POST-INJECTION SITE CARE AND SITE CLOSURE PLAN
40 CFR 146.93(a)

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
43502 Oberlin-Elyria Road
Oberlin, Ohio 44074
832-399-4516/GMcCuistion@republicservices.com

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 Post-Injection Site Care and Site Closure (PISC) plan describes the activities that Lorain Carbon Zero Solutions, LLC (Lorain) will perform to meet the requirements of 40 CFR 146.93. Lorain Carbon Zero Solutions, LLC will monitor ground water quality and track the position of the carbon dioxide plume and pressure front for 50 years. Lorain may not cease post-injection monitoring until a demonstration of non-endangerment of USDWs has been approved by the UIC Program Director pursuant to 40 CFR 146.93(b)(3). Following approval for site closure, Lorain will plug all monitoring wells, restore the site to its original condition, and submit a site closure report and associated documentation.

Pre- and Post-Injection Pressure Differential [40 CFR 146.93(a)(2)(i)]

Based on the modeling of the pressure front as part of the AoR delineation, pressure at the injection well is expected to decrease to within 1% of the pre-injection levels 58 years after the injection well is shut in (year 88 of the simulation), as described below. Additional information on the projected post-injection pressure declines and differentials is presented in the permit application and the AoR and Corrective Action Plan.

The pressure change at the injection well is shown on Figure 1 (in the injection layer at node 11089 in the middle of the injection well where the pressure build up is maximal). The maximum pressure increase of 4.8 MPa occurs at the very end of the injection period (30 years).

