TESTING AND MONITORING PLAN
40 CFR 146.90

Lorain Carbon Zero Solutions, LLC
Class VI Permit Application

Facility Information

Facility name: Lorain County Landfill
Well No. CCS #1

Facility contact: Gary McCuistion/Division VP Business Development
Lorain County Landfill
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Well location: Oberlin, Ohio

Well No. CCS #1 Location (US STP NAD27 Ohio North)		
Location	Easting (X)	Northing (Y)
Surface	2087845	595505.8
Heel	2088075	595833.5
Toe	2090333	599058.5

This Testing and Monitoring Plan describes how Lorain Carbon Zero Solutions, LLC will monitor the Lorain County Landfill pursuant to 40 CFR 146.90. In addition to demonstrating that the well is operating as planned, the carbon dioxide plume and pressure front are moving as predicted, and that there is no endangerment to USDWs, the monitoring data will be used to validate and adjust the geological models used to predict the distribution of the CO_2 within the storage zone to support AoR reevaluations and a non-endangerment demonstration.

Results of the testing and monitoring activities described below may trigger action according to the Emergency and Remedial Response Plan.

Overall Strategy and Approach for Testing and Monitoring

There will be one Class VI well (CCS #1) installed at the Lorain County Landfill that will be located on the southwest part of the property. The well will have an extended lateral (approximately 1200 meters or 3937 feet) and the bottomhole location of the well will extend to the north east. As such we propose two monitor wells. The first monitor well will be located on the same drilling pad as the injection well surface location (approximately 50 feet to the west) and will monitor at the base of the USDW. The second monitor well will be located 0.65 miles northeast of the injection well surface location (updip geologically of the bottomhole location) and approximately 0.35 miles west of the bottomhole location. The second monitor well will monitor just above the Confining Zone depth. The second monitor well is located geologically updip from the CCS #1 bottomhole location.

In the injection well, the schedule for data collection will be to continuously monitor CO_2 concentration, pressure, and temperature data at the wellhead. In addition, bottomhole pressure-temperature sensor will be installed at the packer depth that will provide continuous bottomhole pressure and temperature data. A fiber optic distributed temperature sensor (DTS) apparatus will be installed in the casing-tubing annulus of the monitor wells to examine any changes to the temperature profile. The DTS data will be analyzed to review for anomalous cooling effects that could be caused by the CO_2 waste plume both in the Injection Interval and potentially upwards towards the USDW.

We propose that this data be reviewed weekly for the first 3 months of operation to establish a baseline temperature distribution. After the first 3 months are complete, the DTS data will be downloaded on a monthly basis for 3 months. At the 6-month mark, it may be possible to download DTS data for analysis on a quarterly basis.

In the monitor wells, we propose to conduct sampling of the fluid on a quarterly frequency.

Quality assurance procedures

A quality assurance and surveillance plan (QASP) for all testing and monitoring activities, required pursuant to 146.90(k), will be provided in the Appendix to this Testing and Monitoring Plan.

Reporting procedures

Lorain Carbon Zero Solutions, LLC will report the results of all testing and monitoring activities to the EPA in compliance with the requirements under 40 CFR 146.91.

Carbon Dioxide Stream Analysis [40 CFR 146.90(a)]

Lorain Carbon Zero Solutions, LLC will analyze the CO_2 stream during the operation period to yield data representative of its chemical and physical characteristics and to meet the requirements of 40 CFR 146.90(a).

Sampling location and frequency

Lorain Carbon Zero Solutions, LLC will analyze the CO_2 waste stream during the operation period to grant data representative of its chemical and physical characteristics and to meet the requirements of 40 CFR 146.90(a). At the Class VI well, CO_2 stream sampling will take place quarterly, by the following dates each year: 3 months after the date of authorization of injection, 6 months after the date of authorization of injection, 9 months after the date of authorization of injection, and 12 months after the date of authorization of injection.

Lorain Carbon Zero Solutions, LLC will sample and analyze the CO_2 stream as described in Section 5 of the permit application and presented below.

Analytical parameters

Lorain Carbon Zero Solutions, LLC will analyze the CO_2 for the constituents identified in Table 1 using the methods listed.

Table 1. Summary of analytical parameters for CO_2 stream.

