PRE-OPERATIONAL TESTING PROGRAM
LAC 43:XVII.3619

Project Name: Live Oak CCS Hub

Facility Information

Facility Contact: Live Oak CCS, LLC
14302 FNB Parkway
Omaha, Nebraska 68154
402-691-9500

OOC Code No.: L1135

Well Locations:

Well Name	Latitude (WGS84)	Longitude (WGS84)	Parish	State
LO-01 M[1]	Claimed as PBI [redacted]	[redacted]	West Baton Rouge	Louisiana
LO-01 F[1]	Claimed as PBI [redacted]	[redacted]	West Baton Rouge	Louisiana
LO-02 M	Claimed as PBI [redacted]	[redacted]	West Baton Rouge	Louisiana
LO-03 M	Claimed as PBI [redacted]	[redacted]	Iberville	Louisiana
LO-04 F-M	Claimed as PBI [redacted]	[redacted]	Iberville	Louisiana
LO-05 M	Claimed as PBI [redacted]	[redacted]	Iberville	Louisiana
LO-06 M[1]	Claimed as PBI [redacted]	[redacted]	Iberville	Louisiana
LO-06 F[1]	Claimed as PBI [redacted]	[redacted]	Iberville	Louisiana

[1] For shared well pads, surface hole location spacing is set at a minimum of 15 feet.

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List of Acronyms

AOB-#	Above-Zone Observation Well Number
AoR	Area of Review
CBL	Cement Bond Log
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
EPA	Environmental Protection Agency
ft	Feet
FTS	Flow Through Sampler
Grp	Group
GW-#	Groundwater Observation Well Number
IOB-#	In-Zone Observation Well Number
LDENR	Louisiana Department of Energy and Natural Resources
LMIC	Lower Miocene Injection Complex
LO-#	Live Oak CCS Hub Injection Well Number
MEM	Mechanical Earth Model
MIT	Mechanical Integrity Test
MWD	Measurement While Drilling
NMR	Nuclear Magnetic Resonance
OC	Louisiana Department of Energy and Natural Resources' Office of Conservation
OFIC	Oligocene Frio Injection Complex
PFO	Pressure Fall-Off
psi/psig	Pounds per Square Inch, Gauge
psia	Pounds per Square Inch, Absolute
psi/ft	Pounds per Square Inch per Foot
SAPT	Standard Annular Pressure Test
SP	Spontaneous Potential
TBD	To Be Decided
TD	Total Depth
TVD	True Vertical Depth
UIC	Underground Injection Control
UOB-#	Underground Source of Drinking Water Observation Well Number
USDW	Underground Source of Drinking Water
XRD	X-Ray Diffraction

1. Introduction

Live Oak CCS, LLC plans to drill eight injection wells (i.e., LO-01 M, LO-01 F, LO-02 M, LO-03 M, LO-04 F-M, LO-05 M, LO-06 M, and LO-06 F), targeting two injection intervals (Oligocene Frio Injection Complex or F (OFIC) and Lower Miocene Injection Complex or M (LMIC)), at Live Oak CCS Hub in Iberville and West Baton Rouge parishes, Louisiana (the "project"; Figure 1)**.** This Pre-Operational Testing Program will be implemented to obtain the chemical and physical characteristics of the injection and confining zones and to meet the testing requirements specified under LAC 43:XVII.3617.B. This program will include a combination of logging, coring, formation hydrogeologic testing (e.g., a pump test and/or injectivity tests), and other activities during the drilling and construction phases of the project's proposed observation and CO_2 injection wells listed in Table 1 and shown in Figure 1.

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Table 1: List of all wells for Live Oak CCS Hub.

<table>
<tr><th>Well Types</th><th>Well Acronym</th><th>CCS System Zone</th><th>Zone Formation</th><th colspan="3">Approximate Zone Depth (ft MD)</th><th>Quantity</th></tr>
<tr><td>Shallow Groundwater (GW)</td><td>GW-1</td><td>Shallow USDW</td><td>Chicot Aquifer System</td><td colspan="3">~ 100-500</td><td>1</td></tr>
<tr><td>Deep Observation (UOB)</td><td>UOB-01, UOB-04, UOB-06</td><td>Lowermost USDW</td><td>Jasper Equivalent Aquifer System</td><td colspan="3">UOB-01: ~ 2,500; UOB-04: ~ 2,500; UOB-06: ~ 2,500</td><td>3</td></tr>
<tr><td>Above-Zone Observation (AOB)</td><td>AOB-01, AOB-04, AOB-06</td><td>1st Permeable Zone</td><td>Middle Miocene Sands</td><td colspan="3">AOB-01: ~ 5,019; AOB-04: ~ 4,307 ; AOB-06: ~ 3,940</td><td>3</td></tr>
<tr><td rowspan="8">In-Zone Observation (IOB)</td><td rowspan="8">IOB-01, IOB-02, IOB-03, IOB-04, IOB-05, IOB-06, IOB-07</td><td rowspan="8">Reservoir</td><td rowspan="8">Lower Miocene Sands (M) and Frio Formation (F)</td><th>Well</th><th>Miocene Depth</th><th>Frio Depth</th><td rowspan="8">7</td></tr>
<tr><td>IOB-01</td><td>~ 6,127</td><td>~ 10,440</td></tr>
<tr><td>IOB-02</td><td>~ 4,871</td><td>~ 8,921</td></tr>
<tr><td>IOB-03</td><td>~ 5,070</td><td>~ 9,221</td></tr>
<tr><td>IOB-04</td><td>~ 5,840</td><td>~ 11,060</td></tr>
<tr><td>IOB-05</td><td>~ 5,327</td><td>~ 10,002</td></tr>
<tr><td>IOB-06</td><td>~ 5,049</td><td>~ 9,222</td></tr>
<tr><td>IOB-07</td><td>~ 5,732</td><td>~ 9,821</td></tr>
<tr><td rowspan="9">Injection</td><td rowspan="9">LO-01 M, LO-01 F, LO-02 M, LO-03 M, LO-04 F-M, LO-05 M, LO-06 M, LO-06 F</td><td rowspan="9">Reservoir</td><td rowspan="9">Lower Miocene Sands (M) and Frio Formation (F)</td><th>Well</th><th>Miocene Depth</th><th>Frio Depth</th><td rowspan="9">8</td></tr>
<tr><td>LO-01 M</td><td>~ 6,289</td><td>NA</td></tr>
<tr><td>LO-01 F</td><td>NA</td><td>~ 10,730</td></tr>
<tr><td>LO-02 M</td><td>~ 6,115</td><td>NA</td></tr>
<tr><td>LO-03 M</td><td>~ 6,020</td><td>NA</td></tr>
<tr><td>LO-04 F-M</td><td>~ 6,135</td><td>~ 10,842</td></tr>
<tr><td>LO-05 M</td><td>~ 5,976</td><td>NA</td></tr>
<tr><td>LO-06 M</td><td>~ 5,793</td><td>NA</td></tr>
<tr><td>LO-06 F</td><td>NA</td><td>~ 9,565</td></tr>
</table>

