Orchard Storage Company LLC

Underground Injection Control – Class VI Permit Application for

Orchard No. 1 to No. 7

Section 5 – Testing and Monitoring Plan

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SECTION 5 – TESTING AND MONITORING PLAN

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5.1 Introduction

The operating plans for the proposed Orchard Storage Company LLC (Orchard Storage) Orchard No. 1 through No. 7 injection wells include robust testing and monitoring programs, 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 program.

5.2 Reporting Requirements

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

Per-Occurrence Reporting:

- Any noncompliance with a permit condition or malfunction of the injection system that 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 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 ASAP after 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 ASAP after 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 on semi-annual report
- Description of any event that exceeds operating parameters for either annulus pressure or injection pressure, as specified in the permit
  - Verbal Notification – Reported within 24 hours of the event
  - Written Notification – Reported within ASAP after 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 ASAP after the event
- Any release of CO_2 into the atmosphere or biosphere
  - Verbal Notification – Reported within 24 hours of the event
  - Written Notification – Reported ASAP after 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, plus maximum and minimum values, of injection pressure, flow rate, temperature, volume, and annular pressure
- Description of any event that exceeds operating parameters for either annulus pressure or injection pressure, as specified in the permit
- Monthly volume and/or mass of the CO_2 stream injected over the reporting period, and the volume injected cumulatively over the life of the project
- Monthly volume of annulus fluid added
- Results of any monitoring as described in this section

Annual Reports:

- Any corrective action performed
- Recalculated area of review (AOR), or statement confirming that the monitoring and operational data supports the current delineation of the AOR on file with the Texas Railroad Commission (TRRC)
- Proof of good faith claim to sufficient property rights for the storage facility operation
- Tons of CO_2 injected

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 (MITs)

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

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

Orchard Storage will submit all reports, submittals, and notifications to the Environmental Protection Agency (EPA) and TRRC and ensure that all records are retained throughout the project's life. Per 16 TAC **§5.207(e)** [40 CFR **§146.91(f)**], these records will be maintained for 10 years after site closure—and, after the retention period, delivered to the UIC Director upon request. 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 also be retained for 10 years after site closure.

5.3 Testing Plan Review and Updates

Per 16 TAC **§5.207(a)(3)** [40 CFR **§146.90(j)**], the Testing and Monitoring Plan will be reviewed and revised, as necessary, at least every 5 years—to incorporate collected monitoring data. Plan amendments will also be submitted within 90 days 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. An amendment to the Testing and Monitoring Plan that has changed as a result of routine review (every 5 years) will be submitted to the UIC Director within one year as stipulated by 146.90(j)(1).

5.4 Testing Strategies

5.4.1 Openhole Logging

Orchard Storage plans to run an advanced suite of open-hole logs to obtain data for parameters used in static and dynamic subsurface modeling. The Baker Technology log descriptions provided below simply exemplify the types of logs to be run; the specific logging vendor will be selected just prior to drilling the well, as commercial and supply chain issues may affect the final vendor selection.

A list of planned open-hole logs is provided in Table 5-1.

Table 5-1 – Injection Well Open-Hole Logging Plan

Trip	Hole Section	Logging Suite	Target Data Acquisition	Open Hole Diameter	Depths of Survey
1	Surface Casing	Triple Combo (Gamma Ray (GR), Spontaneous Potential (SP), Photoelectric (PE), Resistivity, Neutron, Density)	Identification of Rock Properties	[redacted]	
2		Sonic (Dipole)			
3	Production Casing	Triple Combo (GR, SP, PE, Resistivity, Neutron, Density)	Identification of Rock Properties		
4		Sonic (Dipole)			
5		Fullbore Formation Microimager (FMI)			
6		Sidewall Cores			

Trip	Hole Section	Logging Suite	Target Data Acquisition	Open Hole Diameter	Depths of Survey
7		Repeat Formation Tester (R FT)/ Modular Formation Dynamics Tester (MDT)		[redacted]	
8		Spectral GR			

Baker Hughes Rockview™ Formation Lithology eXplorer (FLeX) – mineralogical characterization tool equipped with a pulsed neutron spectrometer. Allowing for a resolution of uncertainties compared to traditional petrophysical evaluation methods, this tool includes enhanced porosity determination, clay type/volume determination, and lithofacies identification.

Baker Hughes MR eXplorer (MReX) – 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 gives information on the porosity, pore size, and type of present fluid. Reliable data acquisition is available in almost every borehole environment.

Baker Hughes UltrasonicXplorer (UXPL) – borehole acoustic imaging service using a rotating acoustic transducer. This tool provides high-resolution feedback during drilling, completion, and production operations. It also documents stratigraphic features, unconformities, dip/strike, and borehole shape. The design allows for use in large-diameter boreholes and any mud type, and provides full 360° coverage.

Baker Hughes STAR-XR – high-resolution formation resistivity imaging in conductive mud systems. This tool carries 144 sensors downhole to measure geologic features, coupled with enhanced petrophysical reservoir evaluation. It identifies structural dips, depositional environments, borehole stability, and net pay in thinly bedded sequences. The STAR-XR is also applicable in the well-to-well correlation of sedimentary and stratigraphic information.

Baker Hughes XMAC F1 (XMAC-F1) – acoustic services using monopole and dipole measurements, building on the previous XMAC ELITE—able to log at twice the speed and measure shear slowness up to 1,200 microseconds per foot (μs/ft). The XMAC-F1 service provides (1) quality compressional and shear-wave measurements in both low-velocity and unconsolidated formations, (2) enhanced value and understanding of petrophysics, (3) reservoir characterization, and (4) rock mechanical properties.

5.4.2 Initial Step-Rate Injectivity Test

Before beginning CO_2 injection, Orchard Storage will conduct a step-rate injectivity test to attempt to measure the fracture gradient of the proposed Orchard No. 1 through No. 7 injection wells, 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 each wellbore, with the initial bottomhole pressure and temperature readings measured before injection. All gauges will be calibrated before testing. Initial bottomhole pressure and temperature reading will be taken before starting the injection test.

5.4.2.1 Testing Method

The step-rate test will be performed using brine/water. Brine/water 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 volumetric rate to a mass 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.

Specific wellbore and injection zone properties will define the final test parameters. The following test method outlines the expected test injection rates and times. The injection of brine will begin at 0.5 barrels per minute (bpm) and be held for a minimum of 30 minutes. The injection rates will be stepped up in increments until at least three measurements have been taken, both below and above the estimated formation-fracture initiation pressure, or to a maximum rate of 30% above the planned maximum injection rate, whichever occurs first. Each stage will require a hold duration of at least 30 minutes—or until the pressure has stabilized.

Table 5-2 – Proposed Step-rate Injection Test

Step	Duration (min)	Rate (bpd)	Rate (bph)	Rate (bpm)	Volume (bbl)
1	30	720	30	0.5	15
2	30	1,440	60	1.0	30
3	30	2,160	90	1.5	45
4	30	2,880	120	2.0	60
5	30	3,600	150	2.5	75
6	30	4,320	180	3.0	90
7	30	5,040	210	3.5	105
8	30	5,760	240	4.0	120
9	30	6,480	270	4.5	135
Total	30			5.0	675

A plot of the stabilized injection pressure and rates at each step will be developed. Table 5-3 shows an example of a step-rate test, and the resulting plot is shown in Figure 5-1. The plot should slope linearly unless the fracture initiation pressure is exceeded.

