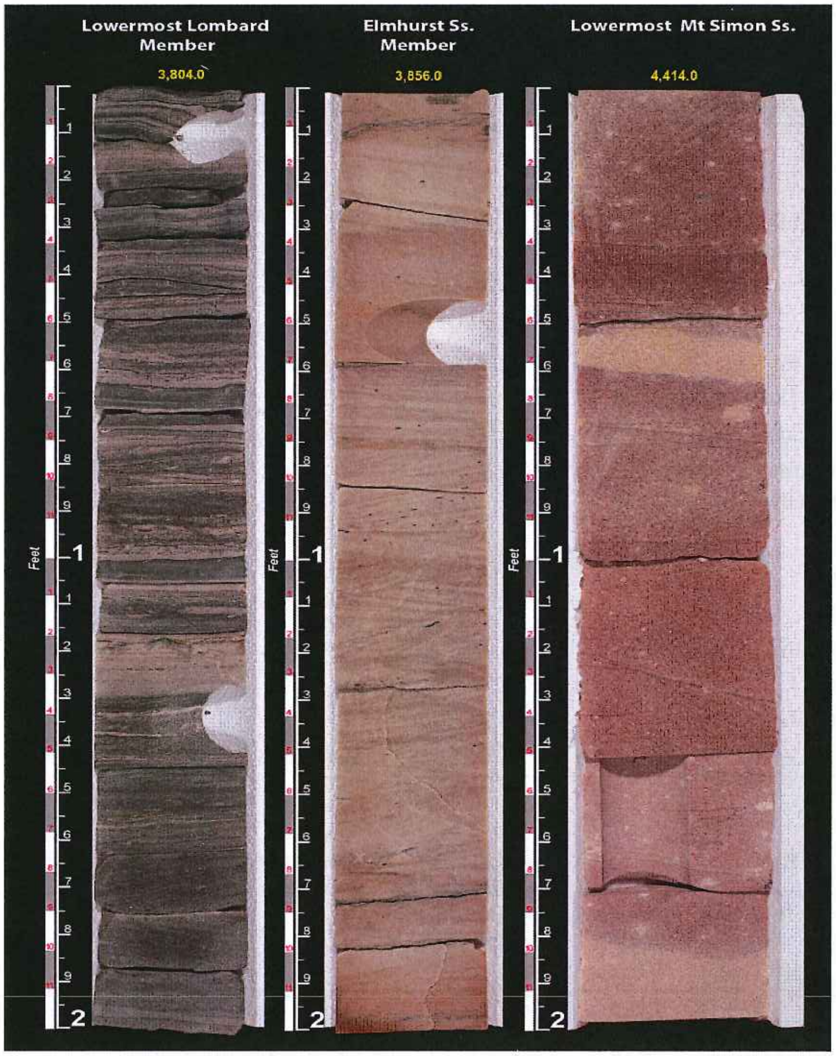

Figure 2.10. Slabbed Whole Core from the Lowermost Lombard Member Mudstones and Siltstones, the Elmhurst Sandstones, and the Lower Mount Simon Sandstones from the Stratigraphic Well

2.1.3.1 Injection Zone

The combined thickness of the proposed injection zone, which includes the Mount Simon and Elmhurst sandstones, is 565 ft (172 m) at the stratigraphic well (Figure 2.9). As observed in cuttings, core logs, and image logs, the Mount Simon Sandstone primarily consists of fine-to-coarse quartz arenite with local granule-rich quartz or arkosic sandstone beds. Based on the computed mineralogy (Elemental Analysis [ELAN]) log, feldspar appears to be considerably more common in the lower part of the Mount Simon Sandstone. In Figure 2.11, cored intervals are indicated with red bars; rotary side-wall core and core-plug locations are indicated to the left of the lithology panel. Standard gamma ray and resistivity curves are shown in the second panel; ELAN-calculated permeability (red curve) is in the third panel, along with two different lab measurements of permeability for each rotary side-wall core. Neutron- and density-crossplot porosity is shown in the fourth panel, along with lab-measured porosity for core plugs and rotary side-wall cores. The proposed injection interval (location of the horizontal wells' injection laterals) is highlighted on the geophysical log panels in Figure 2.11.