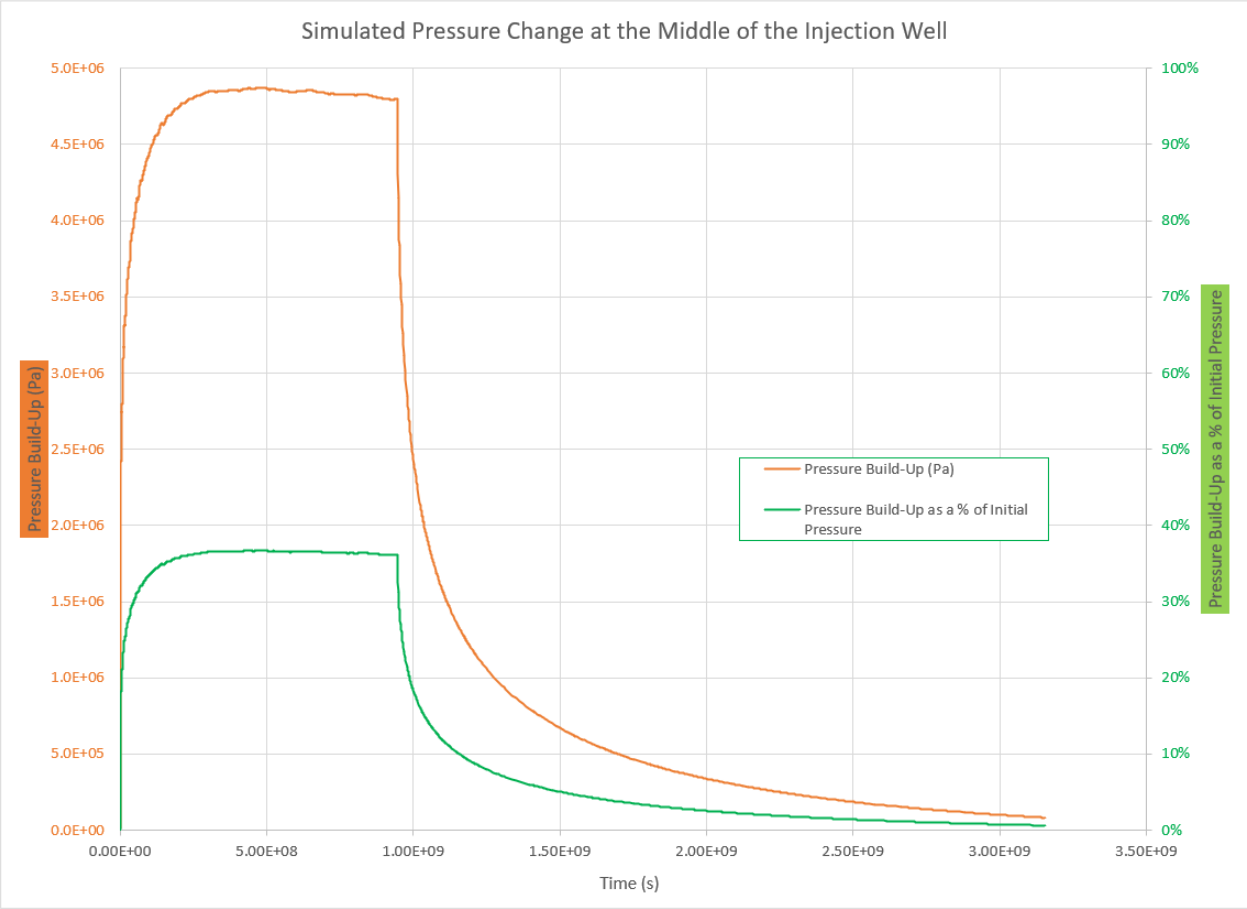

Figure 1: Simulated pressure change at the middle of the injection well

Predicted Position of the CO_2 Plume and Associated Pressure Front at Site Closure [40 CFR 146.93(a)(2)(ii)]

Figure 2 shows the predicted extent of the plume (layer 5, top of the Mt Simon reservoir) and pressure front (layer 1, injection layer) at the end of the injection period (year 30) and at the end of the simulation (year 100, i.e. 70 years after the end of injection). The pressure front is maximal at the end of the injection period and in the injection layer. The pressure front is not shown at the end of simulation because the pressures have returned to near pre-development levels and are well below the threshold pressure of 1.35MPa used for the pressure front. Finally Figure 2 shows that the plume extents at 30 and 100 years are nearly identical, hence demonstrating CO_2 containment. This map is based on the final AoR delineation modeling results submitted pursuant to 40 CFR 146.84.

