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

CTV IV

1.0 Document Version History

Version	Revision Date	File Name	Description of Change
1	4/11/2023	Att E - CTV IV PISC_v1	Original Submission

2.0 Facility Information

Facility name: CTV IV

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This Post-Injection Site Care (PISC) and Site Closure plan describes the activities that Carbon TerraVault Holdings, LLC (CTV) will perform to meet the requirements of 40 CFR 146.93. CTV will monitor ground water quality and track the position of the carbon dioxide (CO_2) plume and pressure front during the post-injection period. CTV will 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, CTV will plug all monitoring wells, restore the site to its original condition, and submit a site closure report and associated documentation.

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

Based on the computational modeling, upper injection zone pressure in the injection area is expected to stabilize [redacted] lower injection zone pressure in the injection area is expected to stabilize [redacted] (see Attachment B Figure 4.5). [redacted]

Using the base case scenario of 100% CO_2 injectate, **Figure 3.1** shows the modeled pressure at monitoring well locations [redacted] at middle perforation point (MPP) during the injection period and [redacted] post injection. **Figure 3.2** shows the pressure increase at monitoring well locations [redacted] at MPP during the injection period and [redacted] post injection. Pressure decline trends are discussed further in Section 6.2, below.

The storage reservoir will be operated such that the bottom hole injection pressures will not exceed the fracture pressure of the reservoir with a 10% safety factor. This operating strategy is to minimize the potential for induced seismicity and to ensure confinement of the injectate.

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

Figure 4.1 shows the predicted maximum extent of the plume (100 years post injection) and pressure at the end of the PISC timeframe, representing the maximum extent of the plume and pressure front. This map is based on the final AoR delineation modeling results submitted pursuant to 40 CFR 146.84 (**Attachment B**).

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

Monitoring during the post-injection phase will include pressure monitoring and fluid composition monitoring within injection zones and above the upper confining zone. The monitoring plan described in the following sections, 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 90 days of the end of each year, as described under "Schedule for Submitting Post-Injection Monitoring Results" below.

The Testing and Monitoring Plan describes the monitoring strategies within the injection zone, above the confining zone, and within USDWs. A quality assurance and surveillance plan (QASP) for all testing and monitoring activities during the injection and post injection phases is provided in Appendix 8.

Pressure monitoring of the upper injection zone and lower injection zone storage reservoirs will monitor for pressure stabilization. This is the best method to confirm confinement of the reservoir. If pressure in the reservoir trends are inconsistent when compared to computational modeling results, CTV will assess for potential leakage. Throughout the AoR there are USDWs in formations overlying the confining zones. As such, ongoing groundwater monitoring of the USDWs will assess potential impacts. Groundwater samples will be analyzed annually for indicators of CO_2 movement into the USDWs.

CTV has obtained surface access rights for the duration of the project.

5.1 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 CTV will employ. **Table 3** presents sampling and recording frequencies for continuous monitoring.

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

CTV will employ direct and indirect methods to track the extent of the CO_2 plume and the presence or absence of elevated pressure.

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

Table 6 presents the direct and indirect methods that CTV will use to monitor the pressure front, including the activities, locations, and frequencies CTV will employ. Direct monitoring will include pressure gauges to monitor the pressure of the CO_2 plume in the two upper injection zone and two lower injection zone monitoring wells. Additionally, seismic monitoring via installed surface and/or shallow borehole seismometers well will be utilized to detect micro-seismic events.

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.

Using the base case scenario of 100% CO_2 injectate, **Figure 5.1** shows the location of the injection wells and the predicted CO_2 plume development through time in plan view for the upper and lower storage reservoirs. **Figures 5.2** shows the location of the injection wells and the predicted CO_2 plume development through time in cross-section.

5.3 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 annual reports submitted within 90 days following the anniversary date on which injection ceases. 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).

6.0 Alternative Post-Injection Site Care Timeframe

An alternative PISC timeframe of 20 years (as compared to the default of 50 years) is appropriate based on the results of the detailed geologic analyses and numerical plume and pressure-front modeling presented in Attachment A (Narrative Permit Application Report) and Attachment B (AoR and Corrective Action Plan). In addition to the factors discussed below, a shorter PISC timeframe is supported because the CTV IV project injection wells will inject for a maximum of [redacted] in the upper injection zone and [redacted] in the lower injection zone (see **Attachment B Table 3.4**).

Injection well and monitoring well construction are presented in the Appendix 5, and wells will be constructed and plugged for the case of the injection wells in order to maintain integrity and prevent fluid leakage.

6.1 Computational Modeling Results

AoR delineation modeling, including methods, results, and sensitivity analyses, are presented in Attachment B (AoR and Corrective Action Plan). These results are used for discussion of plume and pressure front migration below.