NA = Not applicable

The Pre-Operational Testing Program will determine or verify the depth, thickness, mineralogy, lithology, porosity, permeability, and geomechanical information of the primary confining zone (Middle Miocene Confining Zone, Anahuac formation, and Vicksburg Shale), and the injection intervals (Lower Miocene Sand and Frio Formation) to meet the requirements under LAC 43:XVII.3617(B). In addition, formation fluid characteristics will be obtained from both the Lower Miocene Sands and the Frio Formation to establish baseline data against which future measurements may be compared after the start of injection operations. A total of 21 injection and observation wells will be drilled (Table 1). The first in-zone monitoring well drilled (IOB-01) will be used in a phased manner for site characterization including an extensive coring program. Apart from the initial data collection well, as the seven other injection wells are drilled, they will be used to obtain injection zone characterization data through injectivity testing. In addition, an extensive well logging program will be implemented in the injection and in-zone observation wells as per LAC 43:XVII.3617(B)(1)(b) and (c). The results of the testing activities, including interpretation work, will be documented in separate reports for all eight injection wells. These reports will be submitted to the Louisiana Department of Energy and Natural Resources' (LDENR) Office of Conservation (OC). Per LDENR guidance, Live Oak CCS, LLC will provide at least 72-hour notification to the OC prior to conducting any wireline tests, wells tests, or reservoir tests as per 43:XVII.3617(B)(6). In addition, as per the requirements specified under LAC 43:XVII.3619, Live Oak CCS, LLC will submit a completion and site reassessment report for the OC's approval to request authorization to inject.

As per the requirements specified under 43:XVII.3617(B)(2), Live Oak CCS, LLC will take sidewall core and acquire logs from the eight injection wells. Apart from IOB-01, Live Oak CCS, LLC will bypass taking whole-core from the other planned injection and in-zone observation wells due to anticipated larger wellbore sizes and associated coring challenges. We anticipate required whole core analysis based on core collections from the first in-zone observation well (IOB-01) drilled at the site (see subsection 2.3).

Similarly, pressure fall-off and injectivity testing would be conducted in the eight injection wells. These tests are useful in determining reservoir and confining unit fracture gradients as well as zonal injectivity. Detailed geomechanical information gained from core and log analysis will be input into a 1-dimensional Mechanical Earth Model (1-D MEM) to provide understanding of formation mechanical properties and fracture gradients of the formations within the Lower Miocene Sand and Frio Formation, as well as their corresponding confining units.

Live Oak CCS, LLC plans to drill and install a water well to source drilling water at the hub site for various planned injection and monitoring wells. Once all the wells have been drilled, this well will be repurposed as a shallow groundwater monitoring well and can be a part of the routine groundwater monitoring program. A final decision regarding the repurposing of this well, or alternatively, drilling a new ground water monitoring well at an alternate location, as well as any other updates to the monitoring program, will be in consultation with and approval of the OC.

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Claimed as PBI

[redacted]

Figure 1: Locations of proposed injection and observation wells at Live Oak CCS Hub.

Live Oak CCS, LLC will rely on information from geologic and petrophysical tests in the first in-zone observation well (IOB-01) as per the planned drilling sequence, as well as the other project well as required to satisfy the Class VI rule requirements for drilling and constructing injection wells. Specifically, Live Oak CCS, LLC will use the whole and sidewall core samples collected from Middle Miocene Confining Zone, Lower Miocene Sand, Anahuac Shale, Frio Formation, and Vicksburg Shale formations from the selected in-zone observation well (IOB-01), to satisfy the requirement under LAC 43:XVII.3617(B)(2).

Note that the testing activities at the identified wells described in this plan are restricted to the pre-injection phase. Testing and monitoring activities during the injection and post-injection phases are described in the project's Testing and Monitoring Plan, along with other non-well related pre-injection baseline activities such as geochemical monitoring.

2. Pre-Injection Testing Plan – Injection and Observation Wells

This section describes the tests, core collection, and logging activities that will be conducted during drilling and casing installation and after casing installation in the identified wells, in accordance with the testing required under LAC 43:XVII.3617. Table 2 highlights the testing and monitoring activities in the pre-injection phase of the project. This data will be used for baseline and compared with data collected during the injection phase to ensure containment of CO_2 and protection of groundwater resources.

Table 2: Pre-injection testing and monitoring technologies, frequencies, and locations.

