Underground Injection Control – Class VI Permit Application for Luz Solar No. 1

Liberty County, Texas

SECTION 5 – TESTING AND MONITORING PLAN

January 2024

SECTION 5 – TESTING AND MONITORING PLAN

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5.1 Introduction

The operating plans for the proposed BKVerde, LLC (BKVerde) Luz Solar No. 1 injection well include robust testing and monitoring programs in accordance with promulgated regulations, which are designed to satisfy the requirements of 16 Texas Administrative Code (TAC) ***§*5.203(j)** [Title 40, U.S. Code of Federal Regulations (40 CFR) **§146.90**]. This section discusses the key details of this plan.

5.2 Reporting Requirements

In compliance with 16 TAC **§5.207** [40 CFR **§146.91**], BKVerde will provide the following routine reports to the Underground Injection Control (UIC) Program director (UIC Director).

Per-Occurrence Reporting:

- Any noncompliance with a permit condition or malfunction of the injection system, which may cause fluid migration into or between Underground Sources of Drinking Water (USDWs)
  - Verbal Notification – Reported within 24 hours of the event
- Any evidence that the injected carbon dioxide (CO_2) stream or associated pressure front may cause an endangerment to a USDW
  - Verbal Notification – Reported within 24 hours of the event
  - Written Notification – Reported within 5 working days of the event
- Any failure to maintain mechanical integrity
  - Verbal Notification – Reported within 24 hours of the event
- Any significant data that indicate the presence of leaks in the well or lack of confinement to the storage reservoir
  - Verbal Notification – Reported within 24 hours of the event
  - Written Notification – Reported within 5 working days of the event
- Any changes to the physical, chemical, or other relevant characteristics of the CO_2 stream from what has been described in the proposed operating data
  - Written Notification – Reported within 72 hours of composition change
- Description of any event that exceeds operating parameters for annulus pressure or injection pressure, as specified in the permit
  - Verbal Notification – Reported within 24 hours of the event
  - Written Notification – Reported within 72 hours of the event
- Description of any event that triggers a shutoff device, either downhole or at the surface, and the response taken
  - Verbal Notification – Reported within 24 hours of the event
  - Written Notification – Reported within 72 hours of the event

Semiannual Reports:

- Summary of wellhead pressure monitoring
- Any changes to the source of the CO_2 stream
- Any changes to the physical, chemical, or other relevant characteristics of the CO_2 stream from what has been described in the proposed operating data
- Monthly average, maximum and minimum values of injection pressure, flow rate, temperature, volume, and annular pressure
- Description of any event that exceeds operating parameters for annulus pressure or injection pressure as specified in the permit
- Monthly volume and/or mass of the CO_2 stream injected during the reporting period, and the volume injected cumulatively during the life of the project
- Monthly annulus fluid volume added
- Results of any monitoring, as described in this section

Annual Reports:

- Any corrective action performed
- Any new wells installed in the facility and the type, location, number, and information required in 16 TAC **§5.203€**
- Recalculated area of review (AOR) or statement confirming monitoring and operational data that supports the current delineation of AOR on file with the regulatory authority
- Proof of good faith claim to sufficient property rights for storage facility operation
- Tons of CO_2 injected
- Annual statement, signed by the appropriate company official, confirming that BKVerde has reviewed the monitoring and operational data relevant to a decision on whether to reevaluate the AOR and the monitoring and operational data relevant to a decision on whether to update the approved plan; and whether any updates were warranted by material changes in the data
- Other information as the permit requires

Reports to be submitted within 30 days after the following events:

- Any well workover
- Any test of the injection well conducted, if required by the UIC Director
- Any periodic mechanical integrity tests

Notification to the UIC authority [16 TAC **§5.206(c)**], in writing, 30 days in advance of the following:

- Any planned workover
- Any planned stimulation activities
- Any other planned test of the injection well

BKVerde will submit all reports, submittals, and notifications to the EPA and the Texas Railroad Commission (TRRC) and ensure that all records are retained throughout the life of the project. In accordance with 16 TAC **§5.207(e)** [40 CFR **§146.91(f)**], these records will be maintained for 10 years after site closure. The records will be delivered to the UIC Director upon request after the retention period. Monitoring data will be retained for 10 years post-collection, while well-plugging reports, post-injection site care data, and the site closure report will be retained for 10 years after site closure.

5.3 Testing Plan Review and Updates

In accordance with 16 TAC **§5.207(a)(3)** [40 CFR **§146.90(j)**], the Testing and Monitoring Plan will be reviewed and revised, as necessary, at a minimum of every 5 years to incorporate collected monitoring data. Plan amendments will also be submitted within 1 year of an AOR reevaluation following significant facility changes, such as the development of offset monitoring wells or newly permitted injection wells within the AOR, or as required by the UIC Director.

5.4 Testing Strategies

5.4.1 Openhole Logging

BKVerde plans to run an advanced suite of openhole logs in the stratigraphic test well to obtain data for parameters used in static and dynamic subsurface modeling. A list of planned openhole logs is provided in Table 4-16 of *Section 4 – Engineering Design and Operating Strategy*. The following log descriptions provide examples of the types of logs to be run. The specific logging vendor will be selected just before drilling the well. Commercial and supply chain issues may affect the final vendor selection.

Spectral Gamma Ray

The spectral gamma ray is a mineralogical characterization tool equipped with a pulsed-neutron spectrometer. This tool resolves uncertainties compared to traditional petrophysical evaluation methods and provides enhanced porosity determination, clay type/volume determination, and lithofacies identification.

Magnetic Resonance

The magnetic resonance tool is a nuclear magnetic resonance-based instrument. By alternating static and pulsed radio frequency magnetic fields, the pore-space fluid hydrogen protons are aligned and spun when interacting with the two magnetic fields. These "spin echoes" can be recorded and analyzed based on amplitude and echo decay rates. This action gives information on the porosity, pore size, and type of fluid present. Reliable data acquisition is available in almost every borehole environment.

Ultrasonic Borehole Imaging

Borehole acoustic imaging service uses a rotating acoustic transducer. This tool provides high-resolution feedback during drilling and completion operations, and documents stratigraphic features, unconformities, dip/strike, and borehole shape. The design allows for use in any mud type and in large-diameter boreholes, and has full 360° coverage.

<u>Extended-Range Resistivity Imaging</u>
An extended-range resistivity imaging tool provides high-resolution formation resistivity images in conductive mud systems. This tool carries 144 sensors downhole to measure geologic features, coupled with enhanced petrophysical reservoir evaluation. The tool also identifies structural dips, depositional environments, borehole stability, and net pay in thinly bedded sequences. This imaging tool is used for well-to-well correlation of sedimentary and stratigraphic information.

<u>Deep Shear-Wave Sonic/Acoustic</u>
The deep shear-wave sonic and acoustic tool delivers acoustic services using monopole and dipole measurements to provide quality compressional and shear-wave measurements in low-velocity and unconsolidated formations. This tool enhances the value and understanding of petrophysics, reservoir characterization, and rock mechanical properties. The XMAC-F1 service builds on the previous XMAC ELITE, can log at twice the speed, and can measure shear slowness up to 1,200 microseconds per foot (μs/ft).

5.4.2 Coring Plan

During the drilling of the stratigraphic test well, Rayo Luna No. 1, an extensive coring program will be performed. The results from this effort will be used to further refine the static and dynamic reservoir models at the intervals shown in Table 5-1.

Table 5-1 – Planned Core Intervals and Testing Program

Zone	Cored Interval (ft TVD)	Testing Program
Upper Confining Zone – Burkeville Formation	[redacted]	Routine Core Analysis X-Ray Diffraction Scanning Electron Microscopy Special Core Analysis Mercury Injection Formation Damage Testing
Transition Interval – Burkeville to Lower Miocene Sands Formation		
Middle Confining Zone – Anahuac Shale		
Intermediate Injection Interval – Frio Sands Formation		

*TVD – true vertical depth

Additionally, sidewall cores will be obtained and analyzed from the Luz Solar No. 1 injection well.

5.4.3 Initial Step-Rate Injectivity Test

Before initiating CO_2 injection, BKVerde will conduct a step-rate injectivity test to measure the fracture gradient of Luz Solar No. 1, in compliance with 16 TAC **§5.203(f)(2)(A)** [40 CFR **§146.87(d)(1)**] and 16 TAC **§5.203(f)(2)(C)** [40 CFR **§146.87(e)(3)**]. Bottomhole, surface readout pressure and temperature gauges will be run to the total depth of the wellbore. Initial bottomhole pressure and temperature readings will be measured before injection, and all gauges will be calibrated before testing.

The step-rate test will be performed using brine or CO_2. Brine injection rates observed during step-rate testing can be converted to the equivalent CO_2 injection rate by accounting for the difference in fluid properties. The injection rate can be converted from a mass rate of tons per day (tons/D) to a volumetric rate (i.e., barrels per day (bbl/D)) to standard cubic feet per day (scf/D)). The mass rate is more suitable for measuring a compressible fluid such as CO_2.

The densities of the CO_2 at standard conditions and in the reservoir are modeled using the Reference Fluid Thermodynamic and Transport Properties Database (REFPROP, Ver. 10.0), a software program developed by the National Institute of Standards and Technology. This program references thermodynamic, physical, and transport properties of various fluids and fluid mixtures, and implements fluid models to calculate properties at variable temperatures and pressures throughout the liquid, gas, and supercritical states. The most accurate available models are included for 147 industrially important fluids. A wide range of tables and plots can be created within the software to display fluid properties at varying conditions.

Equations:

(Eq. 1) $$Qm = \frac{Qv * \rho BH}{\rho \mathrm{SC}}$$

(Eq. 2) $\rho BH = f(TBH, PBH, Fluid\ Composition)$ ← from $REFPROP\ software$

(Eq. 3) $\rho SC = f(TBH, PBH, Fluid\ Composition)$ ← from $REFPROP\ software$

Where:

Qv = Volumetric flow rate (bbl/day)
Qm = Mass flow rate (scf/D)
TBH = Temperature at bottomhole (°F)
ρBH = Pressure at bottomhole (°F)
ρBH = CO_2 density at bottomhole conditions, pound per cubic foot (lb/ft^3)
ρSC = CO_2 density at standard conditions (lb/ft^3)

5.4.3.1 Testing Method

Specific wellbore and injection zone properties will define the final test parameters. The following test method outlines the expected test-injection rates and times. Brine injection will begin at less than 1 barrel per minute (bpm) and be held for a minimum of 5 minutes. The injection rates will be stepped up in increments until at least three measurements are taken both below and above the estimated formation fracture initiation pressure—or to a maximum rate of [redacted] above the planned operating injection rate. Each stage duration will be based on the time required for the initial step to stabilize.

The proposed step-rate test is provided in Table 5-2.

Table 5-2 – Proposed Step-Rate Injection Test

Step	Duration (min)	Rate (bpd)	Rate (bpm)	Volume (bbl)	Cumulative (bbl)
[redacted]					

bpm – barrels per minute

A plot of stabilized injection pressure vs. injection rate at each step should graphically represent a linearly sloped line, until the fracture initiation pressure is exceeded. Table 5-3 shows a step-rate test example, and Figure 5-2 is the corresponding graphical representation.

