Orchard Storage Company LLC

Underground Injection Control – Class VI Permit Application for

Orchard No. 1 to No. 7

Section 4 – Engineering Design and Operating Strategy

Gaines County, Texas

Prepared for *Orchard Storage Company LLC*
Houston, Texas

By
Lonquist Sequestration, LLC
Austin, TX

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LONQUIST SEQUESTRATION LLC

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 the seven proposed Orchard Project injection wells and associated monitoring wells. The details meet the requirements of Title 16, Texas Administrative Code (TAC) **§5.203(e)** [Title 40, U.S. Code of Federal Regulations (40 CFR) **§146.86**]. Class VI regulations include specific requirements for the design and operation of a carbon capture and storage (CCS) well. This section of the permit application addresses each of those requirements in detail.

4.2 Injection Well Design Strategy

4.2.1 Engineering Design

A Class VI CO_2 sequestration well must be designed to protect any Underground Source of Drinking Water (USDW) from any CO_2 injectate contamination. CO_2 mixed with formation fluids and other injectate components—a combination producing carbonic acid with a pH as low as 3—is highly corrosive to the metallurgy of many of the well components.

The design parameters for Orchard No. 1 through No. 7 and associated monitoring wells will therefore consider injection rates, volumes, pressures plus fluid properties, chemical properties of the injectate fluid, and estimated total storage volumes in the formation—thereby making the wells designed to withstand the corrosiveness of the injectate. Special metallurgies are considered for the casing, tubing, wellhead equipment, and downhole tools.

The drilling program also includes the types of cement used in the wellbore. The cement design and products used to cement the well will create good bonding between the casing and formations while withstanding the injectate fts corrosive nature. The cementing of the casings is designed with a sheath sufficient to (1) protect the wellbore from developing any channeling out of the injection interval, and (2) maintain the CO_2 below the upper confining zone (UCZ) [redacted] The annulus from total depth (TD) to 500 ft above the UCZ will be cemented with an acid-resistant cement.

[redacted]

The tubing and casing annulus pressures will be continuously monitored to ensure that well integrity is maintained. A Supervisory Control and Data Acquisition (SCADA) monitoring system will be in place throughout the life of the wells, able to measure and record downhole temperatures and pressures in the injection interval and monitor the size of the plume.

The monitoring systems include running a fiber optic and electric cable sensor package as the production casing string is run in the hole. The cable and sensors will then be cemented into place.

4.2.2 General Outline of Well Design

Orchard No. 1 through No.7 injection wells were designed with the following specifications:

- Conductor
  - [redacted]
- Surface Casing
  - [redacted]
  - Cemented back to surface
- Production Casing
  - [redacted]
  - [redacted]
  - Cemented back to surface
    - Cement to be comprised of the following:
      - +/- 500 ft above the top of the UCZ to surface – Type I/II salt saturated cement
      - TD to 500 ft above the UCZ – acid-resistant cement, as described in Appendix C-3.[1]
- Injection Tubing
  - [redacted]
  - Annular fluid to consist of corrosion-inhibitor fluid
    - Annular fluid to be designed prior to installation, based on well conditions, and may include corrosion inhibitors, surfactants, buffering agents, solvents
- Permanent Packer (displayed in Figure 4-1)
  - [redacted]

[1] Final vendor to be selected prior to const

  - [redacted]

- Wellhead (displayed in Figure 4-30, in *Section 4.2.10*)
  - [redacted]

Figure 4-1 illustrates how the production tubing will be run into the well with a [redacted]

[redacted]

Figure 4-1 – [redacted]

Before setting the packer, the tubing/production casing annulus will be filled with a noncorrosive fluid as approved by the UIC Director. Orchard anticipates that the annular fluid will be comprised of a treated freshwater with additional additive such as corrosion inhibitors, surfactants, buffering agents, or solvents. Final design will be based on wellbore conditions encountered. Pressure will be maintained and monitored on the annulus at a pressure that exceeds the operating injection pressure of the well.

