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

Liberty County, Texas

SECTION 4 – ENGINEERING DESIGN AND OPERATING STRATEGY

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4.1 Introduction

This section describes the engineering design details and operational strategies employed during the planning of BKVerde, LLC's (BKVerde) proposed Luz Solar No. 1 injection well and associated monitoring wells. The engineering design details meet the requirements of Title 16, Texas Administrative Code (TAC) **§5.203(e)** [Title 40, US Code of Federal Regulations (40 CFR) **§146.86**]. Class VI regulations include specific requirements for the design and operation of a carbon capture and sequestration (CCS) well. This section addresses each of those requirements in detail.

4.2 Injection Well

4.2.1 Engineering Design

The Luz Solar No. 1 design is optimized to permanently sequester supercritical CO_2 fluid, prevent its movement into Underground Sources of Drinking Water (USDW), and account for various operational factors, such as injection volume, pressure, temperature, rate, chemical composition, and physical properties of the injectate fluid, as well as the corrosive nature of the injectate fluid and its impact on well components. The operation of the well will be managed to ensure efficient use of pore space in the injection interval and contain the CO_2 within the authorized injection zones for the duration of the project.

The design of this well considered several key components, including volume, pressure, temperature and rate of injection, chemical composition, physical properties of the injectate fluid, corrosion concerns, metallurgical evaluations, and operational details necessary to maintain proper reservoir management.

Class VI wells are designed similarly to Class I injection wells, including specialized metallurgy to handle potentially corrosive fluids. While CO_2 alone is not corrosive, it can create carbonic acid with a pH as low as 3 when combined with water and other chemical compounds, such as hydrogen sulfide (H_2S). The injection and monitoring wells are designed to withstand the corrosiveness of the injectate. Special metallurgies are considered for the casing, tubing, wellhead equipment, and downhole tools.

The drilling program includes deviation checks and inclination surveys performed every 100 feet (ft) during drilling. The cement design and products used to cement the well create good bonding between the casing and formations while withstanding the corrosive injectate. The cementing of the casings is designed with a sufficient cement sheath to protect the well from developing any channeling out of the injection interval and sequester the CO_2 below the upper confining zone (UCZ).

The Miocene and Frio sands will be used as the storage reservoir for this project and are composed of stacked layers of laterally continuous sand and shale sequences in normal pressure environments. The Miocene and Frio sands in the project area are generally located from [redacted]

[redacted] true vertical depth (TVD), and BKVerde plans to use Luz Solar No. 1 to inject and permanently sequester CO_2 in the Miocene sands from [redacted] 1 ft and the Frio sands from [redacted] ft. The porous, permeable, and unconsolidated nature of the Miocene and Frio sands makes them ideal formations for CO_2 injection and storage. Luz Solar No. 1 will be injecting into several zones of sand through multiple recompletions during the life of the well. The design of the well accounts for this specific type of completion strategy.

The well will be designed with CO_2-resistant casing, which includes a [redacted] Figure 4-1 is the well schematic for Luz Solar No. 1.

[redacted]

Figure 4-1 – Luz Solar No. 1 Well Schematic

This section also features the design and construction of the planned stratigraphic and monitoring wells that will be drilled to support injection into Luz Solar No. 1. BKVerde plans to drill a stratigraphic test well, Rayo Luna No. 1, approximately [redacted] of Luz Solar No. 1. Data will be gathered while drilling through the injection interval (UCZ, injection zones, LCZ) to better support the project and refine the CO_2 plume migration modeling efforts. The well will be cased and completed for future monitoring and reservoir data gathering, as needed.

Injection zone temperatures and pressures will be continuously monitored in Luz Solar No. 1 and in the in-zone monitoring well, Rayo Luna No. 1. Pressure and temperature gauges will be run on tubing encapsulated conductor (TEC) cable. These gauges will be placed within each planned injection stage. Additionally, distributed acoustic sensing (DAS) fiber optic cable will be installed and cemented in the annulus behind the long-string casing of Rayo Luna No. 1. The cable will be designed for use with a vertical seismic profile (VSP) survey.

4.2.2 General Outline of Well Design and Completion Schematic

Luz Solar No. 1 was designed with the following specifications:

- [redacted]

[redacted]

Within 30 days after the completion of Luz Solar No. 1, BKVerde will file a complete record of the well with the Underground Injection Control (UIC) Division showing the current completion details, in accordance with 16 TAC **§5.206(c)(2)**. A complete drilling and completion prognosis has been included in *Appendix D-2.* The mud and cement programs included in the prognosis are representative and therefore may be modified before starting construction.

4.2.3 Detailed Discussion of Injection Well Design

BKVerde plans to inject an average of 0.5 million metric tons per year (MMT/yr) of captured CO_2 into Luz Solar No. 1. This injection translates to a rate of 26.7 million standard cubic feet per day (MMscf/D) at standard conditions. Table 4-1 shows the standard conditions of CO_2 used in the modeling and flow calculations. Detailed modeling analyses were conducted based on the size of the long-string casing, tubing, injectate properties, injectate temperatures and pressures, and proposed injection rates to determine the appropriate grade and weight for the injection tubing. The long-string casing was then designed to accommodate the [redacted] in. tubing.

Table 4-1 – CO_2 Standard Conditions

Temperature (°F)	Pressure (psia)	Density (lbm/ft^3)	Enthalpy (Btu/lbm)	Entropy (Btu/lbm-°R)
60	14.7	0.11666	214.18	0.64759

*psia – pounds per square inch absolute
lbm – pound mass

Tubing design sensitivity analysis, considering calculated pipe-friction losses, exit velocities, and economics, was performed. Detailed reservoir-engineering model runs estimated the bottomhole pressures (BHPs) during injection operations over time (Figure 4-2). The data in Figure 4-2 identifies the maximum BHP in each injection zone during the life of the project, with the resulting maximum injection pressure below the fracture gradient at injection depth for a 0.5 MMT/yr injection rate. This data is informative for designing wellhead equipment, tubing, and casing that exceed industry-standard safety design factors.

[redacted]

Figure 4-2 – Bottomhole Injection Pressure Plot vs. Gas Mass Rate

Injection tubing size of [redacted] has been designed for Luz Solar No. 1 based on the anticipated injection rates and BHP outputs from the simulation model. The injectate composition was derived from the anticipated receiving specifications and input into the reservoir model, as shown in Table 4-2. Table 4-3 values were calculated using input parameters listed in Tables 4-2 and 4-4. Wellhead pressure was determined by calculating a multi-segmented pressure traverse, starting with the known BHP and back-calculating to determine the surface injection pressure.

