

# UIC CLASS VI GEOLOGIC STORAGE OF CO<sub>2</sub> PERMIT APPLICATION

Loving CCS Hub

Loving County, Texas

## Section 6: Testing and Monitoring Plan

[40 CFR §146.90]

*Prepared for:*

**EPA Region 6**

**Underground Injection Control Section**

1201 Elm Street, Suite 500 | Dallas, Texas 75270



*Prepared and submitted by:*

**Milestone Carbon Delaware CCS Hub, LLC**

840 Gessner Rd, Suite 600  
Houston, Texas 77024

*Fiberoptic Design Prepared by:*

**ESG Solutions**

10815 Woodedge Drive  
Houston, Texas 77070

1 August 2024

# Table of Contents

<b>6.0</b>	<b>TESTING AND MONITORING PLAN [146.82(a)(15), 40 CFR 146.90]</b>	<b>4</b>
6.1	Overall Strategy and Approach for Testing and Monitoring	4
6.1.1	Quality Assurance Procedures [146.93]	4
6.1.2	Reporting Requirement [146.91]	4
6.1.3	Testing Plan Review and Updates [146.90 (j) (1) (2) (3)]	5
6.2	Continuous Recording of Operational Parameters [40 CFR 146.88(e)(1), 146.89(b), 146.90(b)]	5
6.2.1	Continuous Monitoring of Injection Wells	5
6.2.1.1	Well Temperature	6
6.2.1.2	Injection Rate, Temperature, Density and Volume	6
6.2.1.3	Injection Pressure	6
6.2.1.4	Annular Pressure and Volume	7
6.2.1.5	Positive Annular Pressure	7
6.2.1.6	Gas Composition	7
6.3	Testing and Monitoring Techniques QA/QC [40 CFR 146.90(k)]	7
6.3.1	Casing and Tubing Inspection Tools	7
6.3.2	Pulsed-Neutron Logging	7
6.4	Corrosion Monitoring [40 CFR 146.90 (c)]	9
6.4.1	Monitoring Location and Frequency	9
6.4.2	Coupon Sampling Methods	9
6.5	Above Confining Zone Water Monitoring [40 CFR 146.90 (d); 40 CFR 146.82(a)(6)]	10
6.5.1	Location of In-zone Monitoring Well	10
6.5.2	Location of USDW Monitoring Wells	10
6.5.3	USDW and Above Zone Water Quality Monitoring	11
6.5.3.1	Discrete Chemistry and Isotope Analysis	11
6.5.4	Sampling and Analytical Methods	12
6.5.5	Values that May Indicate Leakage	12
6.5.6	Laboratory Chain of Custody Procedures	13
6.5.7	Quality Assurance and Surveillance Measures [40 CFR 146.90(k)]	13
6.6	External Mechanical Integrity Testing [40 CFR 146.89, 40 CFR 146.90(e)]	13
6.7	Pressure Fall-Off Testing [40 CFR 146.90 (f)]	13
6.7.1	Testing Method	13
6.7.2	Analytical Methods	14
6.7.3	Quality Assurance/Control	14
6.8	Carbon Dioxide Plume and Pressure Front Tracking [40 CFR 146.90 (g)]	14
6.8.1	Direct Monitoring Methods	14
6.8.2	Indirect Monitoring Methods	15
6.8.2.1	Microseismic Surveys	16
6.8.2.2	Controlled Source Electromagnetic Surveys	16
6.8.2.3	Ineffectiveness of Active Seismic Methods	18
6.9	Fiber Optic Monitoring	20
6.9.1	Distributed Acoustic Sensing (DAS)	20
6.9.1.1	DAS Microseismic	20
6.9.1.2	DAS Strain (LF-DAS)	20
6.9.2	Distributed Strain Sensing (DSS)	21
6.9.3	Distributed Temperature Sensing (DTS)	21
6.9.4	Fiber Optic Data Retention	22
6.10	Passive Seismicity Monitoring	23