Within 30 days after the completion of Orchard No. 1–No.7, Orchard Storage Company LLC (Orchard Storage) will file a complete record of the wells with the Underground Injection Control (UIC) Division showing the current completion details, per 16 TAC **§5.206 (c)(2).** A complete drilling and completion prognosis has been included in *Appendix C*. The mud and cement programs included in the prognosis are representative and may be modified before starting construction.

4.2.3 Orchard Project Design Specifics

Orchard Storage plans to inject between 252 and 663 thousand metric tons per year, on average, of captured carbon gas into the Orchard injection wells. These masses translate to rates of approximately 13.3 to 16.4 million standard cubic feet per day (MMscf/d) at standard conditions. These rates are the determining factor in selecting the size of the production tubing. Detailed modeling programs were run based on the size of the production string, properties and temperatures of the injectate, and the rate of injection, to determine the production-tubing grade and weight. The casing was then designed to accommodate the [redacted] tubing.

Table 4-1 shows the standard conditions of CO_2 used in the modeling and flow calculations.

Table 4-1 – CO_2 Standard Conditions

Temperature °F	Pressure psia	Density lbm/cu ft	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 was run, considering calculated pipe-friction losses, exit velocities, and economic considerations. Detailed reservoir-engineering model runs estimated the bottomhole injection pressures (BHIPs) over time (Figure 4-3). The data in Figure 4-3 not only identifies when the maximum BHIP occurs during project life and the resulting maximum injection pressure at the surface, but also allows for the proper design of the casing, tubing, and wellhead configurations.

Table 4-2 provides the pipeline specifications for the CO_2 stream to be injected in the Orchard injection wells.

Table 4-2 – [redacted]

Component	Value
CO_2	[redacted]
Water	
Temperature	
H_2S	
Nitrogen	
Sulphur	
Oxygen	
Hydrocarbons	
Glycol	
Carbon Monoxide	
NO_x	
SO_x	
Particulates	
Amines	
Hydrogen	
Mercury	
Ammonia	
Argon	
Liquids	
Lube Oil	

Parameters for the injectate composition were [redacted], for input into the reservoir model. The chemical composition modeled is outlined in Table 4-3.

Table 4-3 – CO_2 Injection Composition

Composition	% mole
[redacted]	

Injection tubing size of 4 ½ in. has been selected for the Orchard wells based on anticipated injection rates and bottomhole pressures output from the simulation model.

Tables 4-4 and 4-5 provide the input parameters from the plume model and assumptions used in the determination of the tubing hydraulics. Parameters tabulated in Table 4-4 were calculated using input parameters listed in Table 4-5. Wellhead pressure was determined by calculating a multi-segment pressure traverse starting with the known bottomhole pressure.

Table 4-6 lists the top and base of the injection zone, and the upper and lower perforations, for each well in both subsurface depths and measured depths (from ground level elevation).

Table 4-4 – Calculated Injection Parameters, Orchard No. 1-No. 7

Parameter	Orchard No. 1	Orchard No. 2	Orchard No. 3	Orchard No. 4	Orchard No. 5	Orchard No. 6	Orchard No. 7
Formation Temperature (Mid-Perforation) - (°F)	[redacted]						
Formation Pressure (Mid-Perforation) - (psi)	[redacted]						
Formation Density at Reservoir Conditions (lb/ft^3)	[redacted]						
Injectate Density in Formation (lb/ ft^3)	[redacted]						
Wellhead Injection Pressure (typical) - (psi)	[redacted]						
Wellhead Injection Temperature (typical) - (°F)	[redacted]						
Bottomhole Injection Pressure (typical)	[redacted]						
Bottomhole Injection Temperature (typical) - (°F)	[redacted]						
Average Wellbore Density (lb/ ft^3)	[redacted]						
Pipe Friction Pressure Loss (psi)	[redacted]						
Fluid Column Head Pressure (psi)	[redacted]						

*lb/ft^3 – pounds per cubic fo[redacted]