6.2 Predicted Timeframe for Pressure Decline

Figure 3.1 to this Plan displays simulated pressure at the location of the monitoring wells and **Figure 4.5** to **Attachment B** displays average pore volume pressure in the AoR region for the upper and lower injection zones.

In the upper injection zone, average initial pressure [redacted]

In the lower injection zone, [redacted]

The pressure at the monitoring well locations is plotted in **Figure 3.1** for reference. [redacted] which is denoted by the "star" symbol.

6.3 Predicted Rate of Plume Migration

Figure 5.1 displays the location of the simulated upper and lower injection zone CO_2 plumes at various times. For the upper injection zone plumes are shown 1, 5, 10, 20, 23 (end of injection period), and 77 and 100 years post injection. The upper zone CO_2 plume is predicted to move slowly after the injection period, [redacted] For the lower injection zone plume outlines are shown for 1, 5, 10, 20, 25 (end of injection), 75 and 100 years after injection ends and [redacted]

At no time during the lifetime of the project or afterwards is the separate-phase CO_2 plume predicted to reach sensitive receptors including abandoned wells (**Attachment B Figure 5.1**). EPA Class VI Well Plugging, PISC and Site Closure Guidance states that when the plume is migrating at a negligible rate as compared to the location of sensitive receptors the plume migration rate may be considered sufficiently minor as to not pose an endangerment to USDWs. The rate of movement predicted for the CTV IV storage project and lack of interface with sensitive receptors supports a PISC timeframe of 20 years.

6.4 Site-Specific Trapping Processes

At the CTV IV site, simulations indicate trapping occurs primarily by capillary trapping and CO_2 dissolution in the brine. Equilibrium geochemical modeling presented in Appendix 3 indicates minor CO_2 mineralization. Attachment B includes a detailed discussion of simulated CO_2 fate after injection (see **Attachment B Figure 4.3**). Most of the CO_2 is trapped as separate-phase carbon dioxide ("capillary trapping"), consistent with scientific understanding of key storage processes in saline reservoirs (e.g., Krevor et al., 2015[1]). As discussed below the fraction of CO_2 predicted to be stored via capillary trapping in pore space remains relatively constant in the post-injection period, supporting a reduced PISC timeframe.

[redacted]

[redacted]

6.5 Confining Zone Characterization

The narrative permit application report (**Attachment A**) includes a detailed evaluation of the [redacted] that acts as the upper confining zone for the storage project. T[redacted] The geometric average permeability of the upper confining zone is 0.33 mD (**Attachment A** Section 2.4.2.1). Geochemical modeling indicates that [redacted] will not be significantly reactive with CO_2 (**Appendix 3**). [redacted] These attributes indicate that the confining zone will restrict upwards fluid movement and support a reduced PISC timeframe.

[1] https://doi.org/10.1016/j.ijggc.2015.04.006

6.6 Assessment of Fluid Movement Potential

The AoR and Corrective Action Plan (**Attachment B**) presents information on abandoned wells within the AoR. There are six wells within the AoR that penetrate both the upper and lower injection zones. If isolation of this formation is determined to be deficient in such a way that USDW may be impacted, corrective action plans will be communicated and implemented prior to injection to ensure non-endangerment of USDW. Before the date of site closure all of these wells will have been evaluated and if necessary appropriately plugged and will not be a potential conduit for fluid movement.

6.7 Location of USDWs

Delineation of the depth to the top of the injection zone and the depth of the lowermost USDW are discussed in the narrative permit application report (**Attachment A**). **Attachment A Figure 2.2-4** presents a cross section showing the USDW depth and key geologic formations. [redacted] There is significant thickness that exists between the injection zone and lowermost USDW, which as described in Attachment A consists of several fine-grained geologic units (upper confining zone and a secondary confining zone). Along with the other analyses described above, the significant thickness between the injection zone and lowermost USDW is another assurance of the limited risk to USDWs and supports a shorter PISC timeframe.

7.0 <u>Non-Endangerment Demonstration Criteria</u>

Prior to authorization of site closure, CTV will submit a demonstration of non-endangerment of USDWs to the Director as per 40 CFR 143.93(b)(2) or (3).

CTV will provide a report to the Director that demonstrated USDW non-endangerment based on the evaluation of site monitoring data. The report will detail how the non-endangerment determination is based on site-specific conditions, supported with the computational model. All relevant monitoring data and interpretations will be provided.