Parameter	Analytical Method(s)
Oxygen	ISBT 4.0 (GC/DID) GC/TCD
Nitrogen	ISBT 4.0 GC/DID GC/TCD
Carbon Monoxide	ISBT 5.0 Colorimetric ISBT 4.0 (GC/DID)
Oxides of Nitrogen	ISBT 7.0 Colorimetric
Total Hydrocarbons	ISBT 10.0 THA (FID)
Methane	ISBT 10.1 (GC/FID)
Acetaldehyde	ISBT 11.0 (GC/FID)
Sulfur Dioxide	ISBT 14.0 (GC/SCD)
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)
Ethanol	ISBT 11.0 (GC/FID)
CO_2 Purity	ISBT 2.0 Caustic absorption Zahm-Nagel ALI method SAM 4.1 subtraction method (GC/DID) GC/TCD

Sampling methods

CO_2 stream sampling will occur at a sampling station installed downstream at the last stage of compression in the compressor building (or equivalent structure if a compressor is not needed). The sampling station will have the ability to purge and collect samples into a container that will be sealed and sent to the authorized laboratory for analysis.

All sample containers will be labeled with indestructible labels and ingrained markings. A unique sample identification number and sampling date will be recorded on the sample containers.

Laboratory to be used/chain of custody and analysis procedures

Samples will be analyzed by a third party laboratory using standardized procedures for gas chromatography, mass spectrometry, detector tubes, and photo ionization.

Continuous Recording of Operational Parameters [40 CFR 146.88(e)(1), 146.89(b) and 146.90(b)]

Lorain Carbon Zero Solutions, LLC will install and use continuous recording devices to monitor injection pressure, rate, and volume; the pressure on the annulus between the tubing and the long string casing; 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).

Monitoring location and frequency

Lorain Carbon Zero Solutions, LLC will perform the activities identified in Table 2 to monitor operational parameters and verify internal mechanical integrity of the injection well and monitor injection pressure, rate, volume, and annular pressure as required at 40 CFR 146.88, 146.89, and 146.90(b). All monitoring will be continuous for the duration of the operating period and take place at the locations and frequencies shown in the table. The injection well will have pressure/temperature gauges at the surface and a pressure/temperature sensor installed at the packer. There will also be distributed temperature sensing (DTS) fibers in the casing-tubing annulus of the well.

Table 2. Sampling devices and locations for continuous monitoring.

Parameter	Location
Injection Pressure Monitoring	Surface
Injection Pressure Monitoring	Reservoir – near injection packer
Injection Rate Monitoring	Surface
Injection Volume Monitoring	Surface
Annular Pressure Monitoring	Surface
Annulus Fluid Volume	Surface
Temperature Monitoring	Surface
Temperature Monitoring	Reservoir – near injection packer
Temperature Monitoring	Along wellbore to packer using DTS

Monitoring details

Above-ground pressure and temperature instruments shall be calibrated over the full operational range at least annually using ANSI or other recognized standards. A bottomhole pressure/temperature tool will be lowered down to the packer depth on wireline to record bottomhole pressure/temperature data to demonstrate the accuracy of the permanent downhole gauges. Pressure transducers will have a drift stability of less than 1 psi over the operational period of the instrument and an accuracy of ± 5 psi. Sampling rates will be at least once every 5 seconds. Temperature sensors will be accurate to within one degree Celsius. DTS sampling will be once per 10 seconds (and can be expanded later on in the monitoring phase if needed).

Flow will be monitored with a Coriolis mass flowmeter at the compression facility. The flowmeter will be calibrated using accepted standards to be accurate to within ±0.1 percent. The flowmeter will be calibrated for the entire expected range of flow rates.

Injection Rate and Pressure Monitoring

Lorain will monitor injection operations using the distributive process control system as described and presented below.

The Surface Facility Equipment & Control System will limit maximum flow to 387 MT/day and/or limit the wellhead pressure to 2500 psig, which corresponds to the regulatory requirement to not exceed 90% of the injection zone's fracture pressure. All injection operations will be continuously monitored and controlled by the Lorain operations staff using the distributive process control system. This system will continuously monitor, control, record, and will alarm and shutdown if specified control parameters exceed their normal operating range.