Monitoring Parameter	Technology/Test	Baseline Phase Frequency (12 months)	Location
Internal MIT	Annulus Pressure Test	Once Prior to Injection	Injection wells: LO-01 M, LO-01 F, LO-02 M, LO-03 M, LO-04 F-M, LO-05 M, LO-06 M, LO-06 F
External MIT	1) DTS/ Temperature Log 2) Ultra Sonic CBL 3) Electromagnetic CI Logs	Once Prior to Injection	Injection wells: LO-01 M, LO-01 F[1], LO-02 M, LO-03 M, LO-04 F-M[1], LO-05 M, LO-06 M, LO-06 F[1]; In-zone observation wells: IOB-01 through 07
Groundwater Quality	1) Fluid Sampling &Analysis 2) DH P Gauges	1) Quarterly 2) Continuous	Injection wells: LO-01 M, LO-01 F, LO-02 M, LO-03 M, LO-04 F-M, LO-05 M, LO-06 M, LO-06 F; Above zone observation wells: AOB-01, AOB-04, AOB-06; Deep observation wells: UOB-01, UOB-04, UOB-06
Direct Pressure Monitoring	1) P Gauges – Tubing 2) DH P Gauges	Continuous	Injection wells: LO-01 M, LO-01 F, LO-02 M, LO-03 M, LO-04 F-M, LO-05 M, LO-06 M, LO-06 F; In-zone observation wells: IOB-01 through 07; Above zone observation wells: AOB-01, AOB-04, AOB-06; Deep observation wells: UOB-01, UOB-04, UOB-06

Monitoring Parameter	Technology/Test	Baseline Phase Frequency (12 months)	Location
Indirect CO_2 Plume Monitoring Techniques	DTS	12 Months Prior to Injection	In-zone observation wells: IOB-01 through 07
	PNC Logging	1 Prior to Injection	Injection wells: LO-01 M, LO-01 F, LO-02 M, LO-03 M, LO-04 F-M, LO-05 M, LO-06 M, LO-06 F; In-zone observation wells: IOB-01 through 07; Above zone observation wells: AOB-01, AOB-04, AOB-06; Deep observation wells: UOB-01, UOB-04, UOB-06
	3D DAS VSP/ CSP		TBD
Hydrogeologic Testing	Pressure Fall-Off Testing		Injection wells: LO-01 M, LO-01 F, LO-02 M, LO-03 M, LO-04 F-M, LO-05 M, LO-06 M, LO-06 F

[1] LO-01 F, LO-04 F-M and LO-06 F will only include DTS fiber optic deployment in the top cemented long string casing but not in the liner. For the liner sections, external MIT will involve temperature logging.

2.1. Deviation Checks

Deviation measurements (single shot survey) will be conducted at appropriate depth intervals during construction of the wells (LAC 43:XVII.3617(B)(1)(a)). This is important because some injection and observation wells are collocated at the same pad, and the drilling program will aim towards preventing any accidental collision between the corresponding wellbores.

2.2. Well Logs

Open-borehole logs will be collected in the eight injection wells to obtain in-situ structural, stratigraphic, physical, chemical, and geomechanical information for the confining zones and the injection zones. Logs, surveys, and tests will be used to ensure conformance with the injection well construction requirements according to LAC 43:XVII.3617(B) and establish accurate baseline data for future comparison. Open-borehole characterization logs will be obtained after reaching the total depth (TD) in the vertical borehole. Wireline logging will be completed in all injection and in-zone observation wells to verify exact depths of the injection and monitoring intervals. A description of each logging method that will be included in the logging program for the injection and in-zone observation wells is as follows:

2.2.1. Open Hole Logs

- **Geologic Description (Mud Log)** – Provides a continuous visual description of the drill cuttings-based lithology of the formations as the well is drilled. Physical cuttings sample datasets are typically collected and cataloged every 20 to 50 feet for future assessment. Mud logs are also used to evaluate any hydrocarbon or natural gas shows encountered while drilling the well.
- **Triple Combination** – Includes gamma-ray/spontaneous potential, porosity, and resistivity logs.

- **Acoustic Log (i.e., Dipole Sonic)** – This acoustic log measures elastic properties axially, radially, and azimuthally to support geomechanical, geophysical, fractures, and petrophysical modeling. Furthermore, sonic logs, like compressional sonic (DT), can be used along with density logs for preparing synthetic seismic logs.
- **High Resolution Resistivity Imager** – Provides micro-resistivity formation images when using water-based mud. Borehole images can reveal bedding planes and associated contacts, fractures (open, healed, and induced), and reservoir textures (sedimentary structures). A multi-arm caliper run with this tool provides information on hole shape and is used for subsurface stress analysis. The tool also provides borehole inclination and azimuthal information which complement the deviation check surveys taken while drilling the well.
- **Nuclear Magnetic Resonance** – This log provides nuclear magnetic resonance (NMR) measurements of the buildup and decay of the polarization of hydrogen nuclei (protons) in the liquids contained in the pore space of rock formations. One key measurement provided by this log is the total formation porosity. Permeability and effective porosity can be estimated from the free-fluid to bound-fluid ratio and the pore-size distribution. NMR measurement can also be used for fluid identification because this log also provides a hydrogen index measurement.
- **Pulsed Neutron Spectroscopy** – This logging tool is used for measurements and definitions of mineralogy and matrix properties of injection and confining zones. The data from spectroscopy logging can be used to estimate mineral-based permeability, determine well-to-well correlations from geochemical stratigraphy, and determine sigma matrix for case hole and open hole sigma saturation analysis, among others. Elemental analysis or similar processing of these logs yields the volumetric proportions of mineral composition and pore fluids. For example, these logs can reveal the relative proportions of clay minerals, quartz, calcite, and fluid volume in the formation.
- **Wireline Formation Testing** – This wireline tool suite has the capacity to collect reservoir pressure measurements, static fluid levels, and fluid samples that can be kept at formation pressures representative of downhole conditions. The tool can also be run to conduct a *mini-frac* test. These tests provide fracture pressure estimates and far field stress directions (in conjunction with the formation micro imager). Wireline test data can be used as calibration for other stress measurements (sonic logs).
- **Caliper Log** – This tool provides a continuous measurement of the size and shape of a borehole along its depth. The measurements that are recorded can be an important indicator of washouts, cave-ins, or shale swelling in the borehole, which are instrumental in processing and interpreting the results of other well logs.
- **Spontaneous Potential Log** – Spontaneous potential (SP) logs are useful for characterizing formation rock properties. Specifically, they provide indications of permeable formations and their boundaries as well as formation water resistivity.
- **Isotope Log** – This tool allows identification of reservoir connectivity and compartmentalization as well as efficiency and sealing characteristics of caprocks and faults. It involves routine isotope analysis and reporting during drilling operations by sampling and analysis of mud gas samples.