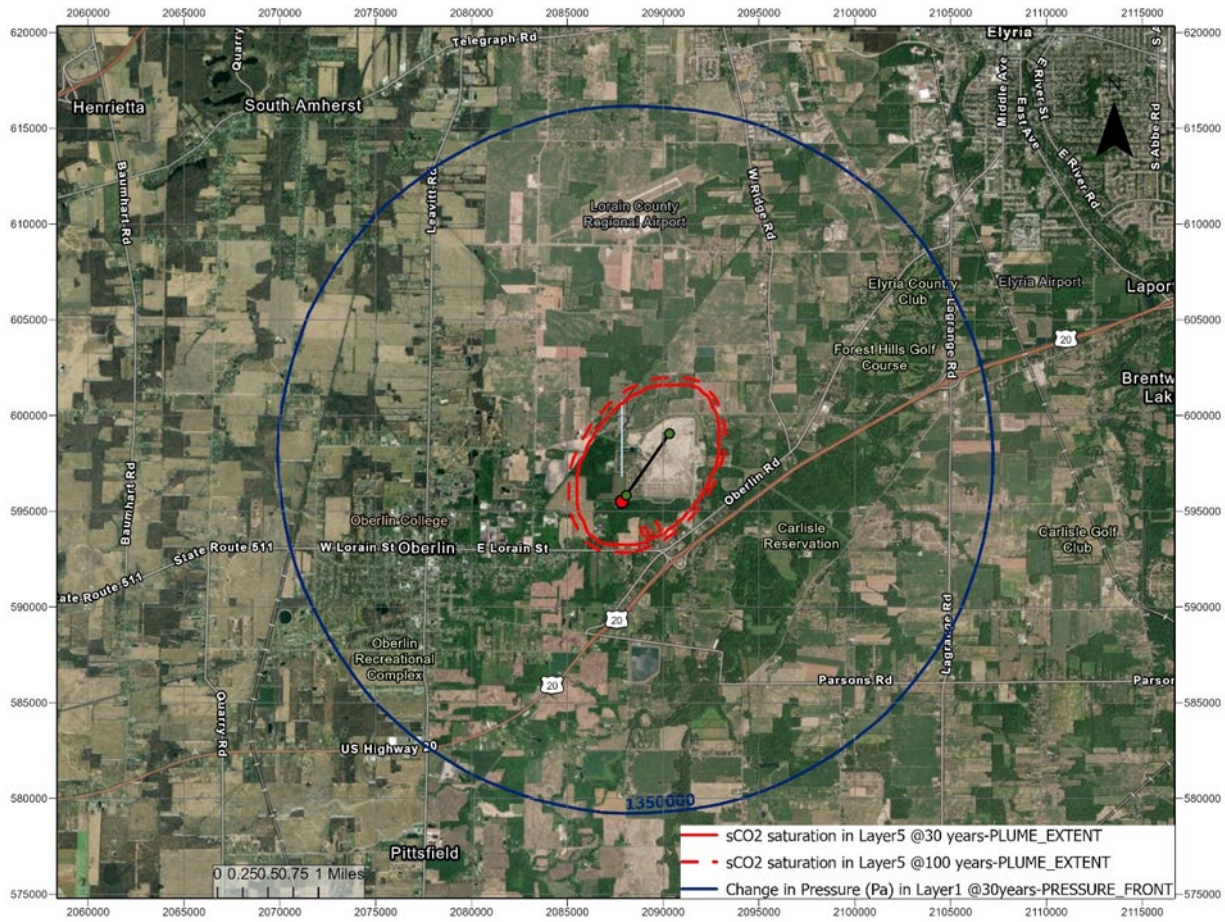

Figure 2. Map of the predicted extent of the CO_2 plume and pressure front at the end of the injection period and at the end of the simulation.

Post-Injection Monitoring Plan [40 CFR 146.93(b)(1)]

Performing fluid sampling and downhole logging surveys across the USDW and confining zones as described in the following sections during the post-injection phase will meet the requirements of 40 CFR 146.93(b)(1). The results of all post-injection phase testing and monitoring will be submitted annually, within 60 days of recording the results, as described under "Schedule for Submitting Post-Injection Monitoring Results," below.

Lorain intends to maintain ownership of the lands throughout the PISC timeframe to ensure access to all monitoring wells.

A quality assurance and surveillance plan (QASP) for all testing and monitoring activities during the injection and post injection phases is provided in the Appendix to the Testing and Monitoring Plan.

Monitoring Above the Confining Zone

Table 1 presents the monitoring methods, locations, and frequencies for monitoring above the confining zone. Table 2 identifies the parameters to be monitored and the analytical methods Lorain will employ.

Table 1. 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	Sampling interval at approximately 1850’	Quarterly for fluid samples; annual after five years should results confirm the modeled plume results.
USDW	Pulse Neutron Logging/ Reservoir Saturation Tool (RST) logs	Monitor wells	1 point location (12 inches outside wellbore) and continuous down to full well depth.	Baseline, Year 2, Year 4

Notes:

1. Quarterly sampling will begin 3 months from the date of cessation of injection operations.

Table 2. Summary of analytical and field parameters for ground water samples.

Parameters	Analytical Methods
USDW	
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

Carbon Dioxide Plume and Pressure Front Tracking [40 CFR 146.93(a)(2)(iii)]

Lorain will employ direct and indirect methods to track the extent of the carbon dioxide plume and the presence or absence of elevated pressure.

Table 4 presents the direct and indirect methods that Lorain will use to monitor the CO_2 plume, including the activities, locations, and frequencies Lorain will employ. The parameters to be analyzed as part of fluid sampling in the Mt. Simon zone (and associated analytical methods) are presented in Table 5.

Lorain will utilize the same methods exhibited in Table 4 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 4.

Fluid sampling will be performed as described in Section B.1 of the QASP; sample handling and custody will be performed as described in Section B.3 of the QASP; and quality control will be ensured using the methods described in Section B.5 of the QASP. Quality assurance procedures for seismic monitoring methods are presented in Section B.9 of the QASP.

Table 3. Post-injection phase plume monitoring.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
DIRECT PLUME MONITORING				
USDW	Fluid Sampling	MW #1 and MW #2	1 point location, 1 interval: collect sample at 2000' in MW #2, collect sample at 1850' in MW #1 Fluid samples to make certain CO_2 not entering into USDW.	Annual; after 5 years, adjust to biennial if data indicates a stable trend.
INDIRECT PLUME MONITORING				
Mt. Simon	Time-Lapse VSP Survey	Either in MW or temporary groundwater well	Fold image coverage ~ 30 acres	Annual
Mt. Simon	3D Surface Seismic Survey	Full coverage focusing on the northern extent of the plume near bottomhole location	Fold image coverage ~ 2,000 acres	Biennial (once every 2 years)

Table 4. 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

Schedule for Submitting Post-Injection Monitoring Results [40 CFR 146.93(a)(2)(iv)]

All post-injection site care monitoring data and monitoring results collected using the methods described above will be submitted to EPA in reports submitted on an annual basis until the PISC timeframe has been satisfied. The reports will contain information and data generated during the reporting period; i.e. well-based *monitoring data, sample analysis, and the results from updated site models.*

Non-Endangerment Demonstration Criteria

Prior to approval of the end of the post-injection phase, Lorain will submit a demonstration of non-endangerment of USDWs to the UIC Program Director, per 40 CFR 146.93(b)(2) and (3).