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

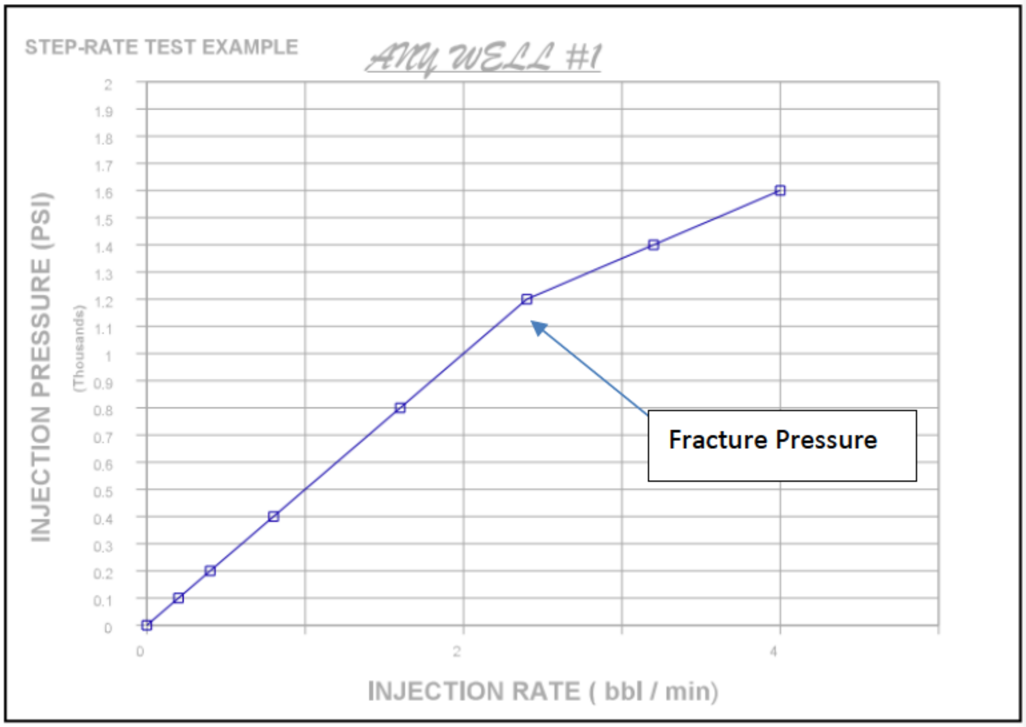

Figure 5-1 – Example of a Step-Rate Injectivity Test[1]

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 bleed-off.

5.4.3 Chemical Composition Confirmation Testing

In compliance with 16 TAC **§5.203(j)(2)(A)** [40 CFR **§146.90(a)**] requirements, Orchard Storage will sample the CO_2 injection stream and evaluate any potential interactions of carbon dioxide and other injectate components. CO_2 injection stream samples will be taken quarterly for chemical analysis of the parameters listed in Table 5-3, plus continuous pressure and temperature analysis.

5.4.3.1 Sampling Methods

Carbon dioxide stream samples will be collected from the CO_2 pipeline, in a location where injection conditions are representative. 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.

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

Table 5-4 – 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
Ethane (%)	Quarterly
Other Hydrocarbons (%)	Quarterly
Hydrogen Sulfide (ppm)	Quarterly
Benzene (%)	Quarterly

*MMscf – million standard cubic feet
ppm – parts per million

5.4.4 Mechanical Integrity Testing – Annulus Pressure Test

In accordance with 16 TAC **§5.203 (h)(1)(C)** [40 CFR **§146.89(b)**], Orchard Storage will demonstrate mechanical integrity by performing annular pressure tests when the wells are completed, before the start of injection, and after any workover operation involving the removal and replacement of the tubing and packer.

The annular pressure tests should demonstrate the mechanical integrity of the casing, tubing, and packer. These tests are 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 gauge will be the electronic pressure monitor connected to SCADA with a chart-style pressure recorder used for back-up to continuously monitor pressures.

Pressures will be continuously recorded while the annulus is isolated, until the pressure stabilizes, then the test pressures will be monitored and recorded for a minimum duration of 30 minutes during the test. 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 on Form H-5 within 30 days of completing the log run.

5.4.5 External Mechanical Integrity Testing – Temperature and Oxygen Activation Logs

In adherence to the requirements of 16 TAC **§5.203 (h)(1)(D)** [40 CFR **§146.89(c)**], Orchard Storage will perform an annual external MIT by deploying a temperature log and an oxygen activation log (OAL) through the tubing. Both 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 these 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 EPA/TRRC within 30 days of completing the log runs.

5.4.5.1 Temperature Log Procedure

When conducting a temperature survey via wireline, the tool will log from the surface to the total depth (TD) of the wells. No logging runs should precede the temperature log, to ensure static conditions in the wellbore. The recommended logging speed is 30 ft per minute, and all depths should be zeroed to the bradenhead flange. The following list highlights the general procedure for the wireline-temperature logging operation for the proposed injection wells:

1. Allow the well to stabilize for 36 hours.
2. Rig up the wireline unit to the wellhead and make up the logging tool (temperature probe and casing collar locator (CCL)).
3. Zero the end of the tool string at the bradenhead flange.
4. Run in the hole while logging from surface to TD at 30 ft per minute. Correlate collar depths to the CCL.
5. Pull out of hole and rig down wireline unit.

5.4.5.2 Oxygen Activation Log Procedure

1. Rig up the wireline unit to the wellhead and make up the logging tool and casing collar locator (CCL)).
2. Conduct a baseline GR log and casing collar locator log from the top of the injection zone to the surface to establish the contribution of naturally occurring background radiation.
3. Stationary readings will be taken while injecting fluid at the normal rate, maintaining constant rate and pressure.
4. Prior to taking the stationary reading, the OAL will be calibrated in a section with no vertical flow behind casing to ensure accurate, repeatable tool response and for measuring background counts.
5. Stationary readings will be taken for at least 15 minutes for each reading at:
    - At the base of the UCZ, at least 10 feet above the top of the injection interval so that turbulence does not affect the readings.
    - At the top of the UCZ
    - Midway between the base of the lowest USDW and the UCZ
    - At the base of the lowest USDW

6. If flow is indicated by the OAL at a location, move uphole or downhole as necessary at no more than 50 ft intervals and take stationary readings to determine the area of fluid migration.
7. Pull out of hole and rig down wireline unit.

5.4.6 Pressure Falloff Testing

Orchard Storage will perform an initial pressure falloff test upon completion of the wells, prior to operation, in accordance with 16 TAC **§5.203 (f)(2)(B)** [40 CFR **§146.87(e)**]. Orchard Storage will then perform a required pressure falloff test every 5 years per 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.

5.4.6.1 Testing Method

Injection rates and pressures will be held as constant as is practical prior to the test. Pressure and rate data will be recorded continuously before and during the falloff period. Pressure gauges to supplement the permanent gauges will be run into the well, if needed, several days prior to initiation of the falloff test—to allow for a period of stable injection prior to shut-in. The length of time for stabilization prior to shut-in will be determined in advance, using pressure-transient well-test design methods that incorporate anticipated rates and formation properties.

Ideally, the falloff test will be run sufficiently long to allow identification and analysis of the Infinite Acting Flow Regime (IARF). Given the heterogeneous nature of the injection interval, it may not be possible to identify this IARF through simple, semi-log straight-line plots. Specialized software for analytical modeling of the pressure-transient response (e.g., Kappa Engineering's "Saphir") will be used to analyze the pressure and pressure-derivative response, to ensure that the test is run sufficiently long to obtain data that includes the IARF effects.

5.4.6.2 Analytical Methods

Mechanical integrity will be determined through standard diagnostic plotting. This determination is accomplished via analysis of 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 rate and pressure data of the injection wells. The additional data may include operational history, offset wells' injection and operational history, and distributed temperature sensing (DTS) sensor data from the injection wells being tested. Depending on the complexity of the pressure response, it may be necessary to incorporate numerical modeling into the interpretation workflow.

Comparing pressure falloff tests can expose significant changes in the wells or reservoir conditions before initial injection with later tests. The effects of the fluid flow as well as the injected fluid's compressibility 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/Control

All field equipment will undergo inspection and testing before operation. Manufacturer calibration recommendations will be adhered to during the pressure gauge use in the falloff test. Documentation certifying proper calibration will also be enclosed with the test results. Further validation of the test results will be recorded using a second bottomhole pressure gauge.

5.4.7 Injection Conformance Monitoring

The Orchard No. 1 through No. 7 injection wells will have seismic distributed acoustic sensing (sDAS) fiber optic cable permanently installed, providing the ability to monitor injection conformance in the wells, in near-real time. Orchard No. 1 through No. 7 will be perforated over [redacted]. The sDAS system will allow discreet temperature monitoring across the perforated interval. The temperature measurement will be used to evaluate relative injection volumes across the open interval and will alert to changes in injection rate at specific perforated intervals. If the rate changes at a specific set of perforations, this data can be used, along with other pressure and rate information, to gain valuable insight into injection conformance. The use of this data will allow changes to operating or completion parameters as necessary for storage-zone management purposes.

Per 16 TAC **§5.206 (d)(2)(F)(i)** [40 CFR **§146.88(e)(2)**], automatic shut-off systems and alarms will be installed to alert the operator and shut in the well when operating parameters such as annulus pressure, injection rate, etc., diverge from permitted ranges or gradients.