Table 4-5 – Input Parameters for Wellbore Calculations, Orchard No. 1-No. 7

Parameter	Orchard No. 1	Orchard No. 2	Orchard No. 3	Orchard No. 4	Orchard No. 5	Orchard No. 6	Orchard No.7	Source
Bottomhole Injection Pressure (typical) - (psi)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Pipeline Delivery Pressure (psi)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Pipeline Delivery Temperature (°F)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Depth for BHP value (ft)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Injection Rate (Typical) - (MMscf/d)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tubing Inner Diameter (in.)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

*BHP – bottomhole pressure

Table 4-6 – Injection Depth References by Well

Reference Point	Depth Reference	Well Number						
		1	2	3	4	5	6	7
Surface elevation	[redacted]							
Top of injection zone	[redacted]							
Base of injection zone	[redacted]							
Upper perforation	[redacted]							
Lower perforation	[redacted]							
Top of injection zone	[redacted]							
Base of injection zone	[redacted]							
Upper perforation	[redacted]							
Lower perforation	[redacted]							
Total well depth	[redacted]							

The pressure differential (Δp) between the top and base of each segment is affected by a combination of the friction pressure and hydrostatic head. 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 is calculated based on the injected fluid density within that segment, evaluated at that segment fts average temperature and pressure. The multi-segment approach of calculating the pressure traverse allows for consideration of variations in the injected fluid fts density and viscosity with temperature and pressure.

The injected fluid temperatures at wellhead and bottomhole conditions are affected initially by the temperature and pressure of the fluid in the pipeline. When the pressure is reduced from pipeline to wellhead pressure, the injected fluid will cool due to Joule-Thompson (JT) effects. As the fluid moves down the wellbore, it will be subject to warming from the surrounding rock as well as temperature changes induced by JT effects as the pressure increases.

From a starting pipeline-outlet pressure and temperature, the JT effects on the injected fluid temperature were calculated over a range of pressures, using Computer Modelling Group fts (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 4-2 shows how injected fluid temperature varies with pressure at different pipeline outlet temperatures. Heat transfer from the surrounding formation has been estimated to add 8°F to the BHT as determined by JT effects. Wellhead temperature is determined by the JT effects between the pipeline outlet and the calculated wellhead pressure, with no additional heat transfer from the surrounding environment.

[redacted]

Figure 4-2 – Injected Fluid Temperature Vs. Pressure

Given the pressures and temperatures calculated for the Orchard Project wells, the injected fluid will remain in the dense phase (liquid or supercritical) from the time it enters the Orchard Storage site through its path into the subsurface storage interval. At the surface, fluid temperature is below the critical temperature (above which supercritical fluid is found). Temperature and pressure will increase as the fluid moves down the tubing and into the storage reservoir, by which time the injected fluid has transitioned (without actual phase change) into the supercritical phase. Figure 4-3 shows a phase diagram for CO_2 for Orchard No. 1, as an example, highlighting its supercritical state within the formation.

[redacted]

Figure 4-3 – CO_2 Flow Conditions

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

- [redacted]

4.3 Detailed Discussions of Individual Orchard Well Designs

Based on the general well design requirements as discussed in Section 4.2, the specifics of each well design and their associated engineering calculations are included in Section 4.3.1 to 4.3.7. Additionally, the drilling and completion prognosis for each injection well is included in *Appendix C-1 Injection Well Prognoses.*

4.3.1 Orchard Well No. 1 Design

Figure 4-4 provides the design schematic for Orchard No. 1.

[redacted]

Figure 4-4 – Orchard No. 1 Wellbore Schematic

4.3.1.1 Conductor Casing

[redacted]

4.3.1.2 Surface Casing

The surface hole will be drilled with a [redacted] bit with casing set approximately [redacted], which is below the lowermost 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. This will help to ensure a quality cement bond and create two barriers between the USDW formation and wellbore during the remaining drilling operations. Cement will be circulated to the surface, and a top job will be provided, if needed, should the cement level fall after the cement has been circulated to the surface. After cementing, a cement bond log will be run to evaluate and verify good bonding throughout the surface hole. Once the production casing has been run and cemented to the surface, there will be four barriers between the USDW formation and the wellbore.