The owner or operator will issue a report to the UIC Program Director. This report will make a demonstration of USDW non-endangerment based on the evaluation of the site monitoring data used in conjunction with the project's computational model. The report will detail how the non-endangerment demonstration evaluation uses site-specific conditions to confirm and demonstrate non-endangerment. The report will include all relevant monitoring data and interpretations upon which the non-endangerment demonstration is based, model documentation and all supporting data, and any other information necessary for the UIC Program Director to review the analysis. The report will include the following sections:

Introduction and Overview

A summary of relevant background information will be provided, including the operational history of the injection project, the date of the non-endangerment demonstration relative to the post-injection period outlined in this PISC and Site Closure Plan, and a general overview of how monitoring and modeling results will be used together to support a demonstration of USDW non-endangerment.

Summary of Existing Monitoring Data

A summary of all previous monitoring data collected at the site, pursuant to the Testing and Monitoring Plan (Attachment C of this permit) and this PISC and Site Closure Plan, including data collected during the injection and post-injection phases of the project, will be submitted to help demonstrate non-endangerment. Data submittals will be in a format acceptable to the UIC Program Director [40 CFR 146.91(e)], and will include a narrative explanation of monitoring activities, including the dates of all monitoring events, changes to the monitoring program over time, and an explanation of all monitoring infrastructure that has existed at the site. Data will be compared with baseline data collected during site characterization [40 CFR 146.82(a)(6) and 146.87(d)(3)].

Summary of Computational Modeling History

The model results are included in the application document and show that the caprock formations are very effective at confining the injected CO_2 within the Mt Simon reservoir: the simulated CO_2 concentrations within the confining formations are minimal at the bottom of these

formations and absent at their top. As there are no known vertical penetrations through these confining formations and no known faults within the area of review, CO_2 is not expected to migrate into the overlying formations.

The model predictions will be refined once the injection well is drilled and tested. Pressure Transient Analysis (PTA) of the injection test and permeability, porosity, and relative permeability and capillary curves developed from core testing, and formation fluid analysis will be used to update model input parameters. The refined model predictions will then be compared to actual operational bottomhole pressure and temperature measurements in the injection well.

A daily injectivity index will be calculated from the measured bottomhole pressure and will be compared to the injectivity index calculated from simulations in terms of trend and variance. Pressure fall-off periods due to operational shut-in periods will also be used to compare model predictions to actual reservoir performance.

The model will be updated based on the actual measurements as required. If corrections to model input and conceptualization are outside reasonable explanation to fit the data additional data collection may be required depending on the discrepancy and risks associated with the discrepancy.

Evaluation of Reservoir Pressure

The pressure front cannot be directly and accurately measured in the absence of numerous observation wells. The pressure front extent will be updated when the reservoir model is updated.

A daily injectivity index will be calculated from the measured bottomhole pressure and will be compared to the injectivity index calculated from simulations in terms of trend and variance. Pressure fall-off periods due to operational shut-in periods will also be used to compare model predictions to actual reservoir performance.

Evaluation of Carbon Dioxide Plume

The absence of gas will be checked in the USDW and in the deep observation wells by sampling any gas build up at the wellheads during the monitoring events.

The plume extent will be updated when the model is updated.

Comments regarding the proposed monitoring plan

Current proposal: 1 USDW monitoring well + 1 monitoring well in the Mt Simon + P/T monitoring in injection well

The current proposal will provide some info on the performance of the Mt Simon reservoir (P/T in injection well) and should detect a large breach of containment (the deep observation well would pick up a large pressure increase in the injection zone).

The current proposal will provide some information to prove that CO_2 remains confined in Mt

Simon and what the plume actually looks like. Pathways for CO_2 vertical migration include a leaky wellbore and natural features such as fractures. The deep observation well should be located near the build section of the injection well to take care of the first pathway. The second pathway cannot be monitored with a single observation well because we don't know where these fractures are located.

