# Class VI Injection Well Application

## Attachment 01: Narrative
**40 CFR 146.82(A)**

Linden Project

30 March 2023

Prepared by:

VAULT 44.01

## Confidential Business Information

Several figures and a table contained within this document, "Attachment 01: Narrative without CBI", contain confidential business information (CBI) that is privileged and exempt from public disclosure. These images will be delivered to the United States (US) Environmental Protection Agency (EPA) in a separate document, "Attachment 01: Narrative with CBI".

The figures and table listed below contain Confidential Business Information and, as such, are redacted from the publicly disclosed version of this document:

**CBI figures:**
CBI Table 6: Average values of total closure stress and pore pressure.
CBI Figure 20: South-north 2D seismic line 1 from the Linden Project site.
CBI Figure 21: West-east 2D seismic line 2 from the Linden Project site.
CBI Figure 22: West-east 2D seismic line 3 from the Linden Project.
CBI Figure 28: Geomechanical data calculated from the Hinton #7 well
CBI Figure 29: IN168045 input data and petrophysical analysis.
CBI Figure 30: IN125110 input data and petrophysical analysis.
CBI Figure 31: IL121830184800 input data and petrophysical analysis.
CBI Figure 32: IN136060 input data and petrophysical analysis.
CBI Figure 33: IN152828 input data and petrophysical analysis.

## Attachments

This document is one of eleven attachments being submitted to the US EPA for approval for a Class VI well for the Linden Project. In its entirety, "Attachment 03: Financial Assurance Plan" is considered CBI and will be delivered to EPA separately from the other ten attachments on the following list.

Full list of attachments:
Attachment 01: Class VI Permit Application Narrative
Attachment 02: Area of Review and Corrective Action Plan
**CBI:** Attachment 03: Financial Assurance Plan
Attachment 04: Injection Well Construction Plan
Attachment 05: Pre-operational Formation Testing Program
Attachment 06: Injection Well Operations Plan
Attachment 07: Testing and Monitoring Plan
Attachment 08: Injection Well Plugging Plan
Attachment 09: Post-injection Site Care and Site Closure Plan
Attachment 10: Emergency and Remedial Response Plan
Attachment 11: Quality Assurance and Surveillance Plan
-End-

# Project Information

Project Name: Linden

Project Operator: Vault Alliance CCS, LP

Project Contact: Sensative, Confidential, or Privileged Information [redacted]

Linden Sassafras Hill Injection Well 1 (LSH INJ1) Location:

Latitude: 40.210756°
Longitude: -86.865219°

# Table of Contents

# List of Figures

## List of Tables

# List of Acronyms

| | |
|---|---|
| 2D | two-dimensional |
| 3D | three-dimensional |
| ACZ | above confining zone |
| ADM | Archer Daniels Midland |
| AoR | Area of Review |
| ARRA | American Recovery and Reinvestment Act |
| CBI | confidential business information |
| CCS | carbon capture and sequestration |
| CCS1 | Illinois Basin–Decatur Project Injection Well drilled on ADM property |
| CCS2 | ADM Illinois Industrial CCS Project $CO_2$ injection well |
| $CO_2$ | carbon dioxide |
| DOE | Department of Energy |
| EGRP | Eastern Granite-Rhyolite Province |
| EPA | Environmental Protection Agency |
| EPSG | European Petroleum Survey Group |
| ERRP | Emergency and Remedial Response Plan |
| fbgl | feet below ground level |
| fbsl | feet below sea level |
| FEMA | Federal Emergency Management Agency |
| GSDT | Geologic Sequestration Data Tool |
| h | Thickness |
| IBDP | Illinois Basin–Decatur Project |
| IDNR | Illinois Division of Natural Resources |
| IEc | Industrial Economics |
| IEMA | Illinois Emergency Management Agency |
| IL-ICCS | Illinois Industrial CCS Project (run by ADM) |
| JV | Joint Venture |
| k | permeability |
| LAS | Log Ascii Standard |
| LA OBS1 | Linden Antilles Deep Observation Well 1 |
| LB USDW1 | Linden Beru USDW Monitoring Well 1 |
| LR ACZ1 | Linden Ralter Above Confining Zone Monitor Well 1 |
| LSH INJ1 | Linden Sassafras Hill Injection Well 1 |
| LCZ | lost circulation zone |
| mD | millidarcy |
| MMT | million metric tons |
| MRCSP | Midwest Regional Carbon Sequestration Partnership |
| MSL | mean sea level |
| Mtpa | million tonnes per annum |
| O&G | oil and gas |
| PISC | Post Injection Site Care and Site Closure |
| TBD | to be determined |
| TD | total depth |

| | |
|---|---|
| TDS | total dissolved solids |
| UIC | Underground Injection Control |
| US | United States |
| USDW | Underground Source of Drinking Water |
| USGS | United States Geological Survey |
| VA | Vault Alliance CCS, LP |

---

# 1. Project Background and Contact Information [40 CFR 146.82(a)(1)]

## *1.1 Project Contact Information*

Project Name: Linden

Project Operator: Vault Alliance CCS, LP

Project Contact: Sensative, Confidential, or Privileged Information [redacted]

Project Location: Montgomery County, IN

Linden Sassafras Hill Injection Well 1 (LSH INJ1) Location:
Latitude: 40.210756°
Longitude: -86.865219°

## *1.2 Project Background*

The objective of the Linden Project is to permanently sequester $CO_2$ from the area around Linden, Indiana, up to a volume of 0.7 Million tonnes per annum (Mtpa.) The initial source of $CO_2$ will be from the ethanol production process of the Valero Renewable Fuels Linden ethanol plant. The Linden Project is proposed by Vault Alliance CCS LP (VA) and will transport supercritical $CO_2$ via underground pipeline and inject it deep into the Mt Simon Sandstone for permanent storage.

The Valero Renewable Fuels Linden ethanol plant employs ~60 full-time employees and is an ethanol production facility located in Montgomery County, Indiana. The plant began operations in 2007 and has an ethanol production capacity of 135 million gallons per year, which comes from the corn fermentation process. A natural by-product of this fermentation process is $CO_2$. Valero will install the facility to capture the $CO_2$ generated at the Linden plant. The facility will use compressors, blowers, cooling units, and scrubbers to purify and condense the $CO_2$ into a supercritical state. Vault Alliance CCS LP will take custody of the supercritical $CO_2$ at the ethanol plant and transport it by underground pipeline to the Linden Sassafras Hill Injection Well 1 (LSH INJ1) well shown in Figure 1 and Figure 2.

VA will be the owner, operator, and permit holder for injection well LSH INJ1. VA will also be the owner and operator of the transport pipeline. Neither an injection depth waiver nor an aquifer exemption expansion is being requested for this project. Based on the maximum anticipated annual volume of 0.7 Mtpa of $CO_2$ over a period of 30 years, the total mass of injected $CO_2$ is anticipated to be approximately 21 million metric tons (MMT).

The Mt. Simon Sandstone is of sufficient depth and temperature at the site to maintain the injected $CO_2$ in a supercritical state. The Mt. Simon Sandstone has served as a suitable injection interval for Class I, II and VI wells in the region for multiple decades. The primary confining zone is the Eau Claire Shale. Other strata including within the Knox Group, the Maquoketa Shale and New Albany Shale will serve as secondary confining zones.

Figure 1 and Figure 2 show the locations of the four primary wells associated with the project: Linden Antilles Deep Observation Well 1 (LA INJ1), Linden Beru USDW Monitoring Well 1 (LB USDW1), Linden Ralter Above Confining Zone Monitoring Well 1 (LR ACZ1), and Linden Sassafras Hill Injection Well 1 (LSH INJ1). Table 1 shows the coordinates, depth, and intended use for each well.

Features not present within the Area of Review (AoR) include deep stratigraphic boreholes, State or Federal EPA approved subsurface clean-up sites, mines, quarries, and State, Tribal, or Territory boundaries. No major surface bodies of water are located within the AoR. Information on oil and gas wells (O&G) and water wells within the AoR can be found in Section 4.1 of Attachment 02: AoR and Corrective Action Plan, 2023.

Sensative, Confidential, or Privileged Information

[redacted]

**Figure 1: Map of the Linden Project location that shows the proposed well locations, simulated extent of $CO_2$ plume at 50-years post-injection, and the AoR. Map base adapted from Esri.**

Sensative, Confidential, or Privileged Information

[redacted]

**Figure 2: Proposed locations of the injection, deep observation, above confining zone monitoring, and the aquifer monitoring wells for the Linden Project. Map base adapted from Esri.**

**Table 1: Location, depth, and purpose of all Linden Project proposed wells (NAD 1983 UTM Zone 16N).**

Sensitive, Confidential, or Privileged Information

[redacted]

The principal objective of this project and UIC Class VI application is to establish that $CO_2$ produced at the Linden facility can be safely and effectively captured and permanently sequestered deep in the Mt. Simon Sandstone. This application seeks approval to continue this effort.

Upon approval, project execution will begin with the drilling and completion of several wells including the $CO_2$ injection well (Figure 2, Table 1). Real-time data will be collected as the wells are drilled and completed. The data gathered will be processed and analyzed to confirm or re-assess the project modeling efforts and current understanding. As necessary, additional data sets will be collected and analyzed.

One injection well is expected to be sufficient to handle the project's intended mass flow rate of 0.7 Mtpa of $CO_2$into the Mt. Simon Sandstone. The Linden Project has been designed to operate for 30 years at a nameplate capacity 0.7 Mtpa of $CO_2$.

## *1.3 Local, State, and Federal Emergency Contacts [40 CFR 146.82(a)(20)]*

**Table 2: Local, state, and federal emergency contacts**

| Agency | Phone Number |
|---|---|
| Linden Town Marshall | 765-339-4550 |
| Madison Township Volunteer Fire Department | 765-339-4861 |
| Montgomery County Sheriff | 765-362-3740 |
| Crawfordsville Fire Department & EMS Division | 765-362-1277 |
| Indiana State Police District 3 | 765-362-8815 |
| Emergency Management and Homeland Security Division (Montgomery County) | 765-364-5154 |
| Federal Emergency Management Agency | 800-621-3362 (FEMA Helpline)<br>312-408-550 (FEMA Region 5 General) |
| Environmental services contractor to be determined (TBD) | TBD |
| Underground Injection Control (UIC) Program Director (Region 5) | 312-353-7648 |
| EPA Region 5 UIC<br>Class VI Wells/Carbon Sequestration | 312-353-3944 |
| EPA National Response Center (24 hours) | 800-424-8802 |
| Indiana Department of Natural Resources | 317-232-4200 |

## 1.4 Summary of Other Permits Required

Table 3 provides a summary of permits required for the Linden Project.

**Table 3. Permits required for the Linden Project.**

| Agency | Program | Permit(s) Required | Regulation or Reference | Notes: |
|---|---|---|---|---|
| US Environmental Protection Agency (EPA), Resources Conservation and Recovery Act (RCRA). | RCRA Hazardous Waste Management Program. | Not required. | 40 CFR 144.31 (e)(1), 40 CFR 144.31 (e)(6)(i) | Not applicable (N/A). $CO_2$ is a non-hazardous waste. |
| US EPA Safe Water Drinking Act (SWDA). | Underground Injection Control (UIC) Program under the SWDA. | Class VI Underground Injection Control (UIC) Permit. | 40 CFR 144.31 (c), 40 CFR 144.31 (e)(1), 40 CFR 144.31 (e)(6)(II) | Application submitted. |
| National Pollutant Discharge Elimination System (NPDES). | NPDES program under the Clean Water Act (CWA). | Stormwater Pollution Plan Prevention (SWPPP) or Stormwater Management Plan (SWMP). | 40 CFR 144.31 (e)(1), 40 CFR 144.31 (e)(6)(iii) | Will submit application prior to pad construction. |
| Prevention of Significant Deterioration (PSD), Clean Air Act (CAA). | Nonattainment program under CAA. | Not required. | 40 CFR 144.31 (e)(6)(v) | N/A. Montgomery County and Tippecanoe County, IN are in attainment for all criteria pollutants. |
| National Emission Standards for Hazardous Air Pollutants (NESHAPS) CAA | NESHAPS Preconstruction approval under the CAA. | Not required. | 40 CFR 144.31 (e)(6)(vi) | N/A. Non-hazardous air pollutants. |
| Marine Protection, Research, and Sanctuaries Act (MPRSA). | Ocean dumping permits under MPRSA. | Not required. | 40 CFR 144.31 (e)(6)(vii) | N/A. Onshore project. |
| Army Corp. of Engineers | Section 404 of CWA. | Not required. | 40 CFR 144.31 (e)(6)(viii) | N/A. Construction activities outside of wetlands and stream areas. No disturbance to waters of US planned nor anticipated. |
| **State or Other relevant environmental permits including state permits. 40 CFR 144.31(e)(6)(ix)** | | | | |
| Indiana Department of Natural Resources (IDNR) | Oil & Gas Resource Management | Carbon Sequestration Permit | Indian H.R. 1209. | Will submit application prior to drilling carbon sequestration well. |

# 2. Site Characterization [49 CFR 126.82(a)(2), (3), (5) and (6)]

Unless otherwise stated, all depths are in reference to feet below ground level (fbgl).

## *2.1 Regional Geology, Hydrogeology, and Local Structural Geology [40 CFR 146.82(a)(3)(vi)]*

The Linden Project, located in northern Montgomery County of west-central Indiana, is at the eastern fringe of the intracratonic Illinois Basin that extends beneath much of Illinois, western Indiana, and western Kentucky (Figure 3). The Illinois Basin and surrounding area are comprised of Cambrian to Permian strata that reach a maximum thickness of nearly 23,000 feet in the southern portion (Collinson et al., 1988).

The Illinois Basin region has been the focus of extensive research into geological carbon sequestration for over two decades through the Midwest Regional Carbon Sequestration Partnership's (MRCSP) Illinois Basin–Decatur Project (IBDP) (Wickstrom, 2005; Greenberg, 2021) and the CarbonSAFE program (Leetaru, 2019; Korose, 2022; Whittaker, 2022; Whittaker and Carman, 2022), both funded by the United States (US) Department of Energy (DOE).

In addition, the American Recovery and Reinvestment Act (ARRA) funded Illinois Industrial Carbon Capture and Storage Project (IL-ICCS) is an active commercial carbon sequestration project taking place at the Archer Daniels Midland (ADM) ethanol facility in Decatur, IL. The IBDP injection well (CCS1) drilled on ADM property and the ADM IL-ICCS $CO_2$ injection well (CCS2) are located approximately 107 miles west-southwest of the proposed location for the Linden Project (Figure 3).