All critical system parameters, e.g., pressure, temperature, and flow rate will have continuous electronic monitoring with signals transmitted back to a master control system. Lorain supervisors and operators will have the capability to monitor the status of the entire system from distributive control centers but mainly from two locations: from the phase 1 compression control room (near CO_2 collection and blower facility) and the phase 2 main compression control room.

The flow rate will be measured using a flow meter with an orifice-plate differential meter. The density of the fluid will need to be estimated using equations of state and pressure temperature readings to calculate the mass flow rate. Even if a mass meter is used, the density needs to be estimated to determine the weight of the CO2 in the tubing for reporting and verification purposes. The density can be estimated using the correlation developed by Ouyang (2011).

Continuous Monitoring of Annulus Pressure

Lorain will follow the program below to monitor annular pressure as described in the permit application.

1. The annulus between the tubing and the long string casing will be filled with brine. The brine will have a specific gravity of 1.08 and a density of 9.0 lbs/gal. The hydrostatic gradient is 0.468 psi/ft. The brine will contain a corrosion inhibitor.

2. The surface annulus pressure will be kept at a minimum of 2600 psi during injection.

3. During periods of well shut down, the surface annulus pressure will be kept at a minimum pressure to maintain a pressure differential of at least 100 psi between the annular fluid directly above (higher pressure) and below (lower pressure) the injection tubing packer set at 4,430 ft KB.

4. The pressure within the annular space, over the interval above the packer to the confining layer, will be greater than the injection zone formation at all times.

5. The pressure in the annular space directly above the packer will be maintained at least 100 psi higher than the adjacent tubing pressure during injection.

The annulus monitoring system consists of a continuous annular pressure gauge, a pressurized annulus fluid reservoir (annulus head tank), pressure regulators, and tank fluid level indicators. The annulus system will maintain annulus pressure by controlling the pressure on the annulus head tank using compressed nitrogen (N2).

The annulus pressure will be maintained in the range of 2600-3000 psi and monitored by the Lorain control system gauges. The annulus heat tank pressure will be controlled by the pressure regulators – one set of regulators to maintain pressure above 2600 psi by adding compressed nitrogen and the other to relieve pressure above 3000 psi by venting gas off the annulus head tank.

Any changes to the composition of the annular fluid will be reported in the following quarterly report submitted to the permitting agency.

If there is lost communication between the annulus monitoring system and the control room for longer than 30 minutes, operations personnel will conduct field monitoring of manual gauges at least twice per shift for both wellhead surface pressure and annulus pressure by recording hard copies of the data until communication is restored.

The average annular pressure and annulus tank fluid level will be recorded daily. The volume of fluid added or removed from the system will also be recorded.

Casing-Tubing Pressure Monitoring

Lorain will monitor the casing-tubing pressure as described the permit.

During injection operations, the casing-tubing pressure will be monitored and recorded in real time. Surface pressure of the casing-tubing annulus is anticipated to be from 2600 to 3000 psi. As detailed in the Emergency and Remedial Response Plan (Attachment 10-1), any significant changes in the casing-tubing annular pressure attributed to well mechanical integrity will be investigated.

Collection and recording of monitoring data will occur at the frequencies described in Table 3 below:

Table 3. Sampling Frequency

Well Condition	Minimum Sampling frequency; once every:	Minimum Recording frequency; once every:

For continuous monitoring of the injection well during operations:	5 seconds	5 minutes
For the injection well when shut-in:	4 hours	4 hours

Note: DTS sampling frequency will be set at every 10 seconds.

Corrosion Monitoring

To meet the requirements of 40 CFR 146.90(c), Lorain Carbon Zero Solutions, LLC will monitor well materials during the operation 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.

Lorain Carbon Zero Solutions, LLC will monitor corrosion using the corrosion coupon method and collect samples according to the description below.

The monitoring will occur quarterly as such: 3 months after the first date of authorized injection, 6 months after first date of authorized injection, 9 months after first date of authorized injection, and 12 months after the first date of authorized injection.

Lorain will monitor corrosion using the corrosion coupon method and collect samples according to the description below.

Monitoring location and frequency

The monitoring location and frequency of the corrosion coupons will be at the inlet of the pipeline and at a testing loop that will be near the outlet of the pipeline at the CCS #1 wellhead.