2.2.2. Cased Hole Logs

- **Ultrasonic Imaging Tool** – This log can provide estimates of well integrity and zonal isolation through measurement of cement acoustic impedance. The information from this log can be used to create maps of the casing integrity and cement, identify corrosion or casing damage, and determine if there is solid (cement), liquid, or gas in between the casing and formation. Modern acoustic cement-evaluation tools, such as ultrasonic logs, are comprised of monopole (axisymmetric) transmitters (one or more) and receivers (two or more). They operate on the principle that acoustic amplitude is rapidly attenuated in good cement bond but not in partially bonded or free pipe. The ultrasonic tool can also provide a casing thickness interpretation.
- **Cement Bond Log (CBL)** – CBL tools use sonic waves to interrogate the integrity of the well's cement. CBLs use acoustic transmitters and receivers to measure signal attenuation to provide a measure of how well the casing and the cement are bonded. CBLs provide an indication of the cement-to-formation bond in the form of a variable density log. Typically, CBLs provide an average measurement, but they can also provide maps where logging tools with multiple transmitters and receivers on pads are used.
- **Temperature Logging Surveys** – The temperature log provides a subsurface temperature profile necessary for characterizing in-situ conditions. Temperature logging is used to identify the top of cement after cementing to help ensure wellbore integrity.

Table 3 lists the various Surface and Long String Casing wireline logging tools that will be deployed in the injection and in-zone observation wells.

Table 3: Wireline logging program for injection and in-zone observation wells.

Approximate Depth Interval[1] (ft)	Log	Log Type	Purpose/Comments
		Surface Casing	
0 – 2,800	Mud Log	Open Hole	Monitor and ensure uninterrupted drilling process as well as provide lithologic information while drilling.
0 – 2,800	Borehole Profile/Caliper	Open Hole	Evaluate borehole condition prior to cementing.
0 – 2,800	Temperature Log	Cased Hole	Determine natural geothermal gradient outside well for comparison to future temperature logs for external mechanical integrity evaluations. Baseline log is run a minimum of 30 days after drilling and casing/cementing the well because temperature anomalies due to circulation of drilling fluid and/or open-borehole injection testing will persist for several weeks to months.
0 – 2,800	Spectral Gamma/ Porosity/ Density/ Resistivity (Triple Combination)	Open Hole	Characterize basic geology (Lithology, formation tops, porosity, etc.).
0 – 2,800	SP Log	Open Hole	Characterize rock formation properties.
0 – 2,800	Cement Bond Log	Cased Hole	Evaluate cement integrity.

Approximate Depth Interval[1] (ft)	Log	Log Type	Purpose/Comments
Long String Casing			
2,800-8,760	Mud Log/ Isotope Log	Open Hole	Monitor and ensure an uninterrupted drilling process as well as provide lithologic information while drilling as well as efficiency and sealing characteristics of caprocks and faults.
2,800-8,760	Borehole Profile/Caliper	Open Hole	Evaluate borehole condition prior to cementing.
2,800-8,760	Temperature Log	Cased Hole	Determine natural geothermal gradient outside well for comparison to future temperature logs for external mechanical integrity evaluations. Baseline log is run a minimum of 30 days after drilling and casing/cementing the well because temperature anomalies due to circulation of drilling fluid and/or open-borehole injection testing will persist for several weeks to months.
2,800-8,760	Spectral Gamma/ Porosity/ Density/ Resistivity (Triple Combo)	Open Hole	Characterize basic geology (Lithology, formation tops, porosity, etc.)
2,800-8,760	Pulsed Neutron Spectroscopy	Open Hole	Characterize basic geology (Gamma Ray, Resistivity, Porosity, Mineralogy).
2,800-8,760	SP Log	Open Hole	Characterize rock formation properties.
2,800-8,760	Isotope Log	Open Hole	Characterize reservoir connectivity and compartmentalization.
2,800-8,760	Nuclear Magnetic Resonance Tool	Open Hole	Enhanced characterization of geologic and geomechanical properties that control injectivity and caprock/seal integrity.
2,800-8,760	Formation Micro Imager	Open Hole	Enhanced characterization of geologic and geomechanical properties that control injectivity and caprock/seal integrity.
2,800-8,760	Wireline Formation Testing	Open Hole	Used to characterize downhole formation fluids and reservoir pressures at selected locations of interest.
2,800-8,760	Dipole Sonic	Open Hole	Determine the reservoir fracture pressure gradient and geomechanical properties of the confining and injection zones.
2,800-8,760	Cement Bond Log/Ultrasonic	Cased Hole	Evaluate cement integrity, internal and external casing condition.

[1] Depth estimates are reported as TVD. Exact logging depths vary by individual well and will depend on the well locations and well design. The specified depths (intermediate depth and bottom of the well) are approximate values for LO-01 M and should be used as reference.

2.3. Cores

Live Oak CCS, LLC is planning to obtain whole cores as well as sidewall cores from multiple wells at the site in a phased approach to satisfy requirements under LAC 43:XVII.3617(B)(2). The coring program as planned is spread out between two phases. Phase 1 will utilize an in-zone observation well (IOB-01) to run planned Measurement While Drilling (MWD) as well as obtain necessary whole cores along the caprocks, injection intervals, and other formations of interest. Additionally, the plan is to run a full suite of wireline logs (Table 2) to better characterize both the OFIC and LMIC for the AoR. The data from Phase 1 will be used to identify the zones for acquiring additional core, particularly sidewall cores under Phase 2 in the injection well closest to the first observation well (LO-01 M). This approach allows optimization of the coring program as any specific coring points within the formations which may have been missed during the cutting of the whole cores in the observation well can be targeted during drilling of the injection well. In addition, sidewall cores will be acquired in all the other injection wells to better characterize the targeted injection complexes (LMIC and OFIC) in each injection well.