Table 5-3 – Step-Rate Injectivity Test Example

Step	Rate (bpm)	Time (min)	Pressure (psi)
0	0	0	0
1	0.25	30	180
2	0.50	30	190
3	0.7	30	200
4	1.0	30	220
5	5.0	30	400
6	10.0	30	1,600
7	15.0	30	1,800
8	20.0	30	2,000
9	25.0	30	2,200

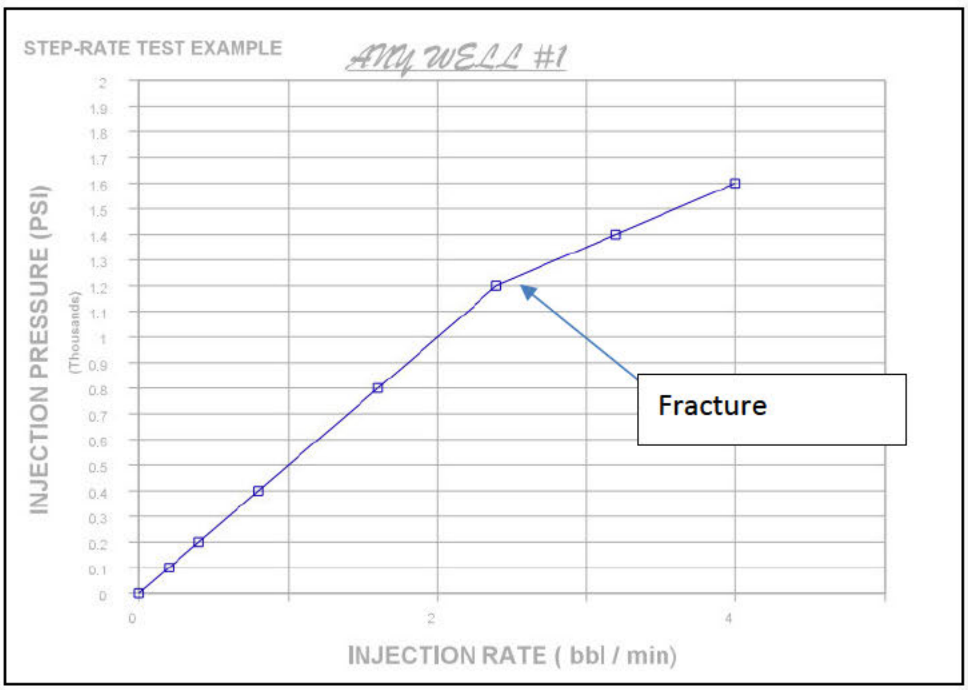

Figure 5-1 – Example Step-Rate Injectivity Test[1]

Upon reaching a stabilized pressure after completing the final step, pressures will be recorded at the highest frequency of the gauge for a period indicated by the step-up phase of testing to calculate the rate of pressure bleedoff.

[1] https://www.epa.gov/sites/default/files/documents/INFO-StepRateTest.pdf.

5.4.4 Internal Mechanical Integrity Testing – Annulus Pressure Test

In accordance with 16 TAC **§5.203(h)(1)(C)** [40 CFR **§146.89(b)**], BKVerde will demonstrate mechanical integrity by performing annular pressure tests when the well is completed, before the start of injection, and after any workover operation involving the removal and replacement of the tubing and packer. Multiple parameters—such as tubing annulus pressures and temperatures, at the surface and downhole—will be monitored continuously, as discussed in *Section 5.5.1*, to satisfy this statute.

The annular pressure tests are designed to prove the mechanical integrity of the casing, tubing, and packer. In accordance with 16 TAC **§3.9.12**, these tests will be conducted by pressuring the annulus to a minimum of 500 pounds per square inch (psi) fluid pressure, then using a block valve to isolate the test pressure source from the test pressure gauge upon test initiation—with all ports into the casing annulus closed, except the one monitored by the test pressure gauge. The test pressure will be monitored and recorded for at least 30 minutes, using a pressure gauge with sensitivities that can indicate a loss of 5%. Any loss of test pressure exceeding 5% during the minimum 30 minutes will indicate a lack of mechanical integrity.

All annulus pressure test results will be submitted to the TRRC/EPA on Form H-5 within 30 days of log run completion. This test will be performed at a minimum of every 5 years.

5.4.5 External Mechanical Integrity Testing – Pulsed-Neutron Log

In adherence to the requirements of 16 TAC **§5.203(h)(1)(D)** [40 CFR **§146.89(c)**], BKVerde will perform an annual external mechanical integrity test (MIT) by deploying a pulsed-neutron noise log through the tubing. These logs will be run before initiating injection operations to establish a baseline against which future logs can be compared. The well will be shut in for approximately 36 hours before running the temperature logs to allow temperatures to stabilize. Satisfactory mechanical integrity is demonstrated by the proper correlation between the baseline and subsequent logs.

All logs recorded during the MIT will be submitted to the TRRC within 30 days of completing the log run.

5.4.6 Pressure Falloff Testing

BKVerde will perform a required pressure falloff test at least every 5 years in accordance with 16 TAC **§5.203(j)(2)(F)** [40 CFR **§146.90(f)**]. The tests will measure near-wellbore formation properties and monitor for near-wellbore environmental changes that may impact injectivity and result in pressure increases. Parameters obtained from the falloff tests will be compared to those determined from the computational modeling and previous tests for indications of fluid leakage during the test.

5.4.6.1 Testing Method

The injection rate and pressure will be held as constant as possible before the beginning of the test, with data continuously recorded during the test. After the well is shut in, a downhole pressure array installed during the completion of the well will continuously take the pressure measurements. This system consists of a tubing encapsulated conductor (TEC) cable equipped with bottomhole pressure gauges within each planned injection stage. Once the pressure decay data plotted on a semi-log plot is a straight line, indicating that radial flow conditions are reached, the falloff period will end.

Detailed Pressure Falloff Test Procedure:

1. Prior to testing, keep the injection rate and pressure as constant as practical and continuously recorded.
    a. The injection rate should be high enough and maintained for a sufficient duration to produce a measurable pressure transient that will result in a valid falloff test.
    b. Offset wells should be shut in prior to and during the test. If shut-in is not feasible, a constant injection rate should be recorded and maintained during the test and then accounted for in the analysis.
    c. Do not shut in two wells simultaneously or change the rate in an offset well during the test.
2. Stop injection and shut in the well completely.
    a. This shut-in should occur over the shortest time possible.
3. During the shut-in period, continue to record temperatures and pressures at the highest obtainable frequency.
    a. The shut-in period should be long enough to observe a straight line of pressure decay on a semi-log plot (i.e., radial flow is achieved). The radial flow portion of the test is the basis for all pressure transient calculations. Therefore, the falloff portion of the test should be designed to reach radial flow, and to sustain a time frame sufficient for analysis of the radial flow period.
    b. A general rule of thumb is to run the test for three to five times the time required to reach radial flow conditions.

5.4.6.2 Analytical Methods

Mechanical integrity and near-wellbore conditions (flow-regimes, well skin, hydraulic property, and boundary conditions) will be determined through standard diagnostic plotting. This determination is accomplished by analyzing observed pressure changes and pressure derivatives on standard diagnostic log-log and semi-log plots using specialized pressure-transient analysis software. The analysis will integrate additional data beyond the injection well's rate and pressure data. The additional data may include operational history, offset well injection and operational history, and information collected from the permanent gauges installed on the TEC cable in the injection well. Depending on the complexity of the pressure response, it may be necessary to incorporate numerical modeling into the interpretation workflow.

Significant changes in the well or reservoir conditions may be identified by comparing the baseline pressure falloff test with subsequent tests. The effects of the fluid flow and the compressibility of the injected fluid will be considered and incorporated into the analysis. The well parameters resulting from falloff testing will be compared against those used in AOR determination and computational site modeling. Notable changes in reservoir properties may dictate that an AOR reevaluation is necessary.

5.4.6.3 Quality Assurance/Quality Control (QA/QC)

All field equipment will undergo inspection and testing before operation. Manufacturer calibration recommendations will be adhered to for the pressure gauges used in the falloff test. Documentation certifying proper calibration will also be enclosed with the test results. Further validation of the test results will be determined by an extended collection of pressure data from the exhausted and plugged injection stages. The continuation of pressure monitoring in deeper, inactive stages allows for recording of the naturally occurring pressure decay. Unexpected pressure communication between stages can be detected.

5.4.7 Cement Evaluation and Casing Inspection Logs

In accordance with 16 TAC **§5.203(h)(2)** [40 CFR **§146.89(d)**], a comprehensive cased-hole logging suite will be run on the long-string casing at the time of initial well completion. This suite of logs will include a cement bond log and a multiple-armed caliper to establish the condition of the casing metal. This survey will characterize the original state of the wellbore materials.

Casing inspection logs will be performed every 5 years or at shorter intervals as needed—or as requested by the UIC Director. The tools that will be run at that time include the following:

- A 5-year casing inspection
  - Casing section below the packer:
    - Multiple-armed calipers to measure the inner diameter of the casing as the tool is raised or lowered into the well
    - Ultrasonic tools to measure wall thickness and provide information about the outer surface of the casing or tubing as well as cement bonding
    - Electromagnetic tools that measure the magnetic flux of the tubular and can provide mapped circumferential images to indicate potential pitting
  - Casing section without tubing in the hole
  - Casing section from packer to surface:
    - Through-tubing casing inspection log
- If tubing must be removed, conventional casing inspection logs only will be run, consisting of the following:
  - Multiple-armed calipers to measure the inner diameter of the casing as the tool is raised or lowered into the well
  - Ultrasonic tools to measure wall thickness and provide information about the outer surface of the casing or tubing as well as cement bonding
  - Electromagnetic tools that measure the magnetic flux of the tubular and can

provide mapped circumferential images to indicate potential pitting

BKVerde will provide a schedule of all logging plans to the UIC Director at least 30 days before conducting the first test. Notice will be provided at least 48 hours in advance of such activity.

5.4.7.1 Casing Log Equipment Overview

Through-tubing logging technology provides the ability to evaluate casing deformation and curve-deviation measurements in conjunction with other well-integrity tools, such as multi-finger calipers and multiple pipe-thickness logging tools. This technology provides quality measurements without requiring the removal of the tubing and packer (Yang et al., 2021).

The following descriptions of the through-tubing logging tools that will be run are provided for information purposes. The final vendor will be selected before operations, based on availability and commercial considerations.

The instruments listed in Table 5-4 use pulsed eddy current (PEC) decay technology to measure the thicknesses of multiple concentric tubulars. Basic PEC decay technology theory is included in the supplemental information at the end of this document. These tools can be run stand-alone or combined with other well integrity and correlation instruments—such as multi-finger imaging caliper, temperature, noise, pressure, fluid density, capacitance, flowmeter, gamma ray, and casing collar locator.

The through-tubing PEC decay measurements are not affected by wellbore fluid types, chemical precipitates, or other foreign material deposits. They are also not affected by the type or distribution of annular materials, such as cement, mud, liquid, or gas.

Table 5-4 – PEC Tool List

Pulsed Eddy Current Decay Thickness Instruments

Tool	Tool O.D.	Max # concentric pipes	Max O.D.	Max Combined Wall Thicknesses	Ratings (degF/K psi)
MTD-B/C	1-11/16"	2	10-3/4"	1.75"	350/15
MTD-G	1-11/16"	3	16"	2.5"	350/15
ePDT-II	2" / 1-11/16"	3-5	30" / 18-5/8"	3.5"	350/20

*O.D. = outer diameter
degF/K = degrees Fahrenheit per thousand pounds per square inch

Logging speeds depend on the size and number of tubulars to be logged. In general, multiple tubulars and larger sizes will necessitate slower data acquisition speeds, which range from 30 feet (ft) per minute to 5 ft per minute, based on the complexity of the wellbore configuration.