The IL-ICCS Project storage complex uses the Cambrian Mt. Simon Sandstone as the injection zone and the overlying Eau Claire Formation as the confining zone (Gollakota and McDonald, 2014) (Figure 4). These same formations are being proposed as the storage complex for the Linden Project.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 3: Mt. Simon Sandstone isopach map (feet) with the Illinois Basin extent, major structural features, the Linden Project site (yellow star), and the IBDP and IL-ICCS Project sites (red star). Modified from Medina and Rupp (2012).**

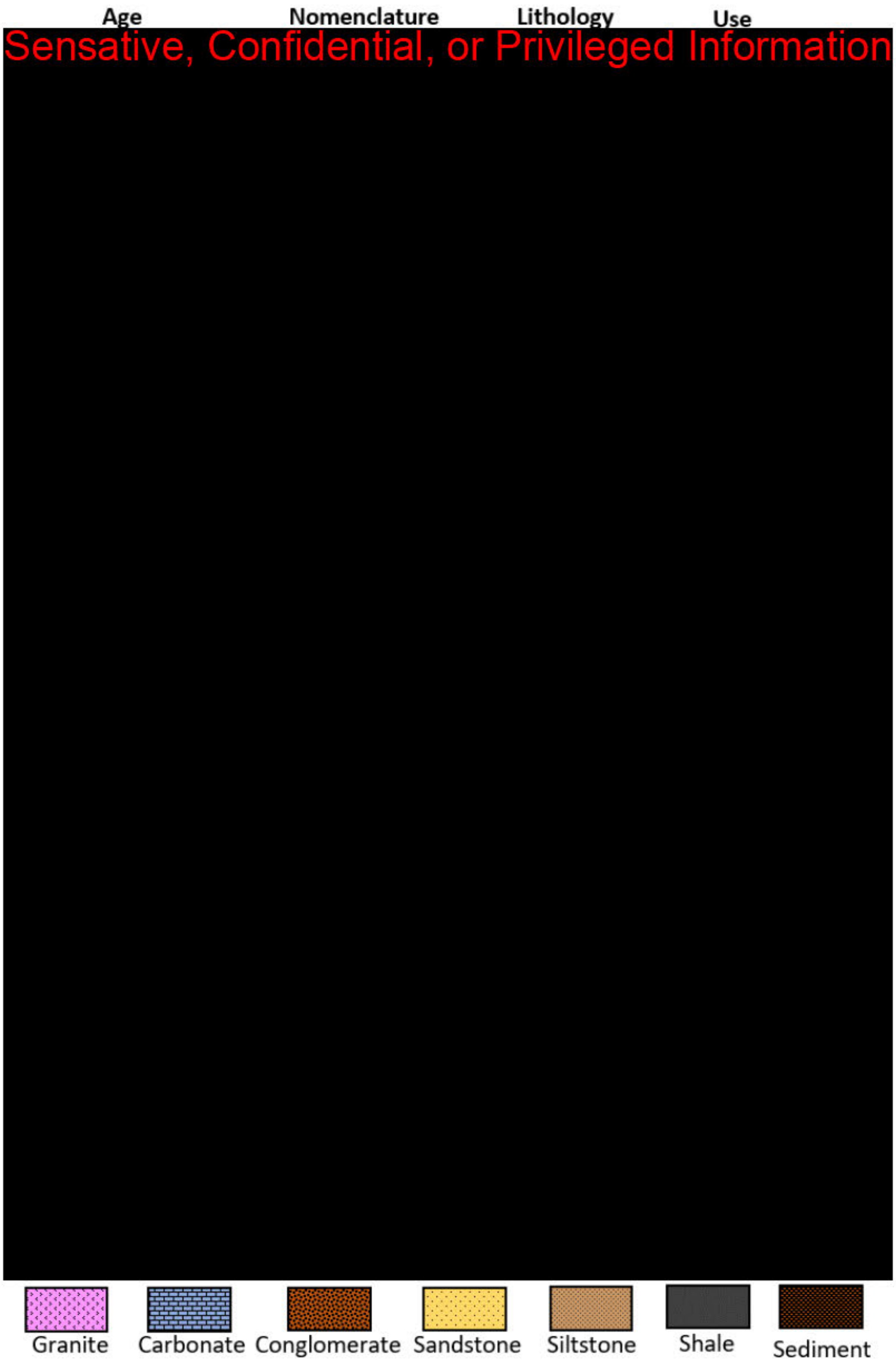


**Figure 4: Linden Project site-specific stratigraphic column with age, nomenclature, generalized lithology, and zone of use.**

Sensative, Confidential, or Privileged Information

[redacted]

**Figure 5: West to east regional cross section A-A' through the project site (see inset map).**

The Illinois Basin formed during the late Precambrian to early Cambrian period as the rift formed during the breakup of the supercontinent Rodinia, (Braile et al. 1986; Kolata and Nelson 1991, 1997, 2010). The Illinois Basin is bounded to the northwest by the Mississippi River Arch, to the north-northeast by the Kankakee Arch and to the east by the Cincinnati Arch (Figure 3). The Linden Project is located between the Kankakee Arch and the eastern boundary of the Illinois Basin.

The Reelfoot Rift and Rough Creek Graben are significant features within the southern portion of the basin related to processes linked to basin subsidence, and thus where the thickest accumulation of sediments exist in the basin (Kolata, 2010). It is noteworthy, however, that the depocenter for Cambrian sediments was more northerly (at present) as shown by the greatest thickness of the Mt. Simon Sandstone in Figure 3. Paleozoic sedimentary strata of the basin unconformably overlie the Precambrian basement, which is broadly composed of felsic intrusives and volcanics of the Eastern Granite-Rhyolite Province (EGRP) (Figure 5; Bradbury and Atherton, 1965; Bickford et al., 1986; Atekwana, 1996; Lidiak, 1996; Green, 2018).

The Cambrian Mt. Simon Sandstone and Cambrian Eau Claire Formation are among the oldest and deepest strata in Indiana and will serve as the injection/sequestration and confining zones, respectively, for the Linden Project. The clastic sediments of the Mt. Simon Sandstone are interpreted to have been deposited in the failed rift basin that ultimately provided up to [redacted] of accommodation space for Mt. Simon Sandstone sediments to accumulate (Figure 3). The Mt. Simon Sandstone is underlain by the Argenta Formation that is variably present in the basin and that was, until recently, considered part of the Mt. Simon Sandstone. An erosional unconformity exists between the Argenta Formation/Mt. Simon Sandstone and the underlying Precambrian basement.

By late Cambrian, the tectonic regime evolved from a rift to a broad embayment, and the Illinois Basin was a slowly subsiding cratonic basin for the remainder of the Paleozoic (McBride and Kolata, 1999). Eustatic sea level fluctuations coupled with tectonics allowed for the accumulation of both marine and terrestrial sediments in the basin. Uplift during the Pennsylvanian to Late Cretaceous isolated the basin and created the present geometry (Kolata and Nelson, 1990, 1997; McBride and Kolata, 1999).

Much of the Illinois Basin was covered by a sea during by the early Ordovician; this was followed by a marine regression that exposed newly deposited marine sediments to erosion and created the Middle Ordovician Knox Group unconformity. A series of transgressions and regressions and periods of both uplift and subsidence dominated the remainder of Ordovician time (Freeman, 1953).

By early to mid-Silurian time, the Illinois Basin was close to wave-base and the surrounding sedimentary basins to the west, north, and east received large quantities of sediment (Janssens, 1968). Sea-level regressed and uplift occurred during the Devonian, causing extensive erosion. A sea level transgression during the Devonian-Mississippian deposited marine shales across the region. Subsidence and uplift continued to the end of the Paleozoic Era, and erosion and/or nondeposition prevailed throughout the Mesozoic and Cenozoic. During the Pleistocene Epoch, the region was covered by continental ice sheets that deposited hundreds of feet of glacial sediment in the region, some of which now serve as shallow groundwater aquifers.

## *2.2 Regional Stratigraphy*

Figure 4 is specific for the Linden Project and will be referred to throughout this narrative.

The regional continuity of the Paleozoic strata in the vicinity of the project site [40 CFR 146.82(a)(3)(i)] is demonstrated through cross-sections of the site model (Figure 5 and Figure 7) and geophysical logs of regional wells Figure 6). Quaternary glacial sediments overlie the bedrock (Figure 4) and are discussed further in 2.7 Hydrologic and Hydrogeologic Information.

To develop a comprehensive understanding of the site-specific geology for this project, a database of publicly available geophysical well logs from Illinois, Indiana, Kentucky, and Ohio was compiled. The well logs were interpreted and used to develop a static model for the project site.

Within 50 miles of the Linden Project, two wells penetrate the Precambrian basement, and five wells penetrate the Upper Mt. Simon Sandstone, all of which were used to assess the site-specific geology. Figure 6 shows the closest wells to the Linden Project that penetrate into the Mt. Simon Sandstone, the nearest of which is 39 miles west of the project site.

Beyond the 50-mile radius, the Manlove gas storage field (approximately 83 miles to the west) uses the Upper Mt. Simon Sandstone as a gas storage reservoir. This field includes the Hinton #7 well that penetrates through the entire Mt. Simon Sandstone into the Precambrian basement.

Sensative, Confidential, or Privileged Information

[redacted]

**Figure 6: Wells that penetrate the Upper Mt. Simon within a 50-mile radius (green circle) of the project site (yellow star) are shown as black dots. The Manlove Field at the west edge of the map (red circles) uses the Upper Mt. Simon for natural gas storage.**

B B’

Sensative, Confidential, or Privileged Information

[redacted]

**Figure 7: Regional cross section B-B’ demonstrates the regional continuity of the Eau Claire Formation, Mt. Simon Sandstone, Mt. Simon Arkose, and Argenta Formation. Gamma Ray Logs (GR norm) are color-filled, deep resistivity (RESD) is red, medium resistivity (RESM) is black, and density (DENS) is orange. Well locations are shown on the inset map. Project location shown as well as yellow star. The cross section is flattened on the Eau Claire Formation top.**

Sensative, Confidential, or Privileged Information

[redacted]

**Figure 8: Elevation map in fbsl of the Precambrian Basement. Structural features are shown in red; black dots indicate wells that penetrate the basement. Linden Project injection well (LSH INJ1) location is shown. The vertical line to the west is the Illinois/Indiana state border.**

### *2.2.1 Precambrian Basement Complex*

The strata of the project site overlie granite, rhyolite, trachyte, and quartzite of the EGRP of the Precambrian basement (Denison et al., 1984). These basement rocks are of extensional tectonic origin (Figure 4) and contribute to the source of Early Cambrian siliciclastic strata (Bickford et al., 1986).

Figure 8 shows that the Precambrian Basement deepens from approximately Sensative, Confidential, or Privileged Information [redacted] in the southwest of the map. The Illinois Basin deepens progressively southward beyond the map limits, and basin structure becomes more complex**.**

## *2.3 Argenta (Cambrian)*

The Precambrian surface represents a 900-million-year depositional hiatus before Cambrian sediments of the Argenta Formation were deposited forming an unconformable contact. The Argenta strata are of variable thickness (Figure 7), in part due to Precambrian topography, and locally the Argenta Formation onlaps against the Precambrian Basement as observed in Figure 5. The Argenta Formation is also in unconformable contact with the overlying Mt. Simon Sandstone (Leetaru, 2015).

Until recently, the Argenta was considered to be part of the Lower Mt. Simon Sandstone but work by the Illinois State Geological Survey (Freiburg, 2015) suggests it is a pre-Mt. Simon sedimentary unit. The Argenta Formation is composed of shallow-marine, shoreface to fan-delta sandstone and conglomerate with some interbedded mudstone. Conglomerates are dominantly clast supported and exhibit inverse and normal graded bedding, as well as planar and cross-beds. Bioturbation is abundant in some sandstone intervals, suggesting a Lower to Middle Cambrian age for this formation, and it was likely deposited during a marine transgression associated with thermal subsidence.

The elevation map of the Argenta Formation is shown in Figure 9 and the thickness map in Figure 10. The Argenta Formation is generally not present due to non-deposition in the eastern part of the mapped area beyond the limits of the Linden Project (Figure 9 and Figure 10) and is thickest in east-central Illinois (Figure 10).

Sensative, Confidential, or Privileged Information

[redacted]

**Figure 9: Elevation map in fbsl of the Argenta Formation. Structural features are in red; black dots are wells that penetrate the formation.**

Sensative, Confidential, or Privileged Information

[redacted]

**Figure 10: Thickness map of the Argenta Formation in feet. Structural features annotated in red; black dots signify wells that penetrate the Argenta Formation.**

Sensative, Confidential, or Privileged Information

[redacted]

**Figure 11: Elevation map (fbsl) of the Mt. Simon Sandstone. Structural features annotated in red; black dots signify wells that penetrate the Mt. Simon Sandstone.**

Sensative, Confidential, or Privileged Information

[redacted]

**Figure 12: Thickness map (in feet) of the Mt. Simon and Eau Claire Silt. Structural features annotated in red; black dots signify wells that penetrate the Eau Claire Silt.**

## 2.4 Mt. Simon Sandstone/Injection Zone (Cambrian)

The Cambro-Ordovician Sauk sequence unconformably overlies the Argenta Formation and includes the Mt. Simon Sandstone, the Eau Claire Formation, and the Knox Group (Figure 4, Figure 5, and Figure 7). Specific to this project, the Mt. Simon Sandstone is the target for the injection and sequestration zone, and the Eau Claire Formation is the confining zone.

The Mt. Simon Sandstone is a transgressive terrestrial to shallow marine sequence that is a laterally extensive deposit in the Illinois Basin and throughout the Midwest (Kolata and Nelson, 1990). It is thickest in northeastern and east-central Illinois (Figure 3; Leetaru and McBride 2009). Mt. Simon Sandstone sedimentology was impacted by a wide range of depositional environments including shallow marine, deltaic, fluvial, eolian, and coastal (Janssens, 1973; Saeed, 2002; Baranoski, 2007, Freiberg et al., 2016). Fine to coarse-grained, poorly sorted, arkosic and quartz sandstone primarily compose the Mt. Simon Sandstone.

Typically, the Mt. Simon Sandstone is subdivided into Lower, Middle, and Upper intervals, with the Lower Mt. Simon Sandstone containing a basal zone having an arkosic lithology. In this report, the arkosic zone will be referred to as the Mt. Simon Arkose and will be differentiated from the overlying Lower Mt. Simon Sandstone (Figure 4).

The Mt. Simon Sandstone has been the focus of considerable research into carbon sequestration in the Illinois Basin through a number of US DOE funded projects including the Regional Carbon Sequestration Partnerships' IBDP's CCS1 well (Greenberg, 2021) and the CarbonSAFE program (Leetaru, 2019; Korose, 2022; Whittaker and Carman, 2022).

The Mt. Simon Sandstone has also been demonstrated as an effective sequestration formation through the IL-ICCS, an active carbon sequestration project at the ADM facility in Decatur, IL using the CCS2 Injection Well (UIC Class VI Permit IL-115-6A-0001).

The Lower Mt. Simon Sandstone and Mt. Simon Arkose are dominantly medium- to fine-grained cross-bedded to ripple-laminated subarkose arenite (Freiberg et al., 2014). They also contain planar-bedded sandstone and conglomerate composed of subarkosic to arkosic arenite, arkosic wacke and mudstone. Grading upwards the Mt. Simon Sandstone contains mixed eolian and fluvial deposits to marine tidal deposits in its upper portions. Porosity in the Mt. Simon Arkose and, to a lesser degree, in the Lower Mt. Simon is largely a result of diagenesis including dissolution of feldspars and by clay (illite) coating quartz grains that restricted formation of porosity occluding cements. The dominant diagenetic cement is quartz, and the presence of authigenic quartz is less in the Arkose and Lower Mt. Simon units than in the Middle and Upper intervals (Freiberg et al., 2016). The Upper Mt. Simon Sandstone also exhibits good reservoir characteristics and is used for natural gas storage at several locations within the Illinois Basin.

The elevation map of the Mt. Simon Sandstone, which represents the top of the planned injection zone, is shown in Figure 11, which shows the continuity of the unit across a wide region and that it is deepening southward toward the basin center. Figure 12 shows the thickness of the Mt. Simon Sandstone/Eau Claire Silt to be increasing westward.

## 2.5 Eau Claire/Primary Confining Zone (Cambrian)

The Eau Claire Formation is the primary confining unit at the Linden Project Site (Figure 4, Figure 5, and Figure 7). The Eau Claire Formation directly overlies the Mt. Simon Sandstone and is the basal unit of the Knox Group (Kolata, 2010). Regionally, the Eau Claire Formation is a thick succession of fine-grained strata that is present across much of the Illinois Basin and surrounding area (Figure 13). The regional thickness of the Eau Claire Formation is shown in Figure 14.

The base of the Eau Claire Formation can be siltstone to very fine-grained sandstone that forms a gradational contact with the underlying Mt. Simon Sandstone and is sometimes referred to as the Elmhurst Member (Willman et al., 1975). However, in this document it is called the Eau Claire Silt and is considered a secondary storage interval. The Eau Claire Formation exhibits a range of mineralogical and textural features across the Illinois Basin and surrounding area, and Neufelder et al., (2012) report five lithofacies in seven Illinois Basin cores: 1) sandstone, 2) clean siltstone, 3) muddy siltstone, 4) silty mudstone, and 5) shale. Lahann et al., (2014) additionally evaluated the sealing properties of the Eau Claire Formation and determined the finer-grained facies, such as mudstones and shale would restrict vertical entry of $CO_2$ into the rocks. Figure 15 shows Eau Claire Formation core and well log porosity and permeability data from four Illinois Basin wells, and these data were divided into the five lithofacies listed above. In general, the coarser grained lithofacies have higher porosities and associated permeabilities, and the finer grained, clay-rich lithofacies have lower values, though there is considerable scatter in this data.