IOB-01 will be used to collect whole cores in the upper confining zones for both the OFIC and LMIC, i.e., the Middle Miocene Confining Zone and Anahuac Formation, respectively. Decisions on necessity and exact location of whole cores will be based on the MWD observations and a thorough evaluation of available characterization at the site. These may include whole cores in either one or both injection zones (i.e., Lower Miocene Sands, Frio Formation), depending on the need for additional characterization. In addition to whole cores, a robust sidewall coring program is planned over the full injection complex including the confining, injection, and base seal zones. Additional sidewall cores may be collected from other injection and in-zone observation wells depending on the need for additional characterization. This whole core and rotary sidewall core analysis of samples will be used to evaluate the project’s proposed injection and confining intervals. The whole cores will go through extensive testing and, due to their location within the AoR, will be representative of the project.

The exact number of cores and coring depths will be identified before Phase 1 of the coring program and finalized during the drilling of the first observation well. These whole and sidewall cores will be preserved on-site and shipped to a commercial core testing/analysis laboratory for analysis. Properties analyzed will include routine core analysis (porosity, permeability, grain density, and residual fluid saturation), where said properties are critical in understanding the exact nature of the rocks. Specialized core analysis, including X-ray diffraction (XRD) for mineralogical analysis and capillary pressure, will be conducted on selected whole core samples as well. If the wireline formation tests fail to determine injection and confining zone mechanical properties, core plug mechanical property tests (e.g., triaxial tests) may be conducted to determine these properties and to estimate fracture pressure. The wireline and core mechanical property results will be used to calibrate wireline logs.

2.4. CO_2 Stream Analysis

CO_2 stream analysis will provide the chemical profiles, for which the injectate is monitored, in the observation wells. Live Oak CCS, LLC will analyze the contents of the CO_2 stream prior to injection, at a sufficient frequency, to yield representative chemical and physical profile data. This information will be used to conduct relevant testing and modeling, particularly with respect to the compatibility of the stream with fluids in the injection zone(s), minerals in the injection and confining zone(s), as well as the materials used in the construction of the wells. Any required updates will be communicated to the OC for approval prior to injection pursuant to LAC:43:XVII.3619(A)(3).

2.5. Baseline Monitoring

Once they have been drilled and completed, baseline pressure monitoring will occur in the injection, in-zone, above-zone, and deep (lowermost USDW) wells. Monitoring will occur continuously using both downhole and wellhead pressure gauges (tubing and annular pressure monitoring). Direct baseline pressure monitoring in injection and in-zone wells will help reveal natural variations in subsurface pressure. This data will help complete the baseline monitoring and reporting requirements under LAC 43:XVII.3617(B)(3). This reservoir zone pressure data will help calibrate model predictions of pressure front propagation and allow for adequate baseline data to help decrease the frequency of false positive and negative loss of containment detection events when compared to injection phase monitoring data. Direct pressure monitoring in the above-zone and deep observation wells will allow for a comparison to injection phase monitoring pressure data for early detection of containment loss due to increased pressures from potential out-of-zone reservoir brine and/or CO_2.

Indirect CO_2 plume baseline monitoring will occur at the project to support monitoring activities later during the injection phase as per LAC 43:XVII.3625(A)(7)(b). Live Oak CCS, LLC plans to implement indirect CO_2 plume monitoring using DTS, and pulsed neutron capture (PNC) logging. Baseline data will be acquired prior to injection for comparison to injection phase monitoring data. In addition, some of the injection and in-zone observation wells may include permanently installed distributed acoustic sensing (DAS) fiber in addition to DTS. These can be used for repeat seismic surveys such as VSP or for passive seismic monitoring if required. However, a decision to utilize these monitoring methods will be contingent on the plume and pressure front progression with time based on other independent direct and indirect observations. Fiber optic deployment in multiple wells will also provide significant redundancy in case of any DTS/ DAS fiber optic cable failures during the life of the project.

PNC logging tools can detect elevated oxygen around the wellbore in the rock formation and therefore the presence of CO_2. PNC log uses induced gamma ray spectroscopy with a pulsed neutron generator where the tool measures the gamma rays that are emitted back after the neutrons are sent into the rock. PNC logging will be conducted once, prior to injection in all injection, in-zone, above-zone, and deep observation wells. This baseline logging data will allow for comparison to injection phase monitoring data to determine the vertical location of CO_2 within the injection and in-zone wells, and for early detection of containment loss for above-zone and deep observation wells. During injection, PNC logging will only be run in the injection wells, any wells with CO_2 breakthrough, and in any wells where monitoring data indicates loss of containment. For the zones above the caprock, PNC logging will be mainly used as a verification technique to help prove the absence of CO_2. Groundwater sampling and analysis will also be used to verify elevated levels of CO_2 and determine if the elevated CO_2 is project related.

DTS data will be used to indirectly monitor the location of the CO_2 saturation plume. All injection wells will include DTS in the cemented long string casing intervals. For LO-01 F, LO-04 F-M, and LO-06 F, the liner intervals within the Frio Sand will not include DTS due to tapered casing strings. The in-zone observation wells will also include DTS in the cemented long string casing and record continuous temperature measurements after well construction and prior to injection. In the injection wells, the deployed DTS fiber optic cables, in combination with temperature logging for LO-01 F, LO-04 F-M and LO-06 F wells, can be used for MIT. Additionally, it will be used for verifying CO_2 breakthrough and vertical extent in the other in-zone wells in conjunction with direct monitoring using pressure and temperature gauges. Reservoir zone intervals taking CO_2, as verified using PNC logging, will then be used to calibrate reservoir models for better prediction of CO_2 saturation plume behavior through time.