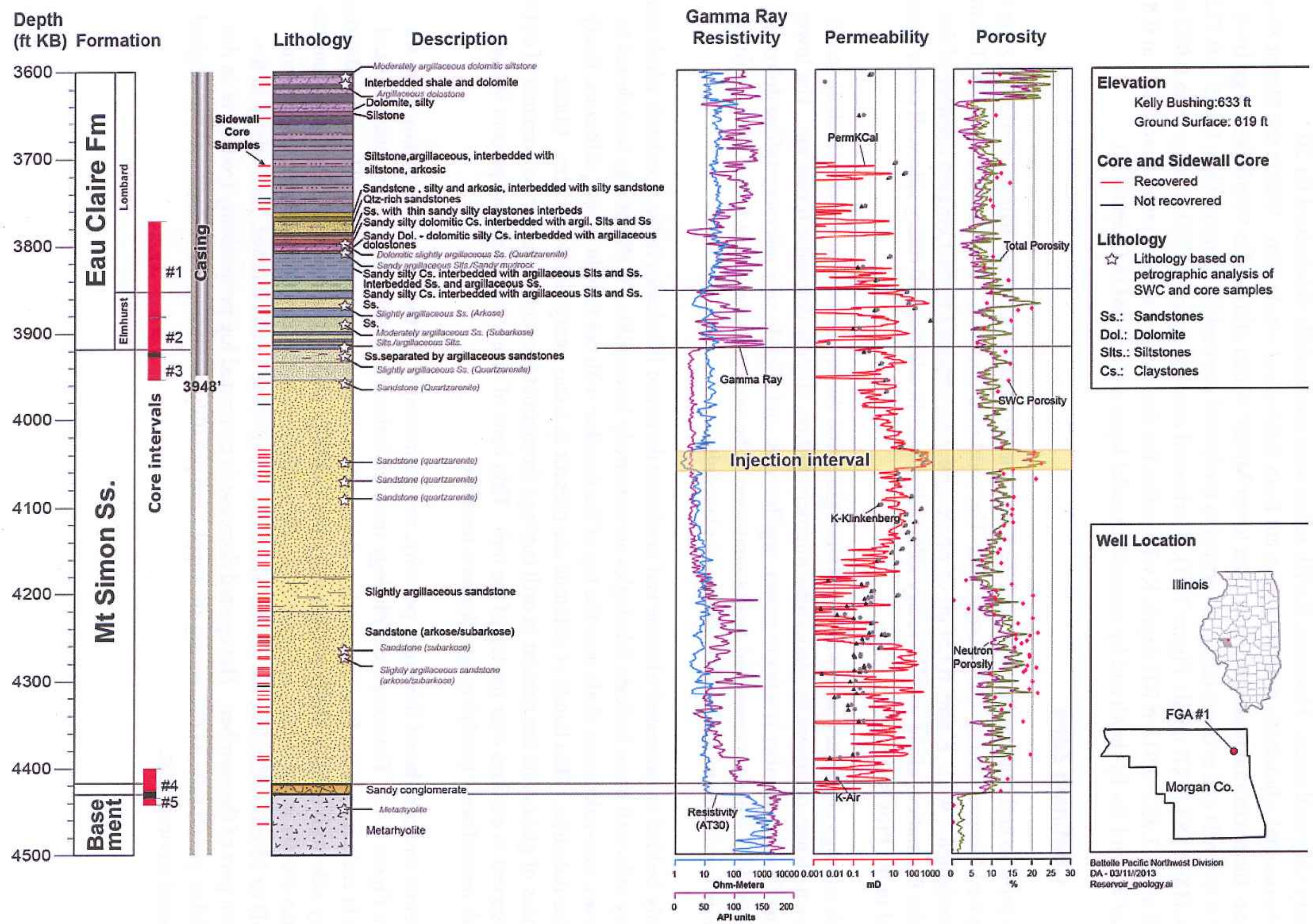

Figure 2.11. Lithology, Mineralogy, and Hydrologic Units of the Proposed Injection Zone (Mt Simon and Elmhurst) and Lower Primary Confining Zone (Lombard), as Encountered Within the Stratigraphic Well. Data are explained in the text.