At the ADM CCS1 well that was drilled as part of the IBDP (Greenberg, 2021), which is located approximately 107 miles west of the Linden Project (Figure 3), the Eau Claire Formation is about 500 feet thick and grades from highly laminated shale to silty shale in the bottom portion to clayey limestone in the top half of the formation (Leetaru and Freiberg, 2014). The shale and muddy siltstone layers isolate the clayey limestone from the injection zone (Leetaru and Freiberg, 2014).

At the Allied Chemical Disposal #1 well (IL121830184800; Figure 14) about 39 miles west of the Linden Project analyses of Eau Claire core indicated permeability of less than 0.001 md and an average porosity of about 4 % (Lohmann-Johnson Pollution Control Inc., 1972). The characteristics of the Eau Claire Formation around the Linden Project site are described in more detail in Section 2.26 Injection and Confining Zone Details.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 13: Elevation map (fbsl) of the Eau Claire Formation. Structural features annotated in red. Black dots indicate wells that penetrate the formation.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 14: Thickness map (feet) of the Eau Claire Formation with structural features annotated in red. Black dots indicate wells that penetrate the formation.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 15: Porosity-permeability models for the Eau Claire Formation lithofacies modified from Neufelder et al., 2012. (A) Cross plot of conventionally derived core porosity and permeability with regression lines for the clean silt lithofacies. (B) Cross plot of traditional core porosity and Kozeny-Carmen calculated permeability with regression lines for the clean silt, muddy siltstone, and silty mudstone lithofacies. (C) Cross plot of traditional core porosity and Kozeny-Carmen calculated permeability for clean silt, muddy silt, and shale lithofacies.**

## *2.6 Ironton-Galesville Sandstones (Cambrian)*

The Eau Claire Formation is overlain by the Ironton-Galesville Sandstones, which are also part of the Knox Group and will serve as the above confining zone (ACZ) monitoring interval for the Linden Project (Figure 4). These sandstones were derived from pre-existing sedimentary rocks, sourced from the northern Michigan Highlands (Emrich, 1966). The sediments were deposited on a broad, shallow shelf with clastic deposition in the north and carbonate deposition in the south. The Ironton Sandstone is a fine to coarse grained, poorly sorted silty sandstone. The underlying Galesville Sandstone is fine to medium grained, well sorted sandstone and, in the lower part, fossiliferous (Emrich, 1966). Due to the gradational nature of the Ironton and Galesville Sandstones, it is difficult to distinguish between these sandstones in well data and they are typically considered together as the Ironton-Galesville Sandstones.

## *2.7 Davis Member/Secondary Confining (Cambrian)*

The Davis Member of the Knox Group overlies the Ironton-Galesville Sandstones and is the lower member of the Franconia Formation. It is composed of a number of carbonate and clastic lithologies, including: 1) brownish gray, silty, glauconitic dolomite with oolites, 2) yellowish gray, feldspathic siltstone with dolomite and glauconite, 3) dark gray, calcareous shale, and 4) gray limestone with interbedded shale, siltstone, and sandstone (Figure 4). They are interpreted to have been deposited in a shallow marine environment (Willman et al., 1975).

## *2.8 Franconia Formation (Derby-Doerun Dolomite, Cambrian)*

The basal Davis Member is conformably overlain by the remainder of the overlying Franconia Formation (Figure 4), which consists of glauconitic, argillaceous sandstone and dolomite that underlies the relatively clean Potosi Dolomite. In extreme northern Illinois, the Franconia Formation primarily consists of gray to pink, fossiliferous, glauconitic, silty, argillaceous, fine-grained, dolomitic sandstone with some interbedded red and green shale (Willman and Templeton, 1951). It becomes increasingly shaly to the south, and the uppermost part grades to silty and sandy dolomite. In north-central Illinois, these two units are separated by a wedge of fine-grained, glauconitic, dolomitic sandstone, which is absent in central and southern Illinois where the silty, shaly sandstone of the Davis is directly overlain by relatively pure dolomite. Because of its diminishing amounts of sand, shale, and glauconite, the upper part of the Franconia Formation is difficult to differentiate from the overlying Potosi Dolomite (Willman et al., 1975). For this project, the Potosi and Franconia Formations will not be differentiated.

## *2.9 Potosi Formation/Secondary Confining Zone (Cambrian)*

The Potosi Formation overlies the Franconia Formation and consists of crystalline, clean to slightly argillaceous, brown to pinkish-gray dolomite (Figure 4). It is sandy at the base and glauconite content increases upward. Drusy quartz sometimes covers the surfaces of small to large cavities within the rock, which is a defining characteristic in both outcrops and well samples, and portions of this formation have relatively high permeability (Willman et al., 1975). Intervals within the Potosi Formation exhibit karst dissolution features (e.g., large vugs) and can be zones of lost circulation while drilling throughout the Illinois Basin.

## *2.10 Oneota Dolomite (Ordovician)*

The Oneota Formation consists of crystalline, light gray to brownish gray, cherty dolomite with minor amounts of sand and thin shaly beds at the base (Figure 4). The rock is generally white, light, or pinkish gray with some sand and oolite layers. The chert occurs in layers, lenses, isolated nodules, and irregularly shaped bodies that have a distinctive branching habit (Oneota, Willman, 1975).

## *2.11 Shakopee Formation (Ordovician)*

The Shakopee consists of argillaceous to pure, crystalline dolomite with some thin beds of medium-grained, cross-bedded sandstone, medium-grained dolomite, green to light gray shale, and buff siltstone. It contains oolitic, partly sandy chert in discontinuous bands and isolated nodules, and some beds are brecciated or conglomeratic, and bedding surfaces have ripple marks and mud cracks (Willman, 1975). Bentonite layers are present in a quarry in northern Illinois (Willman and Templeton, 1951).

## *2.12 St. Peter Sandstone (Ordovician)*

The Knox Group is overlain by the St. Peter Sandstone (Figure 4), which consists of fine to medium, well sorted, rounded, frosted quartz sand grains that are friable or weakly cemented. The St. Peter Sandstone is an exceptionally pure quartz sandstone and was deposited in a near-shore environment (Lamar, 1928a; Willman and Payne, 1942; Buschbach, 1964). Bedding is primarily horizontal with some low-angle cross bed. It has three members:1) the Kress Member at the base (chert, sand, clay, and shale), 2) the Tonti Sandstone Member, and 3) the Starved Rock Sandstone Member (Willman et al., 1975). The St. Peter Sandstone is one of the major freshwater aquifers in Illinois, but it is not an underground source of drinking water (USDW) at the project site.

## *2.13 Joachim Dolomite/Glenwood (Ordovician)*

The St. Peter Sandstone is overlain by the Joachim Dolomite (Figure 4), which can be differentiated into six members regionally within the basin. This rock is generally light gray, argillaceous, silty, or sandy dolomite, and also contains beds of relatively pure dolomite, sandstone, limestone, shale, and chert. Dolomitic algal domes are also found within the Joachim Dolomite. Layers of anhydrite exist in the subsurface but are dissolved where the Joachim Dolomite crops out. The general absence of marine fossils and existence of algal domes suggests that the Joachim was deposited in a shallow, closed basin, and mud cracks and ripples occur in some beds (Willman et al., 1975).

## *2.14 Black River Group (Ordovician)*

The micritic to finely crystalline limestone of the Black River Group was deposited in subtidal to intertidal conditions (Drahovzal, et al, 1992). This formation consists of lithographic limestone with sandstone, chert, and brown shales. Thin interbedded limestone is present in the upper section of the Black River Group, while the lower section contains lenses of fine-grained brown dolomite. Bentonites at the top of the Black River Group are evidence that the Taconic Orogeny was increasing in intensity to the east (Drahovzal, et al, 1992).

Deepening of the sea resulted in the deposition of the basal, subtidal, and open-shelf facies of the Ordovician Trenton Limestone. As a result of the subsidence of the proto-Appalachian Basin and the early stages of the Taconic Orogeny, the deposition of the basal Trenton facies ended, which is marked by a change in depositional strike. This caused shallowing of the sea to the northwest and the deposition of the thick carbonates of the platform facies of the Trenton Limestone. Other formations associated around the same age are Pecatonica, and Plattin (oldest to youngest, Figure 6).

### *2.15 Galena Group/Trenton Limestone (Ordovician)*

Overlying the Black River Group is the Ordovician Trenton Limestone of the Galena Group (Figure 4). This group consists of limestone that becomes increasingly dolomitic in northern Indiana. The Trenton Limestone exists throughout the subsurface of Indiana except in the southeastern part of the state, where the limestone interval is truncated so that the group is entirely calcarenite and calcarenitic limestone (Willman et al., 1975)

### *2.16 Maquoketa Group/Secondary Confining Zone (Ordovician)*

The shale and carbonate of the Maquoketa Group exists in most of the Illinois Basin and surrounding area, unconformably overlies the Galena Group, and truncates the portions of the upper half of the Galena Group in southern Illinois (Figure 4). Silurian strata locally truncate the upper half of the Maquoketa, and the group thins into western Indiana. Throughout most of the Illinois Basin, the Maquoketa Group consists of a lower shale unit (Scales Shale), a middle limestone (Fort Atkinson Limestone), and an upper shale (Brainard Shale) (DuBois, 1945; Gutstadt, 1958b; Templeton and Willman, 1963; Buschbach, 1964). The Maquoketa Group will serve as a significant confining zone for this project.

### *2.17 Silurian System*

The Silurian System unconformably overlies the Maquoketa Group. During this period, a shallow sea transgressed across the Illinois Basin and surrounding area, depositing carbonate sediments. This, in conjunction with the subsidence of the Illinois and surrounding basins, allowed prominent shelf-edge carbonate banks to develop. At the end of the Silurian, eustatic fluctuations, cratonic uplift, and local tectonic events caused sea level to regress. This ended sedimentation, exposing, and eroding the Silurian strata for millions of years (Mikulic et al., 2011). In Indiana, Silurian-age rocks include the Sexton Creek, Salamonie, Pleasant Mills, Wabash, and Salina Groups/Formations (Figure 4).

### *2.18 Muscatatuck Group (Devonian)*

The Muscatatuck Group lies unconformably on the Silurian System rocks (Figure 4; Shaver, 1974) and consists of all Devonian-aged strata beneath the New Albany Shale. The carbonates of the Detroit River and Traverse Formations are part of the Muscatuck Group, though it is difficult to distinguish between these two formations (Shaver, 1974).

### *2.19 New Albany Shale/Secondary Confining (Devonian)*

The New Albany Shale of Middle to Upper Devonian age unconformably overlies Silurian strata and is widely distributed across the Illinois Basin and surrounding areas. Its cumulative thickness of the organic-rich black shales is greatest near the center of the basin and thins toward the basin edge. Organic-poor, greenish-gray shales are thickest in western and west-central Illinois. A broad transitional zone, where these organic-rich and organic-poor facies interfinger and grade laterally into one another, trends northeast-southwest across central Illinois (Cluff and Dickerson, 1982).

### *2.20 Undifferentiated Mississippian Strata and the Borden Group; Lowermost USDW*

Sea level regressed during the Mississippian, and the Illinois Basin contained a river system that flowed southwestward across a swampy lowland, carrying mud and sand from the highlands located to the northeast. This river system formed thin, widespread deltas that prograded into the shallow sea that covered much of present-day Illinois. Because the lowland stood only slightly above sea level, slight changes in relative sea level caused great shifts in the position of the shoreline (Siever, 1951).

The Borden Group is composed of interbedded fluvial to near-shore shale, siltstone, and sandstone and is considered the lowermost USDW at the Linden Project site (Grove, 2009). The New Providence Shale and the Spickert Knob Formation are fine-grained delta-platform clastics that overly the Borden group. Due to the conformable nature of these strata, it is difficult to differentiate these rocks.

### *2.21 Regional Structure*

The state of Indiana (Figure 3) has been affected by three major tectonic episodes during the Phanerozoic Eon, including Rodinia-related rifting; widespread compressional (reverse) faulting during the assembly of the supercontinent Pangea in the late Paleozoic; and extensional (normal) faulting during the Mesozoic related to Pangea's breakup (Denny et al., 2020).

Major structural features in Indiana consist of the Kankakee Arch, the eastern portion of the Illinois Basin, and the southern portion of the Michigan Basin (Figure 3). The structural axis of the Kankakee Arch is approximately 50 miles north of the Linden Project site, extends across northern Illinois and northern Indiana, and separates the Michigan Basin to the northeast from the Illinois Basin to the southwest. The crest of the arch is broad, flat, and up to 75 miles wide. The Linden Project site is located just north of the Illinois Basin limit in eastern Indian and south of the Kanakee Arch.

The closest mapped structural features to the Linden Project site are the normal, northeast-trending Wolcott, Sharpsville, and Royal Center Faults, all of which are north of the project site (36 miles north-northwest, 38 miles east-northeast, and 47 miles northeast, respectively; Figure 16; Gray and Steinmetz, 2015). The Fortville Fault is located about 59 miles east of the site and is also a northeast-trending normal fault that extends for nearly 50 miles. The Mt. Carmel Fault is a north-northwest trending, steeply dipping normal fault located 65 miles south of the Linden

Project site (Melhorn, 1959). The north-trending, asymmetrical Marshall-Sidell Syncline in eastern Illinois is approximately 52 miles east of the site and has relatively gentle dips on the eastern flank (Nelson, 1995).

The Wabash Valley Fault System in southwestern Indiana is approximately 108 miles south-southwest of the site and is composed of high-angle normal faults that die out with depth (Figure 16; Nelson, 1995). The Kentland Impact Structure is 45 northeast of the site and is a circular dome and an associated deformed area that is approximately 8 miles in diameter (Figure 16). This deeply eroded structure is characterized by shatter cones, deformed bedrock, localized faults, and vertical contacts among normally horizontal strata.

High density 2D seismic data acquired specifically for the Linden Project indicates there are no significant structural features identified within the project's AoR that would impact $CO_2$ sequestration and containment. The 2D seismic is discussed in detail in Section 2.3 Faults and Fractures. The structural features listed above are significantly removed from the project area and are not considered impactful to carbon sequestration operations.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 16: Regional structural features in Indiana and Illinois. Inset map highlights the detailed mapped area. Folds are depicted as red lines and faults are shown as purple. The horizontal black line on the left shows the state boundaries. The yellow star indicates the location of the Linden Project site. Modified from Nelson (1995)**

## *2.22 Maps and Cross Sections of the AoR [40 CFR 146.82(a)(2), 146.82(a)(3)(i)]*

Figure 17 shows the AoR for the Linden Project, based on the differential pressure front after 30 years of injection and all the existing water wells within the area. There are no oil and gas wells within the Linden Project AoR. This is the maximum extent of the delta pressure front for all phases of the project. The method for delineation of the AoR is described in the AoR and Corrective Action Plan.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 17: All water wells (51) within the Linden AoR. The LSH INJ1 well is also shown. There are no oil and gas wells within the AoR.**

The Mt. Simon Arkose, Mt. Simon Sandstone, and Eau Claire Silt comprise the injection/ sequestration zone, the Eau Claire Formation is the confining zone, and all extend laterally beyond the AoR limits. This is demonstrated by the regional thickness maps (Figure 12, Figure 14), the cross section shown in Figure 5 in the Regional Geology, Hydrogeology, and Local Structural Geology section of this Narrative, as well as the 2D seismic data discussed below (Figure 18, Figure 19, Figure 20, Figure 21, and Figure 22).

Strata of the Mt. Simon Sandstone and Eau Claire Formation are of consistent thickness with no evidence of stratigraphic pinch-out within the AoR. The thickness of the total storage interval (top of the Eau Claire Silt to the bottom of the Mt. Simon Arkose) [redacted] (Figure 23). The thickness of Eau Claire Formation primary confining zone [redacted] (Figure 24). Additionally, there is no indication that structural trapping by faults or domes could occur within the AoR.

2D seismic data (Figure 18, Figure 19, Figure 20, Figure 21, and Figure 22) acquired specifically for the Linden Project and discussed in Section 2.23 Faults and Fractures of this document also indicate the Mt. Simon Sandstone and Eau Claire strata are laterally continuous and there are no structural features in the AoR that will impact storage and containment. The ductile nature of the Eau Claire Formation and lack of structural features indicate the confining zone has excellent characteristics for $CO_2$ sequestration at the Linden Project site. No potential conduits for injection zone fluids to migrate out of the Mt. Simon injection zone were identified in the AoR of the Linden Project.