Sample description

Samples of material used in the construction of the compression equipment, pipeline, and injection well which come into contact with the CO_2 stream will be included in the corrosion monitoring program either by using actual material and/or conventional corrosion coupons. The samples consist of those items listed in the Table 4 below. Each coupon will be weighed, measured, and photographed prior to initial exposure.

Table 4 List of Coupons and Material of Construction

Equipment Coupon	**Material of Construction**
Pipeline	CS A106B (need to be confirmed)
Long String Casing (Surface – 4400 ft)	Carbon Steel

Long String Casing (4400-5000 ft)	13 Chrome alloy
Injection Tubing	Carbon Steel (fiberglass lining)
Wellhead	Carbon Steel with 13 Chrome alloy wetted parts
Packer	13 Chrome alloy

Each coupon sample will be attached to an individual holder and then inserted in a flow-through pipe arrangement. The corrosion monitoring system will be located downstream of the compression/dehydration/pumping equipment at a point where the pipeline to the wellhead begins in a loop configuration. Therefore, the CO2 stream will go through this loop and the coupons will be exposed to the same concentration and constituents of the CO2 stream (as well as temperature and pressures) as the equipment at the wellhead and downhole. The coupon holders and location of the corrosion monitoring system will be included in the pipeline design and will allow for continuation of injection during sample removal

The coupons will be handled and assessed for corrosion using the American Society for Testing and Materials (ASTM) G1-03, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens (ASTM 2011). The coupons will be photographed, visually inspected with a minimum of 10x power, dimensionally measured (to within 0.0001 inch), and weighted (to within 0.0001 gm).

Above Confining Zone Monitoring

Lorain Carbon Zero Solutions, LLC will monitor ground water quality and geochemical changes above the confining zone during the operation period to meet the requirements of 40 CFR 146.90(d).

To meet the requirements at 40 CFR 146.95(f)(3)(i), Lorain Carbon Zero Solutions, LLC will also monitor ground water quality, geochemical changes, and pressure in the first USDWs immediately above and below the injection zone(s).

The groundwater monitoring plan focuses on the following zones:

- The base of the USDW at 1785 feet BGL
- Just above the Rome Confining Zone at 4427 feet BGL

Monitoring location and frequency

Table 5 shows the planned monitoring methods, locations, and frequencies for ground water quality and geochemical monitoring above the confining zone.

Table 5. Direct Monitoring of ground water quality and geochemical changes above the confining zone.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
USDW	Fluid sampling	Monitor wells and CCS #1	Sensitive, Confidential, or Privileged Information [redacted]	Quarterly for fluid sample
USDW	DTS	CCS #1		Continuous
Conasuaga (Upper Confining Zone)	DTS	CCS #1		Continuous
Conasuaga (Upper Confining Zone)	Pressure/Temperature Monitoring	CCS #1		Continuous
Rome (Lower Confining Zone)	DTS	CCS #1		Continuous
Rome (Lower Confining Zone)	Pressure/Temperature Monitoring	CCS #1		Continuous
Mt. Simon (Injection Interval)	DTS	CCS #1		Continuous

Notes:

1. Baseline sampling and analysis will be completed before injection is authorized.
2. Quarterly sampling will begin 3 months from the date that authorized injection operations begin.

Table 6. Indirect Monitoring of ground water quality and geochemical changes above the confining zone.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
USDW	Pulse Neutron Logging/ Reservoir Saturation Tool (RST) logs	Monitor wells	Sensitive, Confidential, or Privileged Information [redacted]	Baseline, Year 2, Year 4
Mt. Simon (Injection Interval)	Pulse Neutron Logging/RST	CCS #1		Baseline, Year 2, Year 4

Note 1: Baseline sampling and analysis will be completed before injection is authorized.

Analytical parameters

For CO2 stream monitoring, samples will be collected in a clean sample container reated for the appreciate collection pressure (mini cylinders or polybags).

Assay for CO_2 quarterly gas analysis:

- CO_2 Purity (% v/v. [GC])
- Oxygen (O_2, ppm v/v)
- Nitrogen (N_2, ppm v/v)
- Carbon Monoxide (CO, ppm v/v)
- Oxides of Nitrogen (NOx, ppm v/v)
- Total Hydrocarbons (THC, ppm v/v/ as CH_4)
- Methane (CH_4, ppm v/v)
- Acetaldehyde (AA, ppm v/v)
- Sulfur Dioxide (SO_2, ppm v/v)
- Hydrogen Sulfide (H_2S ppm v/v)
- Ethanol (ppm v/v)

For shallow (monitor wells) and deep (CCS #1) groundwater samples, all sample bottles will be new. Sample bottles and bags for analytes will be used as received (ready for use) from the vendor or contracted analytical laboratory for the specimen sample of interest.