The current proposal is weak in terms of linking model predictions to observations b/c the proposed observation wells are located above the model domain and the monitoring results do not provide a 'picture' of the plume extent.

Proposed modifications to the monitoring plan:

i) move the deep obs well near the injection well built section and

ii) consider some seismic survey carried at regular interval (e.g. every 5 years) and compared to baseline to detect plume extent and geophysical anomalies related to the impedance and density differences of CO_2/CO_2 gas vs brine. There are a number of options for seismic surveys that should be explored including a VSP taking advantage of the deep observation well.

Evaluation of Emergencies or Other Events

Artificial penetrations within the modeled plume will be evaluated to determine whether the well construction is compatible with planned CO_2 stream injected via CCS Well #1. Should it be determined that the either the as-built construction (and/or plugging) materials are inadequate, Lorain will employ a realistic effort to re-enter said artificial penetrations to ensure they are competent penetrations, capable of preventing any upward migration of CO_2 into the USDW.

Section 3 of this permit application highlights the nearest wells relative to the proposed CCS Well #1 lateral. The nearest wells (aside from the proposed two monitoring wells) are North and West of the modeled plume.

The quality of well construction will be evaluated using cement bond logs and casing inspection logs for baseline testing during well completion and testing every five years thereafter to assess changes to cement bond or tubulars. For the monitor wells, a baseline cement bond log and casing inspection logs will be conducted. Casing inspection logs will be conducted every five years.

Site Closure Plan

Lorain will conduct site closure activities to meet the requirements of 40 CFR 146.93(e) as described below. Lorain will submit a final Site Closure Plan and notify the permitting agency at least 120 days prior of its intent to close the site. Once the permitting agency has approved closure of the site, Lorain will plug the monitoring wells and submit a site closure report to EPA. The activities, as described below, represent the planned activities based on information provided

to EPA. The actual site closure plan may employ different methods and procedures. A final Site Closure Plan will be submitted to the UIC Program Director for approval with the notification of the intent to close the site.

Plugging Monitoring Wells

Lorain will conduct the plugging of monitoring wells similar to that of the injection well, which has also been detailed in Section 8.

Planned Tests or Measures to Determine Bottom-Hole Formation Pressure

- Lorain will run a bottom-hole pressure gauge to the top of the targeted monitoring formations to record pressure and calculate kill fluid density

Planned External Mechanical Integrity Test(s)

- Lorain will conduct at least one of the tests listed in Table 6 to verify external mechanical integrity prior to plugging the monitoring wells.

Table 6. Planned Monitoring Well MITs.

Test Description	Location
Temperature Log	Along wellbore from total depth to surface using wireline or DTS.
Noise Log	Wireline well log
Oxygen Activation Log	Wireline well log

Information on Plugs

- Lorain will use the balanced method to plug the monitoring wells with cement.
- Calculations will be conducted based on the total depth of the wells, as well as the internal diameter of the innermost cemented casing.
    - The volume and depth of the plug or plugs will depend on the final geology and downhole conditions of the well as assessed during construction.
- The cement(s) formulated for plugging will be compatible with the carbon dioxide stream.
    - The plugs covering the confining zone and approximately 300' immediately above the zone will consist of CO_2-resistant material

(*Evercrete* or equivalent), while the remaining cement (300' above the confining zone to surface) will consist of common API cement.

- The cement formulation and required certification documents will be submitted to the agency with the well plugging plan. The owner or operator will report the wet density and will retain duplicate samples of the cement used for each plug.

Notifications, Permits, and Inspections

- In compliance with 40 CFR 146.92(c), Lorain will notify the regulatory agency at least 60 days before plugging the well and provide an updated Well Plugging Plan, if applicable.