The through-tubing PEC decay instruments measure the increase or decrease of metal thickness for each concentric tubular. PEC decay data combined with inspection of the tubular's inner diameter (ID) using an imaging caliper or other methods can reliably predict the inside vs. outside location of corrosion or flaws on the innermost tubular. Internal wear based on drilling or other known causes of internal damage is readily assessed, assuming that the measured metal loss in such cases is "internal."

The degree of penetration is reported in percent wall loss from the nominal and absolutes value of metal thickness, expressed in inches or millimeters. Because of well-understood and long-established PEC decay physics principles, reported metal gain or loss is assumed to be distributed evenly around the pipe's circumference.

The through-tubing PEC decay instruments measure the increase or decrease of metal thickness, which includes both internal and external corrosion effects. This overall metal thickness/degree of penetration is valid in identifying areas of concern with well integrity. Additionally, integrity assessment of the injection tubulars (i.e., tubing[s] and first casing) is only part of whether a wellbore and its associated tubulars are in such a condition as to be protective of public health, safety, and the environment. The newer-generation through-tubing PEC decay instruments provide an opportunity to assess the state of the protection tubulars (i.e., second casing, surface casing, etc.).

5.4.8 Logging and Testing Reporting

A report that includes log and test results obtained during the drilling and construction of Luz Solar No. 1, and interpreted by a knowledgeable log analyst, will be submitted to the UIC Director in accordance with 16 TAC **5.203(h)(2)** [40 CFR **§146.87(a)**].

5.5 Monitoring Programs

5.5.1 Monitoring Overview

Table 5-5 summarizes the various measurements discussed in the Testing and Monitoring Plan.

Table 5-5– Testing and Monitoring Plan Measurements

Monitoring Type	Monitoring Program	Location	Frequency
CO_2 Injection Stream Composition	• CO_2 sampling station	CO_2 meter run	Continuous
Corrosion Monitoring	• Corrosion coupon system	Facility flowline	Quarterly
Continuous Recording of Injection Pressure, Rate, and Volume	• Surface pressure and temperature gauges • Coriolis mass flowmeter	Wellhead	Continuous
Well Annulus Pressure Between Tubing and Casing	• Annular pressure gauge	Wellhead	Continuous
Groundwater Monitoring	• USDW monitoring well • Groundwater monitoring wells	Facility	Annually
Soil-Gas Monitoring	• Soil-gas monitoring stations	Facility	Annually
In-Zone Monitoring (IZM)	• Pressure/temperature gauges on TEC cable with fiber optic cable installed on outside of tubing	Rayo Luna No. 1	Continuously
Above Confining Zone (ACZ) Monitoring	• Fluid samples • Pressures	AZM Well	Annual
Direct Reservoir Monitoring	• Pressure/temperature gauges on TEC cable installed on outside of tubing	Luz Solar No. 1 Rayo Luna No. 1	Continuously
Indirect Reservoir Monitoring	• VSP surveys	Facility	Every 5 years
Internal and External Mechanical Integrity	• Annulus pressure test • Temperature pulsed-neutron Logs • Casing pressure test • Pressure falloff test • Ultrasonic logs	Luz Solar No. 1	• 5 years • Annually • 5 years • 5 years • 5 years

5.5.2 Continuous Injection Stream Monitoring

BKVerde will continuously monitor the injection pressures, rates and volumes, and annulus pressures to meet the 16 TAC **§5.203(j)(2)(B)** [40 CFR **§146.90(b)**] requirements. A Supervisory Control and Data Acquisition (SCADA) system will be installed to facilitate the operational data collection, monitoring, and reporting. In accordance with 16 TAC **§5.206(d)(2)(B)**, the total volume of CO_2 injected into the Whites Bayou Sequestration Site will be metered through a master meter or series of master meters. The volume or mass of CO_2 injected into Luz Solar No. 1 will be metered through an individual well meter.

Continuous monitoring of the injected CO_2 stream pressure and temperature will be performed using digital pressure gauges or charts installed in the CO_2 flowline, near the flowline-wellhead interface. An onsite SCADA system will be connected to the flowline, and a flowmeter will be installed on the injection well to measure the injected CO_2 flow rate. It will be connected to the SCADA system at the CO_2 sequestration site to ensure continuous monitoring and control of the CO_2 injection rate.

Downhole measurement will be accomplished using a TEC cable to power and communicate with the pressure and temperature gauges.

To meet the requirements of 16 TAC **§5.206(d)(2)(F)(i)** [40 CFR **§146.88(e)(2)**], automatic shutoff systems and alarms will be installed to alert the operator and/or shut in the well when operating parameters, such as annulus pressure, injection rate, etc., diverge from permitted ranges or gradients. A change of 10% in the annular pressure during steady injection operations will result in a shutdown event.

5.5.2.1 Analytical Methods

BKVerde will review and interpret continuously monitored parameters to validate that the operating conditions stay within the permitted limits. The data review will also review trends to help determine any need for equipment maintenance or calibration. These data reports will be submitted semi-annually.

CO_2 Mass Rate to Volumetric Injection Rate Calculation Methodology

If a mass meter is used, the flow rates measured during CO_2 injection can be converted to a volumetric flow rate by considering the density of the fluid. The pressure, temperature, and fluid composition are required to calculate density at specific conditions. To determine the density, REFPROP or a similar fluid-property calculation software may be used.

Output Variables:

Q_{vbh} = Volumetric flow rate at bottomhole standard cubic feet per day (scf/D)

Input Variables:

Q_m = Mass flow rate (scf/D)
ρ_{sc} = CO_2 density at standard conditions (lb/ft^3) (calculated from REFPROP)
T_{bh} = Temperature at standard conditions (°F)
P_{bh} = Pressure at standard conditions (psi)
ρ_{bh} = CO_2 density at bottomhole conditions (lb/ft^3) (calculated from REFPROP)
T_{bh} = Temperature at bottomhole (°F)
P_{bh} = Pressure at bottomhole (°F)

Equation:

(Eq. 4)

$$Q_{vbh} = \frac{Q_m * \rho_{sc}}{\rho_{bh}}$$

5.5.3 Chemical Composition Monitoring

In accordance with 16 TAC **§5.203(j)(2)(A)** [40 CFR **§146.90(a)**] requirements, BKVerde plans to sample the CO_2 injection stream and use the results of those samples to evaluate any potential interactions of CO_2 and other injectate components. CO_2 injection stream samples will be taken quarterly for chemical analysis of the parameters listed in Table 5-6, plus continuous pressure and temperature analysis.

5.5.3.1 Sampling Methods

CO_2 stream samples will be collected from the CO_2 pipeline, in a location representative of injection conditions. A sampling station will be connected to the pipeline inlet meter at a sampling manifold. Sampling cylinders will be purged with the injectate gas to expel laboratory-added gas or vacuum cylinders used to obtain the samples.

Table 5-6 – Injectivity Test Parameters and Analytes Measured and Measurement Frequency

Parameter/Analyte	Frequency
Pressure	Continuous
Temperature	Continuous
CO_2 (%)	Quarterly
Water (lb/MMscf)	Quarterly
Oxygen (%)	Quarterly
Sulfur (ppm)	Quarterly
Methane (%)	Quarterly
SO_2 (%)	Quarterly
NO_x (%)	Quarterly
Ethane (%)	Quarterly
Other Hydrocarbons (%)	Quarterly
Hydrogen Sulfide (ppm)	Quarterly
Benzene (%)	Quarterly

*lb/MMscf – pounds per million standard cubic feet
ppm – parts per million

5.5.4 Corrosion Coupon Monitoring

BKVerde will monitor for corrosion of the well tubing and casing materials in accordance with the 16 TAC ***§*5.203(j)(2)(C)** [40 CFR ***§*146.90(c)**] requirements. A corrosion coupon monitoring system will be employed for this evaluation. Additionally, the casing inspection logs run every 5 years will provide information regarding corrosion of the tubulars.

5.5.4.1 Sampling Methods

Corrosion coupons made from the same material, such as the injection flowline, tubing, and long-string casing, will be placed in the CO_2 injection flowline. These coupons will be removed quarterly and examined for corrosion in accordance with the American Society for Testing and Materials (ASTM) standards for corrosion testing evaluation. After removal, the coupons will be visually inspected for signs of corrosion, including pitting, and measured for weight and size. The corrosion rate will be estimated by applying a weight-loss calculation method that divides the weight loss recorded during the exposure period by the duration.

5.5.4.2 Deviation Response

In any event where the sampling or analysis indicates that there is a variance from the normal baseline, the regulators will be notified, an investigation will take place, and the appropriate response—including any corrective action—will be determined and presented to the regulators for approval and implementation.

5.5.5 Soil-Gas Monitoring

Soil-gas monitoring will be used to check chemical compositions of the near-surface environment and soil vadose zone. These environments are subjected to strong seasonal effects and are influenced by a wide range of natural processes and human activities. As with any of these types of monitoring, establishing a baseline condition is very important. BKVerde intends to install the soil-gas monitoring stations at least 3 months before injection, to better understand baseline conditions through multiple seasons. Best industry practice has shown that fixed soil-gas profile stations provide the most accurate data. The location of the stations will be selected to minimize the agricultural impacts of plowing, planting, irrigation, and harvesting. Samples will be collected and sent to a reputable lab for analysis. Quality assurance and traceability methods will ensure proper handling of samples and lab techniques.

5.5.5.1 Baseline Analysis

Soil-gas samples will be taken after Authorization to Construct is approved, at least 3 months prior to starting injection at Luz Solar No. 1. Table 5-7 will provide the analysis of the baseline samples for the soil-gas monitoring system and include the parameters that will be monitored:

Table 5-7 – Baseline Soil-Gas Sampling Results (TBD)

Sample No.	Date	CO_2, %	O_2, %	N_2, %

5.5.5.2 Deviation Response

In the case of any occurrence wherein the sampling or analysis reveals a deviation from the average of the baseline samples, the proper regulatory authorities will be informed. Subsequently, an inquiry will be conducted, and the suitable course of action—including potential corrective measures—will be identified and submitted to the regulators for endorsement and execution.

5.5.6 Groundwater Quality Monitoring

To meet 16 TAC **§5.203(j)(2)(C)** [40 CFR **§146.90(d)**] requirements, groundwater quality will be monitored in the deepest USDW formation, to detect potential changes that could result from fluid leakage from the injection zone. The groundwater at the Whites Bayou Sequestration Site generally moves to the southwest. Therefore, BKVerde plans to drill three groundwater monitoring wells on the property. These wells will be placed across the anticipated pressure front, to measure any change from baseline parameters that would indicate the migration of CO_2 into the USDW (Figure 5-2). A higher resolution version of this map is provided in *Appendix F-1*.

[redacted]

Figure 5-2 – Location of Monitoring Wells

Samples will be taken quarterly with parameters to be measured as shown in Table 5-8.

Table 5-8 – Groundwater Quality Parameters Measured

Parameter/Analyte	Frequency
Aqueous and pure-phase carbon dioxide	Quarterly
Total dissolved solids (TDS)	Quarterly
pH	Quarterly
Specific conductivity (SC)	Quarterly
Temperature	Quarterly
Density	Quarterly
Other parameters, including major anions and cations, trace metals, hydrocarbons, and volatile organic compounds	Quarterly

5.5.6.1 <u>Sampling Methods</u>

Fluid samples will be acquired from the groundwater monitoring wells using an electric submersible pump. The pump will evacuate a minimum of two wellbore volumes of liquid before collecting a representative sample at the surface.