5.4.8 Cement Evaluation and Casing Inspection Logs

Per 16 TAC **§5.203 (h)(2)** [40 CFR **§146.89(d)**], a comprehensive cased-hole logging suite will be run on the production casing strings at the time of initial well completion. This suite of logs will include a radial cement investigation, a multi-arm caliper, and a digital log, to establish the condition of the casing metal. These surveys will characterize the original state of the wellbore materials. Conventional casing inspection logs will be run prior to tubing installation. Following the tubing and packer installation, initial through-tubing inspection logs will be run. This survey will serve as the baseline for future casing-inspection efforts.

Casing inspection logs will be performed every 5 years using a combination of conventional casing inspection logs and through-tubing surveys. The tools to be run at that time are detailed as follows.

- The 5-year casing inspection involves specific tools below *and* above the packer:
  - Casing section *below the packer*:
    - Multiple-armed calipers to measure the inner diameter (ID) 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 the cement bonding
    - Electromagnetic tools that measure the magnetic flux of the tubular and can

provide mapped circumferential images to indicate potential pitting

- 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:
    - Multiple-armed calipers to measure the ID 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 the cement bonding
    - Electromagnetic tools that measure the magnetic flux of the tubular and can provide mapped circumferential images to indicate potential pitting

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

5.4.8.1 Casing Log Equipment Overview

Through-tubing logging technology provides the ability to evaluate casing deformation and eccentricity 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 prior to operations based on availability and commercial considerations.

The GOWell instruments listed in Table 5-4 utilize 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 logs—such as multi-finger imaging caliper, temperature, noise, pressure, fluid density, capacitance, flowmeter, gamma ray, and casing collar locator.

GOWell PEC decay measurements are not affected by wellbore fluid type, 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 5-5 – 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

Technical specification documents are included in *Appendix E-2*. 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.

GOWell 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 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 with the assumption 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. Due to well-understood and long-established physics principles of PEC decay, reported metal gain or loss is assumed to be distributed evenly around the pipe's circumference.

The GOWell PEC decay instruments' measure of the increase or decrease of metal thickness includes both internal and external corrosion effects. This overall metal thickness/degree of penetration is valid in identifying areas of well integrity concern. Additionally, integrity assessment of the production 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 GOWell PEC decay instruments provide an opportunity to assess the state of the protection tubulars (i.e., second casing, surface casing, etc.). Protection string(s) data is acquired simultaneously with the tubing and production string data.

5.4.9 Logging and Testing Reporting

A report that includes log and test results obtained during the drilling and construction of Orchard No. 1 through No. 7, and interpreted by a knowledgeable log analyst, will be submitted to the UIC Director as per 16 TAC **5.203 (h)(2)** [40 CFR **§146.87(a)**].

5.5 Monitoring Programs

5.5.1 Continuous Injection Stream Monitoring

Orchard Storage 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 Project Orchard Site to facilitate the operational data collection, monitoring, and reporting. Per 16 TAC ***§*****5.206 (d)(2)(B)**, the total volume of CO_2 injected into the Orchard Project facility will be metered through either a master meter or a series of master meters. The volume or mass of CO_2 injected into Orchard No. 1 through No. 7 will be metered through individual well meters.

Continuous monitoring of the injected CO_2 stream pressure and temperature will be performed using digital pressure gauges installed in the CO_2 flowline, near the flowline-wellhead interface. The on-site SCADA system will be connected to the flowline. A flowmeter will also be installed on each of the injection wells and connected to the SCADA system at the CO_2 storage site, to ensure continuous monitoring and control of the CO_2 injection rate.

The wellhead will accommodate continuous annular pressure measurement and injection pressure measurement.

Downhole measurement will be accomplished using fiber-optic-based sDAS and DTS sensors. Additionally, a tubing encapsulated conductor (TEC) will power and communicate with permanently installed pressure gauges. This equipment will be run with the casing and cemented in the annulus behind the long-string casing. The vertical seismic profile (VSP) technology and downhole sensing discussion in *Section 5.5.7* describes the systems in detail.

Figure 5-2 provides an illustration of the control and monitoring systems to be installed at Orchard No. 1 through No. 7.

[redacted]

Figure 5-2 – Typical Injection Well and Injection Skid Flow Schematic

5.5.1.1 Analytical Methods

Orchard Storage will review and interpret continuously monitored parameters to validate that they are within permitted limits. The data review will include trends, to help determine any need for equipment maintenance or calibration. These data reports will be submitted semiannually.

5.5.2 Corrosion Coupon Monitoring

Orchard Storage will monitor for corrosion of the well tubing and casing materials per the 16 TAC ***§*5.203 (j)(2)(C)** [40 CFR ***§*146.90(c)**] requirements, employing a corrosion coupon monitoring system for this evaluation. Additionally, the casing inspection logs to be run every 5 years will provide information regarding corrosion of the tubulars.

5.5.2.1 Sampling Methods

Corrosion coupons, comprised of the same material as the injection flowline, tubing, and production casing, will be placed in the CO_2 injection flowline. These coupons will be removed quarterly and examined for corrosion per 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 of that period.

5.5.3 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 influenced by a wide range of natural process and human activities. As with any of these types of monitoring, establishing a baseline condition is very important. Orchard Storage intends to install soil gas monitoring stations at least 1 year prior to injection, to better understand baseline and background conditions through multiple seasons. Soil gas monitoring implants will be installed adjacent to the pad site of each injection well in an undisturbed location. Ideally, the location of the stations will be selected to minimize the agricultural impacts of plowing, planting, irrigation, and harvesting. Best industry practices have shown that fixed soil-gas profile stations provide the most accurate data. Orchard anticipates utilizing Geoprobe™ permanent soil gas implant systems.

To establish a statistically relevant base of soil gas readings, Orchard intends to sample each of the permanent sampling points a minimum of eight times per year and no more than twelve times per year. As sampling continues, the sampling frequency may be adjusted to meet actual observed conditions. Sampling will be conducted utilizing vacuum canister type samplers. The quantity of samples to be collected will be optimized based on observed soil diffusion rates to avoid unrepresentative samples. Samples will be collected and sent to a third-party lab for analysis. Quality assurance and traceability methods will be used to ensure proper handling of samples and lab techniques.

5.5.4 Groundwater Quality Monitoring

To meet 16 TAC **§5.203 (j)(2)(C)** [40 CFR **§146.90(d)**] requirements, groundwater quality and geomechanical monitoring will be conducted above the confining zone to detect potential changes that could result from fluid leakage from the injection zone. Orchard Storage plans to drill five groundwater monitoring wells across the Orchard Project area. 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 5-3). The groundwater monitoring wells will be drilled at least six months ahead of drilling injection wells to allow for effective baseline testing of the groundwater properties. Orchard will acquire open hole logs in the form of gamma ray, resistivity and porosity measurements during the drilling of these monitoring wells. Following the baseline efforts, sampling will occur quarterly. The parameters to be measured are provided in Table 5-6. Details regarding these parameters are provided in the Quality Assurance and Surveillance (QASP) plan, Section 6.2.1, Table 17.

Table 5-6 – Groundwater Quality Parameters Measured and Measurement Frequency

Parameter/Analyte	Frequency
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

[redacted]

Figure 5-3 – Location of Groundwater, In-Zone and Above-Zone Monitoring Wells

5.5.4.1 Sampling Methods

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 prior to collecting a representative sample at the surface.

5.5.4.2 Analytical Methods

Orchard Storage will test water samples and maintain results for the parameters that were listed in Table 5-4. If the CO_2 injectate contains unique impurities, then groundwater samples will also be tested to flag any concentrations of these impurities exceeding the baseline. Testing results will be stored in an electronic database.

Potential signs that fluid may be leaking from the injection interval(s) in the form of CO_2 or brine 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. “Significant” changes for specific constituents will be established once the baseline values are obtained and analyzed. Specific variability of individual parameters is best established after the baseline data (pre-injection) is obtained and analyzed to account for natural variations in the parameters. Orchard will establish effective percentage change deviations from “normal” readings to alarm and take action to recognize and mitigate potential CO_2 or brine leaks into groundwater. Care will be taken when establishing these limits to reduce the number of false positives that may occur. Examples for a change requiring action include a sudden TDS value greater than 20% over the baseline value or a pH reduction of greater than 20%. All these values will be taken in context with pressure readings within the aquifer, the above zone monitoring interval and location relative to the CO_2 plume and injection zone pressure front.