Table 4-2 – Modeled CO_2 Injection Composition

Composition	% mole
[redacted]	

Table 4-3 – Input Parameters for Well Calculations

Parameter	Value	Source
Pipeline Delivery Pressure	[redacted]	
Pipeline Delivery Temperature		
Injection Rate (typical)		
Tubing Inner Diameter (ID)		
Depth for BHP value		
BHP (typical)		

*psi – pounds per square inch

Table 4-4 – Calculated Injection Parameters

Parameter	Value
Formation Temperature (mid-perforation)	[redacted]
Formation Pressure (mid-perforation)	
Formation Density [redacted]	
Injectate Density in Formation	
Wellhead Injection Pressure (typical)	
Wellhead Injection Temperature (typical)	
BHP (typical)	
Bottomhole Injection Temperature (typical)	

Parameter	Value
Average Well Density	[redacted]
Pipe Friction Pressure Loss	
Fluid Column Head Pressure	

A combination of friction pressure and hydrostatic head affects the pressure differential (Δp) between the top and base of each pressure traverse segment. Friction pressure drops were calculated using conventional pipe-flow relations, as described by Craft, et al. (Craft, Holden, & Graves, 1962). The hydrostatic head component of the Δp within each segment is calculated based on the injected fluid density, average temperature, and pressure therein. The multi-segmented approach of calculating the pressure traverse allows for consideration of variations in the injected density and viscosity of the fluid with temperature and pressure.

The injected fluid temperatures at wellhead and bottomhole conditions are affected initially by the pipeline fluid temperature and pressure. When reduced from pipeline to *wellhead* pressure, the injected fluid will cool because of the Joule-Thomson (JT) effect. That is, as the fluid moves down the well, it will be subject to warming from the surrounding rock and temperature changes as the pressure increases.

From a starting pipeline outlet pressure and temperature, the JT effect on the injected fluid temperature was calculated over a range of pressures using Computer Modelling Group Ltd.'s (CMG) WinProp™ equation-of-state (EOS) simulation software. The EOS simulator was used to generate tables of temperature vs. pressure at constant enthalpy, referenced to pipeline-outlet conditions. Figure 4-3 illustrates how injected fluid temperature varies with pressure for the average-case pipeline outlet temperature of 108°F. Bottomhole temperature (BHT) will be affected by both the JT effect and heat transfer from the surrounding earth. The heat transfer component to the estimated BHT was assumed to have a linear variation with depth, [redacted] temperature is determined by the JT effect between the pipeline outlet and the calculated wellhead pressure, with no additional heat transfer from the surrounding environment.

[redacted]

Figure 4-3 – Injected Fluid Temperature vs. Pressure at Constant Enthalpy

The critical point of CO_2 is [redacted], above which CO_2 exists in a supercritical fluid state. Given the pressures and temperatures calculated for Luz Solar No. 1, the injected fluid will remain in the liquid or dense phase (i.e., supercritical) from the time it enters the BKVerde site, through its path and into the subsurface injection interval. At the surface, fluid temperature will be maintained above the critical temperature. Temperature and pressure will increase as the supercritical CO_2 travels down the tubing and into the injection zone in the supercritical phase. Figure 4-4 shows a phase diagram for CO_2, highlighting its supercritical state within the formation.

[redacted]

Figure 4-4 – CO_2 Flow Conditions. The magenta dot shows the anticipated bottom hole conditions for the injectate. The black dot is the critical point for CO_2.

In support of the tubing size, the following casing and hole sizes were chosen to provide sufficient annular spacing to obtain a good cement sheath that will promote adequate cement bonding, and to provide sufficient protection for the casing.

- [redacted]

<u>Conductor Casing</u>

Conductor casing will be required to maintain the integrity of the hole during the initial drilling of the well. A [redacted] conductor casing will be used for this purpose. The pipe will be driven using a hydraulic ram either to refusal or to approximately 100 ft below ground level (BGL). After the conductor casing is in place, the inside of the pipe will be flushed and drilling can commence.

The selection of the conductor casing is based on the desired bit size for drilling the surface casing borehole. With the conductor casing having an ID of [redacted] can be used to clean out the conductor casing and drill the next section of the well to a depth of [redacted] The casing design-calculation results for the conductor string are provided in Table 4-5.

Table 4-5 – Injection Well Conductor-Casing Engineering Calculation Results

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

bbl/ft – barrels per foot

<u>Surface Casing</u>

The surface hole will be drilled using a [redacted] with casing set below the lowermost USDW at approximately [redacted] ft. A string of [redacted]. casing will be run and cemented with the casing centered in the open hole using centralizers. Being centralized, the size of the annulus chosen will provide a consistent cement thickness between the casing and the open hole. The consistent cement thickness will ensure a quality cement bond and create two barriers between the USDW formation and the well during the remaining drilling operations. Cement will be circulated to the surface, and a top job will be performed, if needed, should the cement level fall after the cement has been circulated to surface. After cementing, a cement bond log (CBL) will be run to evaluate and verify good bonding throughout the surface hole.

Summaries of the engineering calculation results for the surface casing are provided in Tables 4-6 through 4-8.

Table 4-6 – Injection Well Surface-Casing Engineering Calculation Results

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

Table 4-7 – Injection Well Surface-Casing Annular Geometries

Section	ID (in)	MD (ft)	TVD (ft)
[redacted]			

*MD – measured depth

Table 4-8 – Injection Well Surface-Casing Cement Calculation Results

Section	Footage (ft)	Capacity (ft^3/ft)	% Excess (%)	Cement Volume (ft^3)
[redacted]				

To ensure that cement returns to the surface are achieved, [redacted] excess openhole volumes will be used. The equipment and cement will be on location to perform a top job, if needed.

Intermediate Casing

A [redacted]. casing has been selected for the intermediate casing section of the well. This section will be drilled with a [redacted] bit to provide sufficient annular space to cement the casing to surface with good bond. This casing string and an effective cement job will provide two barriers to the USDW during drilling operations. After the surface and intermediate casings are set, four barriers will be between the USDW and the fluid in the well. A CBL tool will be used to verify the quality of the cementing job. Summaries of the engineering calculation results for the intermediate casing are provided in Tables 4-9 through 4-11.

Table 4-9 – Injection Well Intermediate-Casing Engineering Calculation Results

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

Table 4-10 – Injection Well Intermediate-Casing Annular Geometries

Section	ID (in)	MD (ft)	TVD (ft)
[redacted]			

Table 4-11 – Injection Well Intermediate-Casing Cement Calculation Results

Section	Footage (ft)	Capacity (ft^3/ft)	% Excess (%)	Cement Volume (ft^3)
[redacted]				

To ensure that cement returns to the surface are achieved, [redacted] excess openhole volumes will be used. The equipment and cement will be on location to perform a top job, if needed.

<u>Long-String Casing</u>

Long-string casing will be installed from the surface to TD and cemented to surface. The casing's design criteria are chrome [redacted] casing, CO_2-resistant cement, and tools including centralizers and float equipment, a diverter tool, openhole packer, and galvanic crossover. After the surface, intermediate, and long-string casings are set, six barriers will be between the USDW and the supercritical CO_2 fluid in the well.