5.5.6.2 <u>Analytical Methods</u>

BKVerde will test water samples and maintain results for the parameters listed in Table 5-6 (*Section 5.5.3.1*). If the CO_2 injectate contains unique impurities, groundwater samples will also be tested to flag any concentrations exceeding the baseline.

Potential signs that fluid may be leaking from the injection interval(s) may be detected upon observation of the following trends:

- Change in TDS
- Changing signature of major cations and anions
- Decreasing pH
- Increasing concentration of injectate impurities
- Increased concentration of leached constituents
- Increased reservoir pressure and/or static water levels

If a significant change is observed, further investigation may be warranted. These next steps could include, but not be limited to, using a pressure jar to collect a sample of the fluid and dissolved CO_2 to confirm the results.

5.5.6.3 <u>Baseline Samples</u>

Baseline groundwater samples will be taken at least 3 months prior to starting injection at Luz Solar No. 1. Table 5-9 will provide the analysis for the baseline samples of the groundwater.

Table 5-9 – Baseline Soil Gas Sampling Results (TBD)

Well No.	Sample No.	Date	CO_2	TDS	pH	SC	Temp	Density	Other

5.5.6.4 Deviation Response

In the case of any occurrence wherein the sampling or analysis reveals a deviation from the average of the baseline samples, the proper regulatory authorities will be informed. Subsequently, an inquiry will be conducted, and the suitable course of action—including potential corrective measures—will be identified and submitted to the regulators for endorsement and execution. In the case that a sample is determined to be an outlier sample, caused by data error and anomalies, that sample may be deleted from the average. Screening of outliers may include methods such as box-plots, normal probability plots, the Grubbs test, and the Dixon test (Rangeti et al., 2015).

5.5.6.5 Laboratory to Be Used/Chain-of-Custody Procedures

Water sample results will be submitted to the TRRC/EPA after analysis at a federal- or state-approved laboratory. BKVerde will observe standard chain-of-custody procedures and maintain records to allow full reconstruction of the sampling procedure, storage, and transportation, including problems encountered.

5.5.6.6 Quality Assurance and Surveillance Measures

BKVerde will collect duplicate samples and trip blanks for QA/QC. These duplicate samples will validate test results and ensure that samples have not been contaminated.

5.5.6.7 Plan for Guaranteeing Access to All Monitoring Locations

The installation of groundwater monitoring wells is part of the surface-use lease agreements with the landowners across the plume area, thereby ensuring access to the well locations for sampling and maintenance purposes. Unauthorized access will be prevented by capping and locking out the well.

5.5.7 Downhole Monitoring Wells

5.5.7.1 Injection Well – Luz Solar No. 1

[redacted]

[redacted] Details on the proposed equipment are described in *Section 5.5.9.1.*

5.5.7.2 Above-Zone Monitoring Well

One above-zone monitoring (AZM) well will continuously monitor the pressure of the first mappable porous geologic member, the Evangeline aquifer, identified above the upper confining zone (UCZ). Any deviations from baseline pressures or temperature will initiate additional investigations. If necessary, fluid samples can be obtained from this well. The location of the well is shown in Figure 5-2 (*Section 5.5.6*).

[redacted]

[redacted] Construction details for the USDW well are included in *Appendix D-5*.

[redacted]

Figure 5-3 – Proposed Well Schematic, [redacted]

[redacted]

Figure 5-4 – Proposed Well Schematic, [redacted]

5.5.7.4 <u>In-Zone Monitoring Well – Rayo Luna No. 1</u>

BKVerde will drill and complete stratigraphic test well [redacted], as was shown in Figure 5-2 (*Section 5.5.6*). During the drilling of this well, subsurface characterization data will be obtained. The well will be cased and completed with CRA tubulars and corrosion-resistant cement. The IZM well is expected to be inside the CO_2 plume and therefore will contact injected CO_2. Pressure and temperature controls and a TEC cable will be installed behind the [redacted] The proposed well design for Rayo Luna No. 1 is shown in Figure 5-5 (page 29).

The pressure in the injection zone will be monitored directly by downhole pressure/temperature gauges installed in the injection zone on Rayo Luna No. 1. The pressure front will be monitored by downhole pressure/temperature gauges installed outside the tubing and connected to the surface process control system by a TEC cable, to enable continuous measurement. In addition, the Rayo Luna No. 1 downhole measurements will measure the pressure falloff after injection operations have ceased for a specific injection zone. Pressure transient methods can indirectly model the pressure falloff and buildup within the AOR.

[redacted]

Table 5-10 – Monitoring Sequences

Monitoring Completion Stage	Monitoring Zone	Year	Top Depth (ft)	Bottom Depth (ft)
[redacted]				

Monitoring Completion Stage	Monitoring Zone	Year	Top Depth (ft)	Bottom Depth (ft)
[redacted]				

[redacted]

[redacted]

[redacted]

Figure 5-5 – Proposed Well Schematic, Rayo Luna No. 1

5.5.8 Injection Plume Monitoring

BKVerde will use both direct and indirect methods to track the CO_2 plume and the critical pressure front, in accordance with 16 TAC **§5.203(j)(2)(E)** [40 CFR **§146.90(g)**]. The critical pressure front will be directly monitored by continuously recording pressures and temperatures to calculate the extent of this pressure increase. The CO_2 plume will be indirectly monitored using seismic survey technology, such as a VSP.

BKVerde will use these methods to verify reservoir conditions during injection, track plume and critical pressure front migration, and validate the reservoir model. Continuous pressure and temperature monitoring of the injection reservoir in both the injection well and the IZM well will allow for monitoring of reservoir conditions and inform calculations, while VSP surveys will determine the actual CO_2 plume migration. The VSP surveys will be run before injection initiation to establish a baseline, periodically as needed, and every 5 years at a minimum.

5.5.8.1 <u>Direct Monitoring: Rate Transient Analysis</u>

Rate transient analysis, in conjunction with reservoir simulations using known reservoir characteristics, will allow for calculating more complex parameters within the injection intervals. Direct monitoring will be based on continuous pressure, temperature, and injection rate data to calculate the properties of the reservoir and verify the plume model results. Pressure and temperature gauges will be run on TEC cable on the injection well and IZM well.

The reservoir model built during the site evaluation phase will be used to predictively monitor the reservoir conditions during injection operations. Through flow simulation and transient flow analyses, the reservoir model will be regularly updated with injection activity, to evaluate the effect of the injection stream on reservoir conditions. This analysis can be performed to monitor the magnitude and extent of temperature and pressure changes within the injection zone. Continual monitoring of bottomhole pressures and temperatures combined with known reservoir parameters will be used to calculate reservoir conditions throughout the injection intervals.

Any shut-in periods can be observed and treated as a pressure falloff test. To do this during a shut-in period, the shut-in wellhead pressure, bottomhole pressure, and temperature readings will be recorded and used for pressure transient analysis of the reservoir. The analysis results will include the radius and magnitude of pressure buildup and reservoir performance characteristics, such as permeability and transmissibility. Analysis results will then confirm, and adjust as necessary, the previous model realizations.

Through predictive modeling and analysis of recorded pressure and temperature data, BKVerde can closely monitor the effect of the injection well on the subsurface, to help ensure regulatory compliance and safety while contributing to informed decision-making.

5.5.8.2 Indirect Monitoring: Vertical Seismic Profile

BKVerde will use time-lapse VSP as the first method to indirectly monitor the CO_2 plume extent and development per the 16 TAC **§5.203(j)(2)(E)** [40 CFR **§146.90(g)(2)**] requirements. A fiber optic cable with distributed acoustic sensing (DAS) fiber optic cable will be installed and cemented in the annulus behind the long-string casing of the IZM well. This system will enable real-time reservoir monitoring using pressure and temperature gauges and the periodic VSP. The DAS fiber optic cable of the IZM, designed with sensors spaced 1 meter apart, will be used to generate a VSP at the highest possible resolution. The actual injection well will not be equipped with the fiber optic array. Three-dimensional models of the carbon dioxide plume will be created using a walk-away seismic source. The data will be captured by monitoring the injection well and repositioning the surface acoustic source. A vibrating device will be used as the acoustic source, and locations will be determined based on well location and conditions.

As an example of where this technology has been successfully proven, Shell Canada used it to monitor plume movement at its Quest Project (Bacci et al., 2017). Figure 5-6 illustrates the acquisition pattern strategy employed for plume development surveys from two separate wells.

Figure 5-6 – Shell Canada Quest Project VSP Acquisition Patterns

Reservoir monitoring using time-lapse seismic surveys has an extensive history of use in tertiary oil and gas recovery. The methodology has undergone thorough testing in saline aquifers with the presence of CO_2. The time-lapse effect is primarily driven by the change in acoustic impedance, resulting from compressional changes in velocity between high CO_2 concentrations and formation gases and fluids. As CO_2 displaces formation fluids, the difference in acoustic impedance with time is an effective proxy for plume shape and can be visualized.

The work steps involved in a time-lapse VSP survey primarily include the following:

1. Rock Physics Model
2. Petro-Elastic Model
3. Feasibility
4. Baseline Survey (Data Acquisition)
5. Repeat/Time-Lapse Survey (Data Acquisition)
6. Interpretation

The following subsections discuss key portions of these work steps.

5.5.8.2.1 Rock Physics Model

A rock physics model is critical to time-lapse interpretation. This model establishes a relationship between fluid substitution and the change in acoustic impedance. It can be produced with high confidence, provided the reservoir characterization data is accurate. Changes in seismic response can be projected with a synthetic survey design and reservoir model, relying on the rock physics model to calculate formation fluid impact on acoustic impedance. This model determines if the monitoring program can facilitate the detection of expected formation-fluid substitutions.