For dissolved CO_2, the samples will be contained in 60 ml/HDPE, filtered and cooled at 4degC. For the shallow samples, the sample holding time will be 4 weeks. For the deep samples, the sample holding time will be 2 weeks.

The sample chain-of-custody will be as follows: an analysis authorization form will accompany the sample to the lab. For groundwater samples, the chain-of-custody will be documented using a standardized form. Copies of the form will be provided to the person/lab receiving the samples as well as the person/lab transferring the samples. These forms will be retained and archived to allow simplified tracking of sample status. The chain-of-custody form and record keeping is the responsibility of the groundwater sampling personnel.

External Mechanical Integrity Testing

Lorain Carbon Zero Solutions, LLC will conduct at least one of the tests presented in Table 6 periodically during the injection phase to verify external MI as required at 146.89(c) and 146.90.

Testing location and frequency

Table 7. MITs.

Test Description	Location
Temperature Log	Along wellbore using DTS or wireline well log
Noise Log	Wireline Well Log
Oxygen Activation Log	Wireline Well Log

Testing details

Temperature Logging Using Wireline

To ensure the mechanical integrity of the casing of the injection well, temperature data will be recorded across the wellbore from surface down to total depth of the well. Bottom hole pressure data near the packer will also be provided.

The well should be in injection operations for at least 12 hours prior to commencing operations in order to cool down the injection zone (Mt. Simon formation).

1. Move in and rig up an electric wireline logging unit with lubricator.
2. Run a temperature survey from the top of Confining Zone (Rome formation) to the total depth (bottom of Mt. Simon formation) while injecting CO2 at a rate that allows for safe operations.
3. Stop injection, pull tool back to shallow depth and then wait one (1) hour.
4. Run a temperature survey over the same interval in Step 2.
5. Pull tool back to shallow depth and then wait two (2) hours.
6. Run a temperature survey over the same interval as Step 2.
7. Pull tool back to shallow depth, wait 2 hours.
8. Run a temperature survey over the same interval as Step 2.
9. Evaluate the data to determine if additional passes are needed for interpretation. If CO2 migration is interpreted to be at the top most section of the log, additional logging runs over a higher interval will be required to find the top of migration.

10. If additional passes are needed, repeat temperature surveys every 2 hours until 12 hours total are completed, over the same interval as Step 2.

11. Rig down the logging equipment.

12. The temperature data interpretation includes reviewing the time lapse well temperature profiles and observing any temperature anomalies that may indicate a failure of well integrity such as a tubing leak or movement of fluid behind the casing. As the well cools down the temperature profile along the length of the tubing string is compared to the baseline temperature profile. A temperature anomaly would be anything that is observed to vary in the temperature profile from the baseline cooling profile – this could indicate unplanned fluid movement into the annulus or outside the casing.

Temperature Logging Using DTS Fiber Optic Line

The Class VI wells will be equipped with DTS fiber optic for monitoring the well temperature profile in real-time in the casing-tubing annulus from the packer depth to surface. The DTS fiber optic system can also be used for early detection of temperature changes that may indicate a loss of well mechanical integrity using the procedure below:

1. After the well is completed and prior to injection, a baseline temperature profile will be established. This profile represents the natural temperature warmback gradient for each stratigraphic zone.

2. During injection operations, record the temperature profile for 6 hours prior to shutting in the well.

3. Stop injection and record temperature profile for 6 hours.

4. Evaluate data to determine if additional cooling time is needed for interpretation.

5. Start injection and record temperature profile for 6 hours.

6. Data interpretation involves comparing the time lapse well temperature profiles and looking for temperature anomalies that may indicate well integrity failure. Compare the data to the baseline temperature profile. Using DTS, this temperature data can be continuously monitored to provide real time MIT surveillance making this technology superior to wireline temperature logging.