A comprehensive metallurgical analysis considering the chemical composition of the CO_2 injectate and downhole conditions was conducted and is included in *Appendix E – Metallurgy*. The analysis determined that the CO_2 injectate is not corrosive on its own. As recommended in the metallurgical assessment, [redacted] will be run across the injection interval to ensure its ultimate objective, to contain the CO_2 plume.

CO_2-resistant cement will be used to prevent cement from degradation caused by exposure to an acidic environment, thereby extending the integrity and life span of the well. As shown in Figure 4-1 (*Section 4.2.1*), CO_2-resistant cement will be placed at approximately [redacted] above the UCZ and across the entire injection interval. The cement column will be brought back to the surface using a two-stage cement job. The engineering and design parameters for the long-string casing are summarized in Tables 4-12 through 4-14.

Table 4-12 – Injection Long-String Casing Engineering Calculation Results

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

Table 4-13 – Injection Well Long-String Casing Annular Geometries

Section	ID (in)	MD (ft)	TVD (ft)
[redacted]			

Table 4-14 – Injection Well Long-String Casing Cement Calculation Results

Section	Footage (ft)	Capacity (ft^3/ft)	% Excess (%)	Cement Volume (ft^3)
[redacted]				

To ensure that cement returns to the surface are achieved, 20% excess openhole volumes will be used. The equipment and cement will be on location to perform a top job, if needed.

Centralizers

Centralizer selection and installation for the referenced well have two separate functions. The bow-spring centralizer design for the [redacted] surface casing will be planned to protect any shallow aquifer zones according to state regulations. The specific placement ensures that a continuous, uniform column of cement is present throughout the [redacted] annular void. The recommended locations will be as follows:

- [redacted]

Total Centralizers – [redacted]

The bow-spring centralizer design for the [redacted] intermediate casing will be planned to protect any shallow aquifer zones according to state regulations. The specific placement ensures that a continuous, uniform column of cement is present throughout the [redacted] annular void. The recommended locations will be as follows:

- [redacted]

Total Centralizers – [redacted]

The selection and installation of centralizers for the [redacted] long-string casing ensures that a continuous, uniform column of cement is present throughout the [redacted] annular void. The recommended locations will be as follows:

- [redacted]

Total Centralizers – [redacted]

Injection Tubing

The injection tubing size was selected based on the injection rates, injectate composition, exposure time, and ability to remove and replace the tubing. The injectate composition and potential for a corrosive environment were considered when determining the tubing metallurgy. Although the injectate stream is anticipated to be dry and noncorrosive, the planned design allows for a surface upset or invasion of connate water from the reservoir. A complete summary of the metallurgical analysis is included in *Appendix E*. Considering the potential for the presence of carbonic acid, [redacted] material or better is recommended for the tubing string. The tubing will be installed using premium connections.

Table 4-15 lists the tubing specifications, design criteria, and calculated safety factors. The burst design assumes an evacuated annulus with a full column of [redacted] pounds per gallon (ppg) mud, and [redacted] psi applied. The collapse assumes an evacuated tubing and a [redacted] noncorrosive fluid on the backside with [redacted] applied.

Table 4-15 – Injection Tubing Specifications

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

<u>Packer</u>

The injection tubing will be run into the well with a [redacted] injection packer with premium connections, as shown in Figure 4-5.

[redacted]

Figure 4-5 – [redacted] Packer

The tubing and long-string casing annulus will be filled with a noncorrosive fluid as approved by the UIC Director, before setting the packer. Pressure will be maintained and monitored on the annulus at a pressure that exceeds the operating injection pressure of the well.

Pressure Gauge Array

Pressure and temperature gauges will be installed across the active injection zone to provide continuous data in real time for reservoir monitoring purposes. A TEC cable will be installed on the exterior of the tubing completion to power the gauges and provide communication to the surface.

Automatic Surface Shutoff System and Safety Alarm

In accordance with 16 TAC **§5.203(d)(2)(F)(i)** [40 CFR §146.88(e)(2)], an automatic surface shutoff system, safety alarms, and Supervisory Control and Data Acquisition (SCADA) system will be installed to shut in the well—and alert BKVerde when operating parameters such as annulus pressure, injection rate, etc., diverge from permitted ranges or gradients.

Wellhead Discussion

The wellhead is designed to accommodate anticipated working pressures and eliminate corrosion complications. The equipment will be manufactured from a combination of stainless-steel components across the hanger and casing spool. Inconel or equivalent lining will be placed across trims, stems, gates, valves, etc. The final pressure rating will be confirmed before the manufacturing begins. The wellhead will be configured as displayed in Figure 4-6 (page 23). The wellhead design and manufacturer shown may change based on well and commercial factors before drilling this well. In accordance with 16 TAC **§5.203(e)(1)(C)(ii)**, the wellhead for the injection well will be equipped with pressure observation on the tubing and each annulus of the well.

[redacted]

Figure 4-6 – Luz Solar No. 1 Preliminary Wellhead Design

4.2.4 Testing and Logging During Drilling and Completion Operations

Logging Plan

A suite of electric logs will be run in the openhole sections and each casing string for Luz Solar No. 1. The logging plan is detailed in Tables 4-16 and 4-17. BKVerde will provide a schedule of all logging plans to the UIC Director at least 30 days before conducting the first test. Notice will be provided at least 48 hours in advance of such activity.

Table 4-16 – Openhole Logging Plan

Run	Hole Section	Logging Suite	Target Data Acquisition	Openhole Diameter (in.)	Depths (ft)
1	Surface Casing	Quad combo: GR, neutron, density, resistivity, sonic, multi-arm caliper	Identification of rock properties	[redacted]	
2	Intermediate Casing	Quad combo: GR, neutron, density, resistivity, sonic, multi-arm caliper	Identification of rock properties		
3	Injection	Quad combo: GR, neutron, density, resistivity, dipole sonic, multi-arm caliper	Identification of rock properties; target data acquisition		
4	Injection	Borehole imager	Identification of rock properties; target data acquisition		
5	Injection	Formation pressure tester – mini-fracture with dual packer and fluid sampler	Identification of rock properties; target data acquisition		

Table 4-17 – Cased-Hole Logging Plan

Run	Hole Section	Logging Suite	Target Data Acquisition	Casing Dimension (in.)	Depths of Survey (ft)
1	Surface Casing	Ultrasonic, casing collar locator (CCL), CBL, variable density log (VDL), GR, temp (bond log)	Cement investigation	[redacted]	
2	Intermediate Casing	Ultrasonic, CCL, CBL, VDL, GR, temp (bond log)	Cement investigation		

Run	Hole Section	Logging Suite	Target Data Acquisition	Casing Dimension (in.)	Depths of Survey (ft)
3	Intermediate Casing	Pulsed neutron log (PNL) baseline	Cement investigation	[redacted]	[redacted]
4	Injection	Ultrasonic, CCL, CBL, VDL, GR, temp (bond log)	Cement investigation	[redacted]	[redacted]
5	Injection	Pulsed neutron (PNL) baseline	Cement investigation	[redacted]	[redacted]

<u>Coring Plan</u>

Sidewall cores will be obtained from the upper confining, lower confining, and injection zones to supplement the whole cores that will be obtained during the drilling of the stratigraphic test well, Rayo Luna No. 1.