The relative benefit of each analytical measurement will be evaluated throughout the project life to identify the analytes that provide the most benefit to the overall monitoring objectives related to the groundwater monitoring. Any suggested modifications to monitoring plan will be made in consultation with the appropriate UIC regulator.

5.5.4.3 Laboratory to Be Used/Chain of Custody Procedures

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

5.5.4.4 Quality Assurance and Surveillance Measures

Orchard Storage will collect duplicate samples and trip blanks for quality assurance/quality control (QA/QC) purposes. These duplicate samples will validate test results and ensure that samples have not been contaminated.

5.5.4.5 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, ensuring access to the well locations for sampling and maintenance purposes. Unauthorized access will be prevented by capping and locking out the well.

5.5.5 Monitoring Wells

Two above-zone monitoring wells, Orchard MW No. 1 and MW No. 3, will be drilled and completed on the Orchard Storage property, as shown previously in Figure 5-3. These wells will continuously monitor the pressure of the first mappable sand [redacted] identified above the upper confining interval Orchard storage plans to drill these wells in the same drilling campaign as the injection wells. The monitor wells will be logged, one will be cored, and both will be tested utilizing open hole sampling tools (RFT/MDT) to acquire representative fluid samples. The native state logs and fluid samples will be used as baseline data to compare to ongoing injection operations testing. Baseline fluid testing will include TDS, pH, and hydrochemistry, as shown in Table 5-7. Details regarding these parameters are provided in the QASP plan, Section 6.2.1, Table 17.

Table 5-7 – Reservoir Fluid Parameters Measured and Measurement Frequency

Parameter/Analyte	Frequency
Total dissolved solids (TDS)	Baseline
pH	Baseline
Specific conductivity (SC)	Baseline
Temperature	Baseline
Density	Baseline
Other parameters including major anions and cations, trace metals, hydrocarbons, and volatile organic compounds	Baseline

Pressures will also be taken to establish a baseline pressure for the above zone interval. Any significant deviations (+/- 20%) from baseline pressures or temperature will initiate additional investigations in the area. This additional investigation may include fluid sampling for comparison to the baseline using through tubing sample jars, if needed.

The Orchard MW No. 2 well is an existing wellbore that will be utilized as an in-zone monitoring well. Orchard MW No. 2 will be equipped with permanent downhole gauges to continuously monitor pressures [redacted] interval.

5.5.6 Seismic Monitoring

As discussed in *Section 1 – Site Characterization*, this area is seismically quiet. The Bureau of Economic Geology in Texas maintains a seismic monitoring system known as TexNet. The closest monitoring station to the Orchard Project [redacted] Orchard Storage will review the TexNet website regularly for any seismic activity in or around the facility area. If an event greater than 2.5 is detected, Orchard Storage will compare it with the injection history and publicly available data from nearby oil and gas activity to determine if a correlation to injection activity can be determined.

[redacted]

Figure 5-4 – Nearest TexNet Seismic Monitoring Station (red star indicating approximate location of the Orchard Project).

5.5.7 Injection Plume Monitoring

Orchard Storage will use both direct and indirect methods to track the CO_2 plume and the pressure front tracking, in accordance with 16 TAC **§5.203 (j)(2)(E)** [40 CFR **§146.90(g)**]. The critical pressure front will be directly monitored by using continuously recorded 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 vertical seismic profiling (VSP).

Orchard Storage 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 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 prior to injection initiation to establish a baseline, periodically as needed, and every 5 years at a minimum. These results will be submitted to the UIC Director as part of the semi-annual reports for this facility.

5.5.7.1 Direct Monitoring: Rate Transient Analysis

Rate transient analysis, in conjunction with reservoir simulations using known reservoir characteristics, will allow for calculating more complex parameters within the injection interval. 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.

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 updated with injection activity regularly, to evaluate the injection stream's effect 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.

Additionally, any shut-in periods can be observed and treated as a pressure falloff test. To do this, 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, Orchard Storage can closely monitor the effect of the injection wells on the subsurface, to help ensure regulatory compliance and safety while contributing to informed decision-making.

5.5.7.2 Indirect Monitoring: Vertical Seismic Profile

Orchard Storage 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 sDAS/DTS will be installed and cemented in the annulus behind the long-string casing. This system will enable real-time reservoir monitoring using pressure and temperature gauges and the periodic VSP. The sDAS/DTS fiber optic cable, designed with sensors spaced one meter apart, will be used to generate a VSP at the highest possible resolution. Three-dimensional models of the CO_2 plume can be created using a walk-away seismic source. The data is captured by monitoring the injection well and repositioning the surface acoustic source. Vibrator trucks will be utilized as the acoustic source, and locations will be determined based on well location and conditions.

As an example of where this technology has been proven, Shell Canada used it for plume movement monitoring at its Quest Project (Bacci, O'Brien, Frank, and Anderson, 2017). Figure 5-5 illustrates the acquisition pattern strategy employed for plume development surveys from two separate wells.

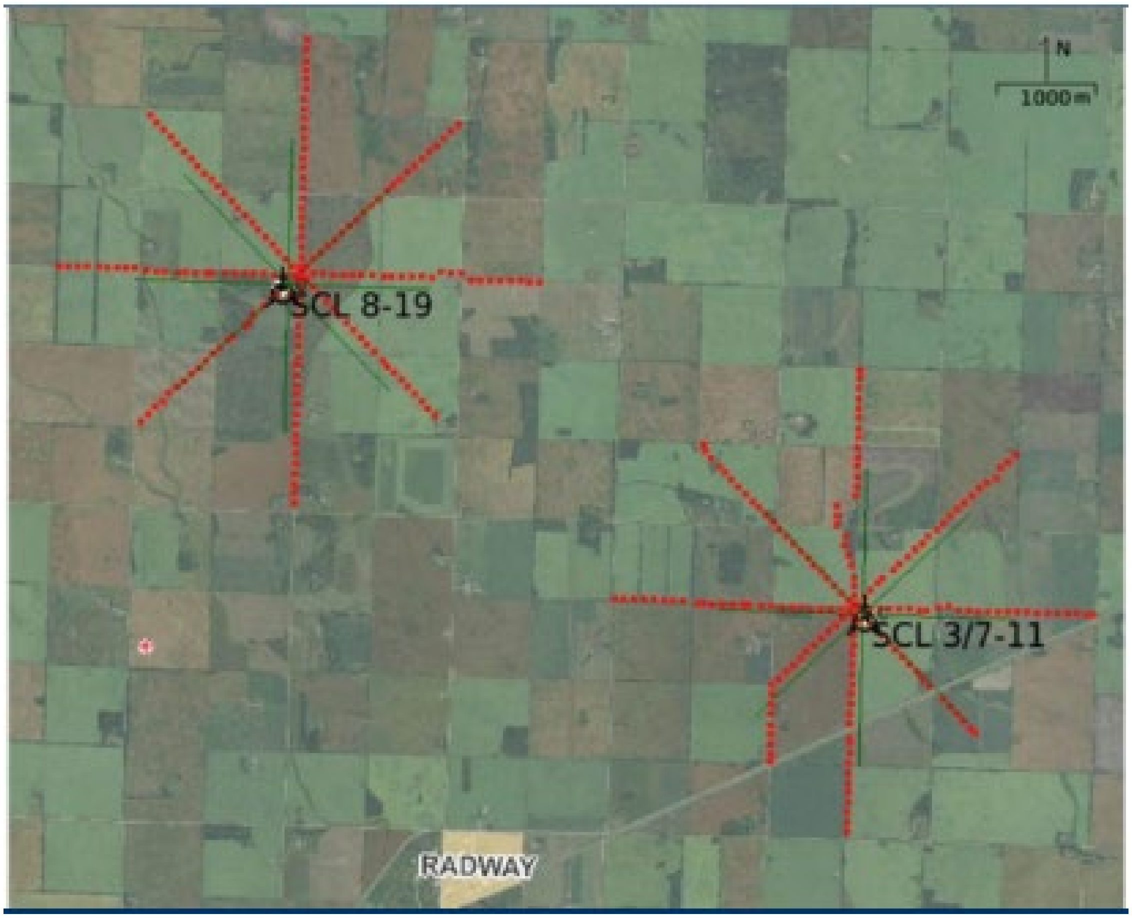

Figure 5-5 – Shell Canada Quest Project VSP Acquisition Patterns

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 therefore 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

5.5.7.3 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 a high degree of 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 whether 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