Plugging Procedures (Applies to each monitoring well)

1. Move in and rig up (MIRU) onto the monitoring wellsite. A well pad walkthrough will be done with the rig supervisor before the rig moves in. Any nearby pipelines near the well will be identified, marked, and discussed with the rig supervisor at that time.
2. Conduct a safety meeting with all personnel on site.
3. Using electric wireline, run a downhole pressure gauge to the top of the targeted confining zone formation (2000' for MW #1; 1850' for MW #2) and record bottomhole pressure to determine kill fluid density.
4. Open all valves on the wellhead tree to check pressures.
5. Test the rig pump and flow line to 2500 psig. Fill the injection tubing with kill fluid (density of kill fluid 10 ppg [maximum density or may be less, TBD] brine). Pump two more volumes of the injection tubing capacity.
6. Pressure up the casing-tubing annulus to 1000 psig and monitor pressure loss for 30 minutes (like an annual MIT). Bleed off the pressure after the test.
7. Monitor the tubing and casing pressure for at least 1 hour. If both the casing and tubing are dead, nipple up the blowout preventors (BOP).
8. If the casing and tubing are not dead, rig up a slickline unit and set a plug in the profile nipple below the injection packer. Circulate the tubing and annulus with kill weight fluid until the well is dead. After the well is dead, nipple up the BOP and conduct a function test on the BOP. The BOP will have pipe rams for the 3-1/2" tubing and a set of blind rams. Test the pipe rams to 250 psig low and 3000 psig high. Test the annular preventer to 250 psi low and 3000 psi high. Test the

TIW safety valve (for latching onto the 3-1/2" tubing) and the BOPs choke and kill lines and choke manifold to 250 psi low and 3000 psi high.

9. Pick up on the tubing string and unlatch the seal assembly from the seal bore in the injection packer.
10. Rig up slickline and retrieve the plug from the profile nipple.
11. Pull out the injection tubing and lay it down.
12. Run in the well with packer retrieval tool on workstring and pull the injection packer out of the well. If unable to retrieve packer, cut tubing 5-10 ft above the packer and remove from the well.
13. Conduct MIT operations including: temperature log, noise log, and oxygen activation log.
14. Rig up cementing operations. Run workstring and tag the total depth of the well. Pump CO_2-resistant cement plug from TD to the top of the target zone. The plug will be CO_2-resistant cement (EverCrete or equivalent) with 15 ppg density.
15. After waiting over night for the cement to set up, run in with the workstring and tag the top of the cement (TOC). If is below the calculated TOC, pump some more CO_2-resistant cement to bring up to depth.
16. Pump the second CO_2-resistant cement plug to 300' above the top of the targeted zone. Wait overnight before tagging. The CO_2-resistant cement plugs will be 16 ppg density, 1.3 ft3/sack yield.
17. Wait overnight and tag the TOC. If the plug is below calculated depth, pump more CO_2-resistant cement to bring up to depth.
18. Pump Class A cement (15.5 ppg, 1.18 ft3/sack yield) from TOC to surface in 500-ft increments. Tag each plug after waiting at least 4-6 hours for cement to gain compressive strength. Repeat this process until all necessary plugs are pumped to surface. Depending on the height of the plug near 400 ft, tag and then calculate the volume for the final plug.
19. After waiting overnight for cement to gain compressive strength for the final plug, nipple down BOP.
20. Cut all casing strings below the plow line (minimum 3 feet below ground level.
21. Rig down all equipment and move out. Clean the well cellar.
22. Weld a plate onto the lowest casing string at 3 feet. The plate will include well name.
23. All procedures described above are subject to change during the plugging process or if any changes are made during installation of the well. These procedures will be revised after the well is installed if needed. The Plugging report will be

certified accurate by Lorain and the plugging contractor and will be submitted to regulatory agencies within 60 days after plugging is completed.

Site Closure Report

A site closure report will be prepared and submitted within 90 days following site closure, documenting the following:

- Plugging of the verification and geophysical wells (and the injection well if it has not previously been plugged),
- Location of sealed injection well on a plat of survey that has been submitted to the local zoning authority,
- Notifications to state and local authorities as required at 40 CFR 146.93(f)(2),
- Records regarding the nature, composition, and volume of the injected CO_2, and
- Post-injection monitoring records.

Lorain will record a notation to the property's deed on which the injection well was located that will indicate the following:

- That the property was used for carbon dioxide sequestration,
- The name of the local agency to which a plat of survey with injection well location was submitted,
- The volume of fluid injected,
- The formation into which the fluid was injected, and
- The period over which the injection occurred.

The site closure report will be submitted to the permitting agency and maintained by the owner or operator for a period of 10 years following site closure. Additionally, the owner or operator will maintain the records collected during the post-injection period for a period of 10 years after which these records will be delivered to the UIC Program Director.

Quality Assurance and Surveillance Plan (QASP)

The Quality Assurance and Surveillance Plan is presented in the Appendix of the Testing and Monitoring Plan.