6.10.1	Near Surface Seismometers.....	23
6.10.2	Downhole Fiber (DAS Microseismic).....	25
6.10.3	Downhole Geophones (Microseismic).....	25
6.11	Soil Gas Monitoring / Other Testing and Monitoring [40 CFR 146.90 (h)].....	26
6.12	Carbon Dioxide Stream Analysis [40 CFR 146.90(a)] .....	26
6.12.1	Validation Sampling frequency .....	26
6.12.2	Validation Sampling methods and Location.....	26
6.12.3	Validation Sample Analysis Methods.....	26

## List of Tables

Table 6-1: Sampling Devices, Locations & Frequencies for Continuous Monitoring in Injection Wells .....	6
Table 6-2: Monitoring of Groundwater Quality and Geochemical Changes above the Confining Zone.....	11
Table 6-3: Summary of Analytical and Field Parameters for Groundwater Samples.....	12
Table 6-4: Summary of Direct and Indirect Plume and Pressure Front Monitoring .....	15
Table 6-5: Fiber Optic Data Parameters, Acquisition and Storage Timeline .....	23
Table 6-6: Summary of Analytical and Field Parameters for Groundwater Samples.....	27

## List of Figures

Figure 6-1: Time Lapse PNx Log Response (Laronga et al., 2023).....	8
Figure 6-2: Map of Monitoring Wells in Relation to Injection Wells.....	10
Figure 6-3: Schematic of EM Survey.....	16
Figure 6-4: Schematic of CSEM Survey Tx-Rx Spacing to Monitor CO <sub>2</sub> Plume Migration at Delaware CCS #2 Well.....	17
Figure 6-5: Wavelet and Power Spectrum Extracted from Seismic Dataset .....	18
Figure 6-6: Fluid Substitution Forward Model of Texaco 35-2 Well.....	19
Figure 6-7: Map of Existing Texnet Detectors at Time of Application.....	24
Figure 6-8: Map of Magnitude of Completeness, Low-to-medium Noise Levels, Depth of 6.096 km (20,00 ft).....	24
Figure 6-9: Seismicity Distribution over Time from Shell Quest Facility (modified after Braim et al., 2023) .....	25



## 6.0 TESTING AND MONITORING PLAN [146.82(a)(15), 40 CFR 146.90]

This Testing and Monitoring Plan describes how Milestone will monitor Wells, pursuant to 40 CFR § 146.90. In addition to demonstrating that the injection wells are operating as planned, the carbon dioxide plume and pressure front are moving as predicted. 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<sub>2</sub> within the injection unit to support AoR re-evaluations and a non-endangerment demonstration. Additional applicable testing methods may be added to reconcile observed and actual results.

Results of the testing and monitoring activities described herein may trigger action according to the AoR Re-Evaluation Criteria (permit **Section 2**) and or the Emergency and Remedial Response Plan (permit **Section 10**).

### 6.1 Overall Strategy and Approach for Testing and Monitoring

The operating plans for the proposed Wells will include a robust testing and monitoring program. Milestone will report the results of all testing and monitoring activities to EPA in compliance with the requirements under 40 CFR § 146.91. This section discusses the key details of this program.

[REDACTED] Milestone does not anticipate any barriers to or issues with accessing the site to conduct monitoring activities.

#### 6.1.1 Quality Assurance Procedures [146.93]

Permit **Section 13, Appendix C** reflects Milestone's QASP for testing and monitoring activities pursuant to the requirements in 40 CFR 146.90(k). This performance-based plan sets forth the procedures and guidelines the EPA will use in evaluating the technical performance of Milestone. Procedures for measurement of various sections of this document are found in **Section 13 Appendix C – QASP**.

#### 6.1.2 Reporting Requirement [146.91]

Per the requirement of 40 CFR 146.91, Milestone will provide semi-annual reports to the UIC Director containing the following:

1. Any changes to the physical, chemical and other relevant characteristics of the CO<sub>2</sub> stream from what has been described in the proposed operating data (CO<sub>2</sub> specifications located in permit **Section 3, Table 3-2**).
2. Monthly average, maximum and minimum values of injection pressure, flow rate and volume, and annular pressure.
3. Description of any event that exceeds operating parameters for annulus pressure or injection pressure as specified in the permit.
4. Description of any event which triggers a shut-off device and the response taken plus any effect it had on the volume or mass of CO<sub>2</sub> injected.
5. Monthly volume and/or mass of the CO<sub>2</sub> stream injected over the reporting period and the volume injected cumulatively over the life of the project and reporting period.
6. Monthly annulus fluid volume added.
7. Results of any monitoring as described in this section or under 40 CFR 146.90.