Permeability in the sandstones, as measured in rotary side-wall cores and plugs from whole core, appears to be dominantly related to grain size and abundance of clay. Horizontal permeability (Kh) data in the stratigraphic well outnumber vertical permeability (Kv) data, because Kh could not be determined from rotary side-wall cores. However, Kv/Kh ratios were successfully determined for 20 vertical/horizontal siliciclastic core-plug pairs cut from intervals of whole core. Within the Mount Simon Sandstone, the horizontal permeabilities of the lower Mount Simon alluvial fan lithofacies range from 0.005 to 0.006 mD and average ratios of vertical to horizontal permeabilities range from 0.635 to 0.722 (at the 4,318–4,388 ft KB depth, Figure 2.11). Horizontal core-plug permeabilities range from 0.032 to 2.34 mD at the 3,852–3,918 ft KB depth; Kv/Kh ratios for these same samples range from 0.081 to 0.833. Details of Kh and Kv by depth and by numerical model layer are covered in Chapter 3.0.

2.1.3.2 Confining Zone

The Proviso and Lombard members of the Eau Claire Formation form the primary confining zone for the proposed Morgan County CO_2 storage site. The combined thickness of these strata is 413 ft (126 m) at the stratigraphic well. Eighty ft (24 m) of whole core were obtained in the Lombard member of the Eau Claire Formation, along with 13 rotary side-wall cores. In addition, 10 rotary side-wall cores were collected in the Proviso member.

Rock cuttings and rotary side-wall core lithologies from the upper Proviso member include tan to light brown, dense, occasionally glauconitic microcrystalline, slightly dolomitic limestone. The lower half of the Proviso member is a tan to cream, argillaceous, and slightly silty microcrystalline dolomite with interbedded siliceous cemented quartz sandstone. The sand grains are very fine- to fine-grained, sub-rounded and clear to white with occasional glauconite.

Thinly bedded to laminated siltstone and mudstone dominate lithologies in the Lombard; whole core and rotary side-wall cores indicate lithologies are extremely heterolithic. Well cuttings include red to light brown, non-calcareous shale near the top of the member with tan to light brown, siliceous, finely crystalline dolomite. Thin bands of dolomite are present in some rotary side-wall cores. Minor abundances of glauconite are present in drill cuttings throughout the section; and trace amounts of oolites were observed in cuttings near the top of the unit. Thin beds of quartz sandstone are present in the Lombard, immediately overlying the Elmhurst member.

Wireline and core-based lithology, porosity, and permeability for the primary confining zone are shown in Figure 2.12. The computed lithology track indicates the upward decrease in quartz silt and increase in carbonate in the Proviso member, along with a decrease in permeability. The permeabilities of the rotary side-wall cores in the Proviso range from 0.000005 mD to 1 mD (Table 2.5); the one sample lower than 0.0001 is not shown in Figure 2.12. Permeabilities in the Lombard member range from 0.001 mD to 28 mD, reflecting the greater abundance of siltstone in this interval, particularly in the lowermost part of the member. The upward decrease in computed log permeability (red curve in the permeability panel) reflects decreasing silt supply and possibly increasing water depths of the original depositional environment.