7.1 Summary of Monitoring Data

A summary of the site monitoring data, pursuant to the Testing and Monitoring Plan and this PISC and Site Closure Plan, including data collected during the injection and PISC phases of the project. Data submission will be in a format acceptable to the Director and will include:

1. A narrative that explains the monitoring activities,
2. Dates of all monitoring events,
3. Changes to the monitoring program over time,
4. An explanation of all monitoring information that has existed at the site,
5. Explanation of how the monitoring data from injection and PISC has varied from the baseline data during site characterization, and

6. Summary of any emergencies that occurred during the injection and post-injection phases of the project. Included will be a description of how any issues have been resolved and that there is no endangerment to the USDW.

7.2 Evaluation of the CO_2 Plume and the AoR

Computational modeling results calibrated with monitoring data (e.g., pressure) will be used to support that the plume has stabilized and that the pressure change is negligible (less than 10 psi per year) and poses no risk for potential vertical migration. Computational modeling results calibrated with monitoring data from storage reservoir, USDW and above zone will be used to demonstrate:

1. The lack of CO_2 leakage over the project timeframe,

2. The accuracy of the model to predict and represent the storage reservoir, and

3. The computational model adequately defined the AoR.

7.3 Evaluation of Reservoir Pressure

Monitoring data will be reviewed to ensure that the CO_2 plume has stabilized post-injection and that the reservoir pressure change is negligible (less than 10 psi per year). This demonstration will be supported by the computational model that has been calibrated with the most recent monitoring data. The plume is trapped by pinch-out of the reservoir sands. Plume migration is minimal, as such pressure stabilization will be used for non-endangerment assessment.

7.4 Evaluation of Potential Conduits for Fluid Movement

Wells that require corrective action will be reviewed and assessed prior to PISC and Site Closure, this includes monitoring wells, injection wells and other wells that penetrate within the AoR and the confining layer. Final demonstration will be made that natural and artificial conduits will not allow fluid migration from the storage reservoir.

7.5 Evaluation of Seismicity Monitoring

Demonstration will be made that the plume has stabilized and the pressure change is negligible (less than 10 psi per year), minimizing the risk for induced seismicity after site closure. Final review will be made with the seismicity monitoring to demonstrate seal integrity and that there is no further endangerment of to the USDW.

8.0 Site Closure Plan

CTV will conduct site closure activities to meet the requirements of 40 CFR 146.93(e), with notification to the permitting agencies at least 120 days prior to its intent to close the site. Upon approval of the permitting agencies, CTV will plug the injection and monitoring wells, restore the site and submit a site closure plan to the EPA.

A site closure report will be prepared and submitted within 90 days following site closure supported by the following:

1. Verification of injector and monitoring well plugging,
2. Notifications to state and local authorities as per 40 CFR 146.93 (f)(2),
3. Composition and volume of the injected CO_2, and
4. Post-injection monitoring records

CTV will record a notation to the property's deed that will indicate:

1. The property was used for CO_2 sequestration, the period of injection and the volume of CO_2 injected,
2. The formation that the fluid was injected, and
3. The name of the local agency to which a plat of survey with injection well locations was submitted.

FIGURES

[redacted]

Figure 3.1: Modeled pressure at monitoring well locations [redacted] at MPP during the injection period and 100 years post injection. Horizontal dashed line indicates initial pressure. The star symbol denotes the critical pressure required at the specific monitoring well locations and as can be seen the pressures drop below critical pressure within 10 years of the end of injection

[redacted]

Figure 3.2: Pressure increase at monitoring well locations [redacted] at MPP during the injection period and 20 years post injection for the storage site.

[redacted]

Figure 4.1: Map of the predicted extent of the CO_2 plume at site closure.

[redacted]

Figure 5.1: Upper Injection Zone plume development through time: 1-year, 5-year, 10-year, 15-year, 20-year, 23-year (end of injection), 77-year, and 100-year post injection (Left). Lower Injection Zone plume development through time: 1-year, 5-year, 10-year, 15-year 20-year, 25-year (end of injection), 75-year, and 100-year post injection (Right).

[redacted]

Figure 5.2. Cross sections showing plume development at varying time steps through the project .