In addition, reports will be submitted within thirty (30) days after the following events:

1. Periodic tests of mechanical integrity.
2. Any well workover.
3. Any other test of the injection well conducted if required by the UIC Director.



Reports will be submitted to the UIC Director within 24 hours of the following:

1. Any evidence that the injected CO<sub>2</sub> stream or associated pressure front may cause an endangerment to a USDW.
2. Any noncompliance with a permit condition, or malfunction of the injection system, which may cause fluid migration into or between USDWs.
3. Any triggering of a shut-off system, either downhole or at the surface.
4. Any failure to maintain mechanical integrity.
5. Any anomalous release of carbon dioxide to the atmosphere outside of normal engineering tolerances for operations.

Notification will be made to the UIC Program Director, in writing, 30 days in advance of:

1. Any planned workover.
2. Any planned stimulation activities, as defined in permit **Section 7: Stimulation Program**.
3. Any other planned non-routine test of the injection well.

All reports, submittals and notifications will be submitted to EPA UIC Program Director and or relevant state agencies in compliance with all applicable regulations. All records will be retained by Milestone throughout the life of the project and for ten (10) years following site closure. Data on the nature and composition of all injected fluids collected will be retained as well for ten (10) years after site closure. The records will be delivered to the UIC Director after the retention period if required by the Director. Monitoring data as described in this permit **Section 6** will be retained for ten (10) years after it is collected. Well plugging reports, post-injection site care data and the site closure report itself will be retained for ten (10) years following site closure. Any records that the EPA UIC Program Director requires will be retained longer than 10 years after site closure. Fiber data retention is described herein **Section 6.9.4**.

#### **6.1.3 Testing Plan Review and Updates [146.90 (j) (1) (2) (3)]**

This testing and monitoring plan will be reviewed and updated to incorporate monitoring data collected as described at least once every five (5) years. An amended testing and monitoring plan will also be submitted within one (1) year of an area of review re-evaluation, following any significant changes to the facility such as the addition of monitoring wells or newly permitted injection wells within the area of review; or as required by the Director (re-evaluation criteria found in permit **Section 2**).

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

#### **6.2.1 Continuous Monitoring of Injection Wells**

Milestone will install and use continuous measurement 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<sub>2</sub> stream, as required under 40 CFR 146.88(e)(1), 146.89(b), and 146.90(b) (**Table 6-1**) within [REDACTED].

[REDACTED]

**Table 6-1: Sampling Devices, Locations & Frequencies for Continuous Monitoring in Injection Wells**

**6.2.1.1 Well Temperature**

(Fig. 3-1 and 3-2) in Section 3.

The wellhead pressure logger (WPL) and a metering device such

**6.2.1.2 Injection Rate, Temperature, Density and Volume**

At the injection well, a metering device such as [REDACTED] to measure injection rate, injectate temperature, injectate density, and energy inputs. [REDACTED] The meter will be placed at a location based on manufacturer specifications immediately upstream of the injector wellhead and downstream of any capture facilities. The meter will be calibrated to manufacturer specifications.

**6.2.1.3 Injection Pressure**

Injection pressure will be monitored [REDACTED]. The injection well will be equipped with [REDACTED] (illustrated in permit Section 3)



[REDACTED]  
required by 40 CFR 146.88(a). Additionally, the Well will be equipped with a wellhead surface pressure logger to ensure the surface pressure remains below allowable wellhead pressures.