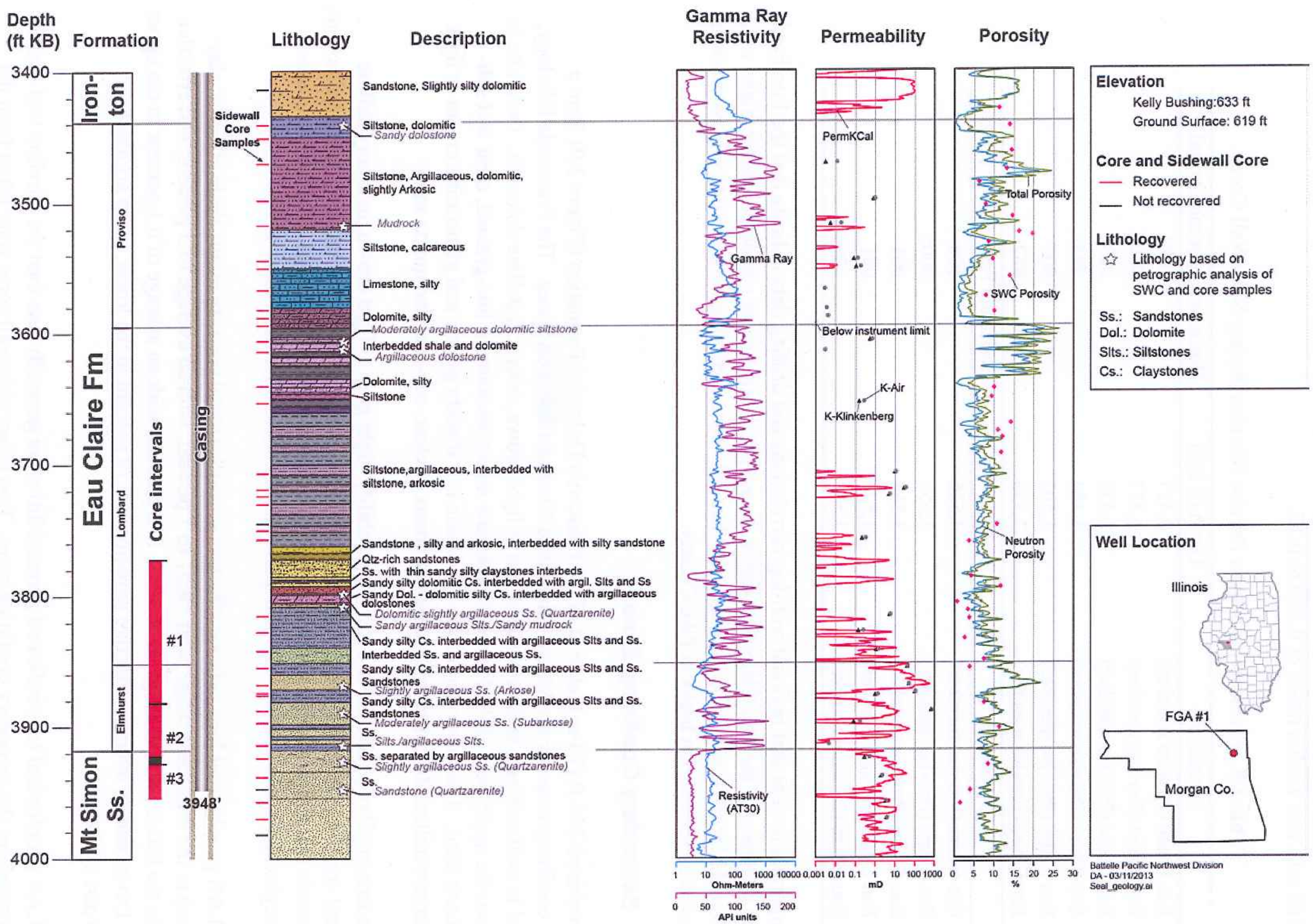

Figure 2.12. Relationship Between Lithology, Mineralogy, Side-Wall Core and Wireline Log Computed (ELAN) Permeability for the Eau Claire Formation and Uppermost Mount Simon Intervals in the Stratigraphic Well. One Proviso sample with permeability below 0.0001 mD is not shown.

Whole core plugs and associated vertical permeabilities are available only from the lowermost part of the Lombard. Thin (few inches/centimeters), high-permeability sandstone streaks resemble the underlying Elmhurst; low-permeability siltstone and mudstone lithofacies have vertical permeabilities of 0.0004-0.465 mD, and Kv/Kh ratios of 0.000 to 0.17.

Table 2.5. Permeabilities from Proviso Member Rotary Side-Wall Cores

Formation	Depth (ft bgs)	Horizontal Permeability (mD)
Eau Claire (Proviso member)	3,427	.0001
Eau Claire (Proviso member)	3,437	.0001
Eau Claire (Proviso member)	3,456	.003
Eau Claire (Proviso member)	3,484	.795
Eau Claire (Proviso member)	3,503	.005
Eau Claire (Proviso member)	3,530	.082
Formation	Depth (ft bgs)	Horizontal Permeability (mD)
Eau Claire (Proviso member)	3,536	.108
Eau Claire (Proviso member)	3,553	.0005
Eau Claire (Proviso member)	3,568	.001
Eau Claire (Proviso member)	3,574	.001
Eau Claire (Proviso member)	3,580	.000005

It is important to note that regional well-log correlations and drilling data indicate that the Lombard and Proviso members of the Eau Claire Formation do not pinch out against paleotopographic highs west of the proposed Morgan County CO_2 storage site. Instead, these confining units are laterally continuous and overstep the Precambrian highs in Pike County.