<u>Initial Formation Conditions</u>

Prior to injection, BKVerde will measure and record the formation fluid temperature, pH, conductivity, reservoir pressure, and static fluid level.

<u>Formation Fluid Testing</u>

Fluid samples will be acquired during the drilling and completion of Rayo Luna No. 1, located [redacted] ft from Luz Solar No. 1. If needed, supplemental samples may be taken from Luz Solar No. 1 during drilling and completion operations or immediately prior to injection operations.

<u>Injectivity Falloff Test</u>

- A nonhazardous fluid, approved by the Texas Railroad Commission (TRRC), will be used during the injection test.
- Injection falloff test
    - The purpose of this test is to evaluate the injectivity index, skin, and permeability (kH) of the injection interval.
    - Inject at a rate [redacted]
    - Shut in the well and record the pressure falloff for at least [redacted] with downhole gauges. The injection falloff test parameters are detailed in Table 4-18.

Table 4-18 – Injection Falloff Test

Duration (hr)	Rate (kbd)	Rate (bph)	Rate (bpm)	Volume (bbl)
[redacted]				

*kbd – thousand barrels per day
bph – barrels per hour
bpm – barrels per minute

<u>Step-Rate Injection Test</u>

- The purpose of this test is to evaluate the fracture pressure of the injection interval. A nonhazardous fluid, approved by the TRRC, will be used during the injection test.
    - Step duration
        - Minimum step duration is [redacted]
        - Actual step duration will be established based on the time required for pressure stabilization during the initial step, and this step duration will be held for all additional steps.
    - Maximum planned injection rate is [redacted] permitted injection rate.
    - Attempt to record at least three steps below and above the fracture pressure.
    - The proposed steps are listed in Table 4-19.

Table 4-19 – Proposed Step-Rate Injection Test

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

4.2.5 Completion/Stimulation Plans

Luz Solar No. 1 may be stimulated to create a negative completion skin to reduce injection pressure vs. an unstimulated case. Stimulation of the perforated stages throughout the injection interval will also ensure good injection conformance, thereby distributing injected CO_2 throughout the injection interval. Stimulation may involve, but is not limited to, flowing fluids into or out of the well, increasing or connecting pore spaces in the injection formation, or other activities that are intended to allow the injectate to move more readily into the injection zone. Advanced notice of proposed stimulation activities will be provided to the EPA or the UIC Director, as detailed below, prior to conducting the stimulation. BKVerde will describe all fluids to be utilized for stimulation activities and will demonstrate that the stimulation will not interfere with containment. BKVerde will submit proposed procedures for all stimulation activities to the EPA or the UIC Director in writing at least 30 days in advance, per 40 CFR **§146.91(d)(2)**. Within the 30-day notice period, the EPA may either deny the stimulation, approve the stimulation as proposed, or approve the stimulation with conditions. BKVerde will carry out the stimulation procedures, including any conditions, as approved or set forth by the EPA.

The purpose of the stimulations is to reduce near-wellbore skin damage created by operations such as drilling, workovers, and perforating. Stimulation may take more than one treatment to reduce skin and restore injectivity. Standard industry stimulation that may be utilized includes the following:

[redacted]

[redacted]

4.2.6 Injection Well Operating Strategy

BKVerde intends to inject 0.5 MMT/yr of CO_2 into Luz Solar No. 1. Because of the high porosity and permeability of the Frio and Miocene sands, the injection interval acts as a pseudo infinite-acting reservoir, quickly accepting and dissipating the injected CO_2 pressure. Luz Solar No. 1 will be operated according to the parameters provided in Table 4-20.

Table 4-20 – Luz Solar No. 1 Operating Parameters

Parameter	Value
Gross Injection Interval (ft)	[redacted]
Average Injection Volume (MMT/yr)	[redacted]
Average Injection Rate (MMscf/d)	[redacted]
Maximum BHP (psi)	[redacted]
Maximum Surface Injection Pressure (psi)	[redacted]
Expected Surface Injection Pressure (psi)	[redacted]
Maximum Annular Pressure	[redacted]

BKVerde plans to inject 0.5 MMT/yr of CO_2 into Luz Solar No. 1. Under downhole well and reservoir conditions, the CO_2 will be in the supercritical phase throughout the project life. Surface injection pressures will be limited to ensure the BHP stays below 90% of the fracture pressure of the injection zone. The estimated fracture and maximum allowable BHP for the well are shown in Table 4-21. Bottomhole pressures will be measured directly using the gauges installed on the TEC cable as described in *Section 4.2.3*.

Table 4-21 – Injection Pressures by Stage

Completion Stage	Year	Top Depth (ft)	Fracture Pressure (psi)	Maximum Allowable BHP (psi)
[redacted]				

Multiple injection zones will be completed to maximize the available pore space. Each discrete injection zone was selected to collectively maximize the acreage position for CO_2 sequestration. A summary of the planned injection strategy is listed in Table 4-22 for Luz Solar No. 1.

Table 4-22 – Injection Stages – Luz Solar No. 1

Completion Stage	Year	Injection Duration (years)	Top Depth (ft)	Bottom Depth (ft)	Net Pay (ft)
[redacted]					

The densities for the CO_2 stream vary from [redacted] This density difference and the vertical permeability in the Frio and Miocene sands allow the non-trapped CO_2 to migrate vertically to the top of each discrete injection zone and laterally under the confining layer of that injection zone. The result is a "mushroom cap" effect, with the top of the mushroom expanding outwardly from the injection well (Figure 4-7).