#### **6.2.1.4 Annular Pressure and Volume**

The annular pressure between the tubing and the injection casing strings and the annular fluid volumes also will be monitored on a continuous basis at gauges located in the wellhead and above the packer. [REDACTED]

#### **6.2.1.5 Positive Annular Pressure**

Per 40 CFR 146.88(c), Milestone will maintain pressure in the annulus [REDACTED]

#### **6.2.1.6**

[REDACTED] Milestone will employ a continuous [REDACTED] meets the temperature, pressure and rate requirements of the project. This is discussed further in permit Section 6.12.

### **6.3 Testing and Monitoring Techniques QA/QC [40 CFR 146.90(k)]**

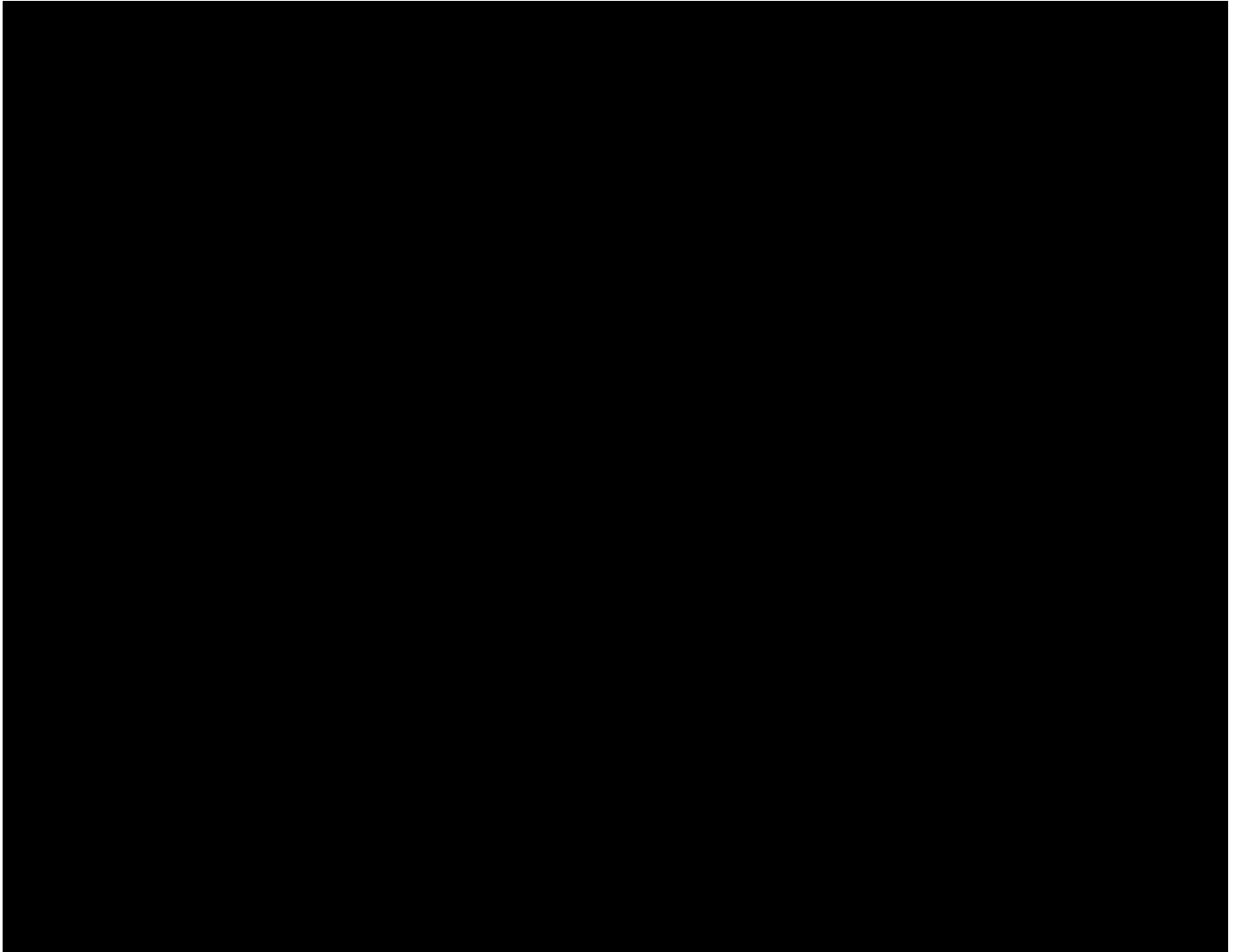
#### **6.3.1 Casing and Tubing Inspection Tools**

For mechanical integrity evaluation, Milestone will use [REDACTED]

[REDACTED]  
found in permit Section 13 – Appendix C, the QASP.