2.1.3.3 Secondary Confining Zone

The combined 244-ft (74-m) interval of the Franconia Dolomite Formation (Figure 2.9) form a secondary confining zone for the Mount Simon and Elmhurst injection zones. The Franconia lithology, as observed in well cuttings, is dominated by tan to light brown, microcrystalline dolomite. Dolomite in cuttings from the upper part of the Franconia contains minor amounts of fine-grained, clear and sub-rounded quartz sand. The lower part of the Franconia is a slightly pyritic and glauconitic cream to light brown, microcrystalline dolomite with scattered grains of clear, sub-rounded quartz sand.

The underlying Davis member is a low-permeability, light gray to light brown, microcrystalline dolomite and argillaceous (shaley), sandy dolomite. The lowermost part of the unit is a tight argillaceous, dolomitic sandstone that marks the upward transition from the Ironton Sandstone. The Davis member dolomites regionally grade laterally into low-permeability shales (Willman et al. 1975).

The ELAN geophysical logs indicate effective porosities (total porosity minus shale effect or clay-bound water) in the Franconia range from <0.01 to 7 percent, with an average of 3 percent; and effective porosities in the Davis interval range from <0.01 to 3 percent, with an average of 0.1 percent in the upper part of the Davis, and an average effective porosity of 0.79 percent in the lower, more argillaceous (clay-rich) part of the unit.

The ELAN geophysical logs indicated permeabilities are generally less than the wireline tool limit of 0.01 mD throughout the secondary confining zone. Two rotary side-wall cores were taken from the

Franconia, and three side-wall cores were cut in the Davis member. Laboratory-measured rotary side-wall core (horizontal) permeabilities (Table 2.6) are very low (0.001–0.000005 mD). The permeabilities of the two Franconia samples were measured with a special pulse decay permeameter; the sample from 3,140 ft bgs (957 m) has a permeability less than the lower instrument limit of 0.000005 mD. A relatively high porosity (7.8 percent porosity with 12.5-mD permeability) was recorded for one Davis side-wall core. This appears to represent an isolated thin (less than 1 ft [15 cm] sand stringer within the lower Davis member).

Table 2.6. Rotary Side-Wall Core Permeabilities from the Secondary Confining Zone

Formation	Depth (ft bgs)	Horizontal Permeability (mD)
Franconia Dolomite	3,140	<.000005
Franconia Dolomite	3,226	.000006
Davis	3,268	.001
Davis	3,291	0.125
Davis	3,303	12.5

Vertical core plugs are required for directly determining vertical permeability and there are no data from the stratigraphic well for vertical permeability or for determining vertical permeability anisotropy in the secondary confining zone. However, Kv/Kh ratios of 0.007 have been reported elsewhere for Paleozoic carbonate mudstones (Saller et al. 2004).

2.2 Injection Zone Water Chemistry

Analyses of two formation fluid samples from the stratigraphic well, collected at a depth of 4,048 ft (1,234 m) below the kelly bushing (bkb) (Sample 11) using Schlumberger's Modular Formation Dynamics Tester (MDT) sampler, are shown in Table 2.16. Based on these initial samples, the best estimate total dissolved solids (TDS) concentration selected for initial simulation is a constant 47,500 mg/L throughout the Mount Simon Sandstone. The EPA (2011) reported TDS for eight samples from the Mount Simon Sandstone from the CCS#1 near Decatur, Illinois (Table 2.7). TDS varied with depth yielding a minimum concentration of 164,500 mg/L at 5,772 ft (1,759 m) and a maximum concentration of 228,100 mg/L at 7,045 ft (2,147 m). Note that these depths are 2,000 to 3,000 ft (610 to 914 m) deeper than those encountered at the Morgan County CO_2 storage site and would represent an upper maximum for TDS at the proposed storage site.