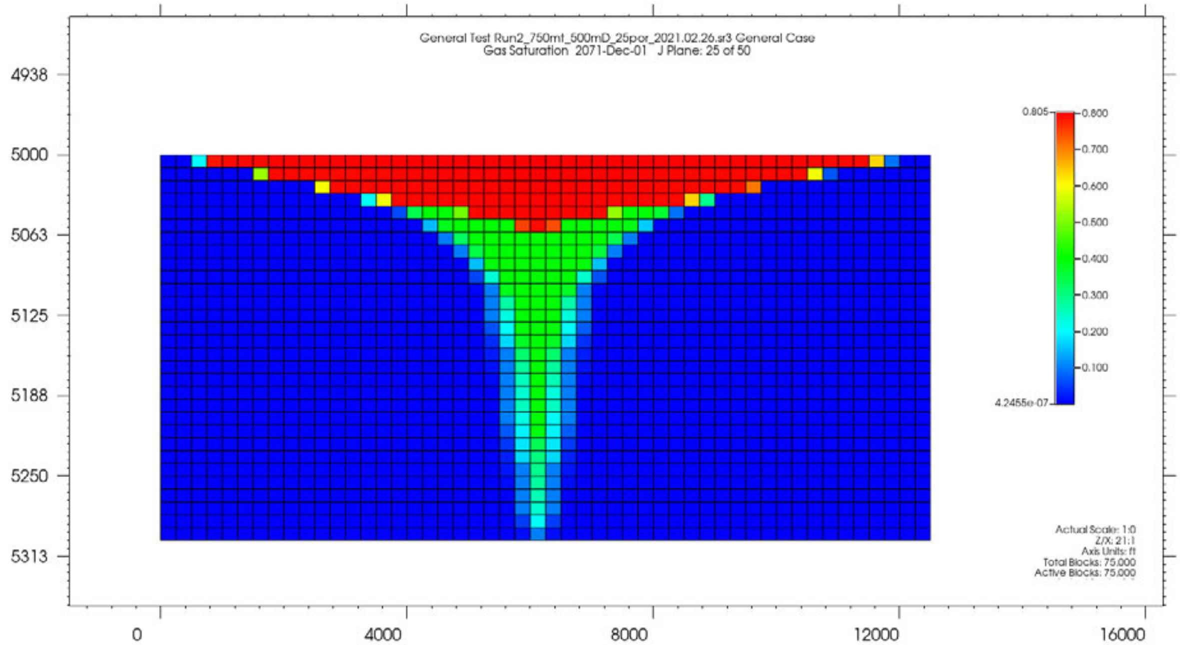

Figure 4-7 – Typical CO_2 Plume Profile in High Permeability Formations

In unconsolidated, high permeability formations, like the Miocene and Frio, the completion strategy is critical. At the end of each injection zone, the well will be recompleted into a new zone. A plug will be set to isolate the previous zone, and [redacted] long-string will be perforated to access the next zone for injection, as shown in Figure 4-8.

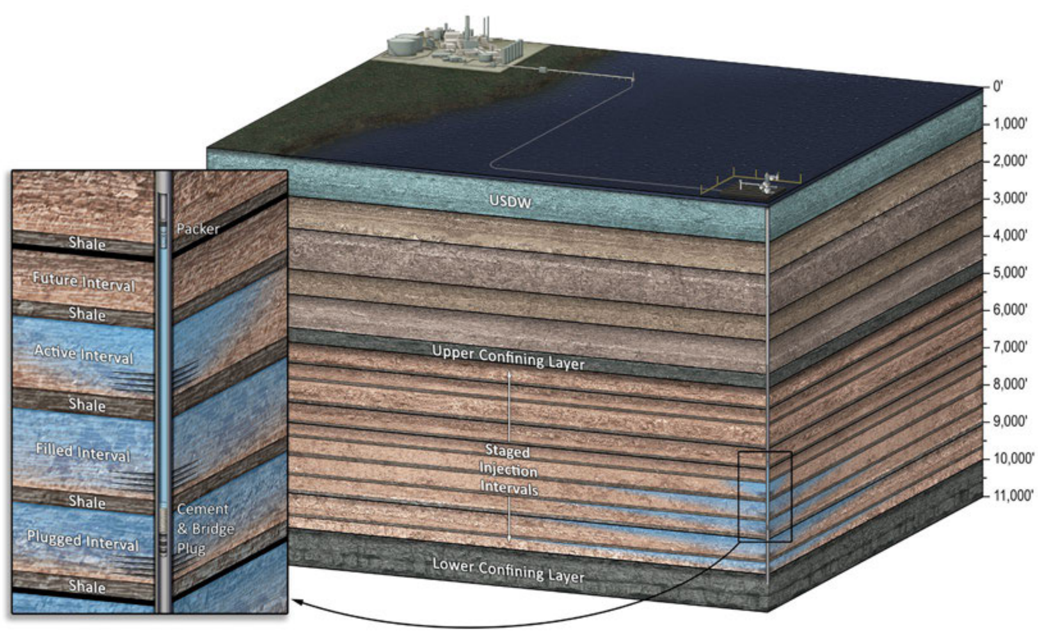

Figure 4-8 – Completion Strategy Illustration

4.2.7 Injection Well Operational Summary

Luz Solar No. 1 is designed to maximize the available pore space and safely sequester CO_2. Formation pressures and temperatures will be measured within the well and used to update the CO_2 plume model and refine future injection strategies. This process will accurately evaluate and provide assurance of where the CO_2 is moving and at what rate, allowing for alteration to the injection and operation strategy if required. After injection ceases, the well will be plugged or converted to an in-zone monitoring well for the project.

4.3 In-Zone Monitoring Well – Rayo Luna No. 1

BKVerde proposes to drill and complete the Rayo Luna No. 1 as a stratigraphic test well that will then be converted into an in-zone monitoring well. This well will be in the CO_2 plume area of review (AOR) and used to monitor pressures and temperatures of the injection interval and to determine the extent of the CO_2 plume from the Luz Solar No. 1 injection. Because this well is in the CO_2 plume, it will require special metallurgy considerations. A metallurgy assessment is attached in *Appendix E*.

4.3.1 General Outline of Monitoring Well Design, Rayo Luna No. 1

The Rayo Luna No. 1 well was designed with the following specifications (as shown in Figure 4-9):

- [redacted]

- [redacted]

- [redacted]

Complete drilling prognoses have been included in *Appendix D-4.* The mud, cement, and wellhead programs included in the prognoses are representative and may be modified before starting construction.

[redacted]

Figure 4-9 – Rayo Luna No. 1 Well Schematic

4.3.2 Engineering Calculations

Conductor Casing

Conductor casing will be required to maintain the integrity of the hole during the initial drilling of the well. [redacted] conductor casing will be used for this purpose. The pipe will be driven using a hydraulic ram either to refusal or to approximately 100 ft below ground level (BGL). The casing design calculation results are provided in Table 4-23.

Once the conductor pipe is established, the inner portions can be flushed out, and drilling can commence.

Table 4-23 – Monitoring Well Conductor Casing Engineering Calculation Results, Rayo Luna No. 1

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

Surface Casing

The surface hole will be drilled with a [redacted]. bit with casing set below the USDW. A string of [redacted] casing will be run and cemented, with the casing centered in the open hole using centralizers. Being centralized, the size of the annulus chosen will provide a consistent cement thickness between the casing and the open hole. Consistency will ensure a quality cement bond and create two barriers between the USDW formation and the well during the remaining drilling operations. Cement will be circulated to the surface, and a top job will be performed, if needed, should the cement level fall after the cement has been circulated to the surface. After cementing, a CBL will be run to evaluate and verify good bonding throughout the surface hole.

Summaries of the engineering calculation results for the surface casing are provided in Tables 4-24 through 4-26.