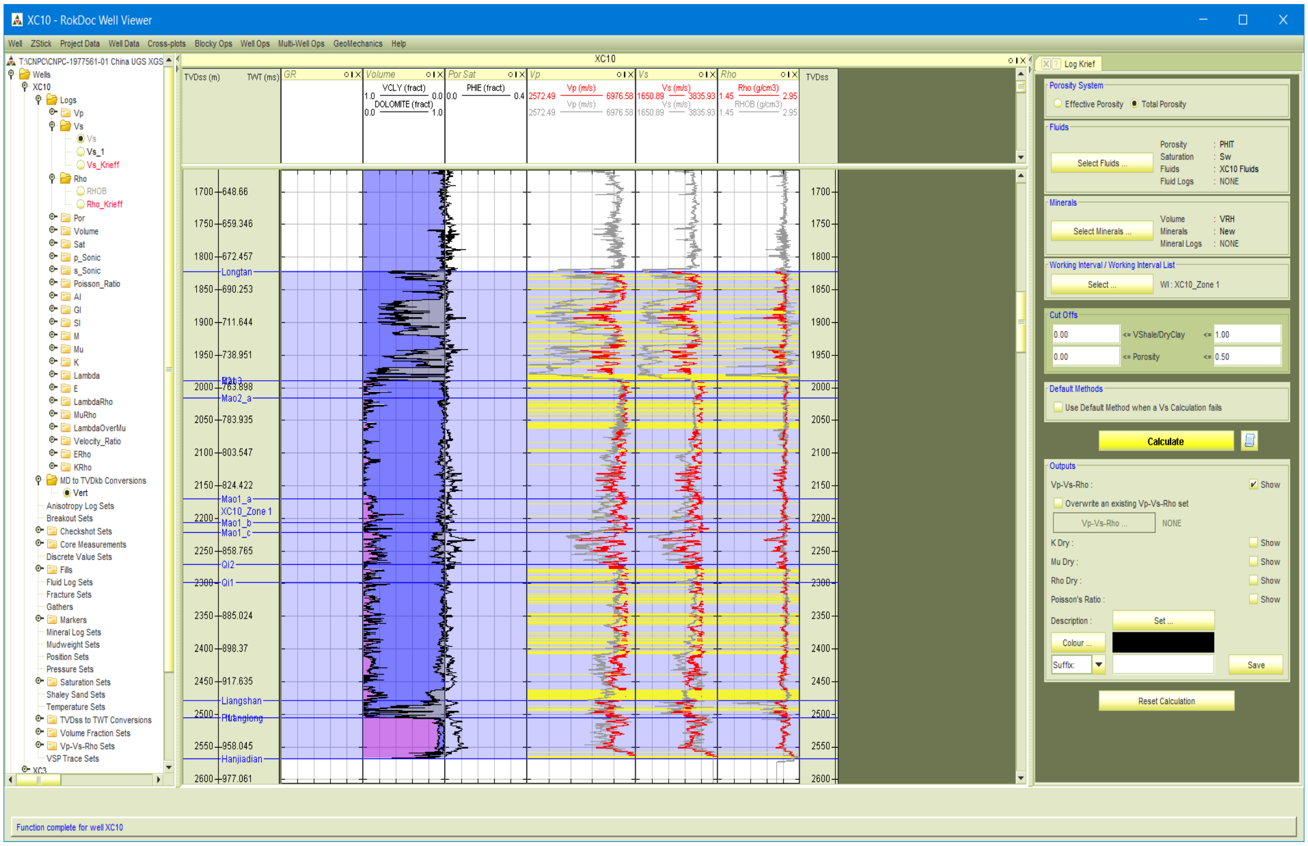

Figure 5-6 – RocDoc Well Viewer

The RocDoc Well Viewer (Figure 5-6), 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 the stabilization of inverted results, evaluation of uncertainty in predicted attributes, and calculation of in situ reservoir properties.

5.5.7.4 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 5-7 illustrates the combination of the rock physics model (shown in red) and the petro-elastic model at 52% water saturation (in 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.

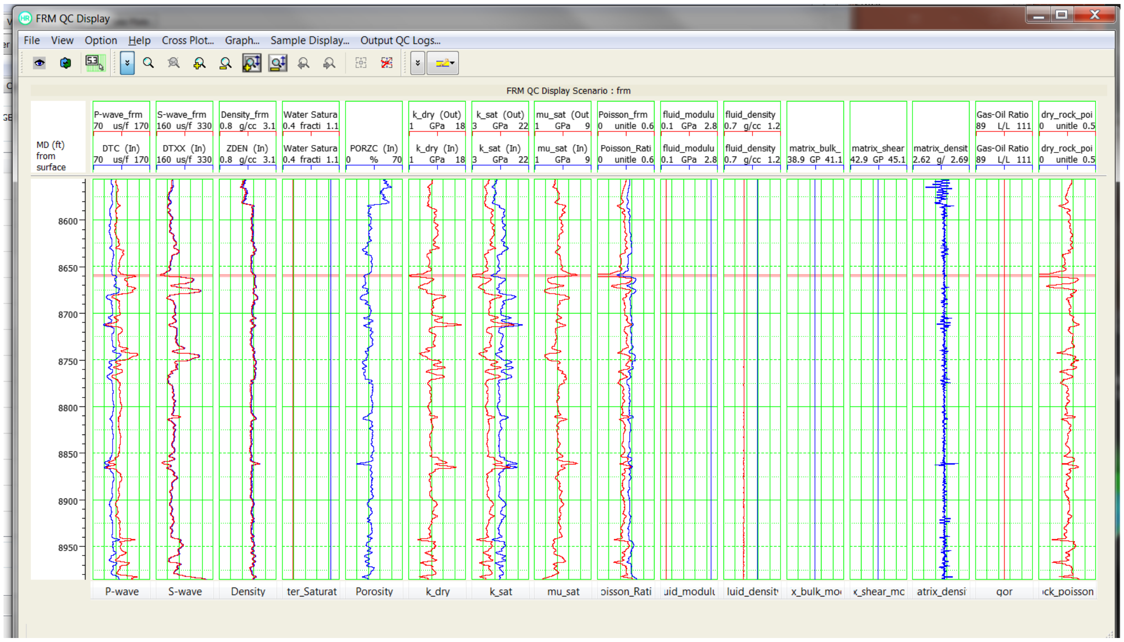

Figure 5-7 – Application of Petro-Elastic Model to Rock Physics Model

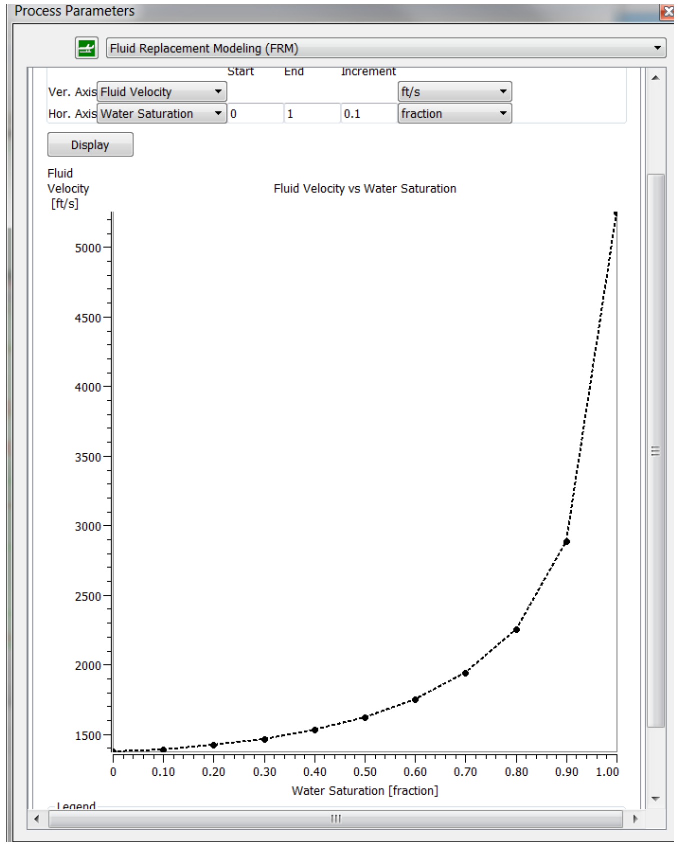

Figure 5-8 – Petro-Elastic Model Predictions of Velocity and Density as a Function of Saturation

Predicting velocity and density as functions of injectate saturation is the final result of the petro-elastic model (Figure 5-8). The seismic response measured during VSP surveys can be determined using the acoustic impedance calculated from both elastic properties.