#### **6.3.2**

[REDACTED]  
Advances in technology have improved the accuracy of the tool to track the movement of the CO<sub>2</sub> plumes in the reservoir and evaluate flow conformance. Figure 6-1 [REDACTED] indicates CO<sub>2</sub> replacing formation brine in the near wellbore region.





#### 6.4 Corrosion Monitoring [40 CFR 146.90 (c)]

To meet the requirements of [40 CFR 146.90(c)], Milestone will monitor the tubing and casing 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.

##### 6.4.1 Monitoring Location and Frequency

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

Coupon initial baseline and periodic measurements will follow the recommendations of AMPP NACE SP0775-2023 (included in permit **Section 13 Appendix C, pp 27, 28**). A brief summary of those requirements is presented herein.

[REDACTED]

## 6.5 Above Confining Zone Water Monitoring [40 CFR 146.90 (d); 40 CFR 146.82(a)(6)]

Milestone will monitor groundwater quality and geochemical changes above the confining zone during the operation period to meet the requirements of [40 CFR 146.90(d)]. The purpose of the ground water monitoring is to detect potential changes that may result from fluid leakage out of the injection unit.

### 6.5.1 Location of [REDACTED]

[REDACTED] Monitoring well location is illustrated in Figure 6-2.

### 6.5.2 Location of [REDACTED]

[REDACTED] to the AoR (Fig. 6-2).

In consideration of a substantial depth difference between the top of the aquifer and the USDW depth, [REDACTED] (Fig. 6-2) as described in permit Section 3.

### 6.5.3 USDW and Above Zone Water Quality Monitoring

All samples in this section will be tested per the program outlined in **Table 6-2**

Per 40 CFR 146.82(a)(6), before drilling, and again before commencing injection, Milestone will

[REDACTED] permit

**Section 3, Figure 3-14.**

Within the USDW monitoring wells, [REDACTED]

[REDACTED]

The number of monitoring locations and frequency of sampling is detailed in **Table 6-2**. A schematic of the USDW monitoring well can be found in **Section 3**.

[REDACTED]

[REDACTED]

[REDACTED]

#### 6.5.3.1 Discrete Chemistry and Isotope Analysis

[REDACTED] in **Table 6-3**. Post injection, water testing will be conducted as outlined in **Section 9**.



#### 6.5.4 Sampling and Analytical Methods

Fluid samples in ground water wells and USDW Monitoring Wells will be collected at the monitored formation temperatures and maintained at the formation pressures within a pressurized sample container to prevent any losses of dissolved gases. [REDACTED]

[REDACTED]

[REDACTED]

Water samples will be tested, and results maintained for the parameters listed above. [REDACTED]

[REDACTED]

#### 6.5.5 Values that May Indicate Leakage

Trends that may indicate fluid leakage and will trigger an investigation, include:

- Major change in TDS, minus seasonal variation.
- Major change in signature of major cations and anions, minus seasonal variation.
- Major change in carbon dioxide concentration, minus seasonal variation.
- Major change in Carbon 13 and Oxygen 18 isotopic values.
- Major change in pH.
- Major increase in concentration of injectate impurities.

#### 6.5.6 Laboratory Chain of Custody Procedures

Water samples will be sent to a third-party commercial water testing laboratory. Standard chain-of-custody procedures will be followed, and records will be maintained to allow a full reconstruction of how the samples were collected, stored and transported, including any problems encountered.

#### 6.5.7 Quality Assurance and Surveillance Measures [40 CFR 146.90(k)]

Water samples will be sent to a third-party commercial water testing laboratory. Standard chain-of-custody procedures will be followed, and records maintained to allow a full reconstruction of how the samples were collected, stored and transported, including any problems encountered.