Deterministic petrophysical analysis estimations can be used to forecast the dry mineral rock components before any saturation modeling. The model accounts for the following rock properties:

- Total porosity
- Effective porosity
- Water saturation
- Clay (type)
- Quartz
- Mineral content
- Oil/gas residual (if any)

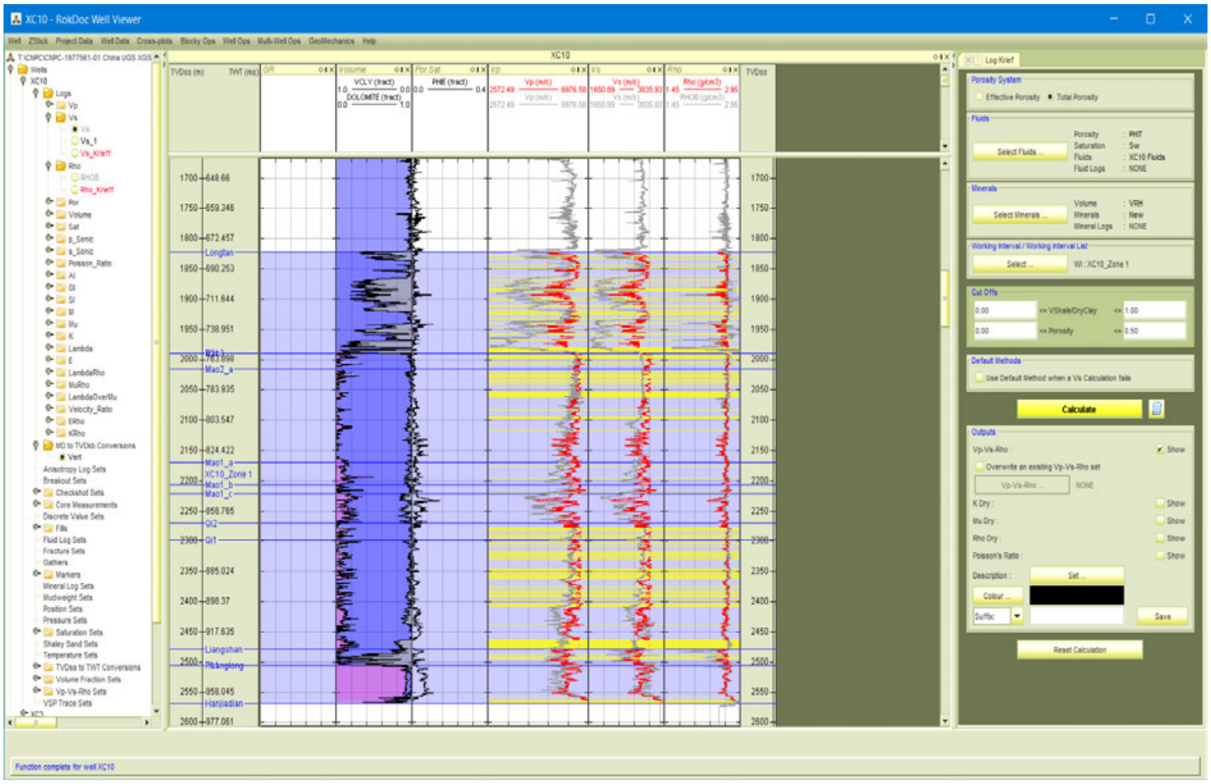

Figure 5-7 – RocDoc Well Viewer

The RocDoc Well Viewer (Figure 5-7), developed by Baker Atlas, is an evaluation product that enables QC of the deterministic inversion of the reconstructed mineral content compared to the observed petrophysical response. The inversion allows for stabilizing inverted results, evaluating uncertainty in predicted attributes, and calculating in situ reservoir properties.

5.5.8.2.2 Petro-Elastic Model

The rock physics model will generate a zero-order dry rock model, which is then used to establish a petro-elastic model by perturbing the elastic parameters for varying degrees of saturation.

Figure 5-8 illustrates the combination of the rock physics model (shown in red) and the petro-elastic model at 52% water saturation (blue). Changes in saturation result in changes primarily to the compressional wave velocity for this type of rock. The effect of gas replacement of the reservoir fluid can be estimated using the fluid saturation and fluid replacement from the rock physics model.

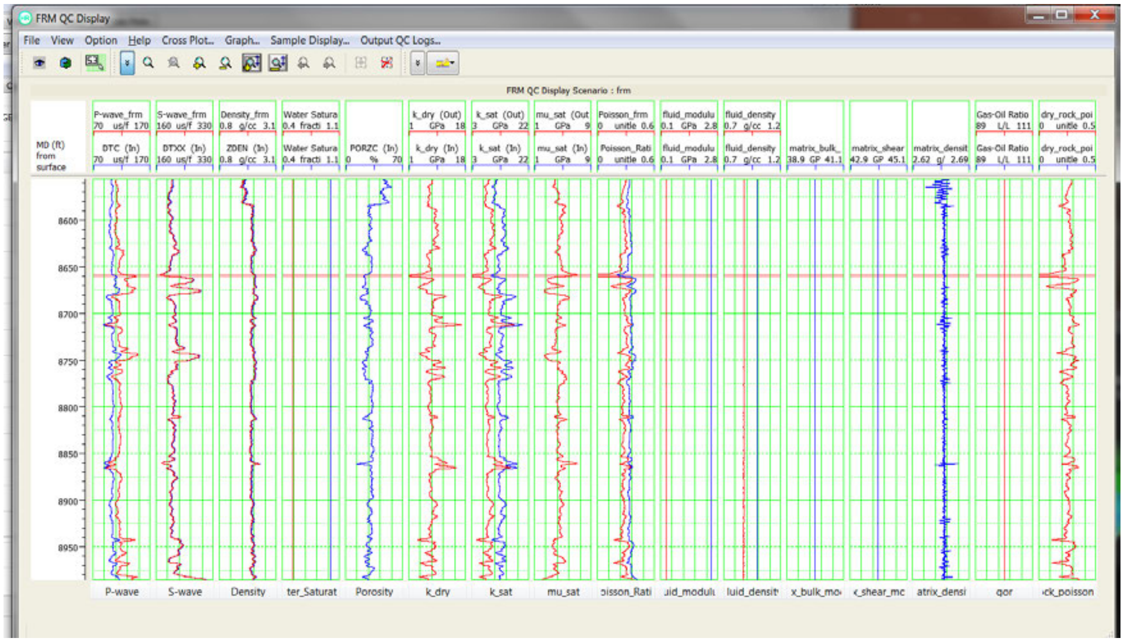

Figure 5-8 – Application of Petro-Elastic Model to Rock Physics Model

Predicting velocity and density as functions of injectate saturation is the result of the petro-elastic model (Figure 5-9). The seismic response measured during VSP surveys can be determined using the acoustic impedance calculated from both elastic properties.

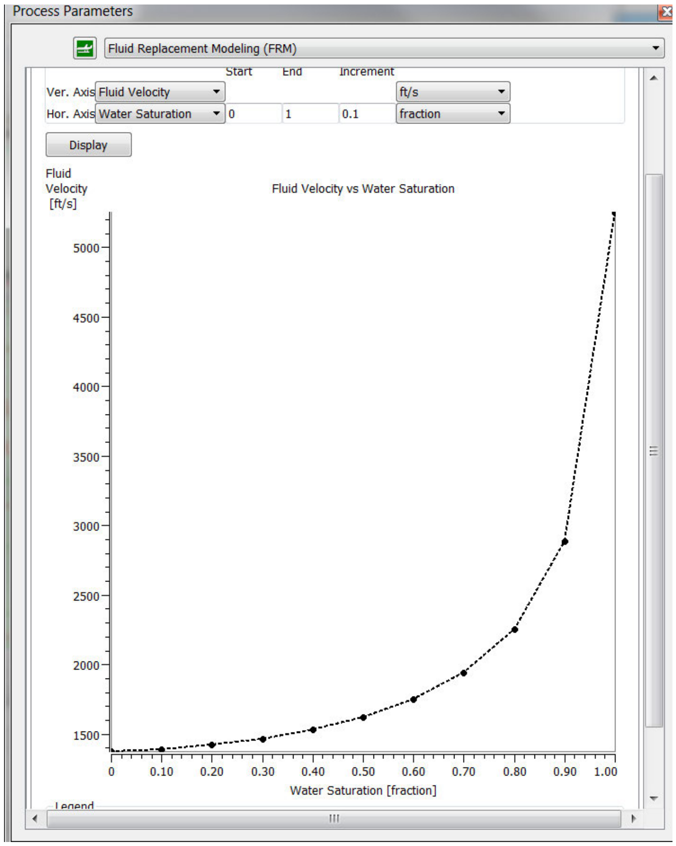

Figure 5-9 – Petro-Elastic Model Predictions of Velocity and Density as a Function of Saturation

A feasibility study will be designed to determine if connate fluids replaced with CO_2 could be detected by the petro-elastic model. This study will be conducted after recovering core material from the injection well. The CO_2 properties will be input into the model as replacement variables for openhole log readings that will be taken while drilling the stratigraphic test well for this project.

5.5.8.2.3 <u>1D and 2D Models</u>

Changes in the magnitude of the CO_2 plume are measured for different scenarios using 1D and 2D models. This section will detail the methodology used to generate these models.

Seismic waves that travel through the Earth are created with seismic surveys, and geophones listen for the waves that are subsequently reflected. The seismic waves can be made with a "shot," referring to explosives or other mechanical sources—most commonly a vibrator, which generates seismic waves by pounding a steel plate against the Earth. Geophones are recorders that detect sound waves reflected to the surface, and the data sent by geophones is then stored using seismographs. The geophones enable geophysicists to calculate the time it takes for seismic waves to reflect off transition zones between formations. Geoscientists can use the variation in sonar velocities to understand subsurface lithology.

Figure 5-10 depicts a standard VSP survey with a geophone configuration.

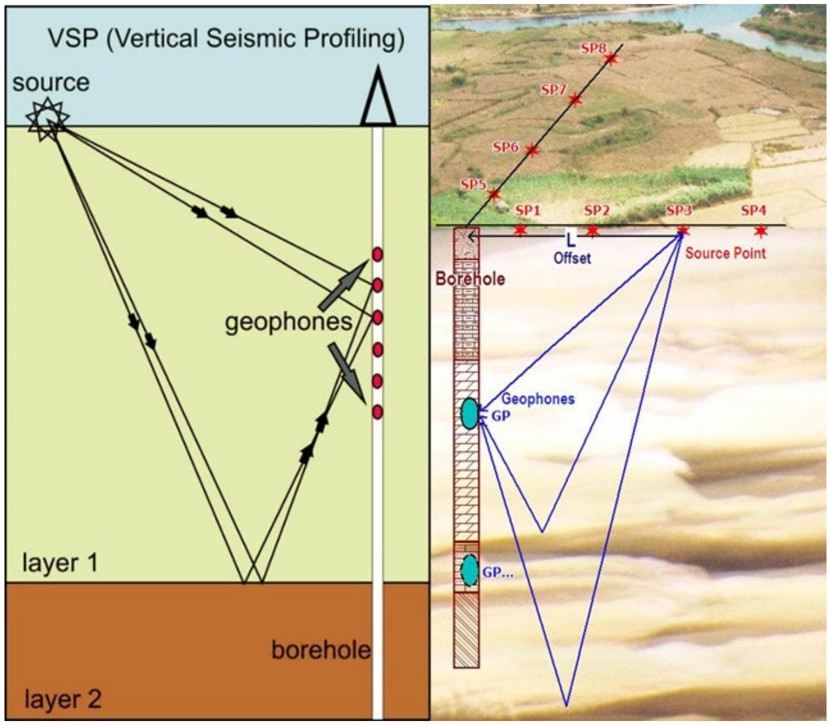

Figure 5-10 – Illustration of a Vertical Seismic Profile Survey

5.5.8.2.4 1D Model

The previously discussed principles apply to 1D seismic surveys. A standard method of obtaining 1D seismic data is with a checkshot survey, as illustrated in Figure 5-11. Geophones are situated vertically along the wellbore while all shots are fired from the surface. This placement allows the geophones to record seismic waves at different depths and provide measurements—at the highest levels of accuracy—of sonic velocities of the geologic layers affected by wellbore construction. These systems are commonly used to generate more accurate 2D, 3D, VSP, and 4D surveys.

The 1D survey methodology assumes that each formation is homogeneous in the horizontal direction; therefore, the surveys can only provide average sonic velocities. The 1D survey data can also be used to correct the sonic logs and create synthetic seismograms, which are used to forecast seismic responses of the subsurface. One variation of 1D seismic surveys is an acoustic log, which generates acoustic data along the wellbore using wireline sonic tools. Although the purposes of these logs differ from those of seismic surveys, they can provide a way to a 1D understanding of variation in velocities.