A feasibility study will be designed to determine if connate fluids replaced with CO_2 could be detected by the petro-elastic model. This 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 injection wells for this project.

5.5.7.5 1D and 2D Models

Changes in the magnitude of the CO_2 plume are measured for different scenarios using 1D and 2D models. This section details 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 5-9 depicts a standard VSP survey with a geophone configuration.

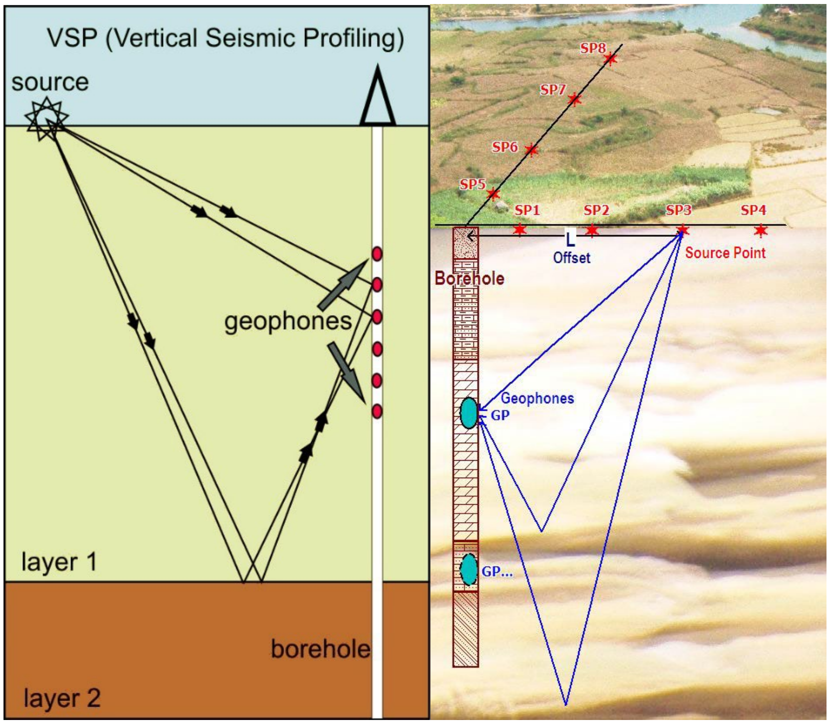

Figure 5-9 – Illustration of a Vertical Seismic Profile Survey

5.5.7.6 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 5-10. Geophones are situated vertically along the wellbore while all shots are fired from the surface. This allows them 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 are commonly used to generate more accurate VSP, 2D, 3D, and 4D surveys.

The 1D survey methodology assumes that each formation is homogeneous in the horizontal direction, so 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.

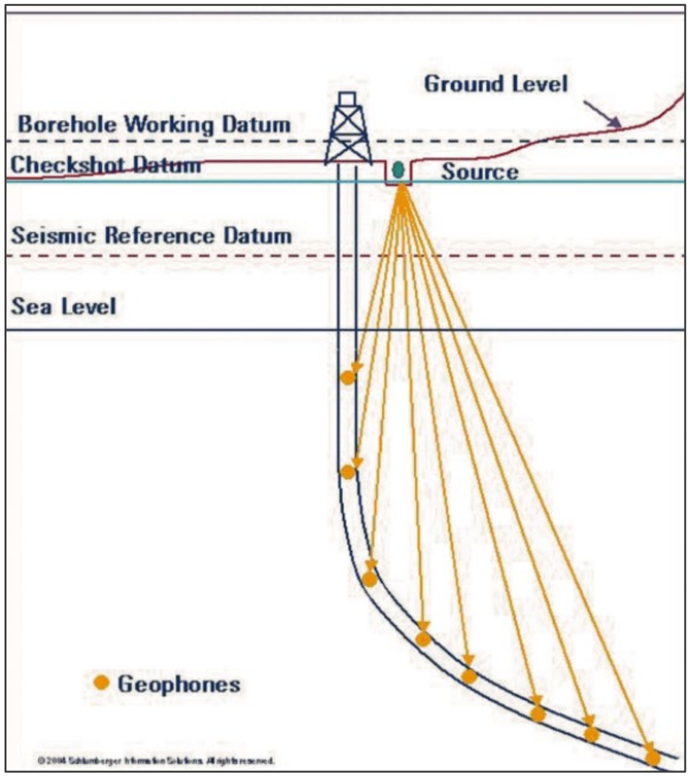

Figure 5-10 – Illustration of a Checkshot Survey

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

5.5.7.7 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; 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 earth's crust. 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 located 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 of an environmental impact than 3D surveys. They are commonly used to explore new areas and allow geologists to visualize the formations lying beneath the surface.

5.5.7.8 Processing Workflow and 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 that have been 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 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 5-11 illustrates a basic workflow example:

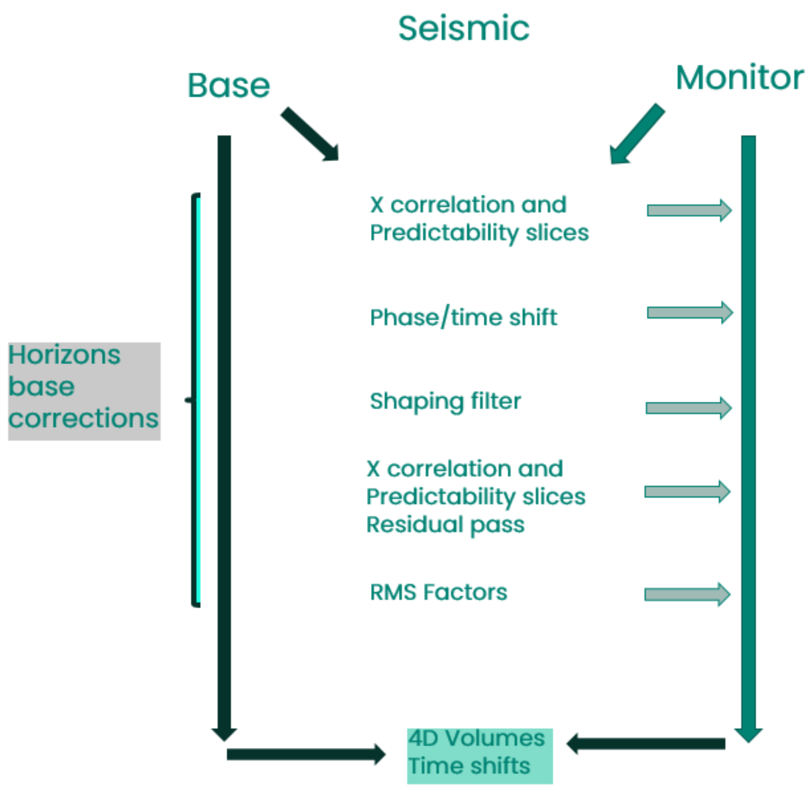

Figure 5-11 – Time-Lapse/4D Processing Workflow Diagram

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 below. Figure 5-12 presents a 4D time-lapse 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 Orchard Storage's VSP surveys at the Orchard Project site.

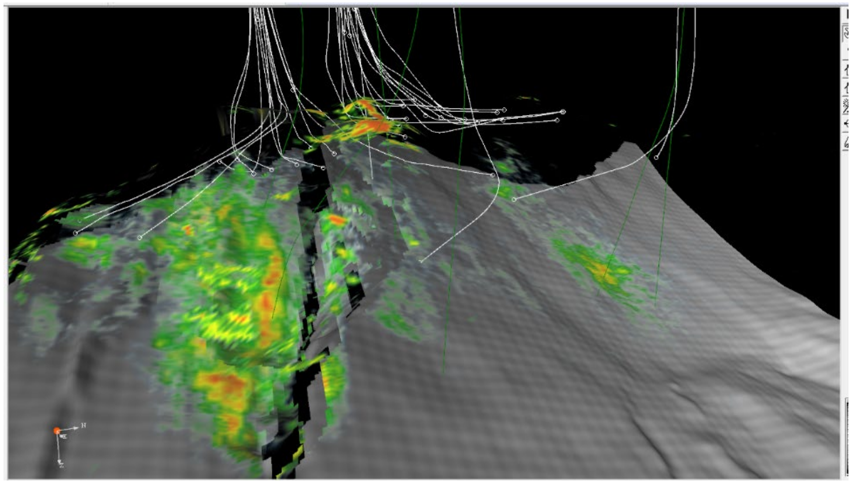

Figure 5-12 – Example of Time-Lapse/4D Model (showing time-lapsed gas-replacement of connate fluids)

5.5.7.9 <u>Inversion Workflow</u>

Log data, post-stack seismic volumes, and a structural model will be used to invert baseline surveys, as Figure 5-13 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.