Table 2.7. Data from Fluid Samples Collected with the MDT Sampler from the Mount Simon Sandstone in the CCS#1 Well at the Decatur Site (modified after EPA 2011)

Sample ID	Depth (ft)	Formation Pressure (psi)	Formation Temperature (degrees F)	TDS (mg/L)	Brine Density (g/L)
MDT-4	5,772	2,582.9	119.8	164,500	1.09
MDT-3	6,764	3,077.5	125.1	185,600	1.12
MDT-14	6,764	3,077.5	125.1	179,800	Not analyzed
MDT-5	6,840	3,105.9	125.0	182,300	1.12
MDT-9	6,840	3,105.9	125.0	219,800	Not analyzed
MDT-2	6,912	3,141.8	125.8	211,700	1.14
MDT-1	7,045	3,206.1	125.7	228,100	1.12
MDT-8	7,045	3,206.1	125.7	201,500	Not analyzed

2.3 Geologic Structure

Known major geologic structures in Illinois are shown in Figure 2.13. The proposed storage site is on the southern flank of the very broad Sangamon Arch. Structural dips on sedimentary strata within the western part of the Illinois Basin are low—generally less than one degree to the east and southeast, based on regional structure maps (Figure 2.6 and Figure 2.8).

2.3.1 Site Geologic Structure

The geologic structure in the vicinity of the proposed Morgan County CO_2 storage site consists of a very gentle, 0.25-degree dip to the southeast, as determined by the three-dimensional (3D) geologic conceptual model developed for the site that used local and regional well data. Low structural dips are confirmed by the resistivity-based image logs (Formation Microimager) acquired in the stratigraphic well. The principal geologic structure in proximity to Morgan County is the very broad Sangamon Arch (Figure 2.13). Neither this map nor any other published sources (Whiting and Stevenson 1965; Kolata and Nelson 1991) indicate the existence of any mapped faults or fracture zones in the vicinity of the proposed Morgan County CO_2 storage site.

2.3.1.1 Reflection Seismic Profiles

Two two-dimensional (2D) surface seismic lines, shown in Figure 2.14, were acquired in January 2011 along public roads near the proposed Morgan County CO_2 storage site. A seismic survey gives an image of the subsurface based on differences in density and seismic wave velocity of the different geologic layers. It allows one to identify formation depths and thicknesses in addition to discontinuities such as faulting.

Both profiles indicate a thick sequence of Paleozoic-aged rocks. The seismic lines are not of optimal quality due to seismic noise,[1] but they do not indicate the presence of obvious faults or large changes in thickness of the injection or confining zones. Apparent discontinuities in the seismic lines appear to be an artifact of processing lines that were acquired along bends in roads as a straight line.

The seismic data acquired along these two seismic profiles were reprocessed by Exploration Development, Inc. in August 2012 to reduce the noise and improve the interpretation (Figure 2.15 and Figure 2.16). Both profiles indicate a thick sequence of Paleozoic-aged rocks with a contact between Precambrian and Mount Simon at 640 ms and a contact between Eau Claire and Mount Simon at 580 ms. Some vertical disruptions, which extend far below the sedimentary basin, remain and their regular spatial periodicity is unlikely related to faults. These discontinuous reflections could also be discontinuities created by collapse features associated with karsts formations that are known to occur in the Potosi Formation.

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[1] Jaqucki P, V Smith, H Leetaru, and M Coueslan. 2011. *Seismic Survey Results and Interpretation – Illinois FutureGen 2.0 Potential Sites*. Schlumberger Carbon Services, Westerville, Ohio. Unpublished report to the FutureGen Industrial Alliance.