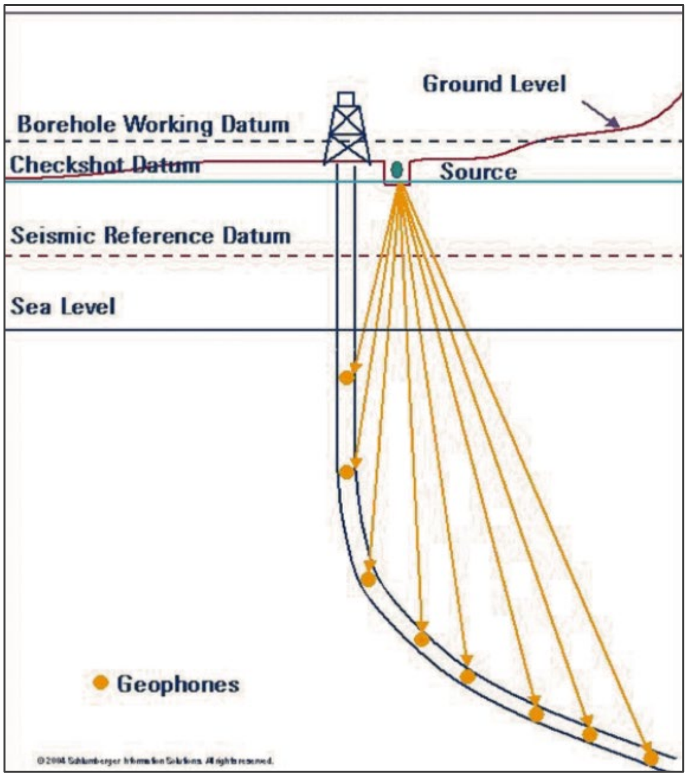

Figure 5-11 – Illustration of a Checkshot Survey

A 1D offset model will be constructed for each case, and differences in reflection amplitudes will be measured.

5.5.8.2.5 2D Model

A geologic model can be built once the results of a 1D model have been interpreted. The model reflects two saturation scenarios: one with connate formation fluid, and the other with CO_2-replaced fluid.

Applying the same principles discussed in the previous section, 2D seismic surveys can provide a snapshot of a thin layer of the crust of the Earth. The geophones for this survey are placed in a line along the surface and record reflected seismic waves from each formation. For best results, 2D surveys require setting multiple lines, ideally parallel to the structure dip and orthogonal to the geologic strike. The surveys provide subsurface information on various formations, faults, and other characteristics. Geologists can interpret contour lines and produce geologic maps using the intersection of numerous 2D surveys, which cost less and have less environmental impact than 3D surveys. They are commonly used to explore new areas and allow geologists to visualize the formations lying beneath the surface.

5.5.8.2.6 Processing Workflow and Time-Lapse/4D Seismic Volume Determinations

To produce the final interpretation, CO_2 volume buildups from consecutive surveys will be observed over time. A time lapse or 4D model is created when VSP, 1D, 2D, or 3D dedicated seismic surveys are combined with a time element (i.e., surveys recorded at various time intervals—Year 1, Year 5, Year 10, etc.). The wheel spoke pattern of 2D survey lines, with the injector and VSP receiving fiber optic at its center, can be interpreted as similar to a 3D survey. Changing volumes of gas buildup, represented by either log shifts on the VSP, 1D, or 2D responses, or heat blooms (i.e., change in fluid density) on the 3D model, are identified in the time-lapse/4D interpretation of a seismic survey.

Figure 5-12 illustrates a basic workflow example:

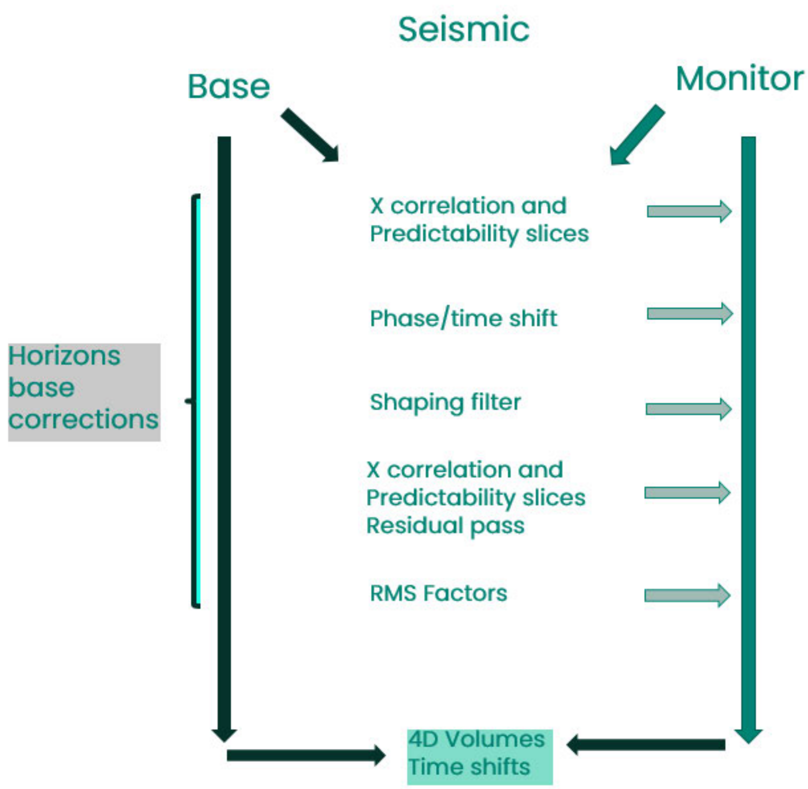

Figure 5-12 – Time-Lapse/4D Processing Workflow Diagram

The 3D horizon model is established from the base survey, and each successive survey creates a reflection differential mapped on the 3D model. The map is used to determine plume geometry, and the process is repeated in time increments to illustrate the time-lapsed development of the injectate plume.

To ensure consistency, all seismic volumes will be processed using the same software and for each workflow step outlined. Figure 5-13 presents a time-lapse/4D model visualization in 3D with analysis software. Color coding is used to display amplitude over time for each horizon. A similar output will be generated from BKVerde's VSP surveys at the Whites Bayou Sequestration Site.

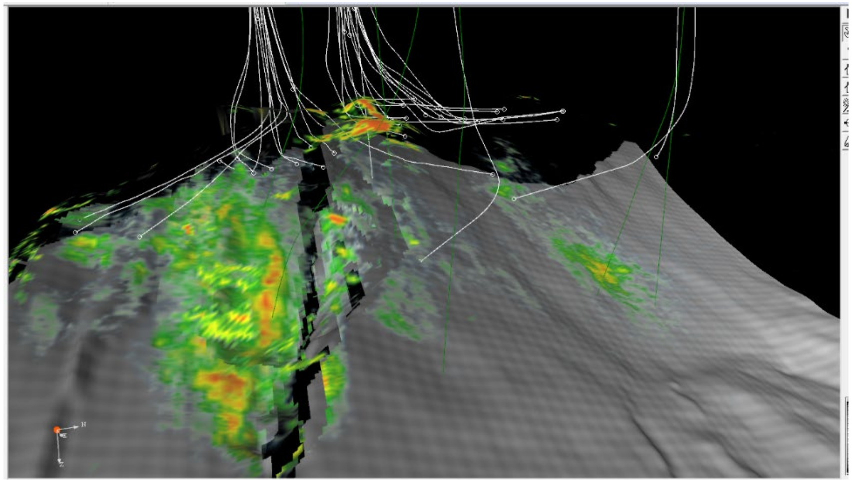

Figure 5-13 – Example of Time-Lapse/4D Model (showing time-lapsed gas replacement of connate fluids)

5.5.8.2.7 <u>Inversion Workflow</u>

Log data, post-stack seismic volumes, and a structural model will be used to invert baseline surveys, as Figure 5-14 shows. Later, monitor surveys will employ the same low component and residual corrections for consistency and the detection of changes over time—changes assumed to result from the injection operations.

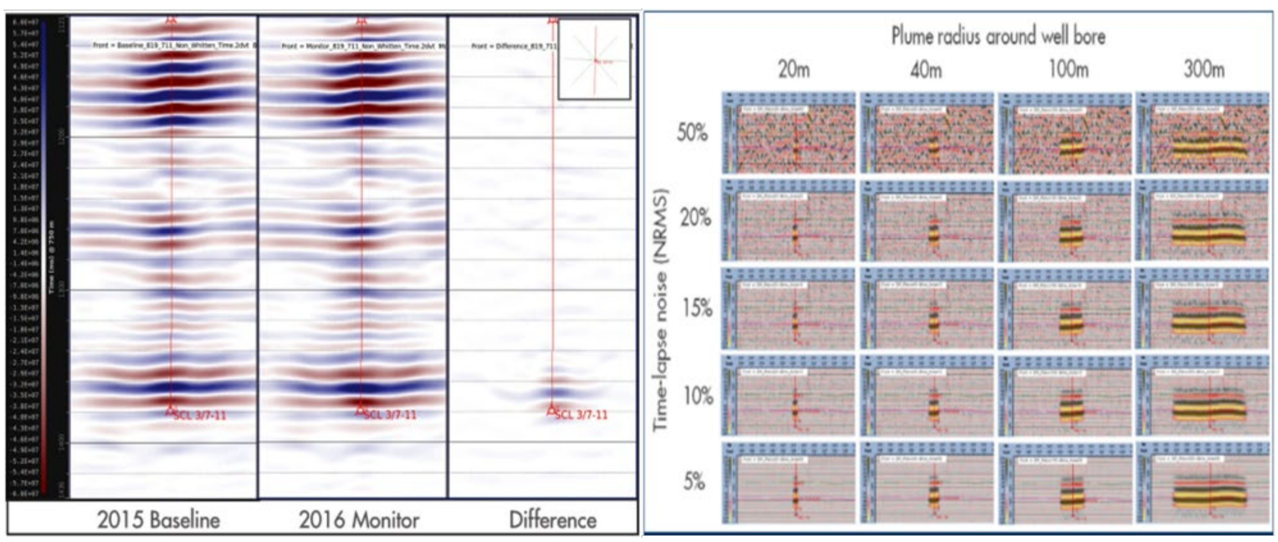

Figure 5-14 – Baseline and subsequent VSP used to determine difference in amplitude attributed to CO_2 injection measured from the injector well itself. At right, estimation of the plume growth over time.

5.5.8.2.8 Baseline Survey

Conducting a quality VSP baseline survey is critical, because it is the only opportunity to capture an image of the reservoir before injection operations or offset activity—either natural or man-made—impact it. Without this survey, the future interpretation of formation changes cannot be assessed. Also, the size of the baseline survey constrains the extent of plume measurement ability. It is essential to acquire a baseline survey with sufficient coverage if the initial reservoir models are not accurately forecasting plume migration.

5.5.8.2.9 Equipment Design and Setup

The proposed equipment for periodic survey operations to determine the CO_2 plume growth over time includes the time-lapse VSP, which uses a DAS fiber optic cable—to be installed in the IZM well and connected to an interrogator box at the surface. The DAS system is synchronized to the seismic acquisition system controlling both the receiver (the DAS fiber optic array cemented in the injection well) and the source (seismic vibrator trucks).

Monitoring Schedule

The plume extent for Luz Solar No. 1 will be monitored using the DAS-VSP on the following schedule:

- The initial DAS-VSP survey will be conducted prior to the injection phase to capture the starting conditions for the formation brine.
- The first monitoring survey will be performed approximately 1 year after injection begins. The timing for this first survey is based on simulations that predict that the plume extent remains within the DAS-VSP imaging cone. This first survey allows early insights into the actual plume migration relative to the predicted model.
- Subsequent monitoring surveys will be conducted at least every 5 years.
- During the post-injection site care phase of the project, surveys will occur immediately after injection ceases into the last injection sand and 5 years after injection ceases. If the plume can be shown to have stabilized, additional DAS-VSP surveys will not be required. Pressures and temperatures will continue to be measured from the offset monitoring wells.