### 6.6 External Mechanical Integrity Testing [40 CFR 146.89, 40 CFR 146.90(e)]

[REDACTED]  
[REDACTED] as required by 40 CFR 146.89(a)(c) and 40 CFR 146.90(e).

Additionally, Milestone will utilize [REDACTED]  
[REDACTED]

Additionally, internal mechanical integrity of [REDACTED] Annular pressure monitoring to satisfy 40 CFR 146.89(b) is described in **Section 6.2**.

In conducting and evaluating the tests enumerated in this section or others to be allowed by the UIC [REDACTED]  
[REDACTED]

### 6.7 Pressure Fall-Off Testing [40 CFR 146.90 (f)]

Milestone 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 fall-off test will be performed in the injection well prior to initiation of CO<sub>2</sub> injection activities and at least once every five (5) years thereafter to demonstrate storage reservoir injectivity. [REDACTED]

[REDACTED] s. These tests will be used to measure formation properties near the injection well and to monitor for any changes in the near-wellbore environment that may impact injectivity and increase pressures.

#### 6.7.1 Testing Method

[REDACTED]  
[REDACTED] see permit **Section 3** for location [REDACTED]  
[REDACTED]

### 6.7.2 Analytical Methods

[REDACTED]

Comparison of pressure fall-off tests prior to beginning injection operations with those performed subsequently can indicate whether significant changes in the well or reservoir conditions have occurred. Analysis will consider the effects of two-phase flow effects, and parameters determined from the fall-off test will be compared to those used in the site computational modeling and AoR determination. Any significant changes in reservoir properties may result in a re-evaluation of the AoR (see permit **Section 2 AoR Re-Evaluation Criteria**). Results of the pressure fall-off test will be reported to the UIC Division within 30 days of the test.

### 6.7.3 Quality Assurance/Control

All field equipment will be inspected and tested prior to use. Pressure gauges used in the fall-off test will be calibrated in accordance with manufacturers' recommendations and calibration certificates will

[REDACTED]

## 6.8 Carbon Dioxide Plume and Pressure Front Tracking [40 CFR 146.90 (g)]

Milestone 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)]. A summary of direct and indirect methods is found in **Table 6-4**.

### 6.8.1 Direct Monitoring Methods

[REDACTED]

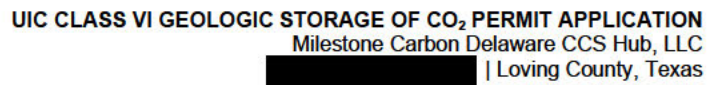
[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]





**Table 6-1 and in Table 6-5**

#### 6.8.2.1 *Microseismic Surveys*

Milestone will conduct a microseismic survey at the [REDACTED]

[REDACTED] (data supporting this statement is found **Section 6.10.3**). See **Section 6.9**  
and **6.10** for [REDACTED]

#### 6.8.2.2 [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]



**6.8.2.3**

[REDACTED]

(Figure 6-5) in the

[REDACTED]

[REDACTED]

[REDACTED]

The basic data used in the generation of the models were:

- A. [REDACTED]

B.

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

**6.9**

Milestone will [REDACTED]

**6.9.1**



[REDACTED]

[REDACTED]  
(Section 2).

[REDACTED]

[REDACTED]

#### 6.9.2

[REDACTED]

[REDACTED]