Noise Logging

To ensure mechanical integrity of the casing of the injection well, a noise log will be run from surface to total depth in the Mt. Simon formation while injection operations occur. If ambient noise is greater than 10 mv, injection will be halted. The following procedure will be used:

1. Move in and rig up electrical wireline logging unit with lubricator.

2. Run a noise survey from the top of the Confining Zone (Rome formation) operations.

3. Make noise measurements at intervals of 100 feet to create a log on a coarse grid.

4. If any anomalies are evident on the coarse log, construct a finer grid by making noise measurements at intervals of 20 feet within coarse intervals containing high noise levels.

5. Make noise measurements at intervals of 10 feet through the first 50 feet above the injection interval and at intervals of 20 feet within the 100-f0oot intervals containing:

    a. The base on the lowermost bleed-off zone above the injection interval and

    b. The base of the lowermost USDW

6. Additional measurements may be made to pinpoint depths at which noise is produced.

7. Use a vertical scale of 1-2 inches per 100 feet.

8. Rig down the logging equipment.

9. Interpret the data from the noise log: determine the base noise level in the well. Identify changes from this baseline level. An increase in noise near the surface due to equipment operating at surface is commonplace. Determine the extent of any movement—flow into or between USDWs indicates a lack of mechanical integrity.

<u>Oxygen Activation (OA) Logging</u>

The OA log will be recorded from total depth to the top of the Confining Zone (Rome formation) using the following program:

1. Move in and rig up an electric wireline logging unit with lubricator.

2. Conduct a baseline Gamma Ray log with casing collar locator (CCL) from the top of the injection zone to the surface prior to taking stationary readings with the OA tool.

3. All stationary readings should be taken with the well injecting fluid at the normal rate with minimal rate and pressure fluctuations.

4. Prior to taking the stationary readings, the OA tool must be properly calibrated in a “no vertical flow behind the casing” section of the well to ensure accurate, repeatable tool response and for measuring background counts.

5. Take a 15-minute (at least) stationary reading adjacent to the Confining Interval located immediately above the Injection Interval. This must be at least 10 feet above the Injection Interval so that turbulence does not affect the readings.

6. Take a 15-minute (at least) stationary reading at a depth midway between the base of the USDW and the Confining Interval.

7. Take a 15-minute (at least) stationary reading at the top of the Confining Zone.

8. Take a 15-minute (at least) stationary reading at the base of the USDW.

9. If flow is indicated by the OA log at a certain location, move uphole or downhole as necessary at 50-foot intervals (or less) and take stationary readings to determine the rea of fluid migration.

10. Interpet the data: identify the differences in the activated water's measured gamma ray count-rate profile versus the expected count-rate profile for a static environment. Differences between the measured and expected may indicate flow in the annulus or behind casing. The flow velocity is determined by measuring the time that the activated water passes a detector.

Pressure Fall-Off Testing

Lorain Carbon Zero Solutions, LLC will perform pressure fall-off tests during the injection phase as described below to meet the requirements of 40 CFR 146.90(f).

A pressure falloff test has a period of injection followed by a period of no-injection or shut-in. Normal injection using the CO2 stream captured at the Lorain facility will be used during the injection period of 2.5 years prior to conducting the shut-in portion of the falloff tests. The normal injection rate is 387 MT/day. One week of continuous injection will precede the shut-in portion of the falloff test. The pressure falloff analysis will use several months of preceding injection data. The data will be measured using a surface readout downhole gauge run on electric wireline.

During shut-in, the well will be shut-in at the wellhead instantaneously with the pipeline, surface equipment, and the injection compression facility in order to reduce wellbore storage effects on the early-time results of the pressure falloff analysis. The sampling rate during the shut-in will be 5 seconds. The shut-in period should be at least four days to allow for proper evaluation of radial flow into the reservoir. A report containing the pressure falloff data and interpretation of the reservoir ambient pressure will be submitted to the permitting agency within 90 days of the test. The downhole gauges will meet or exceed the ASME B 40.1 Class 2A (0.5% accuracy across full range). Wellhead pressure gauge range will be 0-3,000 psi. Downhole gauge range will be 0-10,000 psi.

Carbon Dioxide Plume and Pressure Front Tracking

Lorain Carbon Zero Solutions, LLC will employ direct and indirect methods to track the extent of the carbon dioxide plume and the presence or absence of elevated pressure during the operation period to meet the requirements of 40 CFR 146.90(g).