The calculations used for the design criteria of the surface casing are as follows:

Tensile stress = casing weight x length = 40.5 lb/ft x 2,000 ft = **81,000 lbs**

Collapse pressure = length x max mud weight x 0.052 ft^3/ppg = 2,000 ft x 12.5 ppg x 0.052 ft^3/ppg = **1,300 psi**

Burst Pressure = length x max mud weight x 0.052 ft^3/ppg= 2,000 ft x 12.5 ppg x 0.052 ft^3/ppg = **1,300 psi**

These equations are used to calculate all subsequent design criteria.

Based on the current stimulation case, a maximum injection bottomhole gradient was set to 0.6 psi/ft, which is 90% of the estimated frac gradient of 0.67 psi/ft. Therefore, a conservative mud weight of 12.5 was applied to all casing collapse/burst calculations and corresponds to a gradient of 0.65 psi/ft. This gradient exceeds the maximum bottomhole gradient expected and does not exceed fracture pressure.

Summaries of engineering calculations for the surface casing for Orchard No. 1 are provided in Tables 4-7 through 4-9.

Table 4-7 – Injection Well Surface Casing Engineering Calculations, Orchard No. 1

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

*lb/ft – pound per foot; bbl/ft – barrels per foot

Table 4-8 – Injection Well Surface Casing Annular Geometries, Orchard No. 1

Section	ID	MD	TVD
[redacted]			

TVD – true vertical depth

Table 4-9 – Injection Well Surface Casing Cement Calculations, Orchard No. 1

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

* ft^3/ft – cubic feet per foot

To ensure that cement returns to the surface are achieved, 100% excess openhole volumes will be used. The equipment and cement will be on location to perform a top job if needed.

4.3.1.3 Production Casing

The production (i.e., long-string) casing is the final, permanently cemented string of casing installed in the well, to be run from the surface to TD then cemented back to the surface. There are several critical design criteria for the long string:

- [redacted]
- Fiber optic/electric cable along the exterior of the casing

- Integration of tools such as a galvanic crossover, float equipment, and centralizers
- Acid-resistant cement systems from 500 ft above the UCZ through the injection interval to TD

A detailed metallurgical analysis was performed that considered the chemical composition of the injectate and downhole conditions (Table 4-2) and is included in *Appendix D*. When dry, CO_2 is not considered corrosive. [redacted] The production casing will be installed using premium connections.

The production casing will be cemented with acid-resistant tail cement from TD to 500 ft above the UCZ. These additives will protect the cement in the annulus from carbonic acid damage and prevent channeling. The cement is intended to maintain good bonding between formation and casing to preserve integrity and maximize the life of the well. The annular section from the top of the UCZ to surface will be cemented with a Type I/II salt saturated cement (Figure 4-2, page 8). A detailed proposal for the cement is provided in Appendix C-3. This proposal is representative of materials to be used. Final vendor and product selection will be made prior to beginning construction and will meet or exceed what is included in this proposal. The cement system proposed here is applicable to all seven injection wells.

The engineering and design parameters for the production casing are summarized in Table 4-10 through 4-12.

Table 4-10 – Injection Well Production Casing Engineering Calculations, Orchard 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 4-11 – Injection Well Production Casing Annular Geometries, Orchard No. 1

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

Table 4-12 – Injection Well Production Casing Cement Calculations, Orchard No. 1

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

4.3.1.4 Downhole Monitoring System

The Orchard injection wells will have a continuous downhole monitoring system in place throughout the life of the well. The system will be able to measure and record downhole temperatures and pressures in the injection interval and allow for vertical seismic profile (VSP) surveys of the CO_2 plume. The system will include fiber optic cable with an electric cable sensor package run along the backside of the production casing and cemented in place. Surface monitoring of the injection stream is further described in Section 4.3.8.

4.3.1.5 Centralizers

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

- Above the shoe joint
- Above the float collar
- Subsequent five joints of casing
- Every fourth joint (160 ft) to surface

[redacted] centralizers will be run on the surface casing.