#### 6.9.3

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

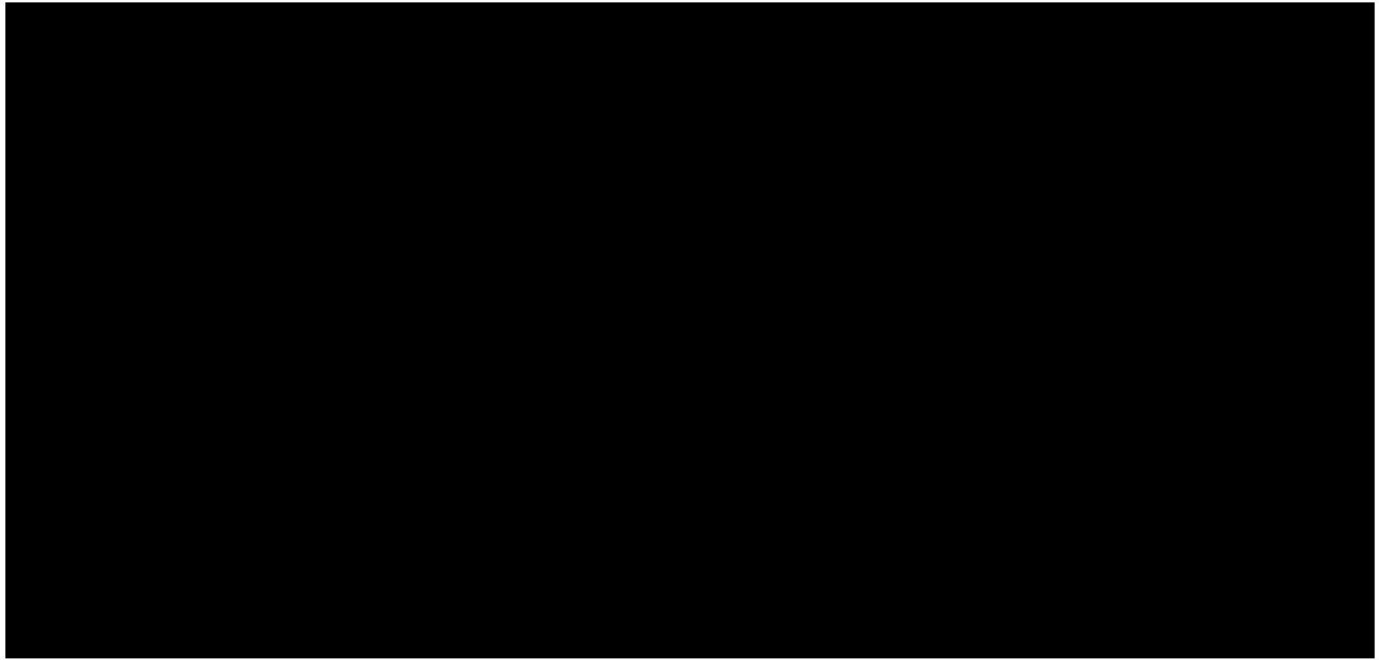
[REDACTED]

**6.9.4** [REDACTED]

[REDACTED] Table 6-5. It should be noted that [REDACTED]

[REDACTED] Section 6.1 to give the [REDACTED]

[REDACTED] Table 6-5, the [REDACTED].



#### 6.10 Passive Seismicity Monitoring

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

It should be noted that as of the time of this permit application, [REDACTED]  
[REDACTED] See **Section 1** for additional  
information on historical seismicity.



**6.10.2**

[REDACTED]

**6.10.3**

[REDACTED]

[REDACTED]



### 6.11 Soil Gas Monitoring / Other Testing and Monitoring [40 CFR 146.90 (h)]

(see Section 6.5) and [REDACTED]

[REDACTED]. [REDACTED]  
[REDACTED] O<sub>2</sub> injection operations. Once injection commences, soil gas will be measured at least annually.

Milestone will amend the monitoring frequency and spatial distribution of surface air monitoring and/or soil gas monitoring using baseline data, and the amended monitoring plan will describe how the proposed monitoring will yield useful information on the area of review delineation and/or compliance with standards under 40 CFR 144.12. An amended soil gas monitoring or surface air monitoring plan will be submitted to the EPA UIC Director within 90 days of receipt of baseline samples.

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

Milestone will analyze the CO<sub>2</sub> 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).

#### 6.12.1 Validation Sampling frequency

Milestone will sample the [REDACTED] using equipment noted at the beginning of Section 6.12. In addition, Milestone will [REDACTED]

#### 6.12.2 Validation Sampling methods and Location

#### 6.12.3 Validation Sample Analysis Methods

[REDACTED] in Table 6-6.