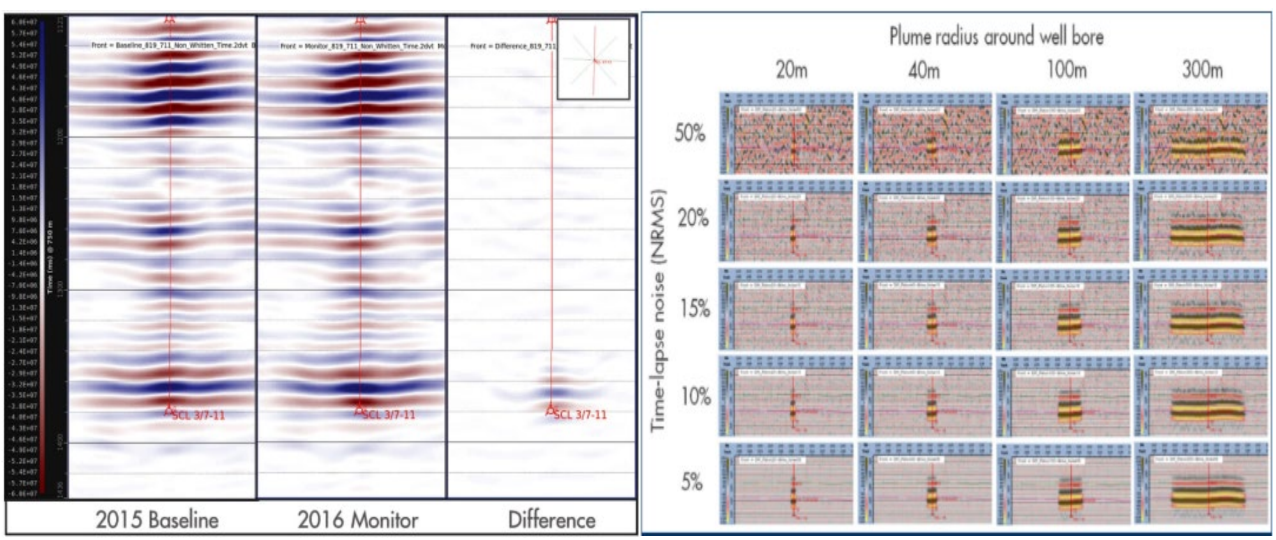

Figure 5-13 – Baseline and subsequent VSP used to determine difference in amplitude attributed to CO_2 injection measured from the injector well itself. At right is the estimation of the plume growth over time.

5.5.7.10 <u>Baseline Survey</u>

Conducting a quality VSP baseline survey is of critical importance, as it is the only opportunity to capture an image of the reservoir before injection operations or offset activity—natural or man-made—impact it. Without this, 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, in the event that the initial reservoir models are not accurately forecasting plume migration.

5.5.7.11 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 an sDAS fiber optic cable—to be installed in the Orchard No. 1 through No. 7 wells and connected to an interrogator box at the surface. The sDAS system is synchronized to the seismic acquisition system controlling both the receiver (the sDAS fiber-optic array cemented in the injection well) and the source (seismic vibrator trucks).

5.5.7.12 Wellbore Overview

[redacted]

Fiber optic cable will be installed on the [redacted] casing string along its outer diameter (OD). This cable will consist of DTS/sDAS/Well Integrity Real-time Evaluation (WIRE) equipment. The DTS fiber will rapidly detect temperature profiles near the production casing and verify cement circulation during the cement job. The CO_2 plume growth will be monitored through repeated VSP seismic processing using the sDAS fiber (as described previously). High-density strain monitoring of the wellbore and surrounding formation is performed using the WIRE-fiber monitoring system to detect, localize, and classify reservoir compaction, shearing, and integrity instances. Approximately [redacted] TEC with pressure and temperature gauges will be installed on the OD of the [redacted] casing, which will be ported to read the pressure inside of the production casing. The tubing gauge will allow for continuous bottomhole pressure and temperature monitoring during injection, throughout the project life, so long as cement does not squeeze off the injector perforations during plugging operations.

Protective casing clamps will be installed on each casing joint collar to ensure the cable has been securely run to depth. Orchard Storage will install blast protectors on each joint 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.

5.5.7.13 Equipment Overview

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

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 that minimizes hydrogen darkening, combined with a layer of hydrogen-absorbing gel. Figure 5-14 illustrates the optical fiber, and Table 5-6 provides the specifications.

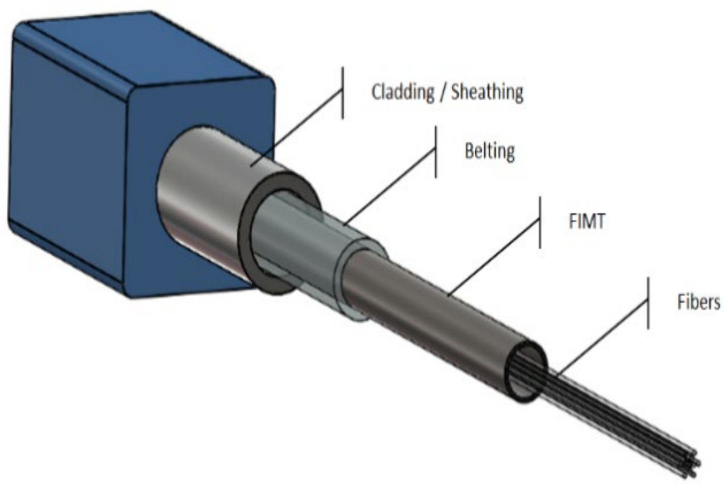

Figure 5-14 – SureVIEW with CoreBright Optical Fiber

Table 5-8 – SureVIEW Downhole Specifications

Description	Specifications
Maximum Pressure	25,000 psi
Overpressure	1.2x maximum pressure
Operating Temperature	• 150°C / 302°F for standard • 250°C / 482°F for high temperature • Higher temperature solutions available upon request
Sheath Material	A825, 316LSS
Crush	>5,000lbf
Fibers	Maximum of 12, any combination of SM and MM
Fiber Protection	• Standard Temperature: Hydrogen-scavenging gel, carbon coating, acrylate buffer • High Temperature: High-temperature stabilized gel, polyimide buffer, optional carbon coating
Dimensions	0.25 inch outside diameter (excluding encapsulation)

<u>SureVIEW DTS</u>

The SureVIEW DTS interrogator provides continuous monitoring, rapidly updating temperature profiles along the length of the completions. Its specifications are listed in Table 5-7.

Table 5-9 – SureVIEW DTS Specifications

Description	Value
Form Factor	19 in. Rack
Height	2U
Depth (in.)	19.8
Certifications	TUV (US, Can), CE
Public Software Interfaces	OPC/UA, Modbus
Maximum Distance Range (km)	20+
Minimum Spatial Resolution (m)	1.0
Minimum Sampling Interval (m)	0.33
Fastest Acquisition Rate (sec)	3.3
Number of Channels	8 or 16
Internal Data Storage Capability	250 GB
Fiber Types	9/125 µm SMF CoreBright™
Optical Connectors	Fiber Pigtails
Computer Interfaces	Ethernet, DPI, USB
Power Consumption (W)	100 W maximum

SureVIEW sDAS

The SureVIEW sDAS 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 5-8).

Table 5-10 – 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	0ºC to +40ºC / 32ºF to +104ºF
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

SureVIEW WIRE

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 5-15 and the technical specifications are provided in Table 5-9.