Table 4-24 – Monitoring Well Surface-Casing Engineering Calculation Results, Rayo Luna No. 1

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

Table 4-25 – Monitoring Well Surface-Casing Annular Geometries, Rayo Luna No. 1

Section	ID (in)	MD (ft)	TVD (ft)
[redacted]			

Table 4-26 – Monitoring Well Surface-Casing Cement Calculation Results, Rayo Luna No. 1

Section	Footage (ft)	Capacity (ft^3/ft)	% Excess (%)	Cement Volume (ft^3)
[redacted]				

To ensure that cement returns to the surface are achieved, [redacted] excess over caliper volumes will be used. The equipment and cement will be on location to perform a top job, if needed.

<u>Intermediate Casing</u>

A [redacted] casing has been selected for the intermediate casing section of the well. This section will be drilled with a [redacted] bit to provide sufficient annular space to cement the casing to surface with a good bond. This casing string along with an effective cement job will provide two additional barriers to the USDW during drilling operations. After the surface and intermediate casings are set, there will be four barriers between the USDW and fluid in the well. A CBL tool will be used to verify the quality of the cementing job. Summaries of the engineering calculations for the intermediate casing are provided in Tables 4-27 through 4-29.

Table 4-27 – Monitoring Well Intermediate-Casing Engineering Calculation Results, Rayo Luna No. 1

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

Table 4-28 – Monitoring Well Intermediate-Casing Annular Geometries, Rayo Luna No. 1

Section	ID (in)	MD (ft)	TVD (ft)
[redacted]			

Table 4-29– Monitoring Well Intermediate-Casing Cement Calculation Results, Rayo Luna No. 1

Section	Footage (ft)	Capacity (ft^3/ft)	% Excess (%)	Cement Volume (ft^3)
[redacted]				

To ensure that cement returns to the surface are achieved, [redacted] excess over caliper volumes will be used. The equipment and cement will be on location to perform a top job, if needed.

Long-String Casing

[redacted] casing has been selected for the long-string casing section of the well. This section will be drilled with a [redacted] in. bit to provide sufficient annular space to cement the casing to surface with a good bond. This casing string along with an effective cement job will provide two additional barriers to the USDW during drilling operations. After the surface, intermediate, and long-string casings are set, there will be six barriers between the USDW and fluid in the well. The long-string casing design criteria includes chrome [redacted] material, CO_2-resistant cement, tools (e.g., centralizers and float equipment), and a fiber optic cable. A CBL tool will be used to verify the quality of the cementing job.

A comprehensive metallurgical analysis, which considered the chemical composition of the CO_2 injectate and the downhole conditions, was conducted and is included in *Appendix E - Metallurgy*. The analysis determined that the CO_2 injectate is not corrosive on its own. However, when CO_2 is mixed with water in the reservoir it will create carbonic acid. As recommended in the metallurgical assessment, [redacted] will be run across the injection interval to ensure its ultimate objective, to contain the CO_2 plume.

Similar to the injection well, CO_2-resistant cement will be used to protect the cement sheath from degradation caused by exposure to an acidic environment, thereby extending the integrity and life span of the well. As shown in Figure 4-9 (*Section 4.3.1*), CO_2-resistant cement will be placed approximately [redacted] above the UCZ and across the UCZ and gross injection interval. A two-stage cement job will be used to ensure the cement is circulated to the surface.

The fiber optic cable will be installed with the production casing and cemented into place. The cable will be used for vertical seismic profiling in the injection zone as part of the overall long-term monitoring system of the project. The perforations in abandoned injection zones will remain open, below CO_2-resistant bridge plugs, to facilitate continuous monitoring of reservoir temperature and pressure with the fiber optic system, per the planned recompletion program.

The engineering and design parameters for the long-string casing are summarized in Tables 4-30 through 4-32.

Table 4-30 – Monitoring Well Long-String Casing Engineering Calculation Results, Rayo Luna No. 1

Description	Casing Wt. (lb/ft)	Setting Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)
[redacted]								

Table 4-31 – Monitoring Well Long-String Casing Annular Geometries, Rayo Luna No. 1

Section	ID (in)	MD (ft)	TVD (ft)
[redacted]			

Table 4-32 – Monitoring Well Long-String Casing Cement Calculation Results, Rayo Luna No. 1

Section	Footage (ft)	Capacity (ft^3/ft)	% Excess (%)	Cement Volume (ft^3)
[redacted]				

To ensure that cement returns to the surface are achieved, [redacted] excess over caliper volumes will be used. The equipment and cement will be on location to perform a top job, if needed.

Centralizers

The bow-spring centralizer placement for the [redacted] in. surface casing is designed to protect any shallow aquifer zones according to state regulations. The specific placement ensures a continuous, uniform column of cement throughout the [redacted]. annular void. The recommended locations will be as follows:

- [redacted]

Total Centralizers – [redacted]

The bow-spring centralizer placement for the [redacted] casing string is designed to ensure a continuous, uniform column of cement throughout the [redacted]. openhole annular void as well as the [redacted] casing annulus. The recommended locations will be as follows:

- [redacted]

Total Centralizers – approximately [redacted]

The placement of centralizers and fiber module protectors for the [redacted] long-string casing strings is designed to ensure a continuous, uniform column of cement throughout the [redacted]—and to allow for orientation of the perforating guns. The recommended locations will be as follows:

- [redacted]

Total Centralizers – approximately [redacted] (will be determined upon design after correlating openhole logs).

<u>Injection Tubing</u>

The injection tubing will consist of [redacted] tubing and a [redacted] assembly. The tubing string will be used to monitor reservoir pressure and temperature changes that indicate the arrival of the CO_2 plume in the injection interval. Pressure falloff testing in the injection zones will also be monitored.

Table 4-33 lists the tubing specifications, design criteria, and calculated safety factors. Because there will be no injection in this well, the collapse design assumes evacuated tubing with a [redacted] ppg brine on the backside, and [redacted] psi applied on the annulus. The burst assumes an evacuated annulus and a full column of [redacted]

Table 4-33 – Monitoring Well Tubing-Engineering Calculations, Rayo Luna No. 1

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in.)
[redacted]								

<u>Packer</u>

The tubing will be run in the well with [redacted]

<u>Pressure Gauge Array</u>

Pressure and temperature gauges will be installed and secured to the outside of the tubing across each reservoir interval to provide continuous data in real time for reservoir monitoring purposes. A TEC cable will be installed on the exterior of the tubing completion to power the gauges and provide communication to the surface.

<u>Wellhead Discussion</u>

The wellhead is designed to accommodate anticipated working pressure. The final pressure rating will be confirmed before beginning the manufacturing process. The wellhead will be configured as illustrated in Figure 4-10 (note that the manufacturer may differ from the one shown).

[redacted]

Figure 4-10 – Rayo Luna No. 1 Preliminary Wellhead Design

4.3.3 Testing and Logging of Rayo Luna No. 1 During Drilling and Completion Operations

<u>Coring Plan</u>

Core samples will be collected during drilling of the Rayo Luna No. 1 well in the UCZ, transition, Anahuac shale, gross injection zones, and LCZ.