5.5.9 Wellbore Overview

5.5.9.1 In-Zone Monitoring Well

The CO_2 plume growth will be monitored indirectly by the IZM well through repeated VSP seismic processing, using the DAS-VSP fiber optic cable as well as pulsed-neutron log-time slices.

[redacted].

Within the IZM well, protective casing clamps will be installed on each casing joint collar to ensure the cable has been securely run to depth. BKVerde will install blast protectors on each joint per design in the injection zone, to locate the cable on the casing string and ensure no damage has occurred to the fiber optic cable and TEC line during oriented wireline perforating. Enhanced location detection through the magnetic resonance tools is also achieved with the addition of metal in the blast protectors.

5.5.9.2 Equipment Overview

This section discusses the typical hardware setup and use of in situ monitoring equipment for temperature, pressure, and seismic that will employ fiber optic cable to communicate with a surface-located interrogator box, to record real-time or periodic data. The equipment described is representative of the technology that will be employed. Specific vendor-proprietary equipment details will be provided when the vendor is selected nearer to the time the well is drilled.

5.5.9.2.1 SureVIEW™ with CoreBright Optical Fiber

SureVIEW downhole cable uses CoreBright optical fiber, which leads the industry in resisting hydrogen darkening—the primary cause of failure for fiber optic systems in high-temperature applications. CoreBright is constructed from pure silica—minimizing hydrogen darkening—combined with a layer of hydrogen-absorbing gel. The Baker Hughes and GE Company (BHGE) standard SureView fiber-optic cable product is a 0.25-in. OD heavy-wall tubing-armor cable that encloses a 0.125-in. OD thin-wall tubing containing optical fiber. The armor is a CRA tube, longitudinally welded and cold worked to its final diameter. It contains an extruded plastic filler (belting) that centralizes and provides a level of shock and vibration damping to the inner tube. The inner tube or fiber-in-metal tube (FIMT) contains up to 12 optical fibers immersed in thixotropic gel. Figure 5-15 illustrates the optical fiber, and Table 5-11 provides the specifications.

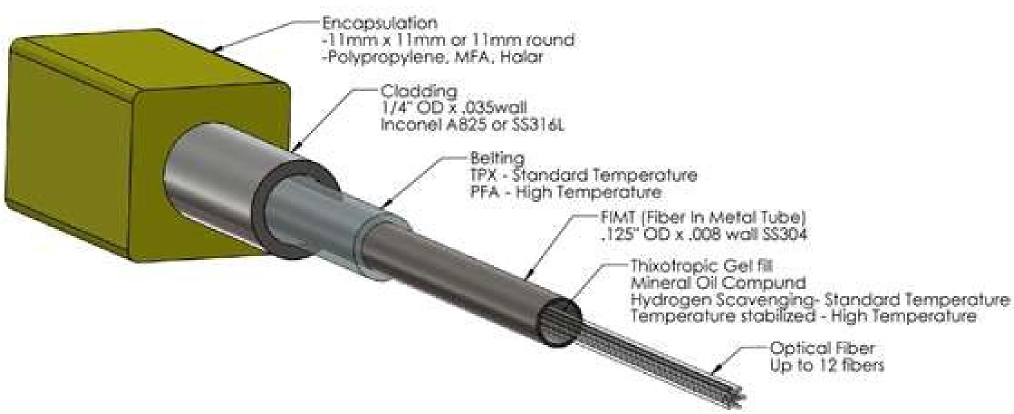

Figure 5-15 – SureVIEW with CoreBright Optical Fiber

Table 5-11 – SureVIEW Downhole Specifications

Description	Value	
Encapsulation	0.433 in.2 (11 mm2) or 0.41 in. round (11-mm OD)	
Cladding	0.250-in. (6.35-mm) OD × 0.035-in. (0.89-mm) wall	
FIMT diameter	0.125-in. (3.18-mm) OD	
Weight with polypropylene 11×11 encapsulation	154 lb/1,000 ft (230 kg/km)	
Weight without encapsulation	101 lb/1,000 ft (150 kg/km)	
Mechanical properties (70°F)*	**A825**	**SS 316L**
Tensile strength (lb)	2,687 (1,219 kg)	2,134 (968 kg)
Yield strength (lb)	2,090 (948 kg)	1,816 (824 kg)
Hydrostatic pressure (kPSI)	25 (17 kg/sq mm)	24 (16.8 kg/sq mm)
Burst pressure (kPSI)	32 (22 kg/sq mm)	22 (15.4 kg/sq mm)
Dynamic bend radius (in.)	14 (355 mm)	25 (635 mm)
Static bend radius (in.)	3 (82 mm)	6.3 (159 mm)
External collapse pressure (kPSI)	24.6 (1729 kg/sq cm)	17 (12.0 kg/sq mm)

*Materials listed should be derated for specific temperature applications. Contact Applications Engineering group for deration factors.

5.5.9.2.2 SureVIEW DAS

The SureVIEW DAS interrogator offers all the benefits of fiber-optic acoustic monitoring—from flow monitoring and optimization, sand detection and stimulation optimization, to seismic and microseismic monitoring, combined in a single interrogator (specifications shown in Table 5-12).

Table 5-12 – SureVIEW DAS VSP Specifications

Technical Specifications	
Technology Supported	SureVIEW DAS VSP
Type	Rackmount
Number of Channels	8
Rack Unit Dimensions	6U
Certifications	CE, TUV
Supply Voltage	110-240 Volts AC, 50 or 60Hz
Typical Power Consumption	Up to 400W
Operating Temperature Range	0°C to +40°C / 32°F to +104°F
Optical Connectors	F3000/APC

Interface Connections	Ethernet, GPS, USB (Geophones) DC Trigger Pulse (GPS Synced)
File Formats	PRODML/HDF5/SEG-Y
Data Storage	960GB (Internal) 8TB (NAS)
Maximum Distance Range	Up to 12 miles (20 km) with CoreBright fiber Up to 50 miles (80 km) with CoreBright EBF
Fiber Type	Single Mode
Spatial Resolution	1.5 meter
Minimum Sampling Interval	0.33 meter
Gauge Length	Selectable 3, 7, 15, 31 meters
Maximum Pulse Rate	10 kHz
Dynamic Range	0.24 nε (over full bandwidth) 1.5pε (narrowband) Up to 1 με

<u>SureVIEW WIRE</u>

The SureVIEW WIRE structural integrity management system enables high-density strain monitoring of the wellbore and surrounding formation to detect, localize, and classify reservoir compaction, shearing, and integrity issues. The cable is deployed in the well along the outside of the casing, where it is cemented into place and brought online. Once online, data can be closely observed across the entire geological interface. An illustration of this technology is shown in Figure 5-16, and the technical specifications are provided in Table 5-13.

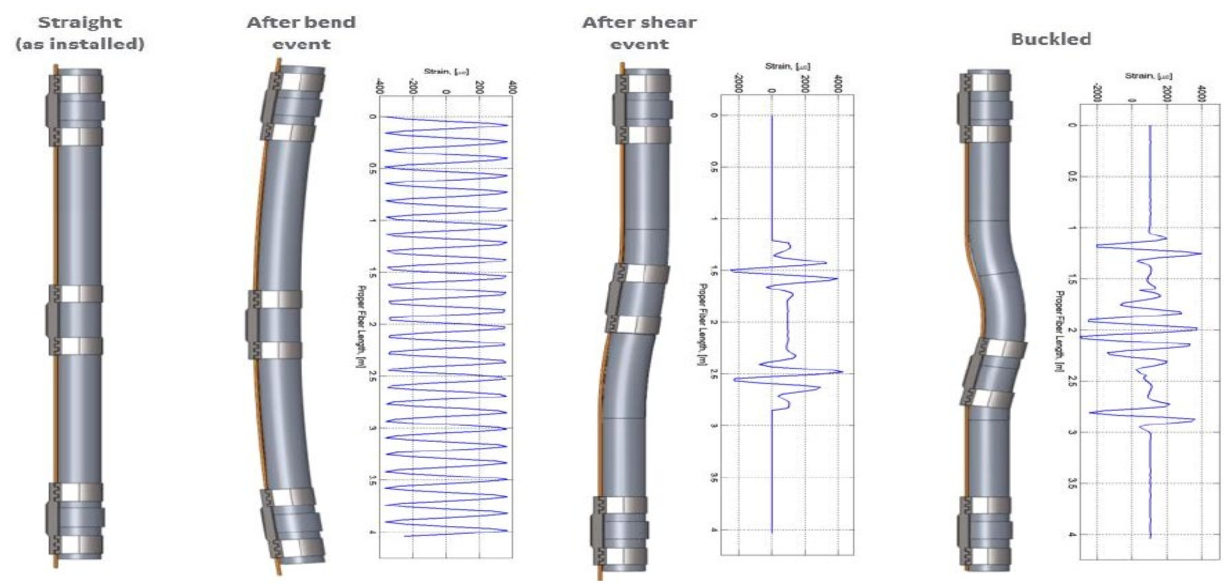

Figure 5-16 – SureVIEW WIRE Illustration

Table 5-13 – SureVIEW WIRE Cable Specifications

SureVIEW™ WIRE Cable	
Specifications	

Low Temperature Cable	• 1/4″ OD
	• 0.035″ Wall
	• Alloy 825
	• Specialty Bragg Grating Fibers
	  • One fiber configuration for Axial Strain Only
	  • Two fiber configuration for Axial and Curvature
	• 300m Max Sensor Length*
	• 120 Deg C Temperature Rating
	• 15,000 psi Pressure Rating

High Temperature	• 1/4″ OD
	• 0.035″ Wall
	• Alloy 825
	• Specialty Bragg Grating Fibers
	  • One fiber configuration for Axial Strain Only
	  • Two fiber configuration for Axial and Curvature
	• 300m Max Sensor Length*
	• 225 Deg C Temperature Rating
	• 15,000 psi 15,000 psi Pressure Rating

**may require multiple cables spliced to achieve desired length*

5.5.9.2.3 <u>Tubing Encapsulated Conductor</u>

TEC is a proven technology that the oil and gas industry has used reliably for more than 25 years. The TEC is installed to electrically support the Quartz Pressure/Temperature (QPT) Elite gauges and is designed for prolonged life in the most hostile downhole environments. The primary function of the TEC is to transmit electronic digital signals and power between subsurface components and a surface interface module used to conduct reservoir management. The Baker Hughes Company standard TEC product is a 0.25-in. OD tubing-armor cable, which includes an insulated 16-American wire gauge (awg) solid conductor. The armor is a metal-clad CRA tube that contains filler materials that centralize the core. An encapsulation material specially designed with safe removal components can be and is recommended to be extruded over the TEC, thereby adding a layer of protection to the metal sheath from abrasion while running downhole. Figure 5-17 illustrates the design of the TEC, and the technical specifications are listed in Tables 5-14 and 5-15.