Centralizer placement for the [redacted] production casing will be designed to install the fiber optic cable. Clamp and eccentric centralizers of the same alloy as the production casing will be utilized to ensure the fiber optic cable is not damaged.

- Two slide-on, eccentric centralizers will be placed across a two-joint shoe track. A cable clamp will be installed above the top eccentric centralizer for security.
- Clamp centralizers will be run every four joints (160 ft) to the surface, and cable detection clamps will be run every three to four joints.
- Fiber module protectors will be installed every five to six joints.

4.3.1.6 Injection Tubing

The injection tubing size was selected based on the injection volumes, rates, and injectate composition, as discussed in Section 4.2. The injectate composition and the potential for a corrosive environment were considered when determining the metallurgy of the tubing as it was for the casing string. 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 D* of this application.) Considering the potential for the presence of carbonic acid, [redacted]

Table 4-13 lists the tubing specifications, design criteria, and calculated safety factors for Orchard No. 1. The burst design assumes evacuated tubing with brine on the backside, and 4,000 psi applied. The collapse assumes an evacuated annulus, a full column of 12 pounds per gallon (lb/gal) mud with 4,000 psi applied.

Table 4-13 – Injection Tubing Specifications, Orchard No. 1

[redacted]

4.3.2 Orchard Well No. 2 Design

Figure 4-5 provides the design schematic for Orchard No. 2.

[redacted]

Figure 4-5 – Orchard No. 2 Wellbore Schematic

4.3.2.1 Conductor Casing

[redacted]

4.3.2.2 Surface Casing

The surface hole will be drilled with a [redacted] bit with casing set approximately [redacted] which is below the lowermost USDW. A string of [redacted] casing will be run and cemented with the casing centered in the open hole using centralizers.

Summaries of engineering calculations for the surface casing are provided in Tables 4-14 through 4-16.

Table 4-14 – Injection Well Surface Casing Engineering Calculations, Orchard No. 2

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

Table 4-15 – Injection Well Surface Casing Annular Geometries, Orchard No. 2

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

Table 4-16 – Injection Well Surface Casing Cement Calculations, Orchard No. 2

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

To ensure that cement returns to the surface are achieved, 100% excess openhole volumes will be used. The equipment and cement will be on location to perform a top job if needed.

4.3.2.3 Production Casing

The engineering and design parameters for the production casing are summarized in the Tables 4-17 through 4-19.

Table 4-17 – Injection Well Production Casing Engineering Calculations, Orchard No. 2

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

Table 4-18 – Injection Well Production Casing Annular Geometries, Orchard No. 2

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

Table 4-19 – Injection Well Production Casing Cement Calculations, Orchard No. 2

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

4.3.2.4 Downhole Monitoring System

The Orchard injection wells will have a continuous downhole monitoring system in place throughout the life of the well. The system will be able to measure and record downhole temperatures and pressures in the injection interval and allow for vertical seismic profile (VSP) surveys of the CO_2

plume. The system will include fiber optic cable with an electric cable sensor package run along the backside of the production casing and cemented in place.

4.3.2.5 Centralizers

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

- Above the shoe joint
- Above the float collar
- Subsequent five joints of casing
- Every fourth joint (160 ft) to surface

[redacted] centralizers will be run on the surface casing.

Centralizer placement for the [redacted] production casing will be designed to install the fiber optic cable. Clamp and eccentric centralizers of the same alloy as the production casing will be utilized to ensure the fiber optic cable is not damaged.

- Two slide-on, eccentric centralizers will be placed across a two-joint shoe track. A cable clamp will be installed above the top eccentric centralizer for security.
- Clamp centralizers will be run every four joints (160 ft) to the surface, and cable detection clamps will be run every three to four joints.
- Fiber module protectors will be installed every five to six joints.

4.3.2.6 Injection Tubing

Table 4-20 lists the tubing specifications, design criteria, and calculated safety factors. The burst design assumes evacuated tubing with brine on the backside, and 4,000 psi applied. The collapse assumes an evacuated annulus, a full column of 12 lb/gas mud with 4,000 psi applied.