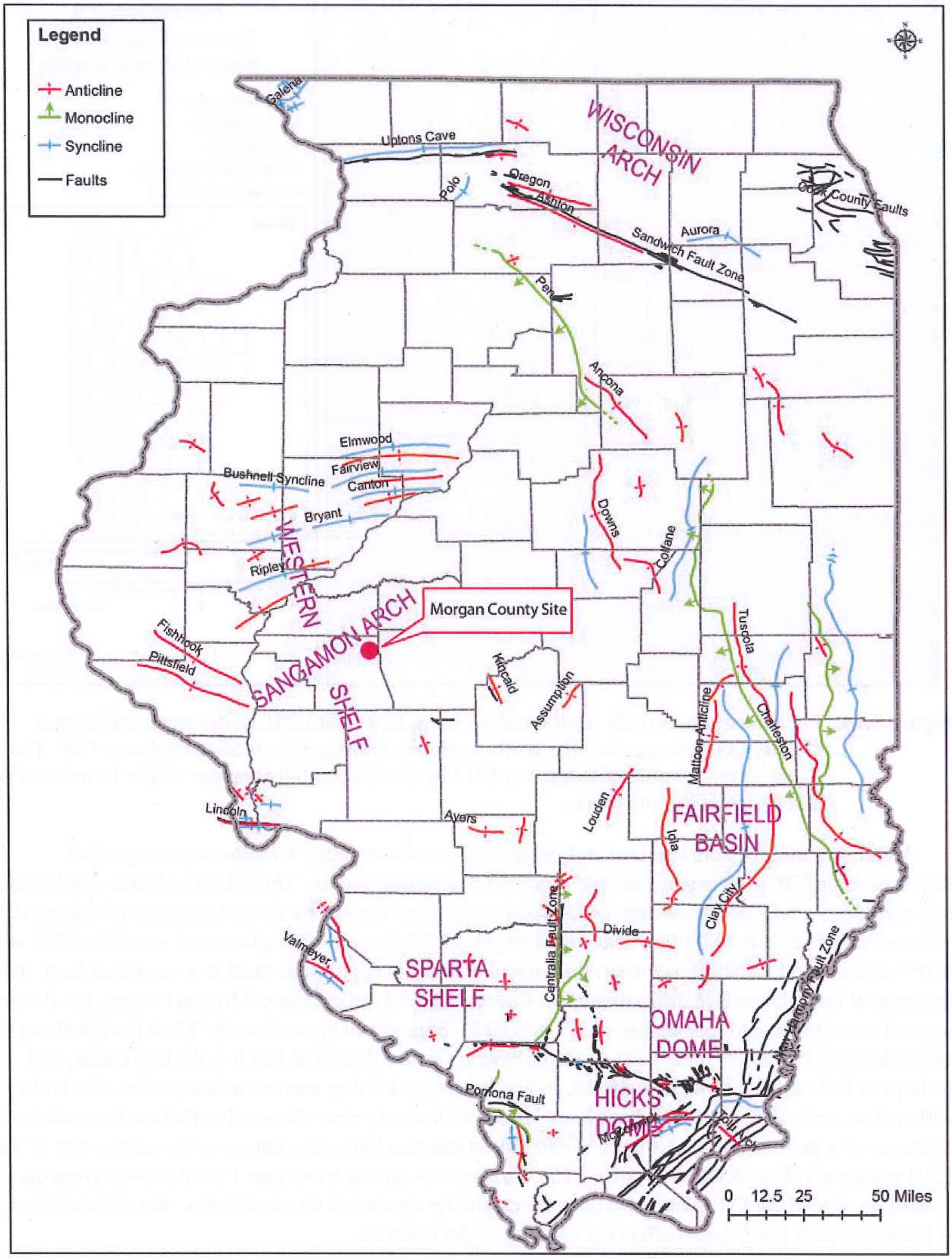

Figure 2.13. Structural Features of Illinois (modified from Nelson 1995)