As deemed necessary, DAS data can be used to indirectly monitor the location of the CO_2 saturation plume using geophysical imaging techniques such as vertical or cross-well seismic profiling. The monitored saturation profiles during the injection phase can be compared to plume front models to verify containment and conformance. Furthermore, the same fiber optic cable can be repurposed and used to monitor passive seismicity at the injection site if required. DAS allows for high resolution data due to higher density of sensing and should provide accurate identification and classification of large seismic events at the site.

Additional details regarding the location and frequency of the baseline monitoring can be found in Table 2.

2.6. Fluid Sampling

The analysis of reservoir fluid samples will be used to satisfy the requirement of LAC 43:XVII.3607(C)(2)(e) and ensure that baseline geochemical properties are established for the OFIC and LMIC within the AoR. Groundwater sampling procedures will be formulated using permanent downhole and wellhead pressure gauges. These gauges will continuously record and transmit pressure data about the groundwater in the intervals mentioned above and allow for an estimate of the water to be purged prior to sample collection. This is particularly important for post drilling sampling operations. For the first sampling operation, any fluids introduced into the formation during drilling, borehole conditioning, cementing, perforation acid treatment, and/or formation (injection) testing would first need to be removed before representative formation fluid samples can be collected. Consequently, Live Oak CCS, LLC will attempt to collect the first fluid samples during the active drilling phase using a Wireline Formation Testing tool rather than collect samples after well completion. The in-zone fluid samples from injection wells will be collected using a formation testing tool while the hole is open. If fluid samples cannot be taken via the formation testing tool, fluid samples can be collected after well completion by swabbing fluid or pumping through tubing with a packer set just above the perforated interval. After an appropriate volume of fluid is swabbed from the well, samples can be taken via a slickline deployed tool, such as a Kuster Flow Through Sampler (FTS) or equivalent. Both fluid sampling methods will sample reservoir pressure and static fluid levels.

Groundwater chemistry will be baselined through fluid sampling and analysis in the injection interval of the Lower Miocene Sands and Frio Sand at the injection wells, the first permeable unit above the caprock in the Middle Miocene Sands (AOB-01, AOB-04, and AOB-06), the lowermost USDW, in the Jasper Aquifer System (UOB-01, UOB-04, and UOB-06), and potentially, the shallow Chicot Aquifer System (GW-01).

The analytic and field parameters for fluid sampling are presented in Table 4. These parameters are consistent with the fluid sampling analysis and processes that are detailed in the Testing and Monitoring Plan and the Quality Assurance Surveillance Plan associated with this permit. Analytes will be tested to create a baseline, which is representative of the pre-operational groundwater geochemistry, that can be compared to operational (injection phase) geochemistry groundwater monitoring data. Groundwater sampling and analysis will occur quarterly, one year prior to injection, to capture seasonal variations in the groundwater geochemistry. Carbon isotope analyses will be run for all baseline analyses to enable Live Oak CCS, LLC to differentiate project and natural/background CO_2.

Table 4: Summary of analytical and field parameters for fluid sampling in the Lower Miocene Sands and Frio Formation.

Parameters	Analytical Methods
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Sb, Se, and Tl	ICP-MS, EPA Method 6020B (*U.S. EPA, 2014a*) or EPA Method 200.8 (*U.S. EPA, 1994a*)
Cations: Ca, Fe, K, Mg, Na, and Si	ICP-OES, EPA Method 6010D (*U.S. EPA, 2014b*) or EPA Method 200.7 (*U.S. EPA, 1994b*)
Anions: Br, Cl, F, NO_3 and SO_4 Dissolved CO_2	Ion Chromatography, EPA Method 300.0 (*U.S. EPA, 1993*) Coulometric titration, ASTM D513-16 (*ASTM, 2016*)
Total Dissolved Solids Water Density Alkalinity pH (field) Specific conductance (field) Temperature (field)	Gravimetry, APHA 2540C (*APHA*) Oscillating body method APHA 2320B (*APHA, 1997*) EPA 150.1 (*U.S. EPA, 1982*) APHA 2510 (*APHA, 1992*) Thermocouple

2.7. Demonstration of Mechanical Integrity

Live Oak CCS, LLC will conduct tests and run logs as needed to demonstrate the internal and external mechanical integrity of all injection wells prior to initiating CO_2 injection, satisfying the hydrogeologic testing requirements under LAC 43:XVII.3617(B)(1) and (5). Internal mechanical integrity refers to the absence of leaks in the tubing, packer, and casing above the packer. External mechanical integrity refers to the absence of fluid movement/leaks through channels adjacent to the injection wellbore that could result in fluid migration into an USDW. Table 5 provides a summary of the mechanical integrity tests (MITs) and pressure fall-off (PFO) tests to be performed prior to injection.

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Table 5: Summary of planned MITs and other tests prior to injection.

Class VI Rule Citation	Rule Description	Test Description
LAC 43:XVII.3617(B)(1)(d)	MIT - Internal	Pressure Test
LAC 43:XVII.3617(B)(1)(d)	MIT - External	Casing Inspection Log
LAC 43:XVII.3617(B)(1)(d)	MIT - External	DTS/ Temperature Log
LAC 43:XVII.3617(B)(5)	Testing prior to operating	PFO, Injectivity Test

Materials used in the construction of each injection well will have sufficient structural strength and will be designed for the life of the geologic sequestration project based on approved engineering data of the cement and casing used in well construction. Apart from submitting cementing job summaries, and prior to drilling out the casing shoe, each casing string will be hydrostatically pressure tested to verify casing integrity. Pursuant to LAC 43:XVII.3617(A)(3)(a), the stabilized test pressure applied at the surface shall be a minimum of 500 pounds per square inch gauge (psig) for surface casing and a minimum of 1,000 psig for all other casing strings. In addition, Live Oak CCS, LLC will ensure that the test pressure does not exceed the rated burst or collapse pressures of the casing. During the test, if any indication of a leak or failure are indicated, then the casing string will be recemented or repaired. Once remedial measures have taken place, the pressure test will be conducted again. All casing pressure tests will be recorded in the driller's log.