The Undifferentiated Mississippian Strata, specifically the Borden Group, is the lowermost USDW present within the AoR. The top of the USDW [redacted]. There are no structural features or faults observed to intersect the undifferentiated Mississippian strata in the AoR. As described in the 2.1 Regional Geology, Hydrogeology, and Local Structural Geology section there are several secondary confining zones within the Knox Group between the Eau Claire Formation and the Mississippian strata in the AoR.

There are no oil and gas wells within the Linden AoR (Figure 17) according to the Indiana Department of Natural Resources public database. The latest water well data search indicates that 51 groundwater wells are located within the Linden AoR; [redacted] (Figure 17).

No existing well in the AoR penetrates the confining strata of the Eau Claire Formation at the Linden Project site.

### *2.23 Faults and Fractures [40 CFR 146.82(A)(3)(ii)]*

A high density 2D seismic program conducted in December 2022 acquired and processed approximately 22.5 miles of seismic data at the Linden Project site to provide information regarding subsurface structure and stratigraphy (Figure 18). A vibrator truck operating on county roads with a 2-120Hz broad band sweep of 20 second duration acquired these data. Source and receiver spacing of 32 feet was used to enable high density processing to identify both shallow and deep subsurface features. Long offsets were obtained to enable additional inversion work to identify any lithological changes at target.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 18: Map of 2D seismic lines 1, 2, and 3 acquired for the project.**

Seismic lines Line 1 (Figure 20), Line 2 (Figure 21), and Line 3 (Figure 22) acquired at the Linden Project site indicate the stratigraphy of the area to be very gently dipping to the west, continuous and without notable structural features. In the eastern Illinois Basin, the Maquoketa, Trenton, and Knox seismic horizons are generally associated with a zone of high amplitude continuous reflectors, representing the impedance contrasts between the high impedance Trenton and Knox dolomites and the low impedance Maquoketa Shale and shaley zones within the greater Knox interval (which includes the Shakopee and Potosi Formations). The Eau Claire Formation confining zone and the Mt. Simon Sandstone storage zone are indicated to be of relatively consistent thickness and with no structural features that would impair storage or containment.

There are no deep wells near the Linden seismic lines that would allow a direct tie to the seismic. The Wabash #1 well, a characterization drilled as part of the CarbonSAFE project (Department of Energy DE-FE0031626), is located about 55 miles to the south-southeast. Data from Wabash #1 is publicly available through the Department of Energy Data eXchange (EDX) website (Korose, 2022). Log data from this well was used to generate a synthetic seismogram which was then used to help correlate the same stratigraphy to the Linden 2D seismic (Figure 19). Although Wabash #1 is located some distance from the seismic lines, which leads to more uncertainty in the seismic interpretation than if a well was located close to the seismic lines, the stratigraphy and resulting seismic stratigraphy in the eastern part of the Illinois Basin is generally well understood.

The Precambrian pick was based upon three factors: 1) the Wabash #1 well tie, 2) analysis of interval velocities of the Wabash #1 well, and 3) the identification of a reflector at about the predicted two-way travel time that showed a subtle but clear angular unconformity visible at the Precambrian reflector on both seismic Lines 1 and 2 (Figure 20 and Figure 21).

One clear seismic artifact is visible on the northern end of Line 1 [redacted] (Figure 20). This feature appears to be formed by the presence of a very low velocity feature in the shallow section, likely in the first few hundred fbgl. The feature displays an upside-down cone shape, expanding as it progresses deeper, with a convex-down shape. These characteristics are indicative of a shallow low velocity anomaly that is not a fault or fracture.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 19: Well logs and synthetic seismogram from the Wabash#1 well (see Figure 6 and Figure 25 for location). The penetrated stratigraphy at the Wabash #1 well location is similar to the Linden Project site and was used to tie the 2D seismic for seismic interpretation.**

**Figure 20: CBI South-north 2D seismic Line 1 from the Linden Project site with annotated interpreted stratigraphy (see Figure 18 for location).**

**Figure 21: CBI West-east 2D seismic Line 2 from the Linden Project site with annotated interpreted stratigraphy (see Figure 18 for location).**

**Figure 22: CBI West-east 2D seismic Line 3 from the Linden Project site with annotated interpreted stratigraphy. The diagonal black line is a possible fault that originates in the Precambrian Basement (see Figure 18 for location).**

### 2.24 Impact on Containment and Tectonic Stability

Previously collected seismic data associated with $CO_2$ sequestration projects in the Illinois Basin suggest that minor faults in the Precambrian and Argenta/Mt. Simon strata are not expected to act as conduits through the confining zone (Greenberg, 2021) and that they present negligible endangerment to USDWs.

A future baseline 3D surface seismic survey will be conducted at the Linden Project site prior to injection. This survey will evaluate injection and confining zone properties, map Precambrian basement topography as well as any subsurface structural features or faults that may potentially be present, and assess their potential impact to storage or containment. The 3D seismic survey will be designed to obtain full fold data over the predicted extent of the $CO_2$ plume after 25 years of injection and proposed PISC period (Attachment 07: Testing and Monitoring, 2023).

The data gathered during the pre-operational phase of the project will be used for geomechanical modeling to evaluate the influence of regional stresses on any minor faults identified in the surface seismic data. The Pre-Operational Testing Program details the geophysical log and core data that will be acquired to evaluate the nature of any identifiable fractures and their impact on long-term integrity of the confining zone (Attachment 5: Pre-Op Testing Program, 2023).

Faults originating in the Precambrian basement and terminating in the basal units of the Argenta and Mt. Simon Sandstone have not been active since Cambrian time. Regionally, thickness changes in the Cambrian-aged Argenta, Arkose, and Lower Mt. Simon formations may be related to interpreted syn-depositional fault movement along the basement-involved faults, but at the Linden Project site no changes in thickness of strata overlying the Mt. Simon Sandstone can be attributed to these faults, suggesting there has been little active faulting since early Cambrian time.

In the area of the Linden Project in Indiana, earthquakes above M 2.5 are rare. See Section 2.6 Seismic History.

### 2.25 Injection and Confining Zone Details [40 CFR 146.82 (a)(3)(iii)]

#### 2.25.1 Injection Zone and Confining Zone Extent and Thickness

The Mt. Simon Arkose, Mt. Simon Sandstone, and the Eau Claire Silt units together represent the injection and sequestration zone for the Linden Project. Within this package, the Middle Mt. Simon unit typically has relatively poor reservoir quality in the Illinois Basin and surrounding area and it serves as a baffle to upward fluid migration. Most of the injected $CO_2$, as simulated and described in Attachment 02: AoR and Corrective Action Plan, 2023 remains in the Mt. Simon Arkose and Lower Mt. Simon Sandstone. The Upper Mt. Simon Sandstone can also have good reservoir characteristics and is used for natural gas storage within the Illinois Basin region.

The Eau Claire Formation above the Eau Claire Silt is the confining zone for the Linden Project (Figure 4). Regional characteristics of the injection and confining zones are also described in Section 2.1.1 Regional Stratigraphy.

Available public data were collected and integrated to develop site-specific subsurface maps, petrophysical relationships, and a static model of the Linden Project site. Geophysical well logs were used to generate thickness maps for the entire injection and sequestration interval between the top of the Eau Claire Silt and the bottom of the Mt. Simon Arkose (Figure 23) and the Eau Claire Formation primary confining zone (Figure 24).

Within the Linden AoR there are only minor elevation variations and no significant thinning of either the injection/sequestration zone (Eau Claire Silt, Mt. Simon Sandstone and Mt. Simon Arkose) or confining zone (Eau Claire Formation). Sensitive, Confidential, or Privileged Information [redacted] (Figure 23). Sensitive, Confidential, or Privileged Information [redacted] (Figure 24). Site specific 2D seismic data discussed in the Faults and Fractures section of this Narrative that confirms the lateral continuity and structural integrity of these strata across the AoR.

$CO_2$ plume development is expected to be controlled dominantly by sedimentological heterogeneities within the injection zone, as structural features will have minimal influence on plume development at this site. The Eau Claire Formation primary confining zone will provide a thick, laterally extensive barrier to prevent upward migration of injection zone fluids over time.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 23: Thickness (feet) of the injection/sequestration zone (Eau Claire Silt, Mt. Simon Sandstone, Mt. Simon Arkose) in the AoR.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 24: Thickness (feet) of the confining zone (Eau Claire Formation) in the AoR.**

### *2.25.2 Porosity and Permeability*

Public log and core information from six wells in Illinois and Indiana provide significant data to characterize the injection and confining zones at the Linden Project site. Available wells that penetrate the Mt. Simon Sandstone or deeper are from gas storage sites, UIC Class I and VI sites, and stratigraphic test wells that have well logs, core, and fluid injection data from the Mt. Simon Sandstone and Eau Claire Formation (Figure 25). The Hinton #7 well is approximately 84 miles west of the Linden Project site in the Manlove Natural Gas Storage Field, Champaign County, Illinois (Figure 25 and Figure 26) and represents an analog for the injection and confining zones. The Allied Chemical well is 39 miles west of the site and also serves as a geologic analog for the storage system (Figure 25 and Figure 27); however, this well does not penetrate below the Middle Mt. Simon Sandstone (Figure 27).

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 25: Wells used for petrophysical analysis of the Linden injection and confining zones.**

### *2.25.3 Mt. Simon Sandstone*

As described in Section 2.1.1 Regional Stratigraphy, the Mt. Simon Sandstone can be divided into Lower, Middle, and Upper intervals with a basal Arkose Sandstone unit (Figure 4) that often has enhanced reservoir quality through secondary porosity development that resulted from the dissolution of feldspar grains (Leetaru and McBride, 2009; Medina and Rupp, 2012; Freiburg et al., 2016; Leetaru et al., 2019). As shown in the cross-section of Figure 5, the sub-units of the Mt. Simon Sandstone are present across a wide expanse within and surrounding the Illinois Basin including the Arkose zone that can be correlated regionally. For example, the Hinton #7 well [redacted] excellent quality reservoir in the Arkose zone with porosity and permeability values up to 25% and 600 millidarcy (mD) as shown in Figure 26, and at ADM CCS1 about 107 miles southwest of the Linden Project site, [redacted]. Very good reservoir quality is found in the Arkose zone at each of these wells including porosity values that are generally over 20% and permeability values of 100's to 1,000's of mD.

The Middle Mt. Simon Sandstone generally has poorer reservoir properties than either the Lower or Upper Mt. Simon units (Leetaru and Freiberg, 2014; Whittaker and Carman, 2022). At Hinton #7, the Middle Mt. Simon Sandstone has lower log-derived porosity and permeability averages (7.6%, 2.1 mD) relative to the Lower Mt. Simon (9.0%, 11.9 mD; Figure 26) and the Upper Mt. Simon Sandstone (9%, 7.6 mD). The Upper Mt. Simon Sandstone may exhibit good reservoir characteristics particularly in thin, tidal flat channel sands such as are utilized for natural gas storage in the basin, as observed in the Hinton #7 well (Morse and Leetaru, 2005; Figure 26). Core data from the Allied Chemical well also shows increased reservoir quality in the Upper Mt. Simon Sandstone compared to the Middle Mt. Simon Sandstone (Figure 27). Leetaru et al. (2019) describe the Mt. Simon Sandstone as heterogeneous with interbedded shale regional log-derived porosity and permeability averages of 8.5% and 5.4 mD, respectively, although more porous and permeable units are present.

At ADM CCS1 and TR McMillen #2 the Middle Mt. Simon consists of planar parallel and low-angle to trough cross-stratified, medium- to coarse-grained pure quartz sandstone, interbedded with thin intervals of feldspar sandstone. The average porosity and permeability of the Middle Mt. Simon strata at ADM CCS1 (Table 4) is 8.7% and 10.2 mD, respectively, and will impair vertical movement of $CO_2$ out of the injection zone.

Average log-derived effective porosities and permeabilities for the Argenta Formation, the Mt. Simon Sandstone intervals, and the Eau Claire Silt for the Hinton #7 well are reported in Table 4 and Figure 26. The Mt. Simon Arkose zone has the best reservoir quality, with a mean log-derived effective porosity of 17.1% and a mean permeability of 146.6 mD. These porosity and permeability data also show that both the Lower Mt. Simon Sandstone and the Upper Mt. Simon Sandstone have relatively higher reservoir quality relative to the Middle Mt. Simon Sandstone. Core porosity and air permeability data from the Allied Chemical well (Figure 27) indicates that the Upper Mt. Simon Sandstone has good reservoir quality; the Lower Mt. Simon Sandstone and the Mt. Simon Arkose were not penetrated in this well and thus petrophysical data is not available for these units in this well.

**Table 4: Hinton #7 depth interval, formation, average effective porosity, and average intrinsic permeability for the Eau Claire Silt, and Mt. Simon Sandstone intervals, and the Argenta Formation.**
[redacted]

Sensitive, Confidential, or Privileged Information

[redacted]

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 26: Hinton #7 (IL12019239960000) geophysical logs with measured depth (MD), formation tops, well log average effective porosity (%), and intrinsic permeability (mD) values. GR_norm=normalized gamma ray log; RESD and RESM =deep and medium resistivity; DPHI SS=sandstone density porosity, NPHI SS=sandstone neutron porosity, PHIE=effective porosity, Perm Vault=permeability in mD, and black circles=core porosity.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 27: Allied Chemical (IL121830184800) geophysical logs with measured depth (MD), formation tops, horizontal/vertical core air and water permeability (mD) values, DPHI SS=sandstone density porosity, NPHI SS=sandstone neutron porosity, PHIE=effective porosity, Perm Vault=permeability in mD, and black circles=core porosity.**

Site specific information from the injection zone will be acquired when the project wells are drilled through the pre-operational testing program and will include, but are not limited to, well logging, fluid sampling, and core acquisition and analysis.

The baseline 3D surface seismic data will be calibrated to the well data and used for inversion analysis. This will allow the project to characterize variations in injection zone porosity and lithology away from the project wells over the imaging area of the 3D surface seismic data volume.

### *2.25.4 Eau Claire Formation*

The low porosity, clay-rich mudstones of the Eau Claire Formation have extremely low permeabilities and serve as an effective seal for gas storage projects in the Illinois Basin (Patrick Engineering, 2011). At the Hinton #7 well (Figure 26), the Eau Claire Formation seal is [redacted] of generally low porosity and permeability mudstone (1% and 0.04 mD, respectively). Core data from the Allied Chemical well indicate that "the Eau Claire Formation has excellent characteristics to serve as a cap-rock for liquid waste disposal in underlying formations," with an average permeability less than 0.001 mD and an average porosity of 4% (Lohmann-Johnson Pollution Control Inc., 1972).

At ADM CCS1, the upper portion of Eau Claire Formation is composed of dense limestone with siltstone stringers, and the lower portion primarily consists of shale (60% clay minerals and 37% quartz and potassium feldspar) with a silt interval at the base of the formation. Twelve sidewall cores were collected from the Eau Claire Formation in ADM CCS1, and the average horizontal permeability for these cores is 0.00034 mD.

Average vertical permeability of the Eau Claire Formation is expected to be lower than horizontal permeability, and regional collection of Eau Claire Formation core from underground injection wells shows that the confining zone has median regional porosity and permeability values of 4.7% and 0.000026 mD, respectively (Patrick Engineering, 2011; Neufelder et al., 2012; Lahann et al., 2014) inferred that MICP values and higher permeabilities of the coarser grained Eau Claire Formation lithofacies may have entry pressures that could allow $CO_2$ to enter the formation and the finer grained, whereas clay-rich lithofacies have MICP values and lower permeability that would restrict $CO_2$ movement (Figure 16).

Experimental results and modeling using samples of Eau Claire Formation from CCS1 (Roy et al., 2014) have shown that advective flow and ionic diffusion of $CO_2$ from the Mt. Simon Sandstone into the Eau Claire is expected to be insignificant.