Sections of whole core cut in 30-ft increments and rotary sidewall cores will be collected from the Burkeville formation (i.e., UCZ) and the Lower Miocene formation (i.e., injection interval), as listed in Table 4-34. Whole core will follow low-invasion acquisition protocol using high-performance, oil-based drilling fluid. Four-inch diameter whole cores will be drilled in the [redacted] section below the intermediate casing. Because of anticipated poor consolidation and lack of cohesion in these siliciclastic rocks, special vented-aluminum, disposable-core inner barrels and full-closure core catchers will be used. Wellsite core handling, stabilization, and preservation will follow strict guidelines to ensure that the confining and injection zone cores remain representative of in situ rock properties. Sidewall cores will be acquired to fill gaps between whole core depths.

Detailed analytical programs will be conducted for confining and injection zone characterization to include the following:

1. Geoscience evaluation for core sedimentological descriptions; petrology and mineralogy to include thin-section petrography, X-ray diffraction, and scanning electron microscopy; fracture characterization (if warranted), and geochemistry.
2. Routine core analysis computed tomography (C/T) and GR scanning, photography, and determination of porosity, permeability, and grain-size distribution. Pilot and fast track studies will be conducted to optimize analytical protocol and expedite results.
3. Rock mechanics will include Mohr-Coulomb failure analysis, quantification of mechanical impact on rock strength because of CO_2 injection and temperature effects (i.e., confining and injection zones), uniaxial strain bulk rock and pore volume compressibility, thick-wall cylinder stability evaluation, and P/S-wave data acquisition.
4. Special core analysis (petrophysics) for electrical characterization, mercury injection to determine pore throat radii distribution and confining capacity, and other petrophysical measurements for wireline log calibration.
5. Special core analysis (reservoir engineering) to determine supercritical CO_2-brine multiphase flow (i.e., relative permeability) under steady-state conditions for drainage and imbibition (hysteresis effects), critical gas, trapped gas, threshold entry pressures, interfacial tension (IFT) and contact angles, and capillary pressure measured using multiple methods.
6. Formation damage testing will include rock-CO_2-brine compatibility studies (static and dynamic) with mineralogical characterization before and after CO_2 contact, fines migration/critical velocity of solids evaluation, and flow analyses to investigate acidity, thermal, and CO_2 fluid throughput effects.

The core analysis program, provided in Table 4-34, has been designed to thoroughly characterize confining and injection zones, determine the effects of rock-CO_2-brine interaction, and be compliant with the EPA Class VI requirements.

Table 4-34 – Planned Core Intervals and Testing Program

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

<u>Logging Plan</u>

Openhole log data will be acquired reflecting in situ, structural, stratigraphic, physical, chemical, and geomechanical information for the Oakville formation, the Burkeville confining unit, and other zones of interest. Wireline-conveyed openhole logs will be acquired at the surface casing point, intermediate casing point, and across the injection interval, including the injection zones. Openhole logs will not be acquired in the conductor casing hole.

Several logging requirements necessary to meet EPA standards and the needs of a responsible operation can be described using the subsets detailed in Tables 4-35 and 4-36. These requirements include the standard, advanced, and cased-hole logs. Standard logs include GR, resistivity, neutron, density, caliper, and spontaneous potential. Spontaneous potential is only used in the zones with water-based mud. This data is used for primary reservoir and fluid characterization, including lithology, porosity, salinity, fracture identification, indications of permeability, and fluid saturations. The standard logs will answer most of the primary reservoir questions related to storage volume.

Advanced logs make up the second set of tools and include a multipole sonic tool, spectral GR, dual oil-based mud imaging tools, and a formation tester. These advanced tools meet the requirements of TAC **§5.203(e)(2)** and **§5.203(f)** [40 CFR **§146.86** and **§146.87**]. The sonic tool is a redundant porosity tool, but is also key in understanding the geomechanics, stress direction, and existence of fractures in the injection and confining zones. The geomechanical interpretation is bolstered by the image logs that can be interpreted for fracture identification, stratigraphy, stress direction, and dip. The formation tester will be used to determine formation pore pressure and mobility through pretests. The gradient produced through the interpretation of individual pore pressures will indicate zones of overpressure or underpressure, and the potential for different reservoir compartments. Based on historical records in the area, overpressure is not expected. With viscosity as a known, the permeability can be easily estimated from mobility or through post-sample buildups. In situ samples acquired at multiple depths will determine the physical and chemical properties of the water, as well as its flowing temperature. Using a formation testing tool in concert with a dual packer will allow the acquisition of a fracture gradient for the confining zones. This information will help to determine optimal injection rates to maintain an effective confining zone. The advanced logs will answer most of the remaining borehole upscale questions, including vertical connectivity, injectability, fluid chemistry, and geomechanics.

The planned cased-hole logs that will be run include CBLs and several other tools to establish baselines for the interval pre-injection (Table 4-36). These baseline logs include casing inspection logs, imaging caliper, PNL, and an oxygen-activation log. Future logging of this zone with the same technology will allow the monitoring of the CO_2 plume and the mechanical integrity of the well.

Table 4-35 – Rayo Luna No. 1 Openhole Logging Plan

Run	Hole Section	Logging Suite	Target Data Acquisition	Openhole Diameter (in.)	Survey Depths (ft)
1	Surface Casing	Quad combo: neutron, density, resistivity, sonic, GR	Identification of rock properties	[redacted]	[redacted]
2	Intermediate Casing	Quad combo: neutron, density, resistivity, dipole sonic, GR	Identification of rock properties	[redacted]	[redacted]
3	Monitoring Casing	Spectral GR – spectroscopy tools – nuclear magnetic resonance (NMR)	Identification of rock properties / target data acquisition	[redacted]	[redacted]
4		Sonic scanner acoustic platform (geomechanics basket)		[redacted]	[redacted]
5		MDT pressure with probe and fluid sampling with Saturn probe, fluid analyzer, MDT pump-out, multisampler (x 2)		[redacted]	[redacted]
6		MDT stress testing with MDT dual packer		[redacted]	[redacted]
7		XL rock (1.5 in. diameter cores)		[redacted]	[redacted]

*MDT – Modular Formation Dynamics Tester

Table 4-36 – Rayo Luna No. 1, Cased-Hole Logging Plan

Run	Hole Section	Logging Suite	Target Data Acquisition	Casing Dimension (in.)	Survey Depths (ft)
1	Conductor Casing	Ultrasonic, CCL, CBL, VDL, GR, Temperature	Cement investigation	[redacted]	
2	Surface Casing	Ultrasonic, CCL, CBL, VDL, GR, Temp (Bond Log)	Cement investigation		
3		PNL – Baseline			
4	Monitoring Casing	Ultrasonic, CCL, CBL, VDL, GR, Temp (Bond Log)	Cement investigation		
5		PNL – Baseline			

4.3.4 Overview of Well Completion Program

After setting and cementing the long-string casing, the injection tubing string will be installed. The completion program includes the following:

1. Make a bit and scraper run to TD.
2. Test casing.
3. Run cased-hole logs as described in Table 4-36.
4. Displace the hole with inhibited packer fluid.
5. Perforate the Frio formation, specific depths to be determined with openhole logs.
6. Run tubing, packers, pressure and temperature gauges, and TEC cable to depth; set and test the same.