Pursuant to LAC 43:XVII.3617(A)(3)(b), Live Oak CCS, LLC will conduct a casing seat test once the casing shoe has been drilled out. Live Oak CCS, LLC will ensure that at least 10 ft of formation below respective casing shoes is drilled before the tests and a minimum of 1,000 psig test pressure is applied at the surface. The test pressure will be maintained for no less than 60 minutes after pressure stabilization. If the observed pressure loss is limited to 5% of test pressure over stabilized test duration, the test will be deemed successful.

After the completion of each of the eight injection wells, which includes the installation of tubing, packer, and annular fluid, a test of each well's internal mechanical integrity will be performed by conducting a standard annular pressure test (SAPT) pursuant to LAC 43:XVII.3617(B)(1)(d) and 3627(A)(2). The annular pressure test is a short-term test wherein the fluid in the annular space between the tubing and casing is pressurized, the well is shut-in (temporarily sealed up), and the pressure of the annular fluid is monitored for any changes. The initial annulus pressure test will be conducted to validate well integrity. The test will include pressurizing the fluid-filled annulus to a specified level, which is at least equivalent to the maximum authorized injection pressure (limited to injection pressure of 2,220 psig for all the wells; refer to subsection 2.1 of the the Summary of Requirements – Class VI Operating and Reporting Conditions for more details) and monitoring the pressure throughout a 60-minute test period. A test will be deemed to be successful if the applied test pressure stabilizes within 5% of the required test pressure for the stabilized testing period, whereas a failed test is one where there is a 5% or greater loss of the applied pressure as per the specifications under LAC 43:XVII.3617(A)(3)(a).

During the injection period, internal mechanical integrity will be continuously monitored by the well annular pressure maintenance and monitoring system, as discussed in more detail in the Testing and Monitoring Plan.

Live Oak CCS, LLC will also employ various methods to demonstrate external mechanical integrity upon the completion of all injection wells and prior to the start of injection operations. Live Oak CCS, LLC will run temperature logs on all injection wells to demonstrate external mechanical integrity to provide confidence that there are no pathways for potential CO_2 or brine migration through the wellbore, casing, or cement prior to injection operations, satisfying the requirement of LAC 43:XVII.3617(B)(1)(d). Additionally, external mechanical integrity will be demonstrated in all in-zone observation wells once prior to injection, using a distributed temperature sensing (DTS) fiber optic cable mechanical integrity test (MIT). Live Oak CCS, LLC plans to use DTS for external MIT in injection wells and additionally, temperature logs will be used in wells LO-01 F and LO-06 F since these two wells will only include DTS in the cemented casing section.

2.7.1. Annulus Pressure Test Procedures for Injection and Observation Wells

The general procedure for the annular pressure test is summarized as follows:

1. The tubing/casing annulus (annulus) will be filled with fluid (see subsection 2.7.1 of the Construction Details for each injection well for details on the annular fluid). Temperature stabilization of the well and annulus liquid is necessary prior to conducting the test. For the injection wells, this will be achieved by filling the annulus with liquid and either ceasing injection or maintaining stabilized injection using water (i.e., continuous injection at a constant rate and constant injection fluid temperature) before and for the duration of the test. For the observation wells, the annulus will be filled with liquid but no changes will be made to the fluid inside the tubing prior to the actual test.
2. No unapproved substances will be added to the annulus liquid.
3. After stabilization, the annulus will be pressurized to a surface test pressure of no less than 500 psig. The exact pressure limit will depend on the casing string being tested. A positive pressure differential between the pressure in the annular space and the injection tubing pressure of at least 100 psi will be maintained throughout the entire annulus (from the top of the packer to the surface). Specific gravity differences between liquids in the annulus and the tubing should be accounted for when determining the appropriate test pressure.
4. Following pressurization, the annular system will be isolated from the source of pressure. The annulus system will remain isolated for a period of no less than 60 minutes.
5. After the SAPT test period has been completed, the valve to the annulus will be opened and liquid returns from the annulus observed and measured.

2.8. Fracture Pressure of Injection and Confining Zone

To satisfy the requirements of LAC 43:XVII.3607(C)(2)(g), once open hole logs have been gathered, at selected depths, formation testing will be used to better characterize the fracture pressure within the injection and confining zones in the eight injection wells and selected in-zone observation wells. Selection of observation wells for formation testing will be finalized once additional characterization data has been acquired at the site. A minifrac test may be used to locally pressure up a small interval in the test formation to the point where it just starts to fracture. This provides the fracture pressure without causing significant damage to the formation being tested.

In addition, to fully satisfy the requirements of LAC 43:XVII.3617(B)(4), Live Oak CCS, LLC intends to run a dipole sonic log (Stoneley wave analysis) in the injection wells, which will allow estimation of the injection and confining zone reservoir fracture pressure.

2.9. Hydrogeologic Testing

After an injection well is complete, including installing the injection tubing and packers as per the well designs, and prior to initiating injection in said well, Live Oak CCS, LLC intends to satisfy the requirements under LAC 43:XVII.3617(B)(5) by running an injection test on the injection formations (Lower Miocene Sand and Frio Formation). This will help determine the large-scale composite injectivity (transmissivity) of the injection intervals and possible presence of nearby hydrogeologic boundaries (Table 7) at the injection well sites. These tests will help better predict plume movement in updated reservoir models. The injectate for this test will be produced formation water (brine) for respective injection formations from either the injection wells or fresh water which will serve as a proxy for CO_2 injection. Live Oak CCS, LLC intends to use the extensive wireline logging program to support and corroborate the hydrogeologic properties that are collected via direct fluid sampling from the injection zones. Additionally, Live Oak CCS, LLC will collect reservoir pressure data from the Lower Miocene Sands and the Frio Sand in the eight injection wells, as applicable, during these injectivity tests.