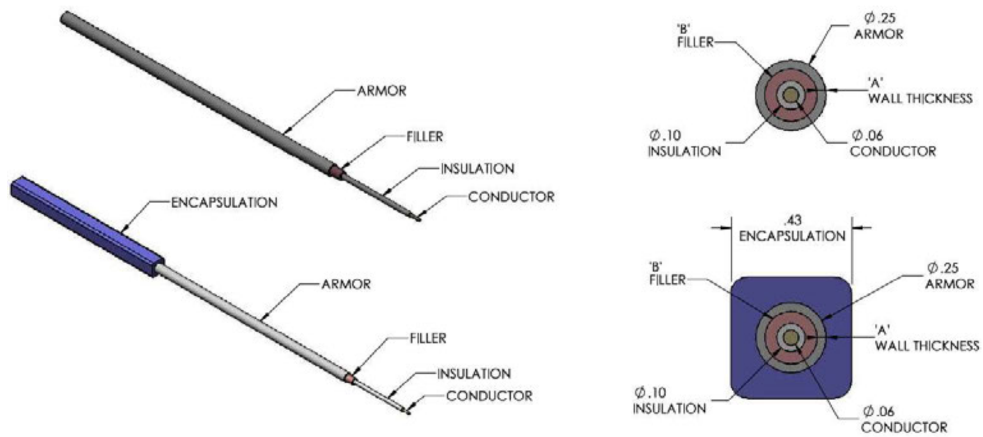

Figure 5-17 – TEC Illustration

Table 5-14 – TEC Specifications, Part I

Description	Value	
Size 0.035-in. Wall TEC		
Materials	316L stainless UNS S31603	Alloy 825 UNS N08825
Weight	198 kg/km (133 lb/1,000 ft)	199 kg/km (135 lb/1,000 ft)
Armor resistance at 20°C	51.2 Ohms/km (15.6 Ohms/1,000 ft)	73.9 Ohms/km (22.5 Ohms/1,000 ft)
Capacitance at 20°C	98 pF/m	
Collapse pressure rating (psi)*	30,000	

Table 5-15 – TEC Specifications, Part II

Wall (in.)	Alloy	Tensile (psi)				Yield (psi)			
		Minimum	Maximum	Average	STD	Minimum	Maximum	Average	STD
0.035	316L	122,000	178,000	153,000	6,800	100,000	158,000	125,000	8,200
0.049		141,000	154,000	145,000	5,100	113,000	130,000	119,000	6,400
0.035	A825	123,000	182,000	144,000	8,400	108,000	150,000	126,000	7,100
0.049		113,000	157,000	139,000	7,300	89,000	139,000	122,000	7,500

5.5.9.2.4 SureSENS Quartz Pressure Temperature Elite Gauge

The reliable, accurate SureSENS QPT Elite gauge (Figure 5-18) measures static and dynamic pressures and temperatures. The highly robust gauge ensures mechanical integrity by deep penetration and high-vacuum, electron-beam fusion welds without filling material. Only two fittings (the pressure port and the TEC) are required to interface the gauge with the carrier. The fittings can be externally tested in the direction that they will experience pressure, eliminating the need for an internal pressure test tool.

Figure 5-18 – SureSENS QPT Elite Gauge Illustration

5.5.9.2.5 QPT Elite Pressure Interface – Pressure Testable Manifold

The gauge-pressure interface connection to the carrier is through a pressure-testable manifold interface attached to the mandrel. Triple metal-seal rings are pressure tested to ensure integrity before deployment. The three metal seals provide redundant metal-to-metal sealing, tested in the same direction as the applied pressure in the final installation. This sealing provides a true, unique metal-to-metal design that is bidirectional and dual-testable. Figure 5-19 illustrates the design, and Table 5-16 lists the technical specifications.

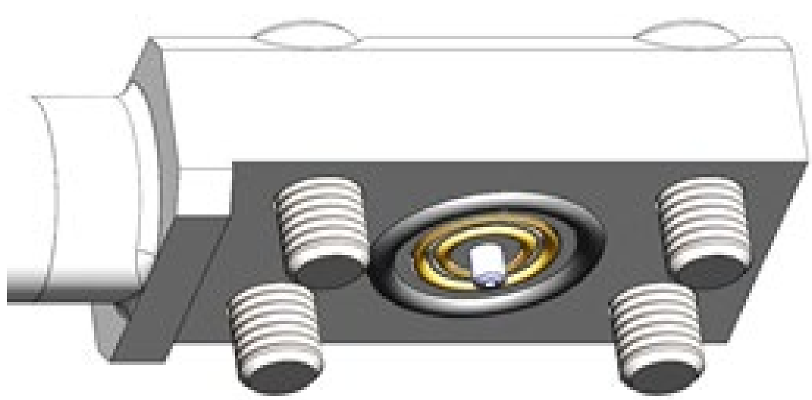

Figure 5-19 – External Sensor Illustration

Table 5-16 – QPT Elite Pressure Interface – Pressure Test Manifold Specifications

Length	25.5 in. to 26.5 in. (64.77 cm to 67.31 cm)					
Height/Width	0.750 in. (19.05 mm) / 1.318 in. to 2.50 in. (33.50 mm to 63.50 mm)					
Seals	Metallic seals and EB welds					
Transducer	Shear mode quartz					
Transducer options	10,000 psi (689.5 bar)	16,000 psi (1103.2 bar)	20,000 psi (1379.0 bar)	25,000 psi (1723.6 bar)	30,000 psi (2068.4 bar)	35,000 psi (2413.7 bar)
Material	Inconel 718	MP35N				
Pressure range	15 psi to 11,000 psi (1 bar to 758.4 bar)	15 psi to 18,000 psi (1 bar to 1241.1 bar)	15 psi to 23,000 psi (1 bar to 1620.3 bar)	15 psi to 28,000 psi (1 bar to 1930.5 bar)	15 psi to 33,000 psi (1 bar to 2275.3 bar)	15 psi to 37,500 psi (1 bar to 2585.5 bar)
Temperature rating (operating)	-99.4°F to 302°F (-73°C to 150°C)	-99.4 to 437°F (-73°C to 225°C)				
Storage temperature	-40°F to 302°F (-40°C to 150°C)					
Temperature shock	5.4°F (3°C) per minute					
Vibration	>10 G, 10 Hz-2 kHz					
Shock	500 G					
Pressure measurement range (calibrated)	200 psi to 10,000 psi (13.8 bar to 689.5 bar)	200 psi to 16,000 psi (13.8bar to 1103.2 bar)	200 psi to 20,000 psi (13.8 bar to 1379.0 bar)	200 psi to 25,000 psi (13.8 bar to 1723.6 bar)	200 psi to 30,000 psi (13.8 bar to 2068.4 bar)	200 psi to 35,000 psi (13.8 bar to 2413.7 bar)
Pressure accuracy	+-0.015% 1.5 psi at full scale	+-0.02% 3.2 psi at full scale	+-0.02% 4.0 psi at full scale	+-0.02% 5.0 psi at full scale	+-0.025% 7.5 psi at full scale	+ -0.03% 10.5 psi at full scale
Pressure resolution	0.0001 psi					
Pressure stability	0.02% full scale, 2.0 psi/year	+-0.02% full scale, 3.2 psi/year	+-0.02% full scale, 4.0 psi/year	+-0.02% full scale, 5.0 psi/year	+-0.02% full scale, 7.5 psi/year	+ -0.03% full scale, 10.5 psi/year
Temperature measurement range (calibrated)	77°F to 302°F (25°C to 150°C)	77°F to 437°F (25°C to 225°C)				
Temperature accuracy	0.27°F (0.15°C)					
Temperature resolution	0.0001°F					
Temperature stability	0.018°F (<0.01°C) per year					
Maximum sample rate/second	>16					
Number of gauges support/TEC	32					
Cable distance transmission	50,000 ft (15,240 m)					

5.5.9.2.6 SureSENS QPT Gauge Carriers

The carrier body is machined from a single bar stock without welding or heat-treating processes. The gauge assembly is installed into a recessed pocket in the carrier, protecting the gauge without needing a cover plate. The uphole end of the gauge is secured to the carrier by a clamp, which is fastened to the carrier by socket head screws. All tubular completion products are designed to meet or exceed the tubing/casing specifications supplied by the customer. All tubular products are also inspected and tested per American Petroleum Institute (API) 5CT requirements for drift and pressure.

5.5.9.2.7 Steel Blast Protectors

The blast protectors are installed above and below each zone over the fiber and TEC lines. The protectors have round steel bars that run the length of and are welded into the channel on both sides of the cables—to increase magnetic mass/signature for detection by the High-Resolution Vertilog (HRVRT) tool, to position the guns away from the cables (Figure 5-20).

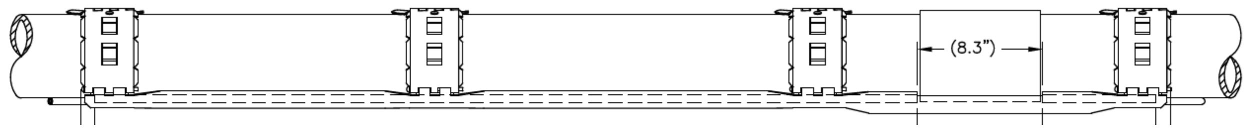

Figure 5-20 – Steel Blast Protector Illustration

5.5.9.2.8 Cross-Coupling Protectors

To protect the downhole cable, cross-coupling cable protectors are mounted at each tubing joint coupling to protect the cable transitions across the coupling. There is a potential for the downhole cable to be damaged because of abrasion or crushing between the tubing and casing internal wall during the installation process—thereby resulting in the loss of functionality of the associated downhole equipment.

5.5.10 VSP Monitoring Conclusion

The VSP method for quantifying carbon dioxide plume development over time has been demonstrated in several worldwide cases. Using offset petrophysical data, modeling results will generate a modeled differential in compressional velocity and density that will produce detectable changes in the reservoir where the connate fluid has been replaced by carbon dioxide. This information provides confidence that deploying the method in a time-lapse format will generate a time-lapse/4D image of the plume's extent and future development.

The fiber optic configuration installed in the IZM well, coupled with pressure and temperature monitoring, will be used in indirect pressure plume calculations and VSP—using a permanently installed optic sensor.

Most importantly, the need to drill additional artificial penetrations for monitoring purposes is reduced, because the VSP system plus direct plume calculations will allow for accurate monitoring of plume and pressure front migration. This monitoring reduces the risk of inadvertently forming a conduit from the confinement zones in the monitoring wells.

5.5.11 Seismic Monitoring

As discussed in *Section 1 – Site Characterization*, this area is seismically quiet. While the likelihood of a seismic event is low, BKVerde will install a seismic monitoring station on the Whites Bayou Sequestration Site property. BKVerde will also work with the Bureau of Economic Geology to tie this station into the TexNet Seismic Monitoring system. If a seismic event of 3.0 magnitude or greater is detected, BKVerde will review the Luz Solar No. 1 injection volumes and pressures to determine if any significant changes occurred that would indicate potential leakage.

5.6 Conclusion

The testing and monitoring plans developed for Luz Solar No. 1 and its associated monitoring wells are designed to acquire essential data to support static and dynamic reservoir modeling, track the growth of the CO_2 plume, and provide early detection to ensure that CO_2 does not reach a USDW or pose a risk to health, safety, or the environment. This plan includes monitoring strategies such as continuous monitoring of the injection stream composition, injection conditions, and reservoir conditions through permanently installed gauges. The interval above the UCZ will be monitored through pressure sensors and regular fluid sampling. The USDW will be monitored through sampling in dedicated wells. The plume extents will be assessed directly and indirectly. The reservoir pressures will be used in rate transient analysis calculations to determine the extent of the plume. The plume extent will also be tracked indirectly through VSP technologies.

5.7 References

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