4.3.5 Monitoring Well Operational Strategy Summary

The Rayo Luna No. 1 well will be completed with four injection stages from the Luz Solar No. 1 being monitored simultaneously as illustrated in Figure 4-9 (*Section 4.3.1.*). Multiple packers, sliding sleeves, profile nipples, pressure/temperature gauges, and downhole retrievable tubing plugs will be employed to accomplish this task. The first stage will monitor for pressure buildup in the first injection stage, while the other three zones monitor the initial reservoir pressure or pressure falloff due to prior injection activities. The sequence of pressure monitoring recompletions in the Rayo Luna No. 1 is presented in Table 4-37. Specific stage depths will be determined upon the drilling of the Rayo Luna No. 1 and Luz Solar No. 1 wells.

Table 4-37 – Monitoring Sequences

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

[redacted]

Continuous monitoring will be implemented with the use of a SCADA system to monitor the tubing pressure and the tubing/casing annulus pressure, as well as BHP and temperature. Any observed pressure or temperature anomalies will be immediately investigated and resolved, or injection will be stopped and further investigation of the incident assessed. After all injection ceases and the CO_2 plume stabilizes, Rayo Luna No. 1 will be plugged according to EPA and TRRC standards.

4.4 Above-Zone and USDW Monitoring Wells

[redacted] This well is intended to monitor the first permeable zone above the confining zone for indications of formation brine or CO_2 leaking out of the confining zone. Fluid sampling, gas detection tubes, temperature, and pressure anomalies are an early warning that injectate from Luz Solar No. 1 may be moving out of the injection interval.

4.4.1 General Outline of USDW Monitoring Well Design, [redacted]

The Sarah A. Quinn et al. No. 1 (42-291-04806) recompletion was designed with the following [redacted]

[redacted]

A detailed recompletion prognosis has been included in *Appendix D-6.* The mud and cement programs included in the prognosis are representative and may be modified before starting construction.

Surface Casing

[redacted] A CBL tool will be used to check the quality of the cementing job.

Summaries of the engineering calculations for the new surface casing are provided in Tables 4-38 through 4-40.

Table 4-38 – Monitoring Well Long-String Casing Engineering Calculation Results, [redacted]

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

Table 4-39 – Monitoring Well Long-String Casing Annular Geometries, [redacted]

Section	ID (in)	MD (ft)	TVD (ft)
[redacted]			

Table 4-40– Monitoring Well Long-String Casing Cement Calculation Results, [redacted]

Section	Footage (ft)	Capacity (ft^3/ft)	% Excess (%)	Cement Volume (ft^3)
[redacted]				

[redacted]

Figure 4-11 – [redacted] Monitoring Well Schematic

4.4.2 General Outline of AZM Monitoring Well Design, [redacted]

[redacted]

A detailed recompletion prognosis has been included in *Appendix D-8*. The mud and cement programs included in the prognosis are representative and may be modified before starting construction.

<u>Long-String Casing</u>

[redacted] A CBL tool will be used to check the quality of the cementing job. Summaries of the engineering calculations for the new long-string casing are provided in Tables 4-41 through 4-43.

Table 4-41 – Monitoring Well Long-String Casing Engineering Calculation Results, [redacted]

Description	Casing Wt. (lb/ft)	Setting Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)
[redacted]								

Table 4-42 – Monitoring Well Long-String Casing Annular Geometries, [redacted]

Section	ID (in)	MD (ft)	TVD (ft)
[redacted]			

Table 4-43 – Monitoring Well Long-String Casing Cement Calculation Results, [redacted]

Section	Footage (ft)	Capacity (ft^3/ft)	% Excess (%)	Cement Volume (ft^3)
[redacted]				

[redacted]

Figure 4-12 – [redacted] Monitoring Well Schematic

4.4.3 Tubing

[redacted]

Tables 4-44 and 4-45 provide the tubing specifications, design criteria, and calculated safety factors for each monitoring well. Because there will be no injection in these wells, the collapse design assumes evacuated tubing with a [redacted]
The burst assumes an evacuated annulus and a full column of [redacted]

Table 4-44 – Monitoring Well Tubing-Engineering Calculation [redacted]

Description	Tubing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

Table 4-45 – Monitoring Well Tubing-Engineering Calculation Results, [redacted]

Description	Tubing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in)	Drift ID (in)
[redacted]								

<u>Packer</u>

The monitoring tubing will be run in the monitoring wells with [redacted] packers as illustrated in Figure 4-13.

[redacted]

Figure 4-13 – [redacted] Packer

Monitoring Intervals

The [redacted] well will be perforated in the lowermost sand of the USDW to allow fluid samples to be taken for monitoring purposes. [redacted] well will be perforated across the first continuous sand above the UCZ, to allow fluid samples to be taken for monitoring purposes.

Table 4-46 – Monitoring Intervals

Well Name	API No.	Monitor Zone	Top Perforation (ft)	Bottom Perforation (ft)
[redacted]				

Wellhead Discussion

The wellheads are designed to accommodate anticipated working pressure. The final pressure rating will be confirmed before beginning the manufacturing process. The wellheads will be configured as illustrated in Figures 4-14 and 4-15 (note that the manufacturer may differ from the one shown).

[redacted]

Figure 4-14 – Monitoring Well Preliminary Wellhead Design, [redacted]

[redacted]

Figure 4-15 - Monitoring Well Preliminary Wellhead Design, [redacted]

4.5 Conclusion

Luz Solar No. 1 and its associated monitoring wells are designed to meet the requirements of Title 16, TAC **§5.203(e)** [40 CFR **§146.86**]. This design—with a robust monitoring, verification, and reporting (MRV) plan, as well as six barriers of construction to protect the USDWs—will allow for the safe injection and sequestration of CO_2.

Appendix D - Construction:

- Appendix D-1 Luz Solar No. 1 Proposed Well Schematic
- Appendix D-2 Luz Solar No. 1 Well Drilling and Completion Prognosis
- Appendix D-3 Rayo Luna No. 1 Proposed Well Schematic
- Appendix D-4 Rayo Luna No. 1 Well Drilling and Completion Prognosis
- Appendix D-5 [redacted] Proposed Well Schematic
- Appendix D-6 [redacted] Prognosis
- Appendix D-7 [redacted] Well Schematic
- Appendix D-8 [redacted] Prognosis

4.6 References

Craft, B., Holden, W., and Graves, E. (1962). Pipe Flow of Newtonian Liquids. In B. Craft, W. Holden, and E. Graves, *Well Design: Drilling and Production*, 18-24. Englewood Cliffs: Prentice-Hall, Inc.