Table 6: Composite injectivity evaluation testing program.

Test	Description	
LMIC and OFIC Composite Injectivity Evaluation	Objectives	**Primary objective:** To determine the large-scale transmissivity of the injection zones and possible presence of nearby hydrogeologic boundaries using produced reservoir brine from the injection wells or using fresh water and provide direct information about the injectivity potential of the injection zones within the Lower Miocene Sands and Frio Formation.
	Test/Depth Zone	Injection zone in 1) Lower Miocene Sands at approximately 5,700 - 9,300[1] ft measured depth and 2) Frio Formation at approximately 9,500 – 11,900[2] ft measured depth. Alternatively, this test may be conducted on one or more discrete depth intervals within these stratigraphic sections.

Test	Description	
	Test Activity/ Summary	The injection tubing and packer would be set just above the top of the two injection formations, i.e., within Lower Miocene Sands and Frio Formation inside the casing string. After the packer is in place, a constant-rate injection utilizing produced reservoir brine from the injection wells or fresh water will be conducted. At the end of injection, the recovery pressure for the composite zone will be monitored for a period approximately 1.5 times or more of the injection period.

[1, 2] Depths are approximate and include varying depths for multiple planned injection wells. Actual test intervals will be finalized once the wells are being drilled and will likely fall within the depth ranges identified in this application.

A pre-operation injection and PFO test will serve as the baseline test for establishing reservoir and well conditions for comparison to results of subsequent PFO tests conducted during the operational period (i.e., during CO_2 injection) as required under LAC 43:XVII.3625(A)(6). Specifically, this comparison is intended to confirm that the pressure increase within the injection interval is less than predicted and ensure that the modeled parameters used in the Area of Review and Corrective Action Plan modeling analysis represent actual conditions.

The PFO tests will be conducted according to the U.S. EPA Region 6 guidance (UIC pressure falloff testing guideline, 2002). These guidelines define a PFO test as a pressure transient test that consists of shutting in an injection well after a period of prolonged injection and measuring the PFO. The fall-off period is a replay of the injection test preceding it; consequently, it is affected by the magnitude, length, and rate fluctuations of the injection period. Fall-off testing analysis provides reservoir and well parameters, including transmissivity, storage capability, skin factor, and well flowing and static pressures. Establishing a baseline value for these parameters will be useful for identifying changes in the well and/or reservoir properties after CO_2 injection begins; for example, an increasing skin factor may be indicative of formation damage which signals a need for well remediation while a decreasing skin factor may indicate near-wellbore cleanup.

2.9.1. Pressure Fall-Off Test Procedures

Baseline PFO tests will be conducted as described in the Testing and Monitoring Plan and in this Pre-Operational Testing Program. The objective of the testing is to periodically monitor for changes in the near wellbore environment that would impact injectivity or cause injection pressures to increase. Baseline PFO testing will be performed on all eight injection wells. A PFO test has a period of injection followed by a period of no-injection or shut-in. Normal injection will be used during the injection period preceding the shut-in portion of the falloff tests. An example approach is highlighted below (UIC pressure falloff testing guideline, 2002):

1. Tag and record the depth to any fill in the test well.
2. Simplify the pressure transients in the reservoir.
    a. Maintain a constant injection rate in the test well prior to shut-in. This 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.
3. The test well should be shut-in at the wellhead to minimize wellbore storage and afterflow. This is because the location of the shut-in valve can impact the duration of the wellbore storage period. Report the exact location of the shut-in valve and its relative distance from the wellhead in the final test report to the OC.
4. Maintain accurate rate records for the test well and any offset wells completed in the same injection interval.
5. Measure and record the viscosity of the injectate periodically during the injectivity portion of the test to confirm the consistency of the test fluid.

The PFO data will be measured using a downhole gauge, sampling at a minimum of 5-second intervals. If required, a gauge can be conveyed via wireline for recording downhole pressures. The shut-in period of the PFO test will be adequate to assure that enough pressure transient data are collected to calculate the average pressure. Quantitative analysis of the measured data will be used to estimate formation characteristics, including transmissivity, permeability, and a skin factor using appropriate diagnostic plots. The measured parameters will be compared to those used in site computational modeling and AoR delineation. A final Falloff test report will be provided to the OC.

The baseline PFO test will be conducted as part of the post-completion injectivity testing.

2.10. Notification

Pursuant to LAC 43:XVII.3617(B)(6), Live Oak CCS, LLC will notify the OC at least 72 hours in advance of conducting wireline logging, well tests, or reservoir tests.

2.11. Reporting

Pursuant to LAC 43:XVII.3609(L), 3617(B), and 3619, Live Oak CCS, LLC will provide the OC with a Completion Report and Site Reassessment for each injection well after completion and testing of that well that includes the following:

- A descriptive report prepared by a knowledgeable log analyst that includes:
  - Interpretation of the results of logs and tests described in this Pre-Operational Testing Program;
  - Well log analyses;
  - Core analyses; and
  - Formation fluid sample information;
- Final AoR based on modeling, using data obtained during logging and testing of the subsurface formations;
- Any relevant updates to information presented in the Application Narrative on the geologic structure and hydrogeologic properties of the proposed storage site and overlying formations;

- Final injection well construction procedures,
- Information on the compatibility of the CO_2 stream: (1) with fluids in the injection zone, (2) with minerals in both the injection and confining zones, and (3) with the materials used to construct the injection well;
- Results of the Pre-Operational Testing Program;
- Status of corrective action on wells in the AoR;
- Demonstration of mechanical integrity as described in subsection 2.5 above;
- Updates to the following that are necessary to address new information collected during the Pre-Operational Testing Program:
    - Area of Review and Corrective Action Plan;
    - Testing and Monitoring Plan;
    - Injection Well Plugging Plan for each injection well;
    - Post-Injection Site Care and Site Closure Plan; and
    - Emergency and Remedial Response Plan.

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