Similar to the injection zone, well logs, core analyses, and seismic data collected as part of the pre-operational testing program will be used to further characterize the porosity and permeability of the confining zone (Attachment 05: Pre-Op Testing Program, 2023). The capillary pressure of the confining zone is not yet known at the Linden Project site; however, the permeability of the confining zone is expected to be very low and unlikely to allow vertical migration of $CO_2$. Capillary pressure and permeability will be measured as part of the Eau Claire Formation core analysis reported in Attachment 05: Pre-operational Formation Testing Program, 2023.

As the Eau Claire Formation regionally exhibits effective seal characteristics, it is expected to be a thick, competent seal for the underlying Mt. Simon Sandstone injection zone at the Linden Project site.

#### *2.25.5 Knox Group*

The thick Knox Group carbonates above the Eau Claire Formation are considered a secondary confining zone. These formations include the Potosi/Eminence, Oneota, and Shakopee Formations (Figure 4). The low-porosity Knox Group carbonates may function as locally effective seals for $CO_2$ injection (Leetaru, 2014) though the Potosi Formation may have permeable intervals (Willman et al., 1975). At the base of the Knox Group, porous members of the Ironton-Galesville Sandstones will be used for ACZ monitoring.

Well logs acquired as part of the pre-operational testing program will be used to further characterize the porosity and permeability of the Knox Group formations and verify that some of the formations will provide an effective secondary confining zone (Attachment 05: Pre-operational Formation Testing Program, 2023).

#### *2.25.6 Maquoketa Group/Formation*

The regional Maquoketa Shale generally exceeds 100 feet thickness within the Illinois Basin and surrounding area, and regionally serves as a seal for hydrocarbons in the underlying Trenton Limestone (Patrick Engineering, 2011). Young (1992) indicates the Maquoketa Shale is a low permeability groundwater-confining unit throughout the Midwest. Core from Kentucky reveals that the Maquoketa is a black, fissile shale dominated by clay minerals and has both sufficiently low permeability and high compressive strength to serve as confining zone for an underlying $CO_2$ injection zone. In the Decatur area of the central Illinois Basin, the Maquoketa Shale contains higher fractions of quartz and carbonate minerals relative to clays and is thinly laminated with low effective porosity (<3%) and permeability ($<9.86 \times 10^{-12}$ $cm^2$ [1 mD] (Zaluski, 2014).

### *2.26 Geomechanical and Petrophysical Information [40 CFR 146.82 (a)(3)(iv)]*

#### *2.26.1 Geomechanics*

A single well, radial, layer-cake (99 layers) geomechanical model was constructed for the Linden Project to test the integrity of the confining zone as described in Attachment 02: AoR and Corrective Action Plan. Average values of Young's Modulus, Poisson's Ratio, and bulk compressibility were calculated for the Eau Claire and Mt. Simon formations using data from the Hinton # 7 well (Table 5). Average values of total closure stress and pore pressure are shown in Table 6. The large difference between the total closure stress and the pore pressure indicates that there is a sufficient buffer that will allow a significant injection rate to occur without opening existing fractures. Figure 28 is a log with the calculated geomechanics properties calculated on 0.5-foot intervals. The calculated values of total closure stress were compared to actual values from step-rate tests and were found to be in good agreement. These geomechanical data were then used to model the Eau Claire Formation confining zone integrity with an anticipated injection rate of 0.7 Mtpa.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 28: CBI: Geomechanical data calculated from the Hinton #7 well (IL12019239960000).**

**Table 6: CBI: Average values of total closure stress and pore pressure calculated from the Hinton # 7 LAS file.**

| CBI | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

The geomechanical model predicts that fracturing will not occur in the Mt. Simon Sandstone injection zone or the Eau Claire Formation confining zone at operational conditions planned for the Linden Project (i.e., maximum rate = 0.7 Mtpa). To further evaluate operational limitations, a sensitivity case was run using a BHFP constraint equal to the fracture opening stress; this required a corresponding injection rate of 2.3 Mtpa or three times the rate currently proposed. In this case, fractures open near the wellbore in the Upper Mt. Simon Sandstone (injection zone) but do not propagate into the Eau Claire Formation confining zone. Therefore, even at rates three times the planned operational rate, no fractures would be created in the confining zone and no pathway for $CO_2$ leakage through the confining zone would be created.

During the pre-operational phase of the project, a variety of site-specific data from the confining and injection zones will be acquired in the project wells to support further geomechanical modeling (Attachment 05: Pre-operational Formation Testing Program, 2023). These data include:

- Caliper, dipole sonic, and image logs,
- Triaxial testing to establish geomechanical parameters such as rock strength, Young's Modulus, Poisson's Ratio, and fracture gradient,
- Step-rate testing.

### *2.26.2 Petrophysics*

Petrophysical analysis of the Mt. Simon Sandstone and the Eau Claire Formation was completed using six (6) wells in the general region of the Linden Project site (Figure 25 and Table 7). Log ascii standard (LAS) files and routine core data was acquired from the Indiana Geological & Water Survey, the Illinois State Geological Survey, and Illinois Oil and Gas Resources Map.

Sensitive, Confidential, or Privileged Information

[redacted]

Core and log data were calibrated to well test data that was publicly available from the Hinton #7 and Allied Chemical wells. Cross plots and histograms were made using this data which enabled better analysis of wells that did not have core data and an improved the geologic model (Figure 29, Figure 30, and Figure 31.).

Petrophysical analyses were completed to evaluate the characteristics of the confining and injection zones (Figure 28, Figure 29, Figure 30, Figure 31). Geophysical well logs, core plugs, and well test data were used to calibrate the petrophysical calculations to derive effective porosity and permeability (Figure 29 and Figure 30). These analyses will be re-visited once the project acquires site-specific well logs and core data in the project wells (Attachment 05: Pre-operational Formation Testing Program, 2023).

Pre-processing work on the raw log data, including depth shifting, unit conversion, and synthetic log generation, was performed prior to the petrophysical calculations. Gamma, neutron porosity, sonic, PE, and density logs were used to derive the petrophysical properties for the six wells, which included:

- Effective Porosity
- Permeability
- Mineralogy (where data quality was reliable)
    - Volume Shale (VSH_V)
    - Volume Quartz (Quartz_V)
    - Volume Limestone (Limestone_V)
    - Volume Dolomite (Dolomite_V)
    - Volume Sphalerite (Sphalerite_V)
    - Precambrian (Basalt_V)
    - Bound Water (BVW_V)

Table 8 and Table 9 summarize petrophysical values determined from geophysical well logs and calibrated using data from core and reservoir testing for the Mt. Simon Sandstone and Eau Claire Formation, respectively. The petrophysical values are incorporated into the static model for the

Linden Project site (Attachment 02: AoR and Corrective Action Plan, 2023). Of the wells evaluated that have data throughout the entire Mt. Simon Sandstone interval, the Hinton #7 and the Allied Chemical wells have the highest Mt. Simon Sandstone average porosity and permeability values, whereas IN168045 has relatively lower values.

The effective porosity/permeability cross plots (Figure 29), effective porosity histograms (Figure 30), and permeability histograms (Figure 31) indicate that the Upper, Lower, and Mt. Simon Arkose Sandstone intervals have the highest porosity and permeability values. The Middle Mt. Simon has slightly poorer reservoir quality. The Argenta Formation and Eau Claire Shale have the lowest porosity and permeability values. (Attachment 02: AoR and Corrective Action Plan, 2023)

The petrophysical and core data show that the Mt. Simon Sandstone is primarily composed of quartz sandstone with some interbedded shale layers and demonstrates that the Lower and Upper Mt. Simon Sandstone intervals generally have better reservoir quality. The Eau Claire Formation primary confining zone has significantly lower effective porosity and permeability values and higher shale content compared to the underlying Mt. Simon Sandstone, and the carbonate content increases upward (Figure 29 and Figure 30).

**Table 8: Summary of log-derived porosity values for the Mt. Simon Sandstone, Eau Claire Formation, and the Ironton-Galesville Sandstones from wells in the region. Cells without data indicates the well logs did not penetrate the entire formation.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Table 9: Summary of log-derived permeability values for the Mt. Simon Sandstone, Eau Claire Formation, and the Ironton-Galesville Sandstones from wells in the region. Cells without data indicates the well logs did not penetrate the entire formation.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 29: CBI: Effective porosity (PHIE) and permeability cross plots with core plug values (grey squares). A) the Eau Claire Formation confining zone above Eau Claire Silt, B) the Upper Mt. Simon Sandstone and the Eau Claire Silt storage zone, C) the Middle Mt. Simon Sandstone, D) the Lower Mt. Simon Sandstone, E) the Mt. Simon Arkose, and F) the Argenta Formation.**

**Figure 30: CBI: Effective porosity (PHIE) histograms of the key petrophysical wells. The plots are divided into the various storage and confining intervals: A) the Eau Claire Formation confining zone above Eau Claire Silt, B) the Upper Mt. Simon Sandstone and the Eau Claire Silt storage zone, C) the Middle Mt. Simon Sandstone, D) the Lower Mt. Simon Sandstone, E) the Mt. Simon Arkose, and F) the Argenta Formation.**

**Figure 31: CBI: Permeability (mD) histograms of the key petrophysical wells. The plots are divided into the various storage and confining intervals: A) the Eau Claire Formation confining zone above Eau Claire Silt, B) the Upper Mt. Simon Sandstone and the Eau Claire Silt, C) the Middle Mt. Simon Sandstone, D) the Lower Mt. Simon Sandstone, E) the Mt. Simon Arkose, and F) the Argenta Formation confining zone.**

**Figure 32: CBI: Hinton #7 (IL12019239960000) geophysical logs and petrophysical results. Normalized gamma-ray API (Gamma), resistivity (Res), and porosity (PHI) logs are shown. Effective porosity (PHIE), permeability (Perm), mineralogy/rock type (Limestone, Dolomite, Sphalerite, Sandstone), and bound water (Water). Core porosity data are represented by black circles.**

**Figure 33. CBI: Allied Chemical (IL12183018480000) geophysical logs and petrophysical results. Normalized gamma-ray API (Gamma), resistivity (Res), and porosity (PHI) logs are shown. Effective porosity (PHIE), permeability (Perm), mineralogy/rock type (Limestone, Dolomite, Sphalerite, Sandstone), and bound water (Water). Results from petrophysical analyses are also displayed. Core porosity data are represented by black circles.**

### *2.27 Seismic History [40 CFR 146.82(a)(3)(v)]*

Based on Federal Emergency Management Agency (FEMA) classification the Linden Project site has a very small probability of experiencing damaging earthquake effects. The site is more than 240 miles north of the Strongest Shaking Zone E associated with the New Madrid Seismic Zone (Figure 34). All earthquakes since 1800 having a magnitude of 2.5 or greater and within a 100-mile radius of the Linden Project site are shown in Figure 35 and listed in Table 10 (USGS 2023). The largest earthquake within this 100-mile radius occurred in 1909 approximately thirty-four miles southwest with a magnitude of 5.1 Mw. The most recent earthquake occurred on 17 June 2021, approximately thirty-five miles southwest from the project site near the Indiana/Illinois border and had a magnitude of 3.8. No earthquakes have been recorded that have an epicenter within the project AoR.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 34: FEMA Earthquake Hazard Map shows that the project site (yellow star) is located in the lowest earthquake hazard category A. The New Madrid Seismic Zone is in Zone E.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 35: Map of earthquake epicenters with 2.5 or greater magnitude that occurred between 1 January 1800 to 8 February 2023 within 100 miles (black circle) of the Linden AoR. (USGS 2023).**

**Table 10: Events 2.5 or greater magnitude from 1800 to February 2023 with epicenters within 100 miles (USGS, 2023).**

| Date | Latitude | Longitude | Depth | Magnitude | Place |
|---|---|---|---|---|---|
| 09/27/1909 | 39.80 | -87.20 | | 5.1 | 4 km NNE of Rockville, Indiana |
| 03/14/1921 | 39.50 | -87.50 | | 4.4 | 3 km WSW of Saint Mary-of-the-Woods, Indiana |
| 02/16/1978 | 39.80 | -88.23 | 5 | 2.7 | 4 km E of Tuscola, Illinois |
| 06/12/1984 | 38.92 | -87.46 | 3 | 3.4 | 5 km NNW of Oaktown, Indiana |
| 07/28/1984 | 39.22 | -87.07 | 10 | 4.0 | 6 km SE of Middlebury, Indiana |
| 08/29/1984 | 39.11 | -87.45 | 10 | 3.1 | Illinois-Indiana border region |
| 12/29/1988 | 38.99 | -87.73 | 5 | 2.9 | 1 km SSE of Robinson, Illinois |
| 01/03/1989 | 38.99 | -87.72 | 5 | 2.8 | 2 km SE of Robinson, Illinois |
| 12/17/1990 | 40.07 | -87.04 | 10 | 3.2 | Illinois-Indiana border region |
| 12/20/1990 | 39.59 | -86.63 | 5 | 3.7 | 5 km S of Stilesville, Indiana |
| 11/11/1991 | 38.91 | -87.71 | 0 | 3.8 | 3 km W of Flat Rock, Illinois |
| 12/16/1996 | 39.50 | -87.40 | 5 | 3.1 | 3 km NNE of Terre Haute, Indiana |
| 04/14/2000 | 39.76 | -86.75 | 5 | 3.6 | 4 km NW of Heritage Lake, Indiana |
| 09/12/2004 | 39.60 | -85.66 | 2.40 | 3.8 | 4 km NW of Manilla, Indiana |
| 11/28/2007 | 39.06 | -87.66 | 3.16 | 2.5 | 5 km S of Hutsonville, Illinois |
| 12/30/2010 | 40.43 | -85.91 | 5 | 3.8 | 6 km SE of Greentown, Indiana |
| 05/10/2012 | 38.82 | -87.46 | 8.89 | 2.7 | 1 km NNW of Emison, Indiana |
| 05/10/2012 | 38.82 | -87.46 | 10.70 | 3.1 | 0 km NW of Emison, Indiana |
| 06/17/2021 | 39.83 | 87.29 | 6.26 | 3.82 | Illinois-Indiana border region |

## *2.28 Hydrologic and Hydrogeologic Information [40 CFR 146.82(a)(3)(vi), 146.82(a)(5)]*

The following sections provide information regarding available drinking water resources and delineation of the lowermost Underground Source of Drinking Water (USDW), which is the Mississippian strata overlying the New Albany Group around the project site. Water well, monitoring well, and dry well records were collected for the project AoR from the Indiana Geological Survey. A total of 51 shallow water wells are located within the AoR. Attachment 02: AoR and Corrective Action Plan, 2023 includes a detailed discussion of the number and locations of the groundwater wells within the AoR. Shallower USDW sources occur in the unconsolidated glacial sediments overlying Mississippian bedrock.

### *2.28.1 Near Surface Aquifers*

The study site is located within the Wea Creek sub-basin of the Wabash River Watershed. This watershed drains rural, agricultural land and communities across much of Indiana and is a tributary to the Ohio River (Figure 36). The AoR is located on the Wisconsin Tipton Till Plain, which has flat to gently rolling topography created by glaciers and is composed of glacial deposits and Pleistocene fill (Figure 37). The average ground elevation within the AoR is approximately 760 feet above mean sea level (MSL).

Indiana glacial deposits overly bedrock and affect surface hydrology and aquifers in the region. During the Pleistocene Epoch, Indiana experienced several glacial intervals, and glacial processes and post-glacial streams deposited [redacted] till and valley fill in certain areas of the state. Specific to glacial geology, [redacted] of unconsolidated glacial drift and moraine deposits of the Wisconsin Tipton Till Plain (Figure 38) overlie the Mississippian-aged Borden Group bedrock (Figure 39).

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 36: Map of the Wabash River Watershed with cities and EPA Toxics Release Inventory (TRI) sample locations along the river. HUC = hydrologic unit code. From Stone and Latimer (2018).**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 37: Map of Indiana glacial deposits shows that the Linden Project site is located on glacial deposits composed of till, sand, and gravel. Modified from (Wayne, 1958)**

[redacted]

**Figure 38: Map of glacial drift thickness in feet. At the project site, [redacted] glacial drift are expected. Modified from IndianaMap.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 39: Bedrock geology underlying unconsolidated glacial drift. The Project site, indicated by the yellow star, is located above the Mississippian Borden Group bedrock.**

### *2.28.2 Local Hydrology*

There are four main sources of groundwater in southern Tippecanoe and northern Montgomery Counties: 1) the unconsolidated Iroquois/Tipton Till unconsolidated aquifer, 2) the Mississippian Borden Group bedrock aquifer, 3) the Devonian New Albany Shale bedrock aquifer, and 4) the Silurian and Devonian carbonate bedrock aquifer (Grove, 2009b, 2009a). Specifically, the area within and surrounding the Linden Project site utilizes the Iroquois/Tipton Till unconsolidated aquifer and Mississippian Borden Group bedrock aquifer. As the Mississippian strata is difficult to differentiate, the top of the New Albany Shale is interpreted to be the base of the undifferentiated Mississippian strata.

The sand and gravel of the Iroquois/Tipton Till aquifer tend to be thin and discontinuous; although, wells extracting water from this aquifer are capable of meeting the needs of most domestic and some high-capacity users. Wells producing from this aquifer system are typically 55 to 110 feet deep (Grove, 2009a, Grove 2009b).

The project site is underlain by [redacted] fine grained clastics of the Mississippian Borden Group (Figure 39 and Figure 40). This system is generally not productive and used only when glacial deposits do not contain permeable sediment. The Borden Group is described as an aquitard in areas in Indiana, and wells that produce from these rocks access fractures [redacted] in Tippecanoe and Montgomery Counties (Grove 2009a). Domestic wells either produce from the overlying unconsolidated deposits, access fractures in the New Albany Shale north of the project or produce water from the Racoon Creek clastics south and east of the project site. Reported well depths within the Linden AoR range from 18 to 410 feet deep. Well # 397902 is a 'test' well that was initially drilled to [redacted] depth, penetrating bedrock [redacted], and then subsequently plugged [redacted] (Indiana Department of Natural Resources, 2006).

As stated in the Regional Stratigraphy Section of this Narrative, the New Albany Shale consists mostly of organic-rich black shale and organic-poor gray shale with minor amounts of dolomite and quartz sandstone. Wells completed in the shale typically have little to no yield (Grove, 2009a; Grove, 2009b) and some contain sulfur (Figure 42) and are not considered sources of potable water. The United States Geological Survey (USGS) cross section in Figure 41 shows that unconsolidated glacial deposits and Mississippian bedrock are the primary aquifers for the area.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 40: Aquifer map of southern Tippecanoe County and northern Montgomery County. Modified from Grove (2009a, 2009b).**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 41: North-south hydrogeologic cross section through Tippecanoe and Montgomery Counties (Fenelon et al., 1994).**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 42: Well record (well #15882) shows that sulfur water was found [redacted] in the New Albany Shale.**

### *2.28.3 Determination of Lowermost USDW*

A USDW is defined by the EPA as an aquifer that (40 CFR 146.3):

- Supplies any public water system
- Contains a sufficient quantity of groundwater to supply a public water system; and
    - Currently supplies drinking water for human consumption, or
    - Contains fewer than 10,000 mg/l total dissolved solids (TDS),
- Which is not an exempted aquifer.

At the Linden Project site, the Mississippian Borden Group is the lowermost USDW. For the purposes of this project, the lowermost USDW will be mapped as the top of the Upper Devonian New Albany Shale so as to include all undifferentiated Mississippian bedrock.

Cable and Robison (1974) presented analyses of groundwater in Montgomery County from Quaternary aquifers and Mississippian bedrock aquifers. Water samples from Quaternary aquifers [redacted] had TDS ranging from 378 to 520 ppm. Water samples from Mississippian bedrock aquifers [redacted] had TDS from 369 to 562 ppm. They further note that water is increasingly mineralized with depth.

The St. Peter Sandstone is predicted to have a TDS value near 50,000 mg/l in the region of the Linden Project and is not considered to be a USDW at the Linden Project site (Figure 43). At the Allied Chemical well 39 miles west of the Linden Project (Lohmann-Johnson Pollution Control Inc., 1972) the St. Peter Sandstone formation fluids have a TDS of 14,900 mg/L. Based on regional data and mapping, the Mt. Simon Sandstone injection and storage zone formation water TDS is expected to be more than 150,000 mg/L at the Linden Project site (Figure 44).

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 43: Map of the St. Peter Sandstone TDS, and the yellow star represents the project site. This is unpublished work by the Illinois State Geological Survey**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 44: Map of TDS concentration contours in the Mt. Simon Sandstone formation water. The project site is represented with a yellow star and sample locations are shown by orange circles. (Modified from Mehnert and Weberling, 2014)**

### *2.28.4 Topographic Description*

The Linden Project is located in Section 3, Township 20N, Range 4W, Montgomery County at an elevation of approximately 760 feet above sea level. It is part of the Tipton Till Plain Physiographic Province, which is characterized by generally flat or gently sloping topography with glacial deposits overlying bedrock. This is an area of minimal flood hazard as established by the FEMA, and a Zone A flood hazard (1% chance of annual flooding) is located more than 1.5 miles to the north of the site along the flood plain of the Romney-Fraley Ditch (Figure 45; FEMA, 2022).

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 45: National Flood Hazard Layer from the FEMA Flood Map web site. The LSH INJ1, LA OBS1, LB USDW1, and LR ACZ1 wells are shown. No flood hazards exist within the Linden Project AoR.**

## 2.29 Geochemistry [40 CFR 146.82(a)(6)]

### 2.29.1 Data Sources, Analyses

There has been extensive research into the regional understanding of the geochemistry of fluids and lithology of most strata within the Illinois Basin and surrounding area from numerous studies by the Illinois State Geological Survey as well as detailed work at CCS projects in the Illinois Basin including the IBDP (Greenberg, 2022), IL-ICCS (Gallokata and McDonald, 2014), and CarbonSAFE Illinois – Macon County (Whittaker and Carman, 2022). Although local variations will exist, there is high confidence in the bulk lithology and mineralogy of rock and geochemistry of formation fluids in injection zone and confining zone in the Linden AoR. Formation fluids, full-diameter rock core, and side-wall core samples have been collected and analyzed by the projects identified above.

The Pre-Operational Testing Program details the data that will be acquired in the Linden Antilles Deep Observation Well 1 (LA OBS1) and LSH INJ1 that may be used to support future geochemical evaluation (Attachment 5: Pre-Op Testing Program, 2023). The mineralogy of the injection zone and confining zone will be determined through a combination of core analysis and well logging. Well log data will also be acquired through the lowermost USDW and ACZ monitoring zone to assist in establishing the mineralogy of these formations. Fluid samples will also be collected and analyzed from Mississippian strata above the New Albany Formation, (lowermost USDW), the Ironton-Galesville Sandstones (ACZ), and the Mt. Simon Sandstone (injection zone).

The Testing and Monitoring Plan details the parameters and analytes that will be used to establish baseline conditions for these formations as well as during the injection phase of the project (Attachment 7: Testing and Monitoring Plan, 2023). The aqueous geochemistry data gathered during the pre-operational phase of the project will also be used to support future geochemical modeling work. Geochemical modeling will likely focus on reactions in the injection zone and any reactions in the confining zone that may impact long-term containment and endangerment of USDWs.

### 2.29.2 Fluid Geochemistry

Many fluid samples have been collected from the Mt. Simon Sandstone in the central Illinois Basin (e.g., Locke et al., 2013). To fulfil the requirements for Underground Injection Control (UIC) Class I or VI permits for the IBDP and IL-ICCS projects, the Illinois State Geological Survey has collected fluid samples since 2011 from both the Mt. Simon Sandstone and St. Peter Formation from these sites at Decatur, IL about 107 miles west-southwest of the Linden Project site. Mt. Simon Sandstone fluids are of the Na-Ca-Cl type with Cl/Br ratios typically ranging 165±15 (Panno et al., 2013). The general range of TDS measured for fluids from Mt. Simon Sandstone at the Decatur, IL, sites is from 150,000 - 200,000 mg/L and the salinity at the Linden Project site is expected to be slightly lower around 100,000 mg/L (Figure 43).

### 2.29.3 Solid-Phase Geochemistry

The mineralogy of the Mt. Simon Sandstone has been regionally characterized by numerous studies (Carroll et al., 2013; Freiburg et al., 2014; Yoksoulian et al., 2014; Davila et al., 2020; Shao et al., 2020) that indicate it is dominated by quartz (63-95%) with lesser amounts of feldspar (2-22%), authigenic clay, and detrital clay minerals (Freiburg et al., 2014). The clay-sized fraction of minerals usually present in the Mt. Simon Sandstone are a very small percentage (1–3% by volume). The comparison of the clay mineral components of the Mt. Simon Sandstone in central Illinois is fairly consistent among wells and are predominantly illite, montmorillonite, fine mica, and minor kaolinite.

### 2.29.4 Geochemical Reactions and Modeling

Laboratory batch studies have been conducted using rock samples collected from Mt. Simon Sandstone and Eau Claire Formation at the IBDP wells to investigate the geochemical interaction of rock, brine, and $CO_2$ (Carroll et al., 2013; Yoksoulian et al., 2014; Shao et al., 2020). The experiments were conducted under relevant reservoir conditions to identify the reaction mechanisms, kinetics, and solid-phase products that are likely to occur when rock and brine are exposed to injected $CO_2$. The results of batch studies were also used to constrain the conceptual geochemical model, calibrate mean parameter values, and quantify parameter uncertainty in reactive-transport simulations.

The batch reactor experiments with Mt. Simon Sandstone generally indicated that limited dissolution of rock minerals occurs (Carroll et al., 2013; Yoksoulian et al., 2014; Shao et al., 2020). A decrease of pH occurs quickly in these experiments after $CO_2$ is introduced because of its dissolution into the brine and dissociation of carbonic acid. Reaction of the Mt. Simon Sandstone can be characterized by an increase in dissolved Si and Al after the reaction, suggesting the dissolution of aluminosilicate minerals, such as feldspar and clay minerals.

The amount of mineral dissolution is limited, however, as the mass of Al that dissolved from the solid phase into aqueous phase accounted for less than 0.3% of total Al in the rock samples. The liquid to solid ratios in batch experiments were much higher than aquifer conditions suggesting that under aquifer conditions less than 0.002% of Al would be mobilized. Results from XRD analyses indicated the bulk mineral composition remained unchanged for all sandstone samples after reaction (1-4 months), indicating that the influence of rock-brine-$CO_2$ interaction on bulk rock composition was negligible.

Batch experiments introducing $CO_2$ to crushed Eau Claire shale indicated mineral dissolution from Eau Claire samples were more significant than Mt. Simon sandstone samples (Carroll et al., 2013; Shao et al., 2020). This is likely, in part, due to the processing of rock samples to small fragments that increased the reactive surface area, thus accelerating mineral dissolution of Eau Claire rock. The Eau Claire Formation, however, is a highly laminated, fissile shale to silty shale with the shaliest section near the base (above the Eau Claire Silt) and advective flow from the Mt. Simon Sandstone into the Eau Claire is expected to be insignificant (Roy et al., 2014). Modeling of ionic diffusion into the Eau Claire has also shown this to be insignificant (Roy et al., 2014).

Numerical simulations with PHREEQC 2.17.0 geochemical code (Carroll et al., 2013) suggested that the geochemical alteration of the Mt Simon Sandstone and Eau Claire shale can be modeled by incongruent dissolution of annite, illite, K-feldspar, and formation of montmorillonite, amorphous silica, and kaolinite. However, the formation of these secondary minerals were not confirmed with available characterization techniques.

Potential geochemical reactions at the Linden Project site were also modeled using Computer Modelling Group (CMG) Generalized Equation Model (GEM). As modeling mineralization is computationally expensive, two up-layered models were used: one had 59 layers and a second with twelve layers. The four main expected mineral components and their percentages used in the model are based on Mt. Simon Sandstone core from VW#1 (Leetaru and Freiberg, 2014):

- Quartz (70 %);
- K-feldspar (20%);
- Illite (5%); and
- Illite-smectite (5%).

The modeling results from the 59-layer model indicate that some precipitation of K-feldspar as well as some dissolution of smectite will occur over the 30-year injection period (Figure 46). There is little reaction with quartz or illite. A very small amount of mineralization is predicted to occur in this timeframe (0.02% of injected $CO_2$). Any change (reduction) in porosity is negligible during the injection period.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 46: Modeled geochemical reaction products during the 30-year injection period at the Linden Project site.**

The geochemical modeling also predicted the main $CO_2$ trapping mechanisms. Figure 47 displays the evolution of the main trapping mechanisms during injection and PISC periods. Initially, a large percentage of the $CO_2$ is structurally trapped. As the fluids gravity segregate, the amount of residual (immobile) gas increases. Dissolution of $CO_2$ into brine also begins at a slow rate. Dissociation of dissolved $CO_2$ into aqueous ions also occurs but only accounts for a small percentage of the trapping. Mineralization is a slow process that generally takes hundreds or thousands of years to become a significant trapping mechanism. Table 11 indicates the evolution of trapping mechanisms and percentage of $CO_2$ trapped over time at the Linden Project site.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 47: Graph of the relationships and evolution of $CO_2$ trapping mechanism during 30 years of $CO_2$ injection followed by a 50-year PISC period at the Linden Project site.**

**Table 11: $CO_2$ trapping mechanisms and percentages trapped after 30-years injection and 50-years post-injection.**

| Trapping Mechanism | % of $CO_2$ trapped after 30 years of injection | % of $CO_2$ trapped 50 years post-injection |
|---|---|---|
| Structural | 75.7 | 45.97 |
| Residual (immobile) Gas | 11.2 | 36.44 |
| Dissolved gas | 12.7 | 17.04 |
| Aqueous ions | 0.4 | 0.52 |
| Mineralization | 0.02 | 0.03 |

#### 2.29.5 Mineral trapping

Computational modeling for the Linden Project site investigated the effect of mineralization on long-term trapping of $CO_2$ based on the potential reactions between brine-$CO_2$-rock matrix as part of the PISC Alternative Timeframe using the information currently available (Attachment 09: PISC, 2023). This modeling confirmed that mineralization is not expected to play a significant role in trapping for thousands of years (Table 11).

### *2.30 Other Information (Including Surface Air and/or Soil Gas Data, if Applicable)*

The(Attachment 05: Pre-operational Formation Testing Program, 2023) presents the data that will be collected in order to determine and verify the depth, thickness, mineralogy, lithology, porosity, permeability, and geomechanical information of the injection zone, confining zone, and other relevant geologic formations via petrophysical logging and analysis, and core acquisition and testing (Attachment 05: Pre-operational Formation Testing Program, 2023). In addition, baseline 3D surface seismic data will be acquired during the pre-injection phase of the project to assist in characterizing injection zone and confining zone rock properties away from the project wells.

At this time, the project does not plan to acquire baseline atmospheric or soil gas data nor are there plans to pursue atmospheric or soil gas monitoring during the injection phase of the project.

### *2.31* Site Suitability *[40 CFR 146.83]*

#### 2.31.1 Summary

The Mt. Simon Sandstone at the Linden Project site meets all requirements necessary to serve as a competent injection zone and can sequester 0.7 Mtpa of $CO_2$ over a 30-year period (21 MMT total), as evident through geologic evaluation, static modeling, and computational modeling results. The Eau Claire Formation at the project site has sufficient thickness, continuity, and low porosity and permeability to be a competent confining zone for the proposed volume of $CO_2$. The IBDP and ongoing commercial IL-ICCS project near Decatur, IL have each provided significant data that supports that the Mt. Simon/Eau Claire storage complex are highly suitable for long-term carbon sequestration.

Specifically, the Mt Simon Sandstone has the following properties at the proposed project site:

- Sensitive, Confidential, or Privileged Information [redacted]
- Lateral continuity of the Mt. Simon Sandstone over the region.
- Estimated average porosity of the Mt. Simon Arkose and Lower Mt. Simon Sandstone and injection zone: 13.1% and 8.9%, respectively.

- Estimated average porosity of the Middle and Upper Mt. Simon Sandstone injection zone: 7.5% and 8.0%, respectively.
- Estimated average permeability of the Mt. Simon Arkose, Lower Mt. Simon Sandstone injection zone: 82.3 and 17.7 mD, respectively.
- Estimated average permeability of the Middle Mt. Simon and Upper Mt. Simon Sandstone injection zone: 4.1 and 6.4 mD, respectively.

$CO_2$ plume development will likely be controlled by heterogeneities within the injection zone, and these heterogeneities will be characterized using a combination of well log, core, and 3D surface seismic data (Attachment 05: Pre-operational Formation Testing Program, 2023). The AoR and Corrective Action Plan includes discussion of the capacity estimates for the injection zone (Attachment 02: AoR and Corrective Action Plan, 2023).

No deep wells penetrate the confining zone within the AoR. The closest well penetrating the Eau Claire Formation (API 121830184800) is more than 35 miles to the west, which is a significant distance outside of the Linden AoR.

FEMA classifies the project site to have a very small probability of experiencing damaging earthquake effects and a low probability of experiencing annual flooding.

### *2.31.2 Primary Seal*

The Eau Claire Formation above the Eau Claire Silt will be a competent confining zone. It is estimated to be [redacted] at the project site and is laterally continuous across the Illinois Basin and surrounding area. Its dominant clay content indicates it to be ductile and not prone to brittle fracturing. Based on the petrophysical analysis of wells in the region, it is expected to have low porosity and permeability of 1% and significantly less than 1 mD, respectively, at the proposed site.(Attachment 02: AoR and Corrective Action Plan, 2023). Data gathered during the pre-operational phase of the project will be used to verify that the Eau Claire Shale is a highly competent confining zone (Attachment 05: Pre-operational Formation Testing Program, 2023).

### *2.31.3 Lowermost USDW*

The undifferentiated Mississippian strata overlying the New Albany Shale is the lowermost USDW at the project site and is expected to be [redacted] the Eau Claire Formation confining zone.

### *2.31.4 Secondary Confinement Strata*

There are multiple secondary confining beds within the Knox Group and the Maquoketa Group to prevent fluids from reaching the lowermost USDW should they migrate past the primary confining zone. The Argenta Formation will act as a lower confining zone with an average permeability of 2.0 mD estimated for the project site.

### *2.31.5 Structural Integrity*

2D seismic data acquired for the project indicate there are no faults or fractures, or other natural conduits, which can be identified that would allow injection zone fluid migration beyond the confining zone.

### *2.31.6 Capacity and Storage*

The AoR and Corrective Action Plan show that the Mt. Simon Sandstone at the Linden Project Site storage location has the capacity and hydrogeologic characteristics necessary to store of 0.7 Mtpa of $CO_2$ over a period of 30-years (21 MMT total). Computational modeling was used to simulate multiphase (brine and $CO_2$) flow in the subsurface and considered the reservoir geologic and hydrogeologic characteristics. The simulation included one injection well within the sequestration site and resulting AoR. Major $CO_2$ trapping mechanisms modeled include structural/stratigraphic trapping, residual phase trapping, solubility trapping, and mineral trapping. The model showed that in the post-injection phase and beyond, the pressure front dissipates rapidly, and the $CO_2$ plume stabilizes and remains confined to the injection zone.

### *2.31.7 Reservoir and Compatibility with the Injectate*

Studies using laboratory experiments and reactive transport modeling of the Mt. Simon Sandstone from the Illinois Basin suggest that there is minimal reactivity of the rock with brine and $CO_2$. Experiments using Mt. Simon Sandstone core samples suggest minor dissolution of aluminosilicate minerals, such as feldspar and clay minerals may occur, but the bulk of the mineralogy (i.e., quartz) is effectively inert. Results from XRD analyses indicated the bulk mineral composition remained unchanged for all sandstone samples after reaction and indicates that the influence of rock-brine-$CO_2$ interaction on bulk rock composition was negligible. Computational modeling indicates that some carbonate minerals may precipitate as a result of feldspar dissolution, but it would take hundreds of years to see any impact of mineral trapping. These reactions will be monitored using fluid samples that will be taken from the injection zone in LA-OBS1 during the injection phase of the project (Attachment 7: Testing and Monitoring Plan, 2023).

The well casing, tubing, and cement used through the confining zone and injection zone will be $CO_2$ resistant (Attachment 04: Injection Well Construction Plan, 2023).

## 3. AoR and Corrective Action

Computational modeling has delineated the AoR for the Linden Project shown in Figure 48. The AoR and Corrective Action module (Attachment 02: AoR and Corrective Action Plan, 2023) provides a detailed summary of the modeling parameters. After a thorough review of all identified wells in the region, it has been determined that there are no wells within the AoR that penetrate the confining zone, and there are no requirements for corrective action.

| AoR and Corrective Action GSDT Submissions |
| --- |
| ***GSDT Module:*** AoR and Corrective Action<br>***Tab(s):*** All applicable tabs<br><br>Please use the checkbox(es) to verify the following information was submitted to the GSDT:<br>☐ Tabulation of all wells within AoR that penetrate confining zone ***[40 CFR 146.82(a)(4)]***<br>☐ AoR and Corrective Action Plan *[40 CFR 146.82(a)(13) and 146.84(b)]*<br>☐ Computational modeling details ***[40 CFR 146.84(c)]*** |

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 48: Map of Linden Project location, proposed location of the injection and deep observation wells, simulated extent of the $CO_2$ plume 50 years post injection, and extent of AoR.**

## 4. Financial Responsibility

The financial assurance estimation for the project was divided into four components: 1) Corrective Action, 2) Injection Well Plugging and Abandonment, 3) Post Injection Site Care and Closure, and 4) the Emergency and Remedial Response Plan (ERRP). Components 1, 2, and 3 will be covered by Sensitive, Confidential, or Privileged Information. These items will be set up using a yet-to-be-determined financial institution. Prior to commencement of injection operations, the financial institution of choice will be selected and proper information and updates to the permit application will be provided.

Internal estimates and external vendor quotes were used to assemble the estimates for the first three components. All appropriate quotes that were provided from vendors are provided with the submittal documentation. The cost estimate for the ERRP was developed in tandem with Industrial Economics (IEc). Their full report is provided with the submittal documentation. Further detail is provided in the Financial Assurance section of this permit application (Attachment 03: Financial Assurance Plan, 2023).

| Financial Responsibility GSDT Submissions |
|---|
| ***GSDT Module:*** Financial Responsibility Demonstration<br>***Tab(s):*** Cost Estimate tab and all applicable financial instrument tabs<br><br>Please use the checkbox(es) to verify the following information was submitted to the GSDT:<br>☐ Demonstration of financial responsibility ***[40 CFR 146.82(a)(14) and 146.85]*** |

## 5. Injection Well Construction

VA intends to use materials of construction (casing, cement, etc.) that are verified by independent third-party sources as suitable for the worst-case corrosive load expected to occur during the life of the project. Verification of the suitability is provided as part of the supporting documents for Attachment 04: Injection Well Construction Plan, 2023.

This section summarizes the methods and materials to be used for the construction of the LSH INJ1 well. Schematics of the well that illustrate its construction are provided in the well construction plan attachment of the permit application. Please note that these schematics are not meant to portray final products and are subject to change pending availability of materials listed and the completion of well installation.

The work will be performed in accordance with guidance documents, approved work plans, and reporting timelines as approved by the EPA. LSH INJ1 will be constructed with multiple casing strings, each string smaller in diameter than the previous and cemented to surface to provide multiple layers of protection for USDWs.

The injection well proposed in this document will be constructed as a new well. The injection well will be drilled into the Argenta Group with enough hole present such that the Argenta Formation can be properly characterized. It is noted that, while LA OBS1 is currently planned to be the well that penetrates the Precambrian basement, LSH INJ1 will potentially serve to collect the Precambrian basement characterization data should the efforts to identify the Precambrian basement from LA OBS1 fail.

Once the basement characterization data has been collected, whether in LSH INJ1 or LA OBS1, the open basement section will be plugged back to the injection zone such that the $CO_2$ will not be directly injected into the basement. This will be done prior to running and cementing the long string casing in place.

The Mt. Simon Sandstone, the targeted storage formation for the project, is a thick sandstone. The Eau Claire Shale [redacted] and serves as the primary confining layer for the project.

Wellheads will be used with appropriately sized components and materials of construction based on the build of the wellbore. The wellhead will vary depending on whether the intermediate contingency section is needed or not. Following installation of the long string casing and cement, perforations will be made into the casing to access the Mt. Simon Sandstone for injection.

Schematics for the wellbore and wellhead (planned and contingency) are provided in the well construction plan attachment of the permit application.

Further details on the proposed stimulation program, construction plan, and materials of construction are provided in this section as well as in the well construction attachment.

## *5.1 Proposed Stimulation Program [40 CFR 146.82(a)(9)]*

It is not currently anticipated that any additional stimulation will need to be performed on the well after initial completion, other than to clean out the perforations made in the long-string casing.

VA reserves the right to perform intermediate stimulation on this well, should the need arise. A list of some of the common remediation techniques that may be deployed in the future is listed below. Note that this is not an exhaustive list and additional technologies or treatments may be used. Further detail on methods, materials, and chemicals to be used during treatments is provided in (Attachment 04: Injection Well Construction Plan, 2023)

- Matrix acid stimulation,
- Coil tubing chemical stimulation,
- Coil tubing mechanical stimulation,
- Perforations.

Stimulations will occur as necessitated by well conditions. These will be identified by evaluating well performance over time. The necessary notification will be provided to the Agency prior to any field mobilization. Within this notification, detail on the proposed procedure, equipment, and chemicals to be used will be provided.

## *5.2 Construction Procedures [40 CFR 146.82(a)(12)]*

The injection well will be drilled as a new well. Multiple strings of carbon steel and 13-Chrome casing will be installed and cemented in place to protect the USDWs and other strata overlying the injection formation. Fluids will be injected into the Mt. Simon Sandstone using internally coated carbon steel casing landed in in a nickel coated packer. The Mt. Simon Sandstone will be accessed through perforations in the long string casing.

A high-level procedure is provided below. A more detailed schedule and procedure is provided in Attachment 04: Injection Well Construction Plan, 2023.

1. Conductor casing will be drilled then cemented in place.
2. Surface hole will be drilled. This hole will be drilled to a sufficient depth below the base of the USDW such that the entire USDW can be logged during open and cased hole logs.
3. Open hole logs will be run.
4. Casing will then be run and cemented in place.
5. After allowing sufficient time for the cement to harden, cased hole logs will be run, and the casing will be pressure tested.
6. Long string hole will be drilled. This hole will be drilled into basement (if LA-OBS1 does not penetrate it) or above basement (if LA-OBS1 does penetrate it).
    a. Should a substantial lost circulation zone (LCZ) occur during drilling the long string section, an intermediate contingent string of casing will be run.
    b. Prior to operations, well control and loss prevention measures will be implemented until the well is stable.
    c. The hole will be reamed up to size and open hole logs will be run.
    d. Casing will then be run and cemented in place.
    e. After allowing sufficient time for the cement to harden, cased hole logs will be run, and the casing will be pressure tested.
7. Open hole logs will be run.
8. Casing will then be run and cemented in place.
9. After allowing sufficient time for the cement to harden, cased hole logs will be run, and the casing will be pressure tested.
10. Perforations will be made in the long string casing into the Mt. Simon Sandstone.
11. The tubing, packer, and wellhead will then be installed.

Specifications on the tools, equipment, casing, cement, and other things are provided in more detail in Attachment 04: Injection Well Construction Plan, 2023. All materials of construction are designed to API standards.

## *5.3 Casing and Cementing*

Table 12 and Table 13 display the safety factors and safety factor loads based on the proposed well design. It is noted that an 80% derating factor is applied prior to any analyses. This implies an additional 1.20 safety factor on top of those displayed in the table. Additionally, material and specification derating based on tensile loading is also considered. Finally, worst-case analyses (i.e., evacuated casing while pumping cement while also pulling up at the max tensile rating) were considered in casing evaluation. Anticipated loads are displayed first, followed by worst case loads.

In addition to these analyses, cyclic and temperature loading analysis was performed. The results of this analysis are presented in the Well Construction Plan (Attachment 04: Injection Well Construction Plan, 2023).

Table 14 displays the setting depths and specifications of the casing to be used for the well. All casing conforms with API specifications. Table 15 shows the design parameters of the casing, tubing, and packer to be used for the well.

Details on the cement program are provided in the Well Construction Plan (Attachment 04: Injection Well Construction Plan, 2023). All cement used conforms with API standards. Corrosion resistant cement will be used from the bottom of the well to above the top of the Eau Claire Formation.

Mechanical integrity will be demonstrated as part of the initial completion, and routinely as discussed in (Attachment 05: Pre-operational Formation Testing Program, 2023) and (Attachment 07: Testing and Monitoring, 2023).

All materials of construction are suitable for the anticipated loading and are not anticipated to decrease in suitability over time.

**Table 12: Casing safety factors for design.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Table 13: Casing safety factor loads for design.**

| String | Sensitive, Confidential, or Privileged Information |
|---|---|
| | [redacted] |
| Surface | [redacted] |
| Intermediate (Contingency) | [redacted] |
| Long String | [redacted] |
| Injection Tubing | [redacted] |

**Table 14: Casing and tubing details.**

| Casing String | Sensitive, Confidential, or Privileged Information |
|---|---|
| Surface | [redacted] |
| Intermediate (contingency) | [redacted] |
| Long String | [redacted] |
| Long String (chrome) | [redacted] |
| Injection Tubing | [redacted] |
| *Internal diameter of long string casing | |

**Table 15: Casing and tubing design parameters.**

| Material | Sensitive, Confidential, or Privileged Information |
|---|---|
| Surface casing | [redacted] |
| Intermediate (contingency) | |
| Long string casing | |
| Injection tubing | |

### *5.4 Tubing and Packer*

The tubing will be internally coated [redacted] pipe and is designed for $CO_2$ service. The internal coating to be used has been routinely used in waste disposal and enhanced oil recovery projects. Further detail on the suitability is provided in Attachment 04: Injection Well Construction Plan, 2023.

The injection packer will use $CO_2$ resistant materials for the $CO_2$-wet surfaces. The body of the packer will be manufactured from a chrome/nickel alloy and will be typical for disposal wells and designed to prevent corrosion or leakage. Further details on the packer are provided in Attachment 04: Injection Well Construction Plan, 2023.

## 6. Pre-operational Logging and Testing

Details on the pre-operation testing plan are provided in the relevant section of this permit application (Attachment 05: Pre-operational Formation Testing Program, 2023).

| Pre-Operational Logging and Testing GSDT Submissions |
| --- |
| ***GSDT Module:*** Pre-Operational Testing<br>***Tab(s):*** Welcome tab<br><br>Please use the checkbox(es) to verify the following information was submitted to the GSDT:<br>☐ Proposed pre-operational testing program ***[40 CFR 146.82(a)(8) and 146.87]*** |

# 7. Well Operation

This section is meant to provide a brief overview of the well operation conditions. Further details on the well operation program are provided in (Attachment 06: Well Operations Linden 2023).

## *7.1 Operational Procedures [40 CFR 146.82(a)(10)]*

Table 16 displays the operational parameters that will be used during injection operations. Details on the methods of calculations and inputs for these values are provided in (Attachment 06: Well Operations, 2023). Values provided in this table are designed to stay below the critical fracture pressure, while also managing the pressure loading experienced during operations to protect equipment. It is not anticipated that significant deviation from these values will occur during the life of the project.

**Table 16: Proposed operational procedures.**

| Parameters/Conditions | Sensitive, Confidential, or Privileged Information | Unit |
|---|---|---|
| Maximum Injection Pressure | [redacted] | |
| Surface | [redacted] | psi |
| Downhole | [redacted] | psi |
| Average Injection Pressure* | [redacted] | |
| Surface | [redacted] | psi |
| Downhole | [redacted] | psi |
| Maximum Injection Mass | [redacted] | |
| Annual | [redacted] | kilotonnes |
| 30-year Project | [redacted] | kilotonnes |
| Average Injection Rate ** | [redacted] | |
| Mass Injection Rate | [redacted] | kilogram/minute |
| Volumetric Injection Rate | [redacted] | gallons/minute |
| | [redacted] | barrels/day |
| Annulus Pressure | [redacted] | |
| Maximum | [redacted] | psi |
| Minimum | [redacted] | psi |
| Operational | [redacted] | psi |

* Based on the projected computational modeling results after stable injection operations have occurred
** Calculations made based on annual maximum injection volume, assuming the provided density provided in Section 4

## *7.2 Proposed $CO_2$ Stream [40 CFR 146.82(a)(7)(iii) and (iv)]*

The $CO_2$ injection stream will be sourced from the Valero Linden ethanol production facility located in Montgomery County, Indiana and is anticipated to have the fluid composition as shown in Table 17. VA will analyze the $CO_2$ stream during the injection phase of the project to provide data representative of its chemical characteristics and to meet the requirements of 40 CFR 146.90 (a). Details on the testing and monitoring of the $CO_2$ stream are provided in the testing and monitoring section of this permit. Additional details on technical standards, QA/QC policy, sample collection and storage policies, and analytical methods are provided in the Quality Assurance and Surveillance Plan (Attachment 11: QASP, 2023).