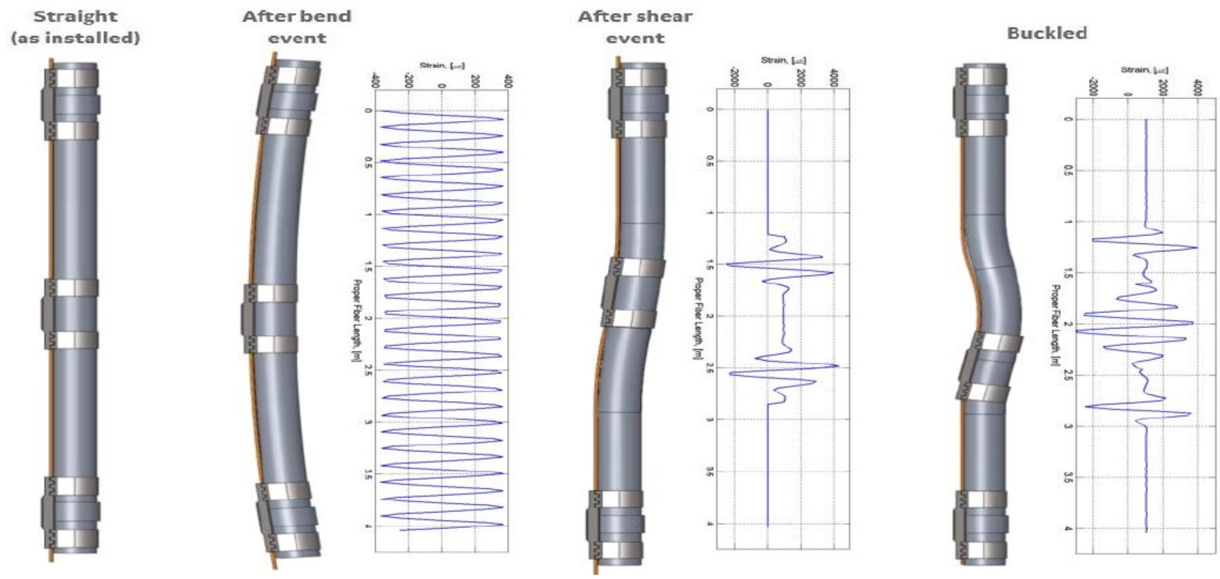

Figure 5-15 – SureVIEW WIRE Illustration

Table 5-11 – 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*

<u>Tubing Encapsulated Conductor</u>

The TEC is installed to support the Quartz Pressure Temperature (QPT) Elite gauges electrically 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 TEC is produced as a single, solid conductor wire coated with a protective sheath and encapsulated in a metal-clad CRA tube. Figure 5-16 illustrates the TEC design, and Tables 5-10 and 5-11 list the technical specifications.

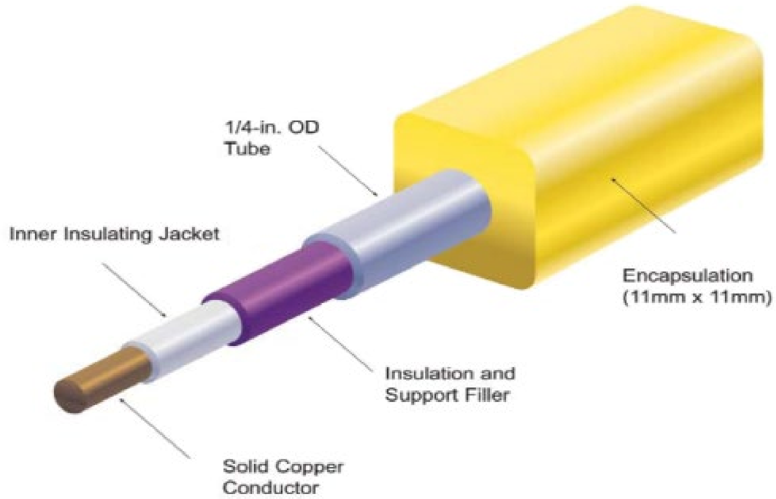

Figure 5-16 – TEC Illustration

Table 5-12 – 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 5-13 – 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

SureSENS Quartz Pressure Temperature Elite Gauge

The reliable, accurate SureSENS QPT Elite gauge (Figure 5-17) 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, thereby eliminating the need for an internal pressure test tool.

Figure 5-17 – SureSENS QPT Elite Gauge Illustration

QPT Elite Pressure Interface – Pressure Testable Manifold

The gauge-pressure interface connection to the carrier is via 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 provides a true, unique metal-to-metal design that is bidirectional and dual-testable. Figure 5-18 illustrates the design, and Table 5-12 lists the technical specifications.

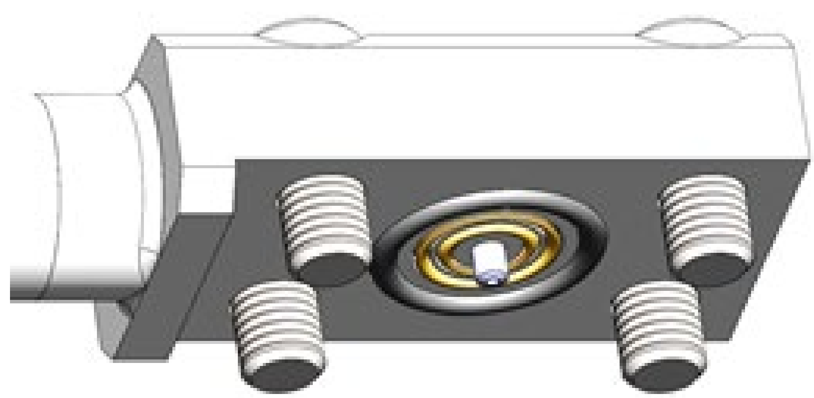

Figure 5-18 – External Sensor Illustration

Table 5-14 – QPT Elite Pressure Interface – Pressure-Testable 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)					

<u>SureSENS QPT Gauge Carriers</u>

The carrier body is machined from a single bar stock with no requirement for welding or heat-treating processes (Figure 5-19). The gauge assembly is installed in a recessed pocket in the carrier, providing protection for 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.

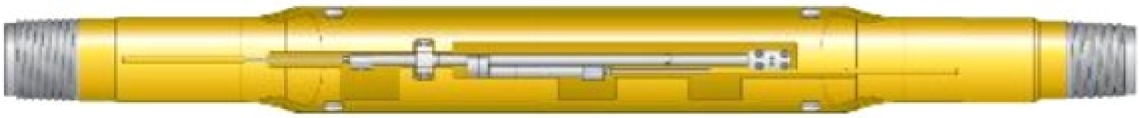

Figure 5-19 – SureSENS QPT Gauge Carrier Illustration

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).

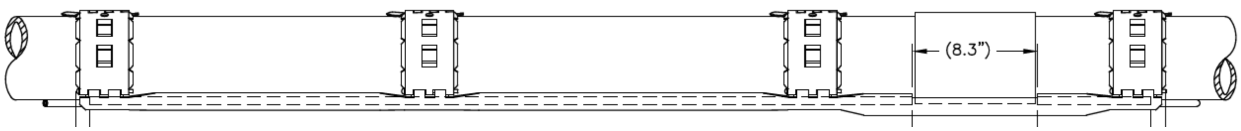

Figure 5-20 – Steel Blast Protector Illustration

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 as shown in Figure 5-21. There is a potential for the downhole cable to be damaged due to abrasion or crushing between the tubing and casing internal wall during the installation process, resulting in the loss of functionality of the associated downhole equipment.

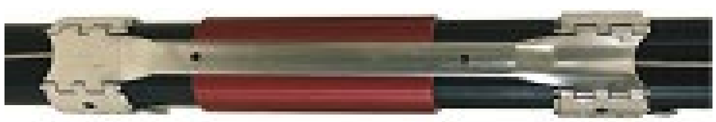

Figure 5-21 – Image of Cross Coupling Protector

5.5.8 VSP Monitoring Conclusion

The VSP method for quantifying CO_2 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 4D image of the extent and future development of the plume. Further, employing the VSP in the injection wells with a permanently installed fiber optic sensor will create an image centered on the injection location, with higher resolution than a traditional wireline-deployed geophone array. This method eliminates the need for additional penetrations within the injection formations for monitoring purposes.

The fiber optic configuration installed in Orchard No. 1 through No. 7, coupled with pressure and temperature monitoring, will be used in indirect-pressure plume calculations.

Most importantly, the need to add artificial penetrations for monitoring purposes is reduced, as the VSP system plus direct-plume calculations will allow for accurate monitoring of plume migration. This reduces the risk of inadvertently forming a conduit from the confinement intervals in the monitoring wells.

5.6 Conclusion

The testing and monitoring plans developed for Orchard No. 1 through No. 7 are designed to acquire essential data to support static and dynamic reservoir modeling, track the growth of the CO_2 plume, and ensure that CO_2 does not reach USDWs or pose a risk to health, safety, or the environment.

A larger scale map of the monitoring wells is included as Appendix E-1 and specification sheets for the planned technologies are provided in *Appendix E-2*.

5.7 References

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