TABLES

Table 1. Monitoring of ground water quality and geochemical changes above the confining zone

Target Formation	Monitoring Activity	Device	Data Collection Location(s)	Spatial Coverage or Depth	Frequency (Injection Phase)
[redacted] Ground Water Monitoring Above Confining Zone	Fluid Sampling	Pump	[redacted]	[redacted]	Annual
	Pressure	Pressure Gauge	[redacted]	[redacted]	Continuous
	Temperature	Temperature Sensor	[redacted]	[redacted]	Continuous
	Temperature	Fiberoptic cable (DTS)	[redacted]	[redacted]	Continuous
[redacted] Direct Monitoring Above Confining Zone	Fluid Sampling	Sampling Device	[redacted]	[redacted]	Annual
	Pressure	Pressure Gauge	[redacted]	[redacted]	Continuous
	Temperature	Temperature Sensor	[redacted]	[redacted]	Continuous
	Temperature	Fiberoptic cable (DTS)	[redacted]	[redacted]	Continuous

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

Parameters	**Analytical Methods**
USDW and [redacted]	
Cations (Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Se, Zn, Tl)	ICP-MS EPA Method 6020
Cations (Ca, Fe, K, Mg, Na, Si)	ICP-OES EPA Method 6010B
Anions (Br, Cl, F, NO3, SO4)	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration ASTM D513-11
δ13C	Isotope ratio mass spectrometry
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)
Oxygen, Argon, and Hydrogen	ISBT 4.0 (GC/DID) GC/TCD
Total Dissolved Solids	Gravimetry; Method 2540 C
Alkalinity	Method 2320B
pH (field)	EPA 150.1
Specific Conductance (field)	SM 2510 B
Temperature (field)	Thermocouple

Table 3. Sampling and recording frequencies for continuous monitoring

Parameter	Device(s)	Location	Min. Sampling Frequency	Min. Recording Frequency
During active injection	Pressure gauge	USDW Monitoring Well	5 hours	5 hours
Post injection	Pressure gauge	USDW Monitoring Well	12 hours	12 hours

Notes:

- 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.

Table 4. Post-injection phase plume monitoring

Monitoring Category and Class VI Rule Citation	Target Formation	Monitoring Activity	Data Collection Location(s)	Spatial Coverage or Depth	Frequency (Post Injection Phase)
Plume Monitoring [40 CFR 146.90(g)] **DIRECT MONITORING**	Upper Injection Zone	Fluid Sampling	[redacted]	[redacted]	Annual
		Pressure		[redacted]	Continuous
		Temperature		[redacted]	Continuous
	Upper Injection Zone	Fluid Sampling	[redacted]	[redacted]	Annual
		Pressure		[redacted]	Continuous
		Temperature		[redacted]	Continuous
	Lower Injection Zone	Fluid Sampling	[redacted]	[redacted]	Annual
		Pressure		[redacted]	Continuous
		Temperature		[redacted]	Continuous
	Lower Injection Zone	Fluid Sampling	[redacted]	[redacted]	Annual
		Pressure		[redacted]	Continuous
		Temperature		[redacted]	Continuous
Plume Monitoring [40 CFR 146.90(g)] **INDIRECT MONITORING**	Upper Injection Zone	Pulsed Neutron Log	[redacted]	[redacted]	Every 5 years
			[redacted]	[redacted]	
	Lower Injection Zone	Pulsed Neutron Log	[redacted]	[redacted]	Every 5 years
			[redacted]	[redacted]	

Table 5. Summary of analytical and field parameters for fluid sampling in the injection zone

Parameters	Analytical Methods
Upper and Lower Injection Zones	
Cations (Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Se, Zn, Tl)	ICP-MS EPA Method 6020
Cations (Ca, Fe, K, Mg, Na, Si)	ICP-OES EPA Method 6010B
Anions (Br, Cl, F, NO3, SO4)	Ion Chromatography, EPA Method 300.0
Dissolved CO_2	Coulometric titration ASTM D513-11
δ13C	Isotope ratio mass spectrometry
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)
Oxygen, Argon, and Hydrogen	ISBT 4.0 (GC/DID) GC/TCD
Total Dissolved Solids	Gravimetry; Method 2540 C
Alkalinity	Method 2320B
pH (field)	EPA 150.1
Specific Conductance (field)	SM 2510 B
Temperature (field)	Thermocouple

Table 6. Post-injection phase pressure-front monitoring

Monitoring Category and Class VI Rule Citation	Target Formation	Monitoring Activity	Data Collection Location(s)	Spatial Coverage or Depth	Frequency (Post Injection)
Pressure-Front Monitoring [40 CFR 146.90(g)] **DIRECT MONITORING**	Lower Injection Zone	Pressure	[redacted]	[redacted]	Continuous
		Temperature			Continuous
	Lower Injection Zone	Pressure	[redacted]	[redacted]	Continuous
		Temperature			Continuous
	Upper Injection Zone	Pressure	[redacted]	[redacted]	Continuous
		Temperature			Continuous
	Upper Injection Zone	Pressure	[redacted]	[redacted]	Continuous
		Temperature			Continuous
Pressure-Front Monitoring [40 CFR 146.90(g)] **INDIRECT MONITORING**	All Formations	Seismicity	Seismic Monitoring Network	Full AOR	Continuous