TESTING AND MONITORING PLAN
40 CFR 146.90

Wabash CCS Project

INSTRUCTIONS

This template provides an outline and recommendations for the Testing and Monitoring Plan.

In this template, examples or suggestions appear in **blue text**. These are provided as general recommendations to assist with site- and project-specific plan development. The recommendations are not required elements of the Class VI Rule. This document does not substitute for those provisions or regulations, nor is it a regulation itself, and it does not impose legally-binding requirements on the EPA, states, or the regulated community.

Please delete the **blue text** and replace the yellow highlighted text before submitting your document. Similarly, please adjust the example tables as necessary (e.g., by adding or removing rows or columns). Appropriate maps, figures, references, etc. should also be included to support the text of the plan.

Remember that, pursuant to 40 CFR 146.90, the requirement to maintain and implement an approved Testing and Monitoring Plan is directly enforceable regardless of whether the requirement is a condition of the permit. For more information, see the Class VI guidance documents at https://www.epa.gov/uic/class-vi-guidance-documents. It is the responsibility of the owner or operator to maintain records of previous revisions to this plan.

Facility Information

Facility name:	Wabash Carbon Services WVCCS1 & WVCCS2
Facility contact:	Rory Chambers, Vice President Operations 444 West Sandford Ave, West Terre Haute, IN 47885 (812) 281-2810 RChambers@wvresc.com
Well location:	WVCCS1 Clinton, Vermillion, IN 39^0 37' 27.88'' N, 87^0 29' 19.17'' W WVCCS2 West Terre Haute, Vigo, Indiana 39º 33' 3.72" N, 87º 29' 16.60" W

This Testing and Monitoring Plan describes how Wabash Carbon Services (WCS) will monitor the Wabash CCS Project site pursuant to 40 CFR 146.90. The WVC CCS Project will utilize two injection wells to achieve the required annual injection rate. Due to this fact the Testing and Monitoring plan includes activities related to both injection wells and the associated CO_2 plumes. 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 (Underground Sources of Drinking Water), 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 Area of Review (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

To ensure that all requirements of the Class VI permitting process are met, USDW non-endangerment is verified, and sufficient site-specific data is collected during the project lifecycle to provide needed information to guide decision making, Wabash Carbon Services (WCS) has developed a robust and detailed Testing and Monitoring Plan. The Testing and Monitoring plan will be executed in conjunction with the Quality Assurance and Surveillance Plan (QASP). Details of the infrastructure placement is displayed in Figure 1.

WCS will construct two injection wells (WVCCS1 & WVCCS2) that will play an important role in the testing and monitoring plan. The injection wells will be equipped with a fiber optic Digital Temperature System (DTS) that will provide continuous monitoring of the temperature profile of the entire well bore allowing for detection of any mechanical integrity issues or flow of formation fluids out of the injection zone beyond the confining layer.

WCS will utilize two (2) in-formation monitoring wells (FM1 & FM2) that, coupled with the instrumentation on the injection wells, will provide detailed data related to the conditions of the CO_2 plume, the effects on the native formation pressure, and the validity of the AoR modeling concerning plume migration over time. These wells will be installed [redacted] to allow for direct monitoring of the injection zone, the Potosi formation. FM1 will have an offset of 1.95 miles from WVCCS1 and FM2 will have an offset of 1.75 miles from WVCCS2. This will allow for monitoring of the pressure rise in the formation fluids. This data when coupled with the injection well downhole pressure monitors will allow for tracking the CO_2 front through the formation. FM1 & FM2 have been located to account for the physical characteristics of the subsurface (dip). The placement of FM1 and FM2 places them on the upslope of the dip, to properly monitor the advancement of the plume to the predicted furthest distance from the injection well. Periodic fluid samples will be analyzed for the presence of CO_2 to further refine plume tracking. Based on the prediction from the AoR modeling the CO_2 plume is expected to reach the formation monitoring wells at year 12 of injection, the final year.