Table 4-20 – Injection Tubing Specifications, Orchard No. 2

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

4.3.3 Orchard Well No. 3 Design

Figure 4-6 provides the design schematic for Orchard No. 3.

[redacted]

Figure 4-6 – Orchard No. 3 Wellbore Schematic

4.3.3.1 Conductor Casing

[redacted]

4.3.3.2 Surface Casing

The surface hole will be drilled with a [redacted] bit with casing set approximately [redacted] which is below the lowermost USDW. A string of [redacted] casing will be run and cemented with the casing centered in the open hole using centralizers.

Summaries of engineering calculations for the surface casing are provided in Tables 4-21 through 4-23.

Table 4-21 – Injection Well Surface Casing Engineering Calculations, Orchard No. 3

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

Table 4-22 – Injection Well Surface Casing Annular Geometries, Orchard No. 3

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

Table 4-23 – Injection Well Surface Casing Cement Calculations, Orchard No. 3

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

To ensure that cement returns to the surface are achieved, 100% excess openhole volumes will be used. The equipment and cement will be on location to perform a top job if needed.

4.3.3.3 Production Casing

The engineering and design parameters for the production casing are summarized in \Tables 4-24 through 4-26:

Table 4-24 – Injection Well Production Casing Engineering Calculations, Orchard No. 3

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 – Injection Well Production Casing Annular Geometries, Orchard No. 3

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

Table 4-26 – Injection Well Production Casing Cement Calculations, Orchard No. 3

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

4.3.3.4 Downhole Monitoring System

The Orchard injection wells will have a continuous downhole monitoring system in place throughout the life of the well. The system will be able to measure and record downhole temperatures and pressures in the injection interval and allow for vertical seismic profile (VSP) surveys of the CO_2 plume. The system will include fiber optic cable with an electric cable sensor package run along the backside of the production casing and cemented in place.

4.3.3.5 Centralizers

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

- Above the shoe joint
- Above the float collar
- Subsequent five joints of casing
- Every fourth joint (160 ft) to surface

[redacted] centralizers will be run on the surface casing.

Centralizer placement for the [redacted] production casing will be designed to install the fiber optic cable. Clamp and eccentric centralizers of the same alloy as the production casing will be utilized to ensure the fiber optic cable is not damaged.

- Two slide-on, eccentric centralizers will be placed across a two-joint shoe track. A cable clamp will be installed above the top eccentric centralizer for security.
- Clamp centralizers will be run every four joints (160 ft) to the surface, and cable detection clamps will be run every three to four joints.
- Fiber module protectors will be installed every five to six joints.

4.3.3.6 Injection Tubing

The injection tubing size was selected based on the injection volumes, rates, and injectate composition.

Table 4-27 lists the tubing specifications, design criteria, and calculated safety factors. The burst design assumes evacuated tubing with brine on the backside, and 4,000 psi applied. The collapse assumes an evacuated annulus, a full column of 12 pounds per gallon mud with 4,000 psi applied.

Table 4-27 – Injection Tubing Specifications, Orchard No. 3

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

4.3.4 Orchard Well No. 4 Design

Figure 4-7 provides the design schematic for Orchard No. 4.

[redacted]

Figure 4-7 – Orchard No. 4 Wellbore Schematic

4.3.4.1 Conductor Casing

The [redacted]

4.3.4.2 Surface Casing

The surface hole will be drilled with a [redacted] bit with casing set approximately [redacted], which is below the lowermost USDW. A string of [redacted] casing will be run and cemented with the casing centered in the open hole using centralizers.

Summaries of engineering calculations for the surface casing are provided in Tables 4-28 through 4-30.

Table 4-28 – Injection Well Surface Casing Engineering Calculations, Orchard No. 4

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

[redacted]

Table 4-29 – Injection Well Surface Casing Annular Geometries, Orchard No. 4

Section	ID (in.)	MD (ft)	TVD (ft)

[redacted]

Table 4-30 – Injection Well Surface Casing Cement Calculations, Orchard No. 4

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

[redacted]

To ensure that cement returns to the surface are achieved, 100% excess openhole volumes will be used. The equipment and cