# ATTACHMENT 7: TESTING AND MONITORING PLAN
# 40 CFR 146.90

## HOOSIER #1 PROJECT

**Facility Information**

Project Name: Hoosier #1

Facility Name: Cardinal Ethanol

Facility Contact: Jeremey Herlyn, Project Manager
Cardinal Ethanol

Well Location: 1554 N. 600 E.
Union City, IN 47390
$CO_2$ Injection Well Location for Cardinal_CCS1
Latitude 40.186587°
Longitude -84.864284°

Operator Name: One Carbon Partnership, LP
1554 N. 600 E.
Union City, IN 47390

# Table of Contents

# List of Figures



# List of Tables

# List of Acronyms

| | |
|---|---|
| 3D | Three-dimensional |
| ACZ | Above Confining Zone |
| ACZ1 | Above Confining Zone Well |
| AoR | Area of Review |
| APT | Annular Pressure Test |
| BGS | Below Ground Surface |
| BHFP | Bottomhole Flowing Pressure |
| $CO_2$ | Carbon Dioxide |
| CCS1 | Proposed Injection well |
| DIC | Dissolved Inorganic Carbon |
| DTS | Distributed Temperature Sensor |
| EPA | Environmental Protection Agency |
| EPSG | European Petroleum Survey Group |
| ERRP | Emergency and Remedial Response Plan |
| FOT | Fall-off Test |
| GR | Gamma Ray |
| ICP | Inductivity Coupled Plasma |
| IBDP | Illinois Basin – Decatur Project |
| MAIP | Maximum Allowable Injection Pressure |
| Mc | Magnitude of completeness |
| MIT | Mechanical Integrity Test |
| MS | Mass Spectrometry |
| OBS1 | Deep Observation Well |
| OES | Optical Emission Spectrometry |
| PISC | Post Injection Site Care |
| PNL | Pulsed Neutron Logging |
| PSI | Pound per Square Inch |
| QA | Quality Assurance |
| QASP | Quality Assurance and Surveillance Plan |
| RAT | Radioactive Tracer |
| SCADA | Supervisory Control and Data Acquisition |

| | |
|---|---|
| TBD | To Be Determined |
| TD | Total Depth |
| TDS | Total Dissolved Solids |
| UIC | Underground Injection Control |
| USDW | Underground Source of Drinking Water |
| USDW1 | Lowermost USDW monitoring well |

# 1 Overall Strategy and Approach for Testing and Monitoring

This Testing and Monitoring Plan presented in this document provides details on how the Hoosier #1 Project will monitor the site pursuant to 40 CFR 146.90.

## 1.1 Testing and Monitoring Plan Strategy

The Hoosier #1 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 (Attachment 1: Narrative, 2022; Attachment 12: Risk Register, 2022). 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 CCS1 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,
- Support Area of Review (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.

Monitoring activities can be separated into three categories based on various objectives: operational, verification, and assurance monitoring.

- *Operational monitoring* focuses on day-to-day injection operations such as system performance.
- *Verification monitoring* confirms that the $CO_2$ remains contained within the selected storage complex. The $CO_2$ and pressure plume development is tracked over time to provide data for model calibration. Integration of verification monitoring data into project models allows the project to demonstrate conformance between the computational modeling and the testing and monitoring data collected during the operations and closure phases of the project's lifecycle.

- *Assurance monitoring* is at surface and near-surface (i.e., soil, groundwater, USDWs, etc.) to monitor for any changes from baseline (taken pre-injection) sample data that might indicate $CO_2$ migration towards surface.

These three categories cover a range of monitoring objectives including

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

Table 1 provides of summary of the general monitoring strategy with subcategories.

**Table 1: Summary of general monitoring strategy for the Hoosier #1 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, microseismic monitoring |
| ACZ Changes | Containment, non-endangerment of USDWs | Downhole pressure and temperature 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, oxygen activation or radioactive (RAT) logging, 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 microseismic monitoring arrays |
| Groundwater monitoring | Containment, non-endangerment of USDWs, assurance | Fluid sampling with aqueous geochemistry and isotope analysis |

## 1.2 Storage Complex

A site-specific stratigraphic chart of geologic formations present in CCS1 is shown in Table 2.

Figure 3 shows a cross section of the $CO_2$ plume at the end of the 10-year Post Injection Site Care (PISC) period.

The specific intervals to be monitored are as follows:

- Mt. Simon Sandstone (injection interval),
- Above Confining Zone (ACZ) (likely in the Knox Formation),
- Maquoketa Shale (suspected lowermost USDW),
- Shallow groundwater.

As a result of the scarcity of well data below the Trenton Formation, the final ACZ monitoring interval will be determined after the first deep well has been drilled for the project. Based on regional knowledge, it is expected that a suitable monitoring interval will be found at or immediately below the Knox Formation unconformity due to the Glenwood Formation's properties that will create an effective barrier to fluid migration in Ohio.

**Table 2: Major stratigraphic units in the AoR with descriptions and role in the project.**

Sensitive, Confidential, or Privileged Information

[redacted]

## 1.3 Area of Review and Project Wells

Figure 1 and Table 3 show the proposed wells for the project. Figure 1 shows the predicted plume development over time as well as the AoR. Figure 2 and Figure 3 illustrate the modeled $CO_2$ plume development ten-years post injection as well as the current AoR. The current $CO_2$ and pressure plume predictions have been used to inform the spatial extent of the Testing and Monitoring Plan.

The AoR and Corrective Action Plan includes a discussion of the technical basis for the current AoR as well as how the monitoring data will be used to re-evaluate the AoR over the injection phase of the project (Attachment 2: AoR and Corrective Action, 2022). Once CCS1 has been drilled, the data gathered as part of the Pre-Operational Testing Program will be used to update the current static model and the computational modeling (Attachment 5: Pre-Op Testing Program, 2022). The updated models will be used to verify or re-evaluate the current AoR and associated Testing and Monitoring Plan should it be necessary (Attachment 2: AoR and Corrective Action, 2022).

The proposed OBS1 well is located a [redacted] south of CCS1 and the Cardinal Ethanol facility on land owned by Cardinal Ethanol (Figure 2). The computational modeling predicts that the $CO_2$ will breakthrough at this well in the Year 3 of injection operations (Attachment 2: AoR and Corrective Action, 2022). The primary objectives of the OBS1 well are to monitor injection zone pressures at a distance from CCS1 and to obtain fluid samples from the well prior to $CO_2$ breakthrough. Fluid samples from the injection zone will allow the project to characterization the changes in aqueous geochemistry and the rock matrix in the early years of the project. Once the $CO_2$ breaks through at OBS1, the project will be able to use PNL to characterize the development of the vertical $CO_2$ plume over time at a distance from CCS1. The far field pressure measurements will be used to calibrate the computational modeling during the operations phase of the project.

**Table 3: Proposed Hoosier #1 Well Locations (European Petroleum Survey Group (EPSG) 2965)**

| Well Name | Well Use | X0, ft | Y0, ft | TD, ft | Status |
|---|---|---|---|---|---|
| CCS1 | [redacted] | | | | |
| OBS1 | | | | | |
| ACZ1 | | | | | |
| USDW1 | | | | | |

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 1: Time-lapse $CO_2$ plume development map over 3, 12, 20, and 30 years of injection as well as 10- and 50-years post injection. Note the relative stability of the $CO_2$ plume radius after injection operations cease.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 2: $CO_2$ plume after 30-years of injection and 10-years post injection. Contour intervals indicate the volume of $CO_2$ contained within the contour bounds. Project AoR is indicated by the blue circle.**

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 3: A-A Cross-section of the $CO_2$ plume after 30 years of injection and 10 years post injection through CCS1 and OBS1. Well total depths (TDs) are annotated for each well.**

## 1.4 Summary of Testing and Monitoring Plan Components

Operational monitoring serves 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 plume development will be monitored with downhole pressure sensors in CCS1 and OBS1 as well as continuous microseismic monitoring.

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 and stable isotopes.

One of the primary goals of the testing and monitoring plan is to continue to demonstrate the activities of this project are safe for the health of the public and environment. In order to help facilitate this demonstration, the Quality Assurance and Surveillance Plan (QASP) has been developed to ensure the quality of the demonstration methods meet the requirements of the EPA Underground Injection Control (UIC) Program for Class VI wells.

Table 4 shows a summary of the activities, monitoring points, and purpose of each activity in the Testing and Monitoring Plan. The activities are discussed on more detail in sections that follow the table in this document.

**Table 4: Summary of Testing and Monitoring Activities**

| Activity | Location(s) | Purpose |
|---|---|---|
| **$CO_2$ stream analysis** | | |
| $CO_2$ stream analysis – downstream | Sensitive, Confidential, or Privileged Information [redacted] | Monitor injectate quality and composition |
| **Continuous Recording** | [redacted] | |
| Injection rate | [redacted] | Monitoring injection rate |
| Injection volume | [redacted] | Calculated injection volume |
| Injection pressure | [redacted] | Monitoring injection pressure |
| Wellhead pressure | [redacted] | |
| Annular pressure | [redacted] | Monitoring annulus pressure |
| Downhole pressure | [redacted] | Monitoring injection zone |
| Downhole temperature | [redacted] | Monitoring injection zone, wellbore integrity |
| Microseismic monitoring | [redacted] | Injection zone and confining zone integrity |
| **Well Integrity** | [redacted] | |
| Corrosion monitoring | [redacted] | Monitoring injectate, wellbore integrity |
| Annular fluid volume | [redacted] | Monitoring annulus fluid volume changes |
| Mechanical integrity (internal) | [redacted] | Wellbore integrity |
| Mechanical integrity (external) | [redacted] | Wellbore integrity |
| Cement Evaluation | [redacted] | Wellbore integrity |
| **Plume Tracking** | [redacted] | |
| PNL | [redacted] | $CO_2$ saturation, vertical plume development |
| Downhole pressure | [redacted] | Monitoring injection zone pressure, plume monitoring, confining zone integrity |
| Microseismic Monitoring | [redacted] | Injection zone and confining layer integrity |

| Activity | Location(s) | Purpose |
|---|---|---|
| Time-lapse 3D Seismic Data | Sensitive, Confidential, or Privileged Information [redacted] | Indirect measurement of plume development and overburden |
| **Fluid Sampling** | | |
| Shallow Ground Water Sampling (Glacial Drift) | Sensitive, Confidential, or Privileged Information [redacted] | Detection of changes in groundwater quality for the shallow USDWs. |
| Lowermost USDW Sampling (Maquoketa Shale) | | Detection of changes in the groundwater quality in the lowermost USDW. |
| Above Confining Zone Sampling (Knox Formation) | | Detection of changes in groundwater quality above the confining zone. |
| Injection Zone Monitoring (Mt. Simon Sandstone) | | Detection of changes in groundwater quality, geochemistry, and $CO_2$ saturation in the injection internal. |

### 1.4.1 $CO_2$ Stream Analysis and Corrosion Monitoring

The chemical composition of the $CO_2$ stream will be monitored downstream of the final compression unit and upstream of CCS1 (40 CFR 146.90 (a)). Corrosion coupons composed of the same material as the well components and $CO_2$-delivery pipeline will be placed in the delivery pipeline and analyzed on a quarterly basis for signs of corrosion and loss of mass that may be indicative of future potential well integrity issues (40 CFR 146.90 (c)). If signs of corrosion are identified in the coupons, this may trigger further well integrity testing (Section 6.2).

### 1.4.2 Injection Well Monitoring

Injection operations will be monitored through a range of continuous, daily, and quarterly techniques as detailed in the (Attachment 6: Well Operations, 2022).

Continuous recording devices will monitor wellhead injection pressure, temperature, and mass flow rate (40 CFR 146.90 (b)). The injection mass flowrate will be directly measured at the surface in order to calculate the cumulative mass of injected $CO_2$ and ensure compliance with the permit injection limits. The storage formation injection volume will be calculated using the mass flowrate combined with the pressure and temperature conditions in the injection zone. The calculated injection volumes will, in turn, be used to update the computational models at regular intervals throughout the injection phase of the project (Attachment 2: AoR and Corrective Action, 2022).

The annular pressure between the tubing and the injection casing strings as well as the annular fluid volumes will also be monitored on a continuous basis (40 CFR 146.90 (b)). These data will be linked into a supervisory control and data acquisition (SCADA) system to record the operations data, control injection rates, or initiate system shutdown, if needed. The SCADA system can also be used to adjust the volume of annular fluid, and thereby pressure, in the annular space to meet the operational and regulatory objectives.

### 1.4.3 Mechanical Integrity Testing

In addition to the annular pressure and fluid volume monitoring, the well integrity of CCS1 and the observation well (OBS1) will be monitored using a range of internal and external mechanical integrity evaluation methods. The same methods of mechanical integrity testing (MIT) will be performed on each well.

#### 1.4.3.1 Internal Mechanical Integrity Testing

The regulatory standard for Part I MIT is performing an annular pressure test (APT). This test will be run to regulatory standards after the well completion to confirm internal integrity as per the (Attachment 6: Well Operations, 2022; Attachment 5: Pre-Op Testing Program, 2022). Further details on the APT standards and methods of performing it are provided in a later section in this document.

#### 1.4.3.2 External Mechanical Integrity Testing

The external mechanical integrity of the wells will be confirmed through annual temperature and PNL. These logs will be compared back to baseline logs to identify any unexpected deviations that could indicate $CO_2$ flow or accumulations behind the casing above the injection zone (40 CFR 146.90 (e)).

Further details on these logs and the methods of performing them will be provided in a later section in this document.

### 1.4.4 Pressure and Temperature Monitoring

The bottomhole pressure and temperature will be measured continuously in the OBS1 well. These gauges will continuously record these data and transmit them to surface.

OBS1 will be located within the area of the predicted 30-year $CO_2$ plume radius; the $CO_2$ plume is expected to intersect the well within the first three years of injection (Figure 3). This well will allow for pressure and temperature monitoring as well as periodic fluid sampling in the Mt. Simon Sandstone. The variations in the pressure and temperature data will be used to calibrate and verify the computational modeling through the pre-operational, injection, and PISC phases of the project (40 CFR 146.90 (g)).

### 1.4.5 Plume Monitoring

A pressure fall-off test (FOT) will be conducted in the Mt. Simon Sandstone in CCS1 after it is drilled to establish the hydrogeologic characteristics of the injection zone (Attachment 5: Pre-Op Testing Program, 2022). During the injection phase of the project, a FOT will be conducted in CCS1 at least once every five years unless increases in injection pressure indicate a need for a FOT sooner (40 CFR 146.90 (f)). The formation characteristics obtained through the FOT will be compared to the results from previous tests to identify any changes over time, and they will be used to calibrate the computational models.

OBS1 will be used to monitor pressure, temperature, and to collect fluid samples from the injection zone to monitor for changes in the aqueous geochemistry of the formation. It will also be used to verify when the leading edge of the $CO_2$ plume reaches the observation well.

PNL will be run in the CCS1 and OBS1 to monitor $CO_2$ saturations and vertical plume development adjacent to the wellbores. This logging can also be used to identify accumulations of $CO_2$ above the confining zone should there be leakage along the wellbore. Once the near wellbore region of CCS1 becomes fully saturated with $CO_2$, routine logging of the injection interval will be suspended but will continue through the ACZ monitoring interval. At this point, logging will occur in OBS1 to monitor $CO_2$ plume development away from CCS1.

Both the pressure and log data will be used to calibrate and verify the computational modeling over the injection and PISC phases of the project.

Beyond the direct measurement techniques that the project will deploy, time-lapse 3D surface seismic data and microseismic monitoring will be used to monitor the development of the $CO_2$ plume and the associated pressure front through the injection and PISC phases (40 CFR 146.90 (g)).

High resolution time-lapse 3D surface seismic data will be used to qualitatively monitor the $CO_2$ plume development and calibrate the computational modeling results over time. The time-lapse 3D surface seismic data will also be used to verify $CO_2$ containment within the injection zone, as any $CO_2$ accumulations in the overburden would result in seismic anomalies that would differ from the baseline seismic data. Source and received spacing and line intervals, and the resulting trace density will be designed to deliver full offset, full azimuth baseline data of sufficient resolution to image the target horizons. The microseismic monitoring will be used to monitor for any induced seismic events within an 8 mi radius of CCS1 in the confining layer that might indicate potential impacts to containment.

### 1.4.6 Shallow Groundwater Sampling and Monitoring

The shallow groundwater monitoring program will used twelve shallow groundwater wells spatially distributed within the AoR in near surface groundwater aquifers, and one dedicated groundwater monitoring well that will be drilled into the lowermost USDW (40 CFR 146.90 (d)).

It is expected that the deepest USDW will be at 450 ft below ground surface (BGS) based on nearby well data and reports from the Indiana Department of Natural Resources (Attachment 1: Narrative, 2022). The deepest USDW will be verified when USW1 is drilled as per the (Attachment 5: Pre-Op Testing Program, 2022).

Baseline groundwater samples will be acquired from these wells to help characterize the variations in water quality within the AoR prior to the start of $CO_2$ injection. In addition to the standard analytes, the groundwater samples will also have their aqueous geochemistry and stable isotopes analyzed.

Throughout the injection and PISC phases of the project, the results of the aqueous geochemistry and stable isotope analyses will be compared to the baseline conditions for any indication of $CO_2$ or brine migration into the shallow groundwater aquifers. If indications of $CO_2$ or brine are found in the shallow groundwater aquifer, it will trigger the emergency response actions found in the Emergency and Remedial Response Plan (Attachment 10: ERRP, 2022).

### 1.4.7 Deep Groundwater Sampling and Monitoring

One deep groundwater well (ACZ1) will be drilled into to a deep saline formation above the confining zone for the project. It is expected that this will be below the Knox Formation unconformity based on regional geology; however, a final determination will be made after the first deep well for the project has been drilled. The ACZ1 well will be in close proximity to CCS1 to monitor a deep saline formation immediately above the confining layer assuming that fluid migration from the injection zone is most likely to occur along a wellbore.

ACZ1 will be used to take fluid samples and monitor pressure changes in the selected saline formation (40 CFR 146.90 (d)). Injection zone fluid migration past the confining layer and into the ACZ monitoring zone will most likely be identified through pressure changes in the formation. Pressure will be monitored at the wellhead.

### 1.4.8 Microseismic Monitoring

The project site is located in an area with low rates of natural seismic activity and risk (Attachment 1: Narrative, 2022). It is not expected that natural seismicity will affect the project. The Illinois Basin – Decatur Project (IBDP) injected $CO_2$ into the basal section of the Mt. Simon Sandstone, and generated microseismic events throughout the injection phase of the project despite injecting $CO_2$ below fracture pressure (Bauer, 2016). This project plans to inject above the basal section of the Mt. Simon Sandstone and will monitor related microseismic activity to assist in managing project risks (Attachment 10: ERRP, 2022; Attachment 12: Risk Register, 2022).

The microseismic monitoring will be used to accurately determine the locations and magnitudes of injection-induced seismic events with the primary goals of:

- Addressing public and stakeholder concerns related to induced seismicity,
- Monitoring the spatial extent of the pressure front from the distribution of microseiseismic events within an 8 mi radius of CCS,
- Identifying activity that may indicate failure of the confining zone and possible containment loss.

A surface-based microseismic monitoring array will be designed with microseismic monitoring stations at a range of azimuths to optimize the accuracy of the event locations and magnitudes. This network can easily be expanded in response to monitoring results or future AoR re-evaluations, if necessary.

### 1.4.9 General Testing and Monitoring Activity Frequency

Table 5 presents the general schedule and spatial extent for the monitoring activities in the baseline and injection phases of the project based on the current understanding of the site. Refer to the (Attachment 9: Post-Injection Site Care, 2022) for discussion of the PISC monitoring plans.

The depth of investigation ranges will be updated once the data from CCS1 has been analyzed and the static model has been updated.

Changes to the monitoring schedule may occur over time as the project evolves. Any such changes to the testing and monitoring plan or the PISC will be made in consultation with the UIC Program Director (40 CFR 146.90 (j)).

**Table 5: General schedule and spatial extent for the testing and monitoring activities for the Hoosier #1 Project**

| Monitoring Activity | Baseline Data Frequency | Injection Phase Frequency* | Location | Depth Range (MD ft)** |
|---|---|---|---|---|
| **Groundwater Monitoring** | | | | |
| Groundwater Sampling | At least one year prior to injection Quarterly | Biannual (twice/yr) | Sensitive, Confidential, or Privileged Information [redacted] | |
| Isotope Analysis | Biannual (twice/yr) | Annually | | |
| **Injection Well Monitoring** | | | | |
| Injection Pressure | NA | Continuous<br>Continuous | Sensitive, Confidential, or Privileged Information [redacted] | |
| Injection Temperature | NA | Continuous | | |
| Injection Rate | NA | Continuous | | |
| Injection Volume (Calculated) | NA | Continuous | | |
| Annular Pressure | NA | Continuous | | |
| Annular Fluid Volume | NA | Daily | | |
| **Mechanical Integrity Testing** | | | | |
| MIT (Part I) | Once<br>Once | Annually<br>Annually | Sensitive, Confidential, or Privileged Information [redacted] | |
| FOT | Once | Every 5 years | | |
| MIT (Part II) | Once<br>Once | Annually<br>Annually | | |
| Emergency Shut-down System Test | NA | Annually | | |
| **Pressure Monitoring** | | | | |
| Annular Pressure | NA | Daily | Sensitive, Confidential, or Privileged Information [redacted] | |
| Wellhead Pressure | NA | Continuous | | |
| Downhole Pressure | NA | Continuous | | |

| Monitoring Activity | Baseline Data Frequency | Injection Phase Frequency* | Location | Depth Range (MD ft)** |
|---|---|---|---|---|
| | | | Sensitive, Confidential, or Privileged Information [redacted] | [redacted] |
| **$CO_2$ Stream Analysis** | | | [redacted] | [redacted] |
| $CO_2$ Stream Analysis | Once | Quarterly | [redacted] | [redacted] |
| Corrosion Coupon Analysis | NA | Quarterly | [redacted] | [redacted] |
| **Plume Verification Monitoring** | | | | |
| Pressure – Temperature Sensors | 3 months prior to injection<br>Continuous<br>Continuous | Continuous<br>Continuous | Sensitive, Confidential, or Privileged Information [redacted] | [redacted] |
| PNL | Once<br>Once | Annually<br>Annually | [redacted] | [redacted] |
| Microseismic Monitoring | 6 months prior to injection | Continuous | [redacted] | [redacted] |
| Time-lapse 3D Surface Seismic Data | Once | Every 5 years | [redacted] | [redacted] |
| *Minimum frequency<br>** To be confirmed after well is drilled<br>***Temperature data will not be collected | | | | |

## 1.5 Quality Assurance Procedures

Data quality assurance and surveillance protocols adopted by the project have been designed to facilitate compliance with the requirements specified in 40 CFR 146.90 (k). Quality Assurance (QA) requirements for direct measurements within the injection zone, above the confining zone, and within the shallow USDW aquifer are described in (Attachment 11: QASP, 2022). These measurements will be performed based on best industry practices and the QA protocols recommended by the service contractors selected to perform the work.

## 1.6 Reporting Procedures

Cardinal Ethanol will report the results of all testing and monitoring activities to the EPA in compliance with the requirements under 40 CFR 146.91. Reports will be submitted every 6 months commencing from the date $CO_2$ injection operations commence.

# 2 Carbon Dioxide Stream Analysis (40 CFR 146.90 (a))

The project 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).

This section describes the measurements and sampling methodologies that will be used to monitor the chemical characteristics of the $CO_2$ injection stream. Additional details on technical standards, QA/QC policy, sample collection and storage policies, and analytical methods are provided in the QASP.

## 2.1 Sampling Location and Frequency

Prior to the start of the injection phase, the $CO_2$ stream will be sampled for analysis during regular plant operations in order to obtain representative $CO_2$ samples that will serve as a baseline dataset. Once the injection phase commences, samples of the $CO_2$ injection stream will be regularly collected from the $CO_2$ delivery pipeline for analysis.

Based on the nature of the ethanol fermentation process, the $CO_2$ stream produced is anticipated to be of high purity. Even so, after fermentation, the $CO_2$ stream will pass through scrubbers and filtration units prior to entering the compressor and the pipeline.

It is anticipated that quarterly sampling of the $CO_2$ injection stream will be sufficient to accurately track the composition of the stream. The regular samples will be taken on quarterly intervals.

Section 4.5 of the QASP document details the quality control mechanisms and activities to be performed should there be a statistically significant variance in an analyte measurement.

## 2.2 Analytical Parameters

Samples of the injection stream will be collected for chemical analysis to provide data representative of its characteristics. Based on data from historic sampling of the off-gas stream from the ethanol plant, the samples will be analyzed for $CO_2$ purity, total hydrocarbons as methane carbon monoxide (CO), nitrogen oxides ($NO_x$), nitrogen ($N_2$), oxygen ($O_2$), methane, hydrogen sulfide ($H_2S$), sulphur dioxide ($SO_2$), acetaldehyde (AA), and ethanol.

Baseline samples of the "injection stream" will be collected prior to the start of injection and the species included for analysis may be expanded depending on the results of those analyses. Gas concentration analyses will be done by a contracted third-party lab. The lab will specialize in gas analyses and routinely perform specialized analyses on $CO_2$ for industrial clients. Samples of the $CO_2$ stream will be collected on a quarterly basis for chemical analysis.

## 2.3 Sampling Method – $CO_2$ Injection Stream Gases

Gas samples of the $CO_2$ stream will be obtained to analyze the components present in the injection stream. Samples of the $CO_2$ stream will be collected at a location in the system where the material is representative of the material injected (i.e., between the compression system and CCS1), [redacted]. Fittings will be consistent with those used by the contracted third-party laboratory who will be performing the analysis will be used.

The $CO_2$ stream will flow from the pipeline through an open ball valve, through a pressure reducer (regulator), and into the cylinder. The pressure regulator will reduce the pressure of the $CO_2$ stream Sensitive, Confidential, or Privileged Information [redacted] to ensure the $CO_2$ is in a gaseous state rather than a super-critical liquid.

Figure 4 provides an example of the sampling procedures used by Atlantic Analytical Company. Cylinders will be purged with sample gas (i.e., $CO_2$) at least five times prior to sample collection to remove laboratory-added helium gas and ensure a representative sample. The QASP (Attachment 11: QASP, 2022) contains more information on sampling methods.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 4: Atlantic Analytical Laboratory gas sampling instruction sheet (Atlantic Analytical Laboratory, 2022)**

## 2.4 Laboratory to be Used/Chain of Custody and Analysis Procedures

A contracted third-party laboratory will analyze the $CO_2$ stream samples. The lab will specialize in gas analyses and routinely perform specialized analyses on $CO_2$ for industrial clients. The contracted laboratory will follow standard sample handling and chain-of custody guidance (EPA 540-R-09-03, or equivalent).

The relevant QASP sections detail the following (Attachment 11: QASP, 2022):

- Sections B.2.f: Laboratory to be used and quality
- Sections B.2.e: Chain of custody
- Sections A.4.a: Analysis procedures

# 3 Continuous Recording of Operational Parameters

The project will install and use continuous recording devices to monitor injection pressure; injection rate (and volume [calculated]); the pressure on the annulus; the annulus fluid volume added; and the temperature of the $CO_2$ stream, as required at 40 CFR 146.88 (e)(1), 146.89 (b), and 146.90 (b). The details are described in the following sections.

## 3.1 Monitoring Location and Frequency

The project will perform the activities identified in Table 6 to monitor operational parameters and verify internal mechanical integrity of CCS1. All monitoring will take place at the locations and frequencies shown in Table 6. All of the data recorded on a continuous basis will be connected to the main facility through a SCADA system.

**Table 6:Sampling devices, locations, and frequencies for continuous monitoring.**

| Parameter | Device(s) | Location | Min. Sampling Frequency | Min. Recording Frequency |
|---|---|---|---|---|
| Wellhead Injection Pressure | Pressure Gauge | [redacted] | Every 10 sec. | Every 10 sec. |
| Formation Injection Pressure | Pressure Gauge | [redacted] | Every 10 sec. | Every 10 sec. |
| Wellhead Injection Temperature | Thermocouple | [redacted] | Every 10 sec | Every 10 sec. |
| Formation Temperature | Temperature Sensor | [redacted] | Every 10 sec. | Every 10 sec. |
| Injection rate | Coriolis Meter | [redacted] | Every 10 sec.<br>Every 10 sec. | Every 10 sec.<br>Every 10 sec. |
| Annular pressure | Pressure Gauge | [redacted] | Every 10 sec | Every 10 sec. |
| Annulus fluid volume | Volume | [redacted] | Every 1 min. | Every 1 min |

See Notes next page also:

- Sampling frequency refers to how often the monitoring device obtains data from the well for a particular parameter. For example, a recording device might sample a pressure transducer monitoring injection pressure once every two seconds and save this value in memory.
- Recording frequency refers to how often the sampled information gets recorded to digital format (such as a computer hard drive). For example, the data from the injection pressure transducer might be recorded to a hard drive once every minute.

Note that all calibration standards, methods of conformance, precision, and tolerance parameters are provided for the devices listed in the QASP (Attachment 11: QASP, 2022).

## 3.2 Monitoring Details

### 3.2.1 Continuous Recording of Injection Pressure

The $CO_2$ injection pressure will be monitored on a continuous basis at the wellhead to ensure that injection pressures do not exceed the calculated maximum allowable injection pressure (MAIP), determined, in part, by using 90% of the fracture pressure of the injection zone per 40 CFR 146.88 (a). If the injection pressure exceeds 90% of the injection zone fracture pressure at any point, then the injection process will be automatically shutdown per the Well Operations Plan (Attachment 6: Well Operations, 2022).

Sensitive, Confidential, or Privileged Information [redacted]

[redacted]

Based on the calculations and detail provided in the Well Operation Program section of this application, the MAIP (at surface) is 2,048 psi. Pressure will be continuously monitored by an electronic pressure transducer to ensure that the MAIP is not exceeded during injection operations. This electronic pressure transducer will feed into the SCADA system.

As is noted in the Well Operations section, several assumptions have gone into the calculations for the MAIP. To assist with the proper hydrostatic gradient evaluations, permanent downhole gauges will be used. The data gathered from this sensor will help to calibrate the surface pressure readings. The current plan is to use these gauges for calibration purposes until sufficient hydrostatic data has been collected. It is noted that these gauges are not considered to be a part of the routine testing and monitoring program, but for gradient calibration and model/simulation verification to be used as part of the testing and monitoring program.

Any anomalies outside of the normal operating specifications may indicate that an issue has occurred within the well, such as a loss of mechanical integrity or blockage in the tubing or may be caused by a change in injection flowrate. Anomalous pressure measurements would trigger the need for further investigation of the cause of the change (40 CFR 146.89 (b)). The wellhead and downhole injection pressures will also be used to calibrate the computational modeling throughout the injection phase and PISC phases of the project.

### 3.2.2 Continuous Recording of Injection Mass Flow Rate

The mass flow rate of $CO_2$ injected into the well will be measured by a mass flow meter. This flow meter will be placed in the $CO_2$ delivery line near the well. A second mass flow meter will be located in the $CO_2$ delivery line just downstream of the final compressor, and the two flow meters will be used together to monitor leakage in the delivery line between the compressor and the well.

The meters will have an analog output. The flow meters will be connected to the SCADA system for continuous monitoring and control of the $CO_2$ injection rate into the well. Using two flow meters will allow confirmation of accurate flow measurements. The mass flow meters will be calibrated at the frequency recommended by the manufacturer.

#### 3.2.3 Injection Volume

The injection volume into the reservoir will be calculated on a continuous basis based on the injection mass and the pressure and temperature conditions in the storage formation. The volume that is calculated will be used in the computational models to determine storage formation capacity and flow.

#### 3.2.4 Continuous Recording of Annular Pressure

As discussed in the Well Operations Plan, the pressure on the annulus between the injection tubing and the long-string casing will be measured by an electronic pressure transducer with analog output that is mounted on the wing valve/annular fluid line connected to the wellhead of CCS1 (Attachment 6: Well Operations, 2022). The transmitter will be connected to the well control system and the SCADA system to regulate the annular pressure.

Annular pressures are expected to vary during normal operations due to atmospheric and $CO_2$ stream temperature fluctuations; however, the well control system will be designed to maintain the annular pressure between -5 and 1,500 psi (Attachment 6: Well Operations, 2022).

In particular, the annular pressure is expected to fluctuate during start-up and shut-in operations as the tubing naturally expands and contracts in response pressure and temperature changes related to $CO_2$ flow, or lack thereof, in the tubing. Sudden changes in the annular pressure during routine injection operations are a sign of potential tubing or tubing packer integrity issues that will trigger further investigation through mechanical integrity testing.

#### 3.2.5 Continuous Recording of Annulus Fluid Volume

As discussed in the Well Operations Plan, the volume of the annulus fluid between the injection tubing and the long-string casing will be measured using the accumulator levels and the brine reservoir level on the well control system (Attachment 6: Well Operations, 2022). The accumulator and brine reservoir levels will be measured using a level transmitter. The transmitters will be connected to the well control system and to the SCADA system.

Similar to the annular pressure, the annular fluid volume is expected to fluctuate as atmospheric and injection stream temperatures change. These changes are expected to be most dramatic during start-up and shut down operations. A significant change in the fluid volume in the accumulator or brine reservoir (i.e., fluid is being pumped from the reservoir to the annulus or fluid being pushed out of the annular space) during routine injection operations may be an indication of well integrity problems, as the fluid volumes would normally remain relatively constant, and will require further investigation.

#### 3.2.6 Continuous Recording of $CO_2$ Stream Temperature

The temperature of the $CO_2$ injection stream will be continuously measured by an electronic thermocouple. The thermocouple will be mounted in a temperature probe in the $CO_2$ line at a location close to the pressure transmitter near the wellhead. The transmitter will be electronically connected to the SCADA system.

### 3.2.7 Bottomhole Pressure and Temperature

Bottomhole pressure and temperature will be monitored prior to and during the injection phase of the project. These data will be used to assist with the calibration of the wellhead pressure measurements to determine the response of the formation to the injected $CO_2$.

The downhole pressure gauge will be set at the bottom of the injection string, just above the packer, [redacted] and will be programmed to continuously record the pressure and transmit it to surface.

After the wellhead/ injection zone pressure relationship has been defined, the wellhead pressure measurement will be the point of compliance for maintaining injection pressure below 90% of formation fracture pressure as per 40 CFR 146.88 (a). The downhole pressure and temperature data will also be used to calibrate the computational models.

# 4 Corrosion Monitoring (40 CFR 146.90 (c))

To meet the requirements of 40 CFR 146.90 (c), the project will monitor well materials and components during the operational period for loss of mass, thickness, cracking, pitting, and other signs of corrosion to ensure that the well components meet the minimum standards for material strength and performance (Table 7). This section discusses the measures that will be taken to monitor the corrosion of well materials used in the casing and tubing. For Class VI injection wells, corrosion monitoring of the well materials is required on a quarterly basis (40 CFR 146.90 (c)).

## 4.1 Monitoring Location and Frequency

The corrosion coupons will be retrieved and analyzed every three months after the date that injection commences. Once injection operations have stabilized, it is not expected that there will be large fluctuations in injection volumes, so there are no plans to monitor the coupons based on injection volumes. If the coupons show evidence of corrosion, CCS1 can be assessed for signs of corrosion using commercially available logging or other inspection tools.

## 4.2 Sample Description

The coupons will be made from the same materials as the long string casing and tubing (Table 7). Prior to placement of the corrosion coupons in the $CO_2$ stream, they will be weighed and measured for thickness, width, and length as a baseline measurement.

**Table 7: List of equipment coupon with material of construction.**

| Equipment Coupon | Material of Construction |
|---|---|
| Long String Casing | 13Cr80 Steel Alloy and Standard Carbon Steel |
| Injection String | Standard Carbon Steel with TK-15XT Coating (Tuboscope) |
| Pipeline | Stainless Steel |
| Wellhead | Xylan coated iron |
| Packer | Nickel coated steel, nitrile |

## 4.3 Monitoring Details

Corrosion monitoring of well materials will be conducted using coupons placed in the $CO_2$ pipeline (Figure 5). The coupons will be made of the same materials that are listed in the table above. An example of one such coupon is provided in Figure 6. The coupons will be removed quarterly and assessed for corrosion using American Society for Testing and Materials (ASTM) G1-03: Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens (ASTM, 2017). This method measures the corrosivity of steel to both aqueous and non-aqueous liquid wastes.

Upon removal, coupons will be inspected visually for evidence of corrosion, which may include pitting, cracking, and loss of mass or thickness. The weight and size (thickness, width, length) of the coupons will also be measured and recorded each time they are removed and compared to the baseline measurements. Corrosion rate will be calculated as the weight loss during the exposure period divided by the duration (i.e., weight loss method).

If the coupons show evidence of corrosion, CCS1 can be assessed for signs of corrosion using commercially available logging or other inspection tools. The frequency of running these inspection logs will be contingent on the corrosion data from the coupon monitoring program.

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 5: Corrosion coupon illustration in pipeline** (Cosasco, 2022)

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 6: Type of corrosion coupons to be used for corrosion monitoring (Cosasco, 2021)**

# 5 Above Confining Zone Monitoring (40 CFR 146.90 (d))

The project will monitor groundwater quality and geochemical conditions above the confining zone during the operational period to meet the requirements of 40 CFR 146.90 (d).

## 5.1 Monitoring Location and Frequency

Table 8 shows the proposed deep ACZ monitoring zone, lowermost USDW, and shallow groundwater monitoring methods, depths, and frequencies. The project will aim to acquire a minimum of one year of shallow groundwater data before injection operations begin. It is anticipated that USDW1 and ACZ1 will be drilled in Q1 2024. Fluid samples will be taken for analysis from these wells twice prior to the start of injection operations.

**Table 8: Schedule for monitoring of pressure, aqueous geochemistry, and stable isotope analysis for the ACZ, USDW1, and shallow groundwater monitoring wells during the pre-operational and injection phases of the project**

| Designated Well(s) | Target Formation | Monitoring Activity | Baseline Frequency | (Minimum) Injection Phase Frequency |
|---|---|---|---|---|
| Sensitive, Confidential, or Privileged Information [redacted] | | Aqueous Geochemistry | Quarterly | Biannual* |
| | | Stable Isotopes | Biannual* | If required |
| | | Aqueous Geochemistry | Biannual* | Biannual* |
| | | Stable Isotopes | Biannual* | Biannual* |
| | | Wellhead Pressure | Continuous | Continuous (Every hour) |
| | | Aqueous Geochemistry | Biannual* | Biannual* |
| | | Stable Isotopes | Biannual* | Biannual* |
| *twice per year | | | | |

Given the thick and continuous nature of the Mt. Simon Sandstone, the highest risk of $CO_2$ or brine migration out of the injection zone is along the CCS1 and OBS1 wellbores that will penetrate the Eau Claire Formation. As such, ACZ1 will be drilled near CCS1 to help monitor for any $CO_2$ leakage or brine migration into the ACZ monitoring zone. As discussed in Section 2.4.7, the deepest ACZ saline formation is expected to be identified in the Knox Formation when the first well is drilled. Fluids from the deepest ACZ saline formation will be sampled twice prior to the start of $CO_2$ injection to characterize any natural variability in the fluids in the formation (Table 8).

Migration of $CO_2$ or brine into the ACZ saline formation will likely first be identified through pressure changes in the formation. An increasing pressure trend in the ACZ monitoring zone would suggest that leakage across the confining zone has occurred. While any increasing trend in pressure will be evaluated, an increase in pressure that deviates more than 5% above baseline values will warrant additional monitoring and inspections to rule out the possibility of fluid leakage out of the injection zone. Such a change in pressure would initiate more frequent fluid sampling and analysis for aqueous geochemistry from the ACZ monitoring zone as well as additional external well integrity investigations in the CCS1 or OBS1. Pressures in the ACZ monitoring interval will be monitored at the wellhead.

The lowermost USDW is expected to be located at a depth of approximately 450 ft (BGS) based on local well data (Attachment 1: Narrative, 2022). USDW1 will be drilled relatively close to CCS1 to be able to properly monitor the fluids in the lowermost USDW.

Figure 7 shows the distribution of the groundwater wells within the AoR including the proposed location of USDW1. The shallow groundwater monitoring program will include approximately twelve existing groundwater wells that will be spatially distributed within the AoR (40 CFR 146.90 (d)). Baseline shallow groundwater samples will be collected from existing shallow groundwater wells within the AoR on a quarterly schedule starting in the third or fourth quarter of 2022 in order to characterize the seasonal variations in groundwater quality within the AoR (Table 8).

Sensitive, Confidential, or Privileged Information

[redacted]

**Figure 7: Shallow groundwater wells within the AoR annotated in blue. Oil and gas wells that have been converted to water wells have been highlighted.**

The accumulation of $CO_2$ or brine in an overlying aquifer will likely result in changes to the following parameters:

- Aqueous geochemistry parameters such as pH and alkalinity
- Reaction of cements, mineral surface coatings, and clay particles with the $CO_2$ will liberate cations and anions into the aqueous phase
- Carbon isotopes can be used to differentiate between existing $CO_2$ sources within the AoR and the injected $CO_2$

If anomalous changes in the aqueous geochemistry are observed in the ACZ monitoring interval or the lowermost USDW, new samples will be obtained from the affected formation to verify the changes. The frequency with which fluid samples are obtained from each of the zones for analysis will also be increased.

If the injected $CO_2$ has a unique isotopic signature from the existing isotopes in the ACZ monitoring interval or the lowermost USDW, a new round of samples will be collected for isotopic analysis from the affected formation. Anomalous changes may also trigger the need for additional well integrity testing in both CCS1 and OBS1 to ensure that no well integrity issues have developed since the last set of external mechanical integrity tests (Section 6.2). Stable isotopes from the shallow groundwater samples will only be analyzed if anomalies are found in the ACZ monitoring interval or lowermost USDW.

A combination of anomalous pressure, geochemical, and well integrity testing results may result in the decision to acquire a time-lapse surface seismic survey to determine the size of a potential leakage accumulation. Further details on any remedial or emergency response are detailed in the ERRP portion of this permit application (Attachment 10: ERRP, 2022).

## 5.2 Analytical Parameters

Table 9 details the full suite of analytes that will be used to establish the baseline conditions from OBS1, ACZ1, USDW1, and the shallow groundwater monitoring wells. Once the project has established baseline conditions, it may reduce monitoring to a subset of analytes that are most likely to change as a result of interactions with $CO_2$; however, no changes would be implemented without consultation with the UIC Program Director. During the injection phase of the project, fluids from these wells will be sampled biannually to identify any changes to parameters aqueous geochemistry or stable isotopes.

**Table 9: Summary of analytical and field parameters for groundwater samples**

| Parameters | Analytical Methods[1] |
|---|---|
| Cations:<br>Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, Zn, Ti<br>Ca, Fe, K, Mg, Na, and Si | <br>ICP[2]-MS[3], EPA Method 6020<br>ICP-OES[4], EPA Method 6010B |
| Anions:<br>Br, Cl, F, $NO_3$, and $SO_4$ | <br>Ion Chromatography<br>EPA Method 300.0 |
| Dissolved $CO_2$ | Coulometric Titration<br>ASTM D513-11 |
| Stable Isotopes of δ13C<br>Dissolved Inorganic Carbon (DIC) | Isotope Ratio Mass Spectrometry[5] |
| Total Dissolved Solids (TDS) | Gravimetry<br>APHA 2540C |
| Water Density (field) | Oscillating Body Method |
| Alkalinity | APHA 2320B |
| pH (field) | EPA 150.1 |
| Conductivity/Resistivity (field) | APHA 2510 |
| Temperature (field) | Thermocouple |

Note 1: An equivalent method may be employed with the prior approval of the UIC Program Director.

Note 2: Inductivity Coupled Plasma

Note 3: Mass Spectrometry

Note 4: Optical Emission Spectrometry

Note 5: Gas evolution technique by Atekwana and Krishnamurthy (1998), with modifications made by Hackley et al. (2007)

Changes in these parameters during the injection phase of the project may provide an indication of $CO_2$ or brine movement above the confining layer. While pH and alkalinity may be indicators of $CO_2$ migration above the confining zone, the dissolved inorganic carbon analysis would provide direct evidence of $CO_2$ migration into these formations. The presence of Carbon-13 or stable isotopes of C (in dissolved inorganic carbon) may provide an indication of fluid or $CO_2$ migration into the ACZ monitoring zone and may also provide information about the origin of any migrating fluids.

The relative benefit of each analytical measurement will be evaluated throughout the design and initial injection testing phase of the project to identify the analytes best suited to meeting project monitoring objectives under site-specific conditions. If some analytical measurements are shown to be of limited use, they will be removed from the analyte list and not carried forward through the operational phases of the project. Any modification to the parameter list in

Table 9 will be made in consultation with the UIC Program Director.

Currently, there are no plans to use tracers during operations; however, as the monitoring plan is designed to be adaptive as project risks evolve over time and may be re-assessed at a later date.

## 5.3 Monitoring and Sampling Methods

Pressure in the ACZ monitoring zone will be monitored from the wellhead. The gauge will record and transmit data the SCADA system once every 10 seconds. The gauge will be installed on the wellhead at least three months prior to any injection to ensure that a sufficient baseline is established.

For ACZ fluid sampling, a bailer system will be used to collect the water samples. Prior to sample collection the well will be flushed to remove stagnant water from the well and ensure representative water is collected from the formation. The fluid removed from the well will be monitored for field parameters that are listed in Table 9. Once these parameters stabilize, it will be an indication that representative formation fluid is in the well at the time the sample is collected.

Preservation/preparation methods, container type, and holding times for the analyte classes are presented in the QASP section of this application.

## 5.4 Laboratory to be Used/Chain of Custody Procedures

The geochemical analyses and the isotopic analyses will be performed by contracted third-party laboratories that meet the standards and guidelines set forth in the QASP. Samples will be tracked using appropriately formatted chain-of-custody forms (Attachment 11: QASP, 2022).

# 6 Mechanical Integrity Testing

## 6.1 Internal Mechanical Integrity Testing

Internal (Part I) mechanical integrity testing (MIT) refers to the testing of the integrity of the seals within and between the: injection string, the long casing string, the packer, and the wellhead. The quality of these seals can be confirmed with an annulus pressure test (APT) and annular pressure monitoring. Both methods will be used during the injection phase of this project to monitor and confirm internal mechanical integrity. Table 10 presents the details for conducting the annular pressure MIT and the annular pressure monitoring.

**Table 10: Internal mechanical integrity monitoring details**

| Testing/Monitoring Method | Frequency | Location of Monitoring | Parameters Measured |
|---|---|---|---|
| APT | Sensitive, Confidential, or Privileged Information [redacted] | [redacted] | Pressure |
| Annular Pressure Monitoring | [redacted] | [redacted] | Pressure, temperature, annular fluid volume |

In addition to performing an APT annually, an APT will be performed after the initial well completion. It is noted that the annulus will be filled with a non-corrosive fluid with some additives.

#### 6.1.1 Annulus Pressure Testing (40 CFR 146.89(a))

The APT will be performed annually to exhibit Part I mechanical integrity, or any time a component of the internal seals, detailed above, are broken or altered. The test will be performed consistent with approved and accepted guidance and regulations. This is consistent with CFR 146.89 (a). In addition, an APT will be performed following an emergency shut-in due to a high-high or low-low annulus alarm should the cause of the alarm not be easily correlated to a change in temperature.

The APT will then be performed by pressuring up the annulus after the well has reached thermal equilibrium. Once this has occurred, the annulus will be pressured [redacted] A calibrated digital gauge will be installed on the annulus, and the pressure will be monitored for a period no less than 60-minutes.

The following procedure will be followed for all APTs that will be run.

1. Ensure well is in thermal equilibrium. Thermal equilibrium will be assumed under the following circumstances:
    a. Injection has not occurred for approximately 24 hours, or sufficient data indicates the wellbore temperature is static. The scenario constitutes a static APT.
    b. Injection is occurring at a constant rate (±5%), often referred to as a dynamic APT.
2. Install calibrated digital gauge on the casing-tubing annulus. Note initial pressures.
3. Increase annulus pressure [redacted].
    a. Ensure to note the fluid level in the system prior to increasing the annulus pressure.
4. Disconnect annulus system and ensure the annulus is isolated.
5. Monitor the annulus and tubing pressure for a period of one-hour, taking readings every 10-minutes.
6. Once the test has concluded, reconnect the annulus system.
7. Blow the pressure down to the normal operating pressure.
8. Note the fluid level in the system.

#### 6.1.2 Annulus Pressure Monitoring

In addition to the APT, the annular pressure will be continuously monitored throughout the operational period in conjunction with the annular pressure monitoring and control system to ensure internal mechanical integrity. Once injection operations commence, injection pressure, annular pressure, and annular fluid volumes will be monitored continuously in order to ensure that internal well integrity and proper annular pressure is maintained (Attachment 6: Well Operations, 2022).

If a change in the annular pressure or annular fluid volume indicates a change that was not a result of temperature or injection rate alteration, the cause of the change will be investigated (Attachment 6: Well Operations, 2022). Note that changes in the temperature of the injection stream can result in changes in the temperature of the annular space, leading to variations in annular pressure. Initial investigations would likely look at correlations between the temperature of the injection stream and the variations in annular pressure.

## 6.2 External Mechanical Integrity Testing (40 CFR 146.90 (e))

The project will conduct external (Part II) MIT annually to meet the requirements of 146.89(c) and 146.90(e).

### 6.2.1 Testing Methodology and Frequency

External mechanical integrity refers to the absence of fluid movement through channels between the long casing string and the borehole or the intermediate casing string. Migration of fluids through this zone could result in contamination of USDWs; therefore, the external integrity of CCS1 and OBS1 will be confirmed throughout the injection phase of the project. Part II MIT activities will occur annually.

This project plans to use temperature and RAT logging to ensure Part II mechanical integrity. It is noted that the practice of running temperature and RAT logs in tandem to ensure Part II mechanical integrity is a generally accepted method used in Class I and II wells across multiple EPA regions.

Table 11 show the logs to be run to display Part II mechanical integrity, as well as the frequency with which they will be run and the depth range they will be run over.

**Table 11: External mechanical integrity tests**

| Test | Well | Depth Range (MD ft) | Schedule |
|---|---|---|---|
| Temperature Log | Sensitive, Confidential, or Privileged Information [redacted] | | Annually |
| | | | Annually |
| Radioactive Tracer Log | | | Annually |

It is important to note that while PNL is not planned to be a direct method of displaying Part II mechanical integrity, it can be used to identify accumulations of $CO_2$ adjacent to the wellbore in intervals above the Mt. Simon Sandstone.

#### 6.2.1.1 Temperature Logging

Temperature logging is used to establish a temperature profile of the well and make year to year comparisons to determine if any unexpected variations are present. Each year, multiple temperature log runs will be made to monitor the temperature decay after injection has stopped.

Temperature logs will be run using the same tool assembly as is presented in the RAT logging Section (7.2.1.2). Following the conclusion of the RAT logging, the well will be shut-in and a baseline temperature log will be run as per the schedule in

Table 12. This will allow for four temperature curves to be plotted for each year that temperature logs will be performed. Temperature logs will be acquired from the bottom up.

**Table 12: Temperature logging schedule for well integrity**

| Temperature Logging Run | Time Increment from Shut-in (hrs) |
|---|---|
| Baseline | Shut-in |
| Second | 1 |
| Third | 3 |
| Fourth | 6 |

#### 6.2.1.2 Radioactive Tracer Logging

The primary purpose of RAT logging is to verify the absence of pathways along the wellbore for the upward migration of injection zone fluids. RAT logging will be performed in accordance with federal and state guidance, if it is available.

RAT logs will be run while fluid is actively being injected into the well. As such, pressure, temperature, and rate data will be collected as part of the logging activities and reporting.

A RAT logging tool will be run on the same string as a gamma ray (GR), casing collar locator (CCL), and temperature tool. A summary of the general testing events is provided below.

1. Run baseline GR log across the zone of interest.
2. Run 5-minute statistical (stat) checks on the tool. These stat checks should be run in an area with a known low GR signature, and in an area with a known, higher GR signature. This check will help to ensure the tool is operating properly.
3. Run tracer chase sequence. A tracer will be ejected at least 300 feet above the packer, after which the tool will chase the tracer down the injection string and into the cased-hole interval by performing successive downward passes through the well. Multiple passes will be made over the perforated interval to ensure that all the tracer has exited the tubing and passed into the Mt. Simon Sandstone
4. Run time-drive sequence. A tracer will be ejected at least 300 feet above the packer. After which the tool will be move to just above the packer. The tool will record the GR measurements at the set depth for a minimum of 30-minutes. During this time, the tracer will be observed passing the tool and never have any upward movement.
5. Run final GR log across the zone of interest.

This sequence of logs will allow for investigation into any potential upward pathways for fluid migration out of the injection interval present during injection.

### 6.2.2 Testing Details

The data from each annual logging event will be compared to the baseline log to determine if there are any inconsistencies between the logs. If inconsistencies appear, the cause of the deviations will be determined, and additional logs will be performed over the entire depth of the well to substantiate results of the MIT logging.

# 7 Pressure Fall-Off Testing (40 CFR 146.90 (f))

The project will perform pressure fall-off tests (FOT) during the injection phase as described below to meet the requirements of 40 CFR 146.90(f).

Pressure fall-off testing involves the measurement and analysis of pressure data from a well after it has been shut-in. FOT tests provide the following information:

- Confirmation of reservoir properties such as flow capacity (kh), which is used to derive average permeability.
- Formation damage (skin) near the well bore, which can be used to diagnose the need for well remediation
- Changes in injection zone performance over time, such as long-term pressure build-up in the injection zone
- Average injection zone pressure that can be used to calibrate computational modeling predictions of injection zone pressure to verify that the operation is responding as modeled/predicted

## 7.1 Testing Location and Frequency

Fall-off tests will be run every five years on CCS1 during injection operations. An initial FOT will be run as part of the pre-operational testing to be performed on the well. The permanent downhole pressure gauges set above the packer will be used for the FOT.

Surface monitoring equipment will be used to monitor injection data for the test.

## 7.2 Testing Details

To begin the FOT, a constant rate injection period will be used for a minimum period of 24-hours. The rate will be kept within ±5% during this period and will be at a rate that is representative of the injection rate for normal operations.

Following this constant rate injection period, injection will cease, and the well will be shut-in at the wellhead. Pressure will be monitored for a period to be no longer than the constant rate injection period. Following the shut-in period, the well will be restarted, and routine injection operations will resume.

Surface monitoring equipment will be used to record the injection data. This test can be performed as a function of routine injection operations and will prevent any additional shut-in of the well other than what is necessary for the test.

The downhole pressure data will be collected, and pressure transient analysis (PTA) will be performed on the data. Analysis of the test data will be completed using PTA techniques that are consistent with guidance for conducting pressure fall-off tests.

# 8 Carbon Dioxide Plume and Pressure Front Tracking (40 CFR 146.90 (g))

The project will employ direct and indirect methods to track the extent of the $CO_2$ plume and the presence or absence of elevated pressure during the operation period to meet the requirements of 40 CFR 146.90 (g).

## 8.1 Plume Monitoring Location and Frequency

Table 13 presents the methods that the project will use to monitor the position of the $CO_2$ plume; this includes the activities, locations, and frequencies the project will employ. The parameters to be analyzed as part of fluid sampling in the injection zone and associated analytical methods are presented in Table 9. Quality assurance procedures for these methods are presented in (Attachment 11: QASP, 2022).

**Table 13: $CO_2$ plume monitoring activities**

| Target Formation | Monitoring Activity | Monitoring Location(s) | Spatial Coverage | Frequency |
|---|---|---|---|---|
| **DIRECT PLUME MONITORING** | | | | |
| Sensitive, Confidential, or Privileged Information [redacted] | Fluid Sampling | Sensitive, Confidential, or Privileged Information [redacted] | | Twice/year until $CO_2$ breakthrough |
| | Isotope Analysis | | | Once/year until $CO_2$ breakthrough |
| | PNL | | | Once/year until fully saturated with $CO_2$<br>Once/year |
| | Downhole Pressure | | | Continuous |
| | Downhole Temperature | | | Continuous |
| **INDIRECT PLUME MONITORING** | | | | |
| Sensitive, Confidential, or Privileged Information [redacted] | Time-lapse 3D Surface Seismic Data | Sensitive, Confidential, or Privileged Information [redacted] | | Every 5-10 years, as appropriate |

Fluid samples will be obtained for analysis from the Mt. Simon Sandstone during the initial well completion and pre-operational testing program (Attachment 5: Pre-Op Testing Program, 2022). The final sampling interval in the Mt. Simon Sandstone will be determined after the well has been drilled and the well logs have been analyzed. The $CO_2$ plume is expected to intersect OBS1 approximately five years after injection commences. Once free phase $CO_2$ breaks through at OBS1, the project will stop taking fluid samples from the Mt Simon Sandstone.

Baseline PNL logs will be acquired in CCS1, OBS1 and ACZ1 prior to the start of injection operations. Once injection starts, PNL logs will be acquired in CCS1 and OBS1 once each year. A baseline 3D surface seismic survey will be acquired in Q4 2022 or Q1 2023. Subsequent time-lapse 3D surface seismic surveys will be acquired every five to ten years after injection operations commence.

At this time, no continuous $CO_2$ plume monitoring has been planned for the project. Likewise, no phased or adaptive monitoring has been planned for the project in terms of expanding the monitoring network. However, if during the reassessment of the AoR during the injection phase of the project, the AoR is shown to have grown, the Testing and Monitoring Plan will be reassessed (Attachment 2: AoR and Corrective Action, 2022).

## 8.2 Plume Monitoring Details

As $CO_2$ is injected into the Mt. Simon Sandstone, the geochemistry of the fluids and isotopes in the formation are expected to change. Geochemical modelling will be used to predict the geochemical changes to the Mt. Simon Sandstone fluids once data from the pre-operational testing program has been collected (Attachment 5: Pre-Op Testing Program, 2022).

The results of the geochemical and isotope analysis will be delivered in the form of lab reports. Section 6.3 of this document details the sampling procedures that will be used. Table 9 summarizes the analytical and field parameters for the fluid sampling. Details on the methods, containers, and preparation methods for the fluid sampling can be found in (Attachment 11: QASP, 2022). The project will stop taking fluid samples from the Mt. Simon Sandstone once free phase $CO_2$ is encountered at the sampling ports.

The PNL logs will be received as LAS files and interpreted products that can be imported into the static model. This logging data will be used to monitor the distribution and saturation of $CO_2$ adjacent to the wellbores in CCS1 and OBS1. The logs will be acquired through the Mt. Simon Sandstone as well to confirm the absence of $CO_2$ accumulations along the wellbore above the confining zone in the ACZ monitoring zone. Technical details on the logging tools can be found in the (Attachment 11: QASP, 2022).

Surface seismic data is delivered in a variety of formats including acquisition and processing reports and SEG-Y data files from a variety of points in the processing flow. In the context of time-lapse analysis, an assessment will be provided on the differences between the baseline and time-lapse surveys as well as data files that can be incorporated into the static model. Once a data processing company is selected for the surface seismic processing, detailed information can be provided on their processing flows; however, it is expected that the company will use industry standard processing flows for noise attenuation, demultiple, pre-stack migration, and time-lapse analysis. The injection of $CO_2$ and expansion of the plume is expected to change the acoustic impedance and travel times of the seismic waves through the Mt. Simon Sandstone, and these changes will be used to track $CO_2$ plume development over time. The time-lapse surface seismic data will also be monitored for changes that may suggest that $CO_2$ has migrated past the confining zone and into the overlying formation(s).

The results of the geochemical and isotope analysis, PNL, and time-lapse 3D surface seismic data will all be integrated to develop a comprehensive understanding of the $CO_2$ plume development over time. The logging and time-lapse 3D surface seismic data can be incorporated into the static model for comparison to the computational modelling predictions at different points in time. The data can be used to constrain the computational modelling results and produce better plume predictions over the course of the project. The logging data will be used to calibrate the computational modelling on a yearly basis and provide information on the vertical and horizontal plume development. It will also provide more detailed and direct measurement of $CO_2$ saturations than indirect seismic methods. The time-lapse 3D surface seismic data will be used to update the models every five to ten years. If the $CO_2$ plume monitoring data diverges significantly from the modelled plume predictions, it may result in a reassessment of the AoR (Attachment 2: AoR and Corrective Action, 2022).

## 8.3 Pressure-Front Monitoring Location and Frequency

Table 14 presents the methods that the project will use to monitor the position of the pressure front; this includes the activities, locations, and frequencies the project will employ. Quality assurance procedures for these methods have been presented in the QASP (Attachment 11: QASP, 2022).

**Table 14: Pressure plume monitoring activities**

| Target Formation | Monitoring Activity | Monitoring Location(s) | Spatial Coverage | Frequency |
|---|---|---|---|---|
| **Direct Pressure-Front Monitoring** | | | | |
| Sensitive, Confidential, or Privileged Information [redacted] | Pressure Monitoring | Sensitive, Confidential, or Privileged Information [redacted] | | Continuous |
| **Indirect Pressure-Front Monitoring** | | | | |
| Sensitive, Confidential, or Privileged Information [redacted] | Microseismic Monitoring | Sensitive, Confidential, or Privileged Information [redacted] | | Continuous |

The pressure/temperature sensors will be programmed to measure and record pressure and temperature readings every 10 sec. The final monitoring interval will be determined after CCS1 has been drilled and the well logs have been analyzed (Attachment 5: Pre-Op Testing Program, 2022). Ideally, the project will start recording pressures in the Mt. Simon Sandstone the quarter before injection operations commence.

Microseismic data will also be recorded on a continuous basis. This data will be sent to a cloud-based service via a cellular connection for data processing and archive. Baseline microseismic data will be acquired for four to six months prior to the start in injection operations.

No phased or adaptive monitoring has been planned for the project in terms of expanding the monitoring network. However, if during the reassessment of the AoR during the injection phase of the project, the AoR is shown to have grown, the Testing and Monitoring Plan will be reassessed (Attachment 2: AoR and Corrective Action, 2022).

## 8.4 Pressure-Front Monitoring Details

Pressure/temperature sensors will be placed on the tubing string of CCS1, OBS1, and ACZ1 to monitor the pressures. The gauges will collect and transmit data to surface continuously. Refer to the QASP for technical information on the potential pressure/temperature gauges (Attachment 11: QASP, 2022).

The pressure/temperature data will be stored as time stamped data pairs. It is expected that the pressure in the injection zone will begin to increase when injection operations begin. This data will be used to calibrate the computational modelling results over the injection and PISC phases of the project. Calibrating the computational model with pressure and temperature data from the injection zone will lead to more accurate predictions of pressure plume behavior over time. The AoR and Corrective Action Plan further discusses how the pressure and temperature data will be used to calibrate the computational modelling, and how it might be used to trigger an early reassessment of the AoR (Attachment 2: AoR and Corrective Action, 2022).

The proposed microseismic monitoring array will have a minimum of five surface stations. One station will be located adjacent to CCS1, and four stations will be distributed around the AoR. The objective of the array will be to monitor induced seismic events within eight (8) miles of CCS1 with a magnitude of completeness (Mc) of 1.5. The physical locations of these stations will be optimized through a design process once the data from CCS1 and OBS1 have been analyzed. The local array will be complemented with the addition of any relevant regional seismometer stations that are available through the Incorporated Research Institutions for Seismology (IRIS) to aid in positioning events from outside the AoR.

Each standalone station will likely consist of a seismometer, digitizer, solar with battery backup, and a cell modem/antenna. Triggered data will be processed to provide magnitude and location error ellipsoids on a real-time basis and results will be reviewed by a data processor and event data can be received by the project on a daily basis. Automatic notifications will be sent for events over a certain size.

The event locations will be incorporated into the static model. It is expected that some induced seismicity may occur in the Precambrian once injection commences, and the pressure plume related to the $CO_2$ injection expands. Microseismic activity will provide qualitative information on the spatial extent of pressure plume over time. Clusters of microseismic activity in the confining zone may be an indication of containment loss that would be cause for further investigation.

## 9 References

*Atlantic Analytical Laboratory*. (2022). Retrieved from https://atlanticanalytical.com/

(2022). *Attachment 1: Narrative.* Class VI Permit Application Narrative; Hoosier#1 Project, Vault 4401.

(2022). *Attachment 10: ERRP*. Emergency And Remedial Response Plan; Hoosier#1 Project, Vault 4401.

(2022). *Attachment 11: QASP*. Project Hoosier#1, Vault 4401.

*Attachment 12: Risk Register.* (2022). Class VI Permit Application Narrative; Project Hoosier#1, Vault 4401.

(2022). *Attachment 2: AoR and Corrective Action.* Area Of Review And Corrective Action Plan; Hoosier#1 Project, Vault 4401.

(2022). *Attachment 3: Financial Responsibility.* Financial Responsibility; Project Hoosier#1, Vault 4401.

(2022). *Attachment 4: Well Construction.* Injection Well Construction Plan; Project Hoosier#1, Vault 4401.

(2022). *Attachment 5: Pre-Op Testing Program.* Pre-Operational Formation Testing Program; Hoosier#1 Project, Vault 4401.

(2022). *Attachment 6: Well Operations.* Well Operation Plan; Hoosier#1 Project, Vault 4401.

(2022). *Attachment 6: Well Operations.* Well Operation Plan; Project Hoosier#1, Vault 4401.

(2022). *Attachment 7: Testing And Monitoring.* Testing And Monitoring Plan; Project Hoosier#1, Vault 4401.

(2022). *Attachment 8: Well Plugging.* Project Hoosier#1, Vault 4401.

(2022). *Attachment 9: Post-Injection Site Care.* Post-Injection Site Care And Site Closure Plan; Project Hoosier#1, Vault 4401.

Bauer, R. A. (2016). *Bauer, R. A., Carney, M., & Finley, R. J.,Overview of microseismic response to CO2 injection into the Mt. Simon saline reservoir at the Illinois Basin-Decatur Project.* Retrieved from International Journal of Greenhouse Gas Control, 54(Part 1), 378-388. : https://doi.org/10.1016/j.ijggc.2015.12.015

*Cosasco*. (2022). Retrieved from https://www.cosasco.com/

EPA. (2013 ). *United States Environmental Protection Agency. Geologic Sequestration of Carbon Dioxide: Underground Injection Control (UIC) Program Class VI Well Testing and Monitoring Guidance, EPA 816-R-13-001. 142 p.*