Plume monitoring location and frequency

Table 8 presents the methods that Lorain Carbon Zero Solutions, LLC will use to monitor the position of the CO_2 plume, including the activities, locations, and frequencies Lorain Carbon Zero Solutions, LLC 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.

Plume monitoring details

Plume monitoring will be conducted with two monitor wells. Monitor Well #1 (MW #1) will be located on the same pad as the CCS #1 surface location. MW #1 will be located 50-75 feet west of the CCS #1 wellhead and will monitor at the base of the USDW. Monitor Well #2 (MW #2) will be located approximately 0.6 miles north of the CCS #1 surface location. MW #2 will monitor just above the Conasuaga confining zone. The site map below shows the anticipated 12-year CO2 plume model (blue lines) and 30-year CO2 plume model (red lines) and the location of the CCS #1 surface and bottomhole locations and the two monitor wells. MW #2 is set geologically updip from the CCS #1 bottomhole location as the CO2 plume is expected to migrate updip due to the low density of the CO2 fluid.

Figure 1. CO2 Waste Plume and Monitor Well Locations

Predicted bottomhole pressure profiles in the Mt. Simon (the injection zone) are presented in Appendix 3-1.

Lorain will deploy pressure/temperature monitors and DTS to directly monitor the position of the pressure front.

Indirect plume monitoring will be conducted using pulsed neutron capture/RST logs (run into open hole) to monitor CO2 saturation. Time-lapse 3D seismic profiles (VSPs) will be utilized to image the developing CO2 plume for indirect plume monitoring. Passive seismic monitoring combination of borehole and surface seismic stations to detect local events over M 1.0 within the AOR will also be performed.

Table 8. Plume monitoring activities.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
DIRECT PLUME MONITORING			Sensitive, Confidential, or Privileged Information [redacted]	
Mt. Simon	Fluid Sampling	CCS #1 and MW #1	[redacted]	Baseline; Year 1-3: Annual
USDW	Fluid Sampling	MW #2 and MW #2	[redacted]	Baseline; Year 1-3: Annual
INDIRECT PLUME MONITORING			[redacted]	
Mt. Simon	Pulse Neutron Logging/RST	CCS #1	[redacted]	Baseline, Year 2, Year 4
Mt. Simon	Time-Lapse VSP Survey	Either in MW #1 or temporary groundwater well	[redacted]	Year 1, Year 2, Year 3
Mt. Simon	3D Surface Seismic Survey	Full coverage focusing on the northern extent of the plume near bottomhole location	[redacted]	Baseline, Year 2

Note 1: Baseline monitoring will be completed before injection is authorized.

Note 2: Annual monitoring will be performed up to 45 days before the anniversary date of authorization of injection each year or an alternate schedule based on approval from the UIC Program Director.

Note 3: Logging surveys will be performed up to 45 days before the anniversary date of authorization of injection each year or an alternate schedule based on approval from the UIC Program Director.

Note 4: Seismic surveys will be performed in the 4th quarter before or the 1st quarter of the calendar year or an altenate schedule based on approval from the UIC Program Director.

Table 9. Summary of analytical and field parameters for fluid sampling in the injection zone.

Parameters	Analytical Methods
Mt. Simon	
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb Se, and TI	ICP-MS, EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010B
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration, ASTM D513-11
Total Dissolved Solids	Gravimetry; APHA 2540C
Water Density (field)	Oscillating body method
Alkalinity	APHA 2320B
pH (field)	EPA 150.1
Specific conductance (field)	APHA 2510
Temperature (field)	Thermocouple
Isotopes: $\delta^{13}C$ of DIC	Isotope ratio mass spectrometry

Note 1: ICP – inductively couple plasma; MS = mass spectrometry; OES = optical emission spectrometry; GC-P = gas chromatography-pyrolysis. An equivalent method may be employed with the prior approval of the UIC Program Director.

Pressure-front monitoring location and frequency

Lorain will utilize the same methods exhibited in Table 8 for plume monitoring to monitor the pressure-front. Whether the pressure-front plume or CO_2 plume propagates away from the wellbore, it will be monitored with the two monitor wells MW #1 and MW #2 via fluids sampling and the methods described in Table 8.

For details including reservoir simulation diagrams on the pressure-front and CO_2 plume model can be found in Appendix 3-1.