The $CO_2$ stream produced from the Valero Linden ethanol plant will be of high purity, based on the nature of the ethanol fermentation process. The $CO_2$ stream from ethanol fermentation typically exceeds 99 % $CO_2$ (mole basis), with minor impurities including common atmospheric gases (ex: $O_2$, $N_2$), alcohols, and $H_2O$. The stream will be further dehydrated prior to entering the pipeline for injection.

Quarterly sampling and analysis of the $CO_2$ injection stream will be performed to track the composition of the stream.

**Table 17: Minimum specification for $CO_2$ injection stream.**

Sensitive, Confidential, or Privileged Information

[redacted]

## 8. Testing and Monitoring

| Testing and Monitoring GSDT Submissions |
| --- |
| **GSDT Module:** Project Plan Submissions<br>**Tab(s):** Testing and Monitoring tab<br><br>Please use the checkbox(es) to verify the following information was submitted to the GSDT:<br>☐ Testing and Monitoring Plan [40 CFR 146.82(a)(15) and 146.90] |

This section is meant to provide a brief overview of the Testing and Monitoring Plan. Further details on the well operation program are provided in (Attachment 07: Testing And Monitoring Linden 2023).

The Linden Project has developed a risk-based Testing and Monitoring Program that includes operational, verification, and environmental assurance components while, at the same time, meeting the regulatory requirements of 40 CFR 146.90. This Testing and Monitoring Program is based on experience gained from other approved Class VI projects, as well as extensive geologic evaluation and computational modeling.

Goals of the monitoring strategy include, but are not limited to:

- Fulfillment of the regulatory requirements of 40 CFR 146.90,
- Protection of underground sources of drinking water (USDW),
- Risk mitigation over the life of the project,
- Confirmation that LSH INJ1 is operating as planned while maintaining mechanical integrity,
- Acquisition of data to validate and calibrate the models used to predict the distribution of $CO_2$ within the injection zone, and
- Support AoR re-evaluations over the course of the project.

The Testing and Monitoring Plan will be adaptive over time, and is subject to alteration should one of the following potential scenarios occur:

- Project risks evolve over the course of the project outside of those envisioned at the beginning of the project,
- Significant differences between the monitoring data and predicted computational modeling results are identified,
- Key monitoring techniques indicate anomalous results related to well integrity or the loss of containment.

The Testing and Monitoring Plan includes a range of monitoring objectives:

- Well operations,
- Containment,
- Non-endangerment of USDWs,
- Capacity,
- Injectivity,
- Injection pressure, and
- Conformance.

Table 18 provides of summary of the general monitoring strategy with subcategories.

**Table 18: Summary of general monitoring strategy for the Linden Project.**

| Monitoring Action | Monitoring Objectives | Monitoring Technology |
|---|---|---|
| $CO_2$ stream analysis | Purity of the $CO_2$ stream | Lab analysis |
| $CO_2$ plume monitoring | Verification/ conformance, containment, non-endangerment of USDWs | Time-lapse seismic data, pulsed neutron logging (PNL), fluid sampling with aqueous geochemistry, and isotope analysis |
| Pressure plume monitoring | Injection pressure, injectivity, verification/ conformance | Downhole pressure sensors in the injection wells, seismic monitoring |
| ACZ Changes | Containment, non-endangerment of USDWs | Downhole pressure sensors in monitor wells, fluid sampling with aqueous geochemistry and isotope analysis, PNL, time-lapse seismic data, |
| Project well integrity | Containment, non-endangerment of USDWs | Temperature logging, PNL, annular pressure monitoring, mechanical integrity tests (MIT), pressure fall-off tests (FOTs), corrosion monitoring, testing of emergency shut-down systems |
| Reservoir performance | Injectivity | Wellhead and downhole pressure sensors |
| Induced seismicity | Containment, non-endangerment of USDWs, induced seismicity | Surface-based or downhole seismic monitoring arrays |
| Groundwater monitoring | Containment, non-endangerment of USDWs, assurance | Fluid sampling with aqueous geochemistry |

The operational monitoring will serve to ensure all procedures and processes associated with the project are safe and well integrity is maintained. Continuously recorded data that will monitor the response of the injection zone includes:

- Injection rate and volume,
- Wellhead injection pressure,
- Injection well annulus pressure and fluid volume, and
- Mt. Simon Sandstone pressure and temperature.

The verification monitoring will provide data that will be used to evaluate the vertical and horizontal $CO_2$ plume development over time and identify any potential $CO_2$ migration beyond the confining zone. The primary components of the $CO_2$ plume monitoring consist of PNL in the project wells and time-lapse three-dimensional (3D) surface seismic monitoring. The pressure front development will be monitored with downhole pressure sensors in LSH INJ1 and LA OBS1 as well as continuous passive seismic monitoring. In addition, LR ACZ1 will provide further verification that the injection zone fluids are being contained below the confining layer through downhole pressure monitoring and fluid sampling in the Ironton-Galesville Sandstones.

The assurance monitoring component of the program will monitor the shallow groundwater aquifers for any indications that injection zone fluids have migrated into the near surface. Fluid samples will be taken from shallow groundwater aquifers on a regular basis to analyze the aqueous geochemistry.

## 9. Injection Well Plugging

Following the conclusion of injection operations, the injection well will be permanently plugged and abandoned. Details on the methods of these operations are provided in Attachment 08: Injection Well Plugging Plan, 2023. The methods and procedures presented in the attachment are consistent with industry standards and the requirements detailed in 40 CFR 146.92. All materials to be used for the plugging and abandonment are suitable for the anticipated corrosive loading below the top of the Eau Claire. Above the top of the Eau Claire Formation, the materials are standard construction materials, conforming the API specifications.

| Injection Well Plugging GSDT Submissions |
| --- |
| ***GSDT Module:*** Project Plan Submissions<br>***Tab(s):*** Injection Well Plugging tab<br><br>Please use the checkbox(es) to verify the following information was submitted to the GSDT:<br>☐ Injection Well Plugging Plan [40 CFR 146.82(a)(16) and 146.92(b)] |

## 10. Post-injection Site Care and Closure

The requested documents listed below have been included in the file submission (Attachment 09: PISC, 2023). These documents address the rule requirements for the EPA citations. The Linden Project is requesting an alternative PISC timeframe.

| PISC and Site Closure GSDT Submissions |
|---|
| ***GSDT Module:*** Project Plan Submissions<br>***Tab(s):*** PISC and Site Closure tab<br><br>Please use the checkbox(es) to verify the following information was submitted to the GSDT:<br>☐ PISC and Site Closure Plan [40 CFR 146.82(a)(17) and 146.93(a)] |
| ***GSDT Module:*** Alternative PISC Timeframe Demonstration<br>***Tab(s):*** All tabs (only if an alternative PISC timeframe is requested)<br><br>Please use the checkbox(es) to verify the following information was submitted to the GSDT:<br>☐ Alternative PISC timeframe demonstration ***[40 CFR 146.82(a)(18) and 146.93(c)]*** |

## 11. Emergency and Remedial Response

The requested documents listed below have been included in the file submission (Attachment 10: ERRP, 2023). These documents address the rule requirements for the above EPA citations.

| Emergency and Remedial Response GSDT Submissions |
|---|
| ***GSDT Module:*** Project Plan Submissions<br>***Tab(s):*** Emergency and Remedial Response tab<br><br>Please use the checkbox(es) to verify the following information was submitted to the GSDT:<br>☐ Emergency and Remedial Response Plan *[40 CFR 146.82(a)(19) and 146.94(a)]* |

# 12. Injection Depth Waiver and Aquifer Exemption Expansion

VA does not intend to apply for a Depth Waiver or Aquifer Exemption. As such, no supplemental documents have been filed.

| Injection Depth Waiver and Aquifer Exemption Expansion GSDT Submissions |
|---|
| ***GSDT Module:*** Injection Depth Waivers and Aquifer Exemption Expansions<br>***Tab(s):*** All applicable tabs<br><br>Please use the checkbox(es) to verify the following information was submitted to the GSDT:<br>☐ Injection Depth Waiver supplemental report ***[40 CFR 146.82(d) and 146.95(a)]***<br>☐ Aquifer exemption expansion request and data ***[40 CFR 146.4(d) and 144.7(d)]*** |

## 13. References

Atekwana, E. A., 1996, Precambrian basement beneath the central Midcontinent United States as interpreted from potential field imagery, *in* B. A. van der Pluijm, and P. A. Catacosinos, eds., Basement and basins of eastern North America: Geological Society of America (GSA), p. 33–44, doi:10.1130/0-8137-2308-6.33.

Attachment 02: AoR and Corrective Action Plan, 2023: Compass.

Attachment 03: Financial Assurance Plan, 2023: Compass.

Attachment 04: Injection Well Construction Plan, 2023: Compass.

Attachment 05: Pre-operational Formation Testing Program, 2023: Compass.

Attachment 06: Well Operations, 2023: Compass.

Attachment 07: Testing and Monitoring, 2023: Compass.

Attachment 08: Injection Well Plugging Plan, 2023: Compass.

Attachment 09: PISC, 2023: Compass.

Attachment 10: ERRP, 2023: Compass.

Attachment 11: QASP, 2023: Compass.

Bickford, M. E., W. R. Van Schumas, and I. and Zietz, 1986, Proterozoic history of the midcontinent region of North America, Geology: p. 492–496.

Bradbury, J. C., and E. Atherton, 1965, The Precambrian basement of Illinois: Circular no. 382.

Cable, L., and T. Robison, 1974, Groundwater Resources of Montgomery County, Indiana, Bulletin 36: State of Indiana Department of Natural Resources Division of Water, 27 p.

Carroll, S., W. McNab, Z. Dai, and S. Torres, 2013, Reactivity of Mt. Simon Sandstone and the Eau Claire Shale under CO2 storage conditions: Environment Science Technology, p. 252–261.

Collinson, C., M. L. Sargent, and J. R. Jennings, 1988, Illinois Basin region, in L.L. Sloss, ed., Sedimentary cover–North American Craton: The Geology of North America, v. D-2, p. 383–426.

Denison, R. E., E. G. Lidiak, M. E. Bickford, and E. G. Kisvarsanyi, 1984, Geology and geochronology of Precambrian rocks in the Central Interior Region of the United States: U.S: Geological Survey Professional Paper, v. 1241– C, p. 20.

Fenelon, J. M., K. E. Bobay, T. K. Greeman, M. E. Hoover, D. A. Cohen, K. K. Fowler, M. C. Woodfield, and J. M. and Durbin, 1994, Hydrogeologic Atlas of Aquifers in Indiana, USGS Numbered Series 92–4142: Reston, VA, U.S. Geological Survey, Water-Resources Investigations Report, doi:10.3133/wri924142.

Freiburg, J. T., 2015, The Argenta Formation; a newly recognized Cambrian stratigraphic unit in the Illinois Basin: Geological Society of America, v. v.47, p. 86.

Gollakota, S., and S. McDonald, 2014, Commercial-scale CCS Project in Decatur, Illinois - Construction Status and Operational Plans for Demonstration: Energy Procedia, p. 5986–5993.

Green, M. R., 2018, Geophysical Exploration of the Upper Crust Underlying North-Central Indiana: New Insight into the Eastern Granite-Rhyolite Province: Wright State University.

Greenberg, S. E., 2021, Illinois Basin-Decatur Project Final Report: An Assessment of Geologic Carbon Sequestration Options in the Illinois Basin: Phase III: United States Department of Energy.

Grove, G. E., 2009a, Bedrock Aquifer Systems of Montgomery County, Indiana.

Grove, G. E., 2009b, Bedrock Aquifer Systems of Tippecanoe County, Indiana.

Indiana Department of Natural Resources, Division of Water, Water Well Record 397902, 2006: <https://secure.in.gov/apps/dnr/water/dnr_waterwell?refNo=397902&_from=SUMMARY&_action=Details> (accessed March 22, 2023).

Janssens, A., 1968, Stratigraphy of Silurian and pre-Olentangy Devonian rocks of the South Birmingham pool area, Erie and Lorain Counties, Ohio: 20 p.

Kolata, D. R., 2010, Cambrian and Ordovician systems (Sauk Sequence and Tippecanoe I Subsequence, *in* D. R. Kolata, and C. K. Nimz, eds., The geology of Illinois: Illinois State Geological Survey.

Kolata, D. R., and W. J. Nelson, 1997, Role of the Reelfoot Rift/Rough Creek Graben in the evolution of the Illinois Basin: Middle Proterozoic to Cambrian rifting, central North America, v. 312, p. 287–298.

Kolata, D. R., and W. J. Nelson, 1990, Tectonic History of the Illinois Basin, *in* Interior Cratonic Basins: American Association of Petroleum Geologists, doi:10.1306/M51530C19.

Korose, C., 2022, Wabash CarbonSAFE Final Report.

Lahann, R., J. Rupp, and C. Medina, 2014, An evaluation of the seal capacity and CO2 retention properties of the Eau Claire Formation (Cambrian): Environmental Geosciences, v. 21, p. 83–106.

Leetaru, H., 2019, Carbon Storage Assurance Facility Enterprise (CarbonSAFE): Integrated CCS Pre-Feasibility CarbonSAFE Illinois East Sub-Basin Final Report.

Leetaru, H. E., 2015, Paleotopography of the Precambrian Surface of Illinois.

Leetaru, H., and J. Freiberg, 2014, Litho-facies and reservoir characterization of the Mt Simon Sandstone and the Illinois Basin-Decatur Project: Greenhouse Gas Science Technology, p. 580–595.

Lidiak, E. G., 1996, Geochemistry of subsurface Proterozoic rocks in the eastern midcontinent of the United States: Further evidence for a within plate tectonic setting: Basement and basins of eastern North America, v. 308, p. 45–66.

Lohmann-Johnson Pollution Control Inc., 1972, Final Drilling and Completion Report: Allied Chemical Well #1: Allied Chemical, 52 p.

McBride, J. H., and D. R. Kolata, 1999, Upper crust beneath the central Illinois Basin, United States: Geological Society of America Bulletin, v. v. 111, p. 375–394.

Neufelder, R. J., B. B. Bowen, R. W. Lahann, and J. A. Rupp, 2012, Lithologic, mineralogical, and petrophysical characteristics of the Eau Claire Formation: Complexities of a carbon storage system seal: Environmental Geosciences, v. 19, no. 3, p. 81–104.

Patrick Engineering, 2011, Underground Injection Control Permit Application IL - ICCS Project.

Roy, W., E. Mehnert, P. Berger, J. Daminco, and R. and Okwen, 2014, Transport modeling at multiple scales for the Illinois Basin - Decatur Project Greenhouse Gas Science and Technology, p. 645–661.

Shao, H., J. T. Freiburg, P. M. Berger, A. H. Taylor, H. F. Cohen, and R. A. Locke, 2020, Mobilization of trace metals from caprock and formation rocks at the Illinois Basin - Decatur Project demonstration site under geological carbon dioxide sequestration conditions: Chemical Geology, v. 550.

Wayne, W. J., 1958, Glacial geology of Indiana: Indiana Geological Survey Atlas Map 10.

Whittaker, S., 2022, Illinois Storage Corridor, *in* NETL, ed.: NETL Annual Review Meeting 2022.

Whittaker, S., and C. Carman, 2022, CarbonSAFE Illinois - Macon County Final Report.

Wickstrom, L. H., 2005, Characterization of Geologic Sequestration Opportunities in the MRCSP Region Phase I.

Yoksoulian, L., P. M. Berger, J. T. Freiburg, and S. M. and Butler, 2014, Geochemical investigations of CO2-brine-rock interactions of the Knox Group in the Illinois Basin: US Department of Energy.