In addition to the in-formation monitoring wells, two (2) confinement monitoring (CM1 & CM2) wells will be used to continuously monitor the pressure and temperature of the formations located directly above the confining zone. In addition to the continuous monitoring CM1 and CM2 will be used to gather formation fluid samples from directly above the primary seal. Analysis of this formation fluid will allow for the early detection of any possible movement of CO_2 or other contaminants from the injection zone through the primary seal. This monitoring in the Silurian formations (the lowermost USDW) will ensure their protection. Pre-injection sampling and analysis will allow for baselines to be set that will allow for determination of any abnormality in the formation fluids. The confinement monitoring wells will be installed [redacted]

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[redacted] Sampling pre-injection will provide baseline data that will inform future decision making around any anomalies detected during the injection and PISC periods.

For the Testing and Monitoring plan the following definitions apply for the frequencies given for the different testing protocols described.

- Continuous: Data is continuously sampled and recorded per the frequencies presented in Table 2 of this document
- Quarterly: Sampling will take place by no more than 5 days before the following dates each year: March 31st, June 30th, September 30th, December 31st.
- Semi-annual: Sampling will take place by the following dates each year: 6 months after the date of authorization of injection and 12 months after the date of authorization of injection.
- Annual: Up to 45 days before March 1st of each year following the reporting year or alternatively scheduled with the prior approval of the UIC Program Director.
- 5 Year: Up to 45 days before the 5th anniversary date of the authorization of injection or alternatively scheduled with the prior approval of the UIC Program Director.

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[redacted]

Figure 1 Map of Injection and Monitoring Wells

Measurement, Monitoring and Verification (MMV) Technologies

Two key objectives of any risk assessment evaluation and the development of a viable MMV plan are to:

(1) Ensure Conformance by demonstrating that storage performance aligns with expectations regarding injectivity, capacity and CO_2 behavior inside the geologic storage reservoir

(2) Ensure Containment, which demonstrates security of CO_2 storage to protect human health, groundwater resources, hydrocarbon resources (if present), and environment and meets regulatory requirements

Quality assurance procedures

A quality assurance and surveillance plan (QASP) for all testing and monitoring activities, required pursuant to 40 CFR 146.90(k), is provided in the Appendix to this Testing and Monitoring Plan.

Reporting procedures

WCS 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)]

Sampling location and frequency

WCS 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 will take place continuously via permanently installed field analysis equipment.

WCS will sample and analyze the CO_2 stream as presented below.

Analytical Parameters

WCS will employ continuous monitoring of the CO_2 stream with in-situ analysis at the inlet of the CO_2 pumps for the following parameters in Table 1

Table 1 CO_2 Stream Analytical Parameters

Parameter	Analytical Method(s)
Oxygen	Mass Spectrometer
Nitrogen	Mass Spectrometer
Carbon Monoxide	Mass Spectrometer
Oxides of Nitrogen	Mass Spectrometer
Total Hydrocarbons	Mass Spectrometer
Methane	Mass Spectrometer

Parameter	Analytical Method(s)
Hydrogen Sulfide	Mass Spectrometer
CO2 Purity	Mass Spectrometer
Moisture	Hygrometer

If at any time this continuous monitoring reveals a substantive change from expected for the CO_2 stream process troubleshooting will begin to determine the root cause of the CO_2 quality deviation. If CO_2 quality falls below permitted injection levels CO_2 will be diverted to atmosphere and injection activities stopped.

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

WCS 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 or produced; 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

WCS will perform the activities identified in Table 2 to monitor operational parameters and verify internal mechanical integrity of the injection well. All monitoring will take place at the locations and frequencies shown in the table.

Table 2. Sampling devices, locations, and frequencies for continuous monitoring.

Parameter	Device(s)	Location	Min. Sampling Frequency	Min. Recording Frequency
Injection pressure at Wellhead	Pressure Transducer	[redacted]	1 Second	1 Second
Injection rate	Coriolis Flow Meter	[redacted]	1 Second	1 Second
Injection volume	Coriolis Flow Meter	[redacted]	1 Second	1 Second
Annular pressure	Pressure Transducer	[redacted]	1 Second	1 Second
Annulus fluid level	Level Instrument	[redacted]	1 Second	1 Second
CO_2 stream temperature	Temperature Transducer	[redacted]	1 Second	1 Second
Injection pressure at Formation	Pressure Transducer	[redacted]	1 Second	1 Second
Temperature at Formation	DTS/Temperature Transducer	[redacted]	1 Second	1 Second
Notes:				

Parameter	Device(s)	Location	Min. Sampling Frequency	Min. Recording Frequency
• 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.				