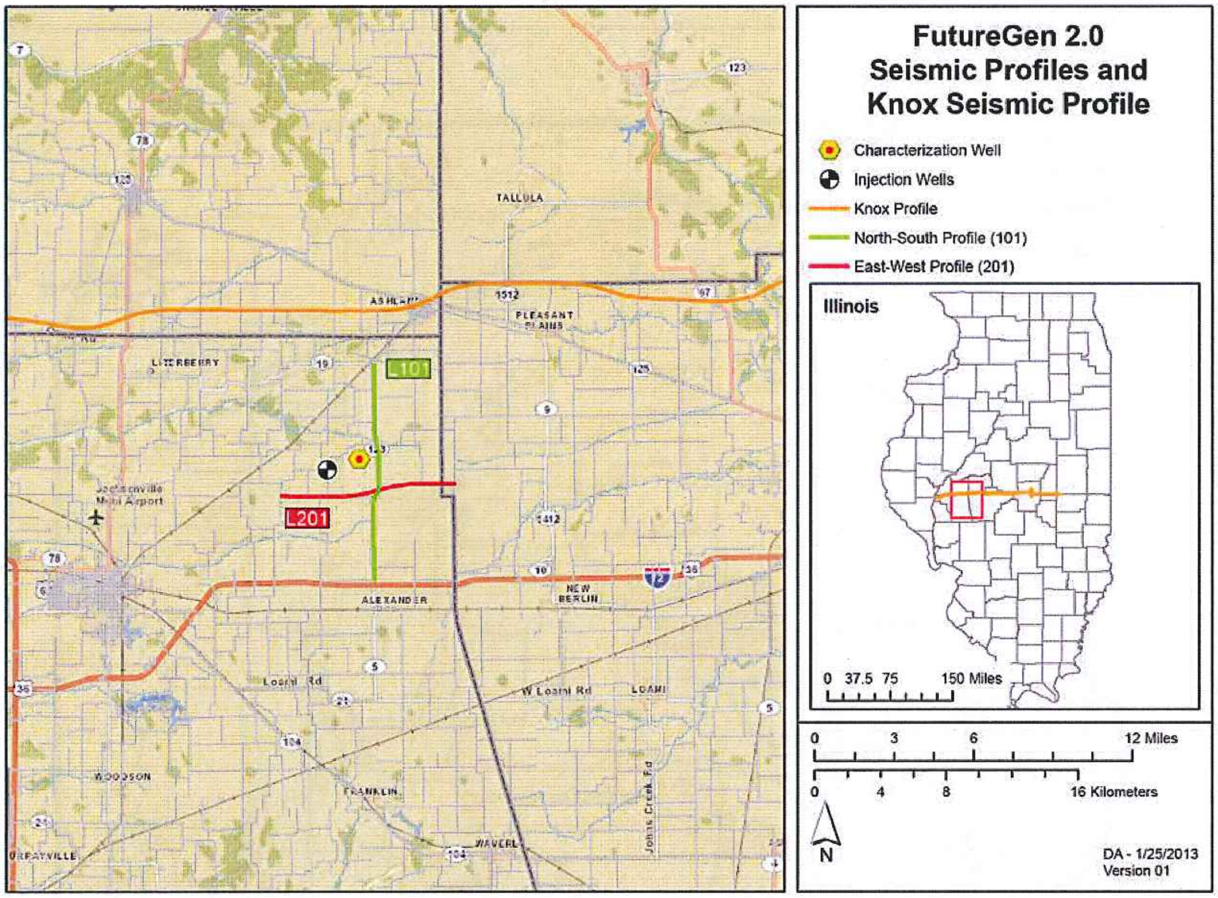

Figure 2.14. Location of the two 2D seismic survey lines, L101 and L201, at the proposed Morgan County CO_2 storage site. The north-south line is along Illinois State Highway 123. The Knox seismic profile completed in 2012 by the ISGS and that passes within 10 miles of the site is also drawn in orange.

A fault can usually be recognized and interpreted in seismic data if it creates a quasi-vertical displacement of 20 ms or more in several successive reflection events. This 20-ms reflector displacement rule represents a reflector discontinuity that most interpreters can see by visual inspection of seismic data. The amount of vertical fault throw that would produce a 20-ms vertical displacement would be (0.01 sec) X (P-wave interval velocity), for whatever interval velocity is appropriate local to a suspected fault. For the interval from the surface down to the Eau Claire at the FutureGen site in Morgan County, the P-wave interval velocity local to seismic lines L101 and L201 ranges from approximately 7,000 ft/s (shallow) to approximately 12,000 ft/s (deep). Thus, faults having vertical throws of 120 ft at the Eau Claire, and perhaps as little as 70 ft at shallow depths, should be detected if they traverse either profile. No faults with a clear vertical displacement have been identified; the only clear observation that can be made is the existence of a growth fault that affects Mount Simon and Eau Claire formations in the eastern part of the L201 profile at offset 28,000 ft (Figure 2.15). This growth fault is more than 1.5 miles away from the outermost edge of the CO_2 plume and does not extend far upward in the overburden. For these reasons, it is highly unlikely that it could affect the integrity of the reservoir.