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. In lieu of removing the injection tubing, downhole gauges will demonstrate accuracy by using a second pressure gauge, with current certified calibration, that will be lowered into the well to the same depth as the permanent downhole gauge. Pressure transducers shall 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 per second. Temperature sensors will be accurate to within one degree Celsius. Distributed Temperature Sensing (DTS) sampling rate will be once per 10 seconds.

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

<u>Injection Rate and Pressure Monitoring</u>

WCS will monitor injection operations using the distributive process control system as presented below.

The Surface Facility Equipment & Control System will limit maximum flow [redacted]

NOTE: The injection pressure limit may be changed if the Fracture Gradient is significantly different during subsequent well testing during the drilling of the injection well(s). All injection operations will be continuously monitored and controlled by the Wabash Valley Resources (WVR) 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.

More specifically, 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. WVR supervisors and operators will monitor the status of the entire system from the main operations control room.

Calculation of Injection Volumes

Flow rate is measured on a mass basis (lb/hr). The downhole pressure and temperature data will be used to perform the injectate density calculation.

The volume of carbon dioxide injected will be calculated from the mass flow rate obtained from the mass flow meter installed on the injection line. The mass flow rate will be divided by density and multiplied by injection time to determine the volume injected.

Density will be calculated using the correlation developed by Ouyang (2011). The correlation uses the temperature and pressure data collected to determine the carbon dioxide density. The density correlation is given by:

$$\rho = A0 + A1*P + A2*P2 + A3*P3 + A4*P4$$

Where ρ is the density, P is the pressure in psi, and A are coefficients determined by the equations:

$$Ai = bi0 + bi1*T + bi2*T2 + bi3*T3 + bi4*T4$$

T is the temperature in degrees Celsius and the b coefficients are presented in Table 3 and Table 4 below.[1]

Table 3 Injection Volume calculation b coefficients, pressure <3000 psi.

	b_{i0}	b_{i1}	b_{i2}	b_{i3}	b_{i4}
i=0	-2.148322085348E+05	1.168116599408E+04	2.302236659392E+02	1.967428940167E+00	-6.184842764145E-03
i=1	4.757146002428E+02	-2.619250287624E+01	5.215134206837E-01	-4.494511089838E-03	1.423058795982E-05
i=2	-3.713900186613E-01	2.072488876536E-02	5.215134206837E-01	3.622975674137E-06	-1.155050860329E-08
i=3	1.228907393482E-04	6.930063746226E-06	1.406317206628E-07	-1.230995287169E-09	3.948417428040E-12
i=4	-1.466408011784E-08	8.338008651366E-10	-1.704242447194E-11	1.500878861807E-13	-4.838826574173E-16

Table 4 Injection Volume calculation b coefficients, pressure >3000 psi.

	b_{i0}	b_{i1}	b_{i2}	b_{i3}	b_{i4}
i=0	6.897382693936E+02	2.730479206931E+00	-2.254102364542E-02	-4.651196146917E-03	3.439702234956E-05
i=1	2.213692462613E-01	-6.547268255814E-03	5.982258882656E-05	2.274997412526E-06	-1.888361337660E-08

1 Ouyang 2011, "New Correlations for Predicting the Density and Viscosity of Supercritical Carbon Dioxide Under Conditions Expected in Carbon Capture and Sequestration Operations," The Open Petroleum Engineering Journal, 2011, 4, 13-21.

i=2	-5.118724890479E-05	2.019697017603E-06	-2.311332097185E-08	4.079557404679E-10	3.893599641874E-12
i=3	5.517971126745E-09	-2.415814703211E-10	3.121603486524E-12	3.171271084870E-14	3.560785550401E-16
i=4	-2.184152941323E-13	1.010703706059E-14	-1.406620681883E-16	-8.957731136447E-19	1.215810469539E-20

The final volume basis will be calculated as follows:

Volume basis (m3 /hr) = Mass basis (kg/hr) / density (kg/m3)

Continuous Monitoring of Annular Pressure

WCS will use the procedures below to monitor annular pressure.

The following procedures will be used to limit the potential for any unpermitted fluid movement into or out of the annulus:

1. The annulus between the tubing and the long string of casing will be filled with brine. The brine will have a specific gravity and a density that meets the requirements of the downhole conditions. The final values will be determined after the construction of the injection wells.

2. The surface annulus pressure will be kept at a minimum of 400 pounds per square inch (psi) during injection (This is subject to changes based upon actual conditions encountered at the injection site).

3. During periods of well shut down, the surface annulus pressure will be kept at a minimum pressure to maintain a pressure differential [redacted] between the annular fluid directly above (higher pressure) and below (lower pressure) the injection tubing packer [redacted] (This is subject to change based on actual depths obtained during the drilling and completion of the wells and the packer setting depths will be reported after the wells are completed and prior to obtaining pre-injection authorization)

4. The pressure within the annular space, over the interval above the packer to the confining layer, will be greater than the pressure of 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.

Figure 2 shows the process instrument diagram for the injection well annulus protection system.

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[redacted]

Figure 2 Example Annulus Protection System

The annular monitoring system consists of a continuous annular pressure gauge, a pressurized annulus fluid reservoir (annulus head tank), pressure regulators, and tank fluid level indication. The annulus system will maintain annulus pressure by controlling the pressure on the annulus head tank using either compressed nitrogen or CO_2.

The annulus pressure will be maintained between approximately [redacted] (subject to change – will finalize after completion) psi and monitored by the WVR control system gauges. The annulus head tank pressure will be controlled by pressure regulators, one set of regulators to maintain pressure [redacted] by adding compressed nitrogen or CO_2 and the other to relieve pressure [redacted] by venting gas off the annulus head tank.

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

If system communication is lost for greater than 30 minutes, project personnel will perform field monitoring of manual gauges every four hours or twice per shift for both wellhead surface pressure and annulus pressure and record hard copies of the data until communication is restored.

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

Casing-Tubing Pressure Monitoring

WCS will monitor the casing-tubing pressure on a continuous basis. During the injection timeframe of the project, the casing-tubing pressure will be monitored and recorded in real time. [redacted] As detailed in the EMERGENCY AND REMEDIAL RESPONSE PLAN significant changes in the casing-tubing annular pressure attributed to well mechanical integrity will be investigated.

Corrosion Monitoring

To meet the requirements of 40 CFR 146.90(c), WCS 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.

Monitoring location and frequency

This monitoring will occur 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.

WCS will monitor corrosion using Corrosion Coupon Method and collect samples according to the description below.

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 Table 5 below. Each coupon will be weighed, measured, and photographed prior to initial exposure (see "Sample Handling and Monitoring") below

Table 5. List of equipment coupon with material of construction.

Equipment Coupon	Material of Construction
Pipeline	[redacted]
Long String Casing (Surface – 3,200 ft)	
Long String Casing (3,200 ft – TD)	
Injection Tubing	
Wellhead	
Packers	

Monitoring details

Sample Exposure

Each sample will be attached to an individual holder and then inserted in a flow through pipe arrangement (*Figure 3*). The corrosion monitoring system will be located downstream of all process compression/dehydration/pumping equipment (i.e., at the beginning of the pipeline to the wellhead). To accomplish this, a parallel stream of high-pressure CO_2 will be routed from the pipeline through the corrosion monitoring system and then back into a lower pressure point upstream in the pumping system. This loop will operate any time injection is occurring. No other equipment will act on the CO_2 past this point; therefore, this location will provide representative exposure of the samples to the CO_2 composition, temperature, and pressures that will be seen at the wellhead and injection tubing. The holders and location of the system will be included in the pipeline design and will allow for continuation of injection during sample removal.

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[redacted]

Figure 3 Corrosion Coupon Monitoring System

Sample Handling and Monitoring

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 weighed (to within 0.0001 gm).

Above Confining Zone Monitoring

WCS 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).

Monitoring location and frequency

Table 6 shows the planned monitoring methods, locations, and frequencies for ground water quality and geochemical monitoring above the confining zone.

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

Target Formation	**Monitoring Activity**	**Monitoring Location(s)**	**Spatial Coverage**	**Frequency**
Pennsylvanian Strata	Fluid Sampling	Sensitive, Confidential, or Privileged Information [redacted]	[redacted]	Year 1-2 Quarterly Year 3-12 Semi-Annual
Silurian	Fluid Sampling	[redacted]	[redacted]	Annual
	Pulse Neutron Logging	[redacted]	[redacted]	

Analytical parameters

Table 7 identifies the parameters to be monitored and the analytical methods WCS will use.

Table 7. Summary of analytical and field parameters for ground water samples.

Parameters	Analytical Methods
Formation: Pennsylvanian	
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, and Tl	ICP-MS EPA Method 6020
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-AES EPA Method 6010B
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography EPA Method 300.0
Dissolved CO2	Gas Chromatographic EPA Method RSK 175
Total Dissolved Solids	Gravimetry SM: 2540C
Alkalinity	Alkalinity by Titration SM:2320 B
pH (field)	Electrometric EPA-NERL: 150.1
Specific conductance (field)	4 AC electrode EPA-NERL: 120.1
Temperature (field)	Thermistor EPA-NERL: 170.1
Formation: Silurian	
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, and Tl	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 CO2	Gas Chromatographic EPA Method RSK 175
Isotopes: $\delta^{13}C$ of DIC	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry SM:2540C
Water Density (field)	Oscillating body method SM 2710

Alkalinity	Alkalinity by Titration SM: 2320B
pH (field)	Glass electrode EPA-NERL: 150.1
Specific conductance (field)	4 AC electrode EPA-NERL: 120.1
Temperature (field)	Thermistor EPA-NERL: 170.1

Sampling methods

Sampling will be performed as described in Section B.2 of the QASP; this section of the QASP describes the groundwater sampling methods to be employed, including sampling SOPs (Section B.2.a/b), and sample preservation (Section B.2.g).

Sample handling and custody will be performed as described in Section B.3 of the QASP.

Quality control will be ensured using the methods described in Section B.5 of the QASP.

Laboratory to be used/chain of custody procedures

Final laboratory selection has not been made at this time. The laboratory selected will meet all requirements set forth in the Testing and Monitoring Plan and the QASP. The Chain-of-Custody procedures will follow the requirements of section B.3.e of the QASP.

Section A.4 Quality Objectives and Criteria of the QASP provides the detection limits and analytical methods to be employed during the Testing and Monitoring of all critical parameters of the project.

External Mechanical Integrity Testing

WCS will conduct at least one of the tests presented in Table 8 periodically during the injection and post-injection phase to verify external MI as required at 146.89(c) and 146.90.

Testing location and frequency

Table 8. MITs.

Test Description	Sensitive, Confidential, or Privileged Information [redacted]	Frequency
Temperature Log	[redacted]	Annual
Digital Temperature System	[redacted]	Continuous
Oxygen Activation Log	[redacted]	Annual

Testing details

The following testing procedures are preliminary examples of the testing protocols expected to be used by WCS. The final procedures will be developed after completion of the injection wells. All procedures will be supplied to the Director for approval.

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 primary caprock. Bottom hole pressure data near the packer will also be provided. The following procedures will be employed for temperature logging: The well should not be in a state of injection for at least 36 hours prior to commencing operations in order to allow for stabilization.

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

2. Calibrate the log if at all possible. This can be done by comparing measurements made using the tool in any two liquids to the known temperatures of those liquids. For instance, both a thermometer and the thermistor to be used for the logging may be used to measure the temperature of water at ambient conditions and a bucket of ice water. Even a single measurement made in a well-mixed bucket of ice water may be very helpful.

3. Run a temperature survey lowering the tool at a rate of no more than 30 feet per minute, from the surface to the deepest point reachable in the Potosi Dolomite.

4. Stop injection, pull tool back to shallow depth, wait 1 hour.

5. Run a temperature survey over the same interval as step 2.

6. Pull tool back to shallow depth, wait 2 hours.

7. Run a temperature survey over the same interval as step 2.

8. Pull tool back to shallow depth, wait 2 hours.

9. Run a temperature survey over the same interval as step 2.

10. Evaluate data to determine if additional passes are needed for interpretation. Should CO_2 migration be interpreted in the top most section of the log, additional logging runs over a higher interval will be required to find the top of migration.

11. If additional passes are needed, repeat temperature surveys every 2 hours until 12 hours, over the same interval as step 2.

12. Rig down the logging equipment.

13. Data interpretation involves comparing the time lapse well temperature profiles and looking for temperature anomalies that may indicate a failure of well integrity; i.e. 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. Any unplanned fluid movement into the annulus or outside the casing creates a temperature anomaly when compared to the baseline cooling profile.

Temperature Logging Using DTS Fiber Optic Line

The injection wells (WVCCS1 & WVCCS2) will be equipped with a DTS fiber optic temperature monitoring system that is capable of monitoring the injection well's annular temperature along the length of the tubing string. The DTS line is used for real time temperature monitoring and, like a conventional temperature log, can be used for early detection of temperature changes that may indicate a loss of well mechanical integrity. The procedure for using the DTS for well mechanical integrity is as follows:

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

2. During injection operation, record the temperature profile for 6 hours prior to shutting in 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 a failure of well integrity, i.e. tubing leak or movement of fluid behind the casing. The DTS system monitors and records the well's temperature profiles at a pre-set frequency in real time. As the well cools down the temperature profile along the length of the tubing string is compared to the baseline. Any unplanned fluid movement into the annulus or outside the casing creates a temperature anomaly when compared to the baseline cooling profile. This data can be continuously monitored to provide real time MIT surveillance making this technology superior to wireline temperature logging.

Oxygen Activation (OA) Logging

To ensure the mechanical integrity of the casing of the injection well, logging data will be recorded across the wellbore from surface down to the base of the casing. Bottom hole pressure data near the packer will also be provided. OA logging will be carried out while injection is occurring. The following procedures will be employed:

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

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

[redacted]

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

5. 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.

6. Take, at a minimum, a 15-minute 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.

7. Take, at a minimum, a 15-minute stationary reading at a location approximately midway between the base of the lowermost USDW and the confining interval located immediately above the injection interval.

8. Take, at a minimum, a 15-minute stationary reading adjacent to the top of the confining zone.

9. Take, at a minimum, a 15-minute stationary reading at the base of the lowermost USDW.

10. If flow is indicated by the OA log at a location, move uphole or downhole as necessary at no more than 50-foot intervals and take stationary readings to determine the area of fluid migration.

11. Interpret the data: Identification of 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 the casing. The flow velocity is determined by measuring the time that the activated water passes a detector.

NOTE: WCS will run one or more of the listed logging tests to verify external mechanical integrity and confirm that there is no upward flow behind casing above the injection zone. However, it is not anticipated that all the logs be run to confirm external mechanical integrity.

The range, precision and QC requirements of the different gauges used for MIT testing are presented in section A.4.a and A.4.g of the QASP.

Pressure Fall-Off Testing

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

Testing location and frequency

Pressure fall-off testing will be performed:

- During injection, at least every five years; and
- At the end of the injection period.

Testing details

WCS will conduct pressure fall-off testing according to the procedures below.

Pressure Fall-off Test Procedure

A pressure falloff test has a period of injection followed by a period of no-injection or shut-in. Normal injection using the stream of CO_2 captured from the WVR facility will be used during the injection period preceding the shut-in portion of the falloff tests. [redacted] Prior to the falloff test this rate will be maintained. Injection will have occurred for 5 years prior to this test, but there may have been injection interruptions due to operations or testing. At a minimum, one week of relatively continuous injection will precede the shut-in portion of the falloff test; however, several months of injection prior to the falloff will likely be part of the pre-shut-in injection period and subsequent analysis. This data will be measured using a surface readout downhole gauge so a final decision on test duration can be made after the data is analyzed for average pressure. The gauges may be those used for day-to-day data acquisition or a pressure gauge will be conveyed via electric line (e-line). To reduce the wellbore storage effects attributable to the pipeline and surface equipment, the well will be shut-in at the wellhead nearly instantaneously with direct coordination with the CO_2 capture facility operator. Because surface readout will be used and downhole recording memory restrictions will be eliminated, data will be collected at five second intervals or less for the entire test. The shut-in period of the falloff test will be at least four days or longer until adequate pressure transient data are collected to calculate the average pressure. Because surface readout gauges will be used, the shut-in duration can be determined in real-time. 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. Pressure sensors used for this test will be the wellhead sensors and a downhole gauge for the pressure falloff test. [redacted]

Carbon Dioxide Plume and Pressure Front Tracking

WCS 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). The primary location for in-formation tracking of the CO_2 plume and pressure front will be FM1 & FM2. FM1 will have an offset of 1.95 miles from WVCCS1 and FM2 will have an offset of 1.75 miles from WVCCS2. FM1 & FM2 have been located to account for the physical characteristics of the subsurface (dip). The placement of FM1 and FM2 places them on the upslope of the dip, to properly monitor the advancement of the CO_2 plume and pressure front to the predicted furthest distance from the injection well. Periodic fluid samples will be analyzed for the presence of CO_2 to further refine plume tracking. Based on the prediction from the AoR modeling the CO_2 plume is expected to reach the formation monitoring wells at year 12 of injection, the final year.

Plume monitoring location and frequency

*Table **9*** presents the methods that WCS will use to monitor the position of the CO_2 plume, including the activities, locations, and frequencies WCS will employ. The parameters to be analyzed as part of fluid sampling in the injection zone and associated analytical methods are presented in *Table **10***.

WCS will conduct fluid sampling and analysis to detect changes in formation fluids in order to directly monitor the carbon dioxide plume. The parameters to be analyzed as part of fluid sampling in the Potosi dolomite (i.e., the injection zone) and analytical methods are presented in Table 8. WCS will deploy pressure/temperature monitors and DTS to directly monitor the position of the pressure front. Indirect plume monitoring will be employed using pulsed neutron capture/RST logs to monitor CO_2 saturation. 3D seismic profiles will be used to image the developing CO_2 plume for indirect plume monitoring.

Plume monitoring details

For information concerning the type and specification of gauges used for the continuous monitoring of the Plume please see QASP Table 12.

Table 9 Plume monitoring activities

Target Formation	**Monitoring Activity**	**Monitoring Location(s)**	**Spatial Coverage**	**Frequency**
DIRECT PLUME MONITORING		Sensitive, Confidential, or Privileged Information [redacted]		
Potosi	Fluid Sampling			Annual
	Pressure Monitoring			Continuous
	Temperature Monitoring			Continuous
INDIRECT PLUME MONITORING				
Potosi	Pulse Neutron Logging/RST			Annual
	3D surface seismic survey			5 year

Table 10. Summary of analytical and field parameters for fluid sampling in the injection zone.

Parameters	**Analytical Methods**
Potosi	

Parameters	Analytical Methods
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, and Tl	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	Gas Chromatographic EPA Method RSK 175
Isotopes: $\delta^{13}C$ of DIC	Isotope ratio mass spectrometry
Total Dissolved Solids	Gravimetry SM:2540C
Water Density (field)	Oscillating body method SM 2710
Alkalinity	Alkalinity by Titration SM: 2320B
pH (field)	Glass electrode EPA-NERL: 150.1
Specific conductance (field)	4 AC electrode EPA-NERL: 120.1
Temperature (field)	Thermistor EPA-NERL: 170.1

Pressure-front monitoring location and frequency

*Table **11*** presents the methods that WCS will use to monitor the position of the pressure front, including the activities, locations, and frequencies WCS will employ.

Quality assurance procedures for these methods are presented in B.5 of the QASP.

Pressure-front monitoring details

Pressure-front monitoring will occur via continuous monitoring of conditions in the Potosi dolomite (injection zone) at FM1 & FM2.

For information concerning the type and specification of gauges used for the continuous monitoring of the pressure front please see QASP Table 12.

Baseline data will be collected from FM1 & FM2 before the start of injection activities. This baseline data will be used generate comparative data between the baseline case of the predictive model and expected rate of change in the formation conditions. As measured pressures and temperatures change the data will be compared to the predicted date from the model. As appropriate, re-evaluation of the model, or further investigation of the downhole conditions will be performed to ensure that no major deviation from the expected behavior of the pressure front is experienced.

Table 11. Pressure-front monitoring activities.

Target Formation	Monitoring Activity	Monitoring Location(s)	Spatial Coverage	Frequency
DIRECT PRESSURE-FRONT MONITORING				
Potosi	Pressure Monitoring	Sensitive, Confidential, or Privileged Information [redacted]		Continuous
	Temperature Monitoring			Continuous

Appendix: Quality Assurance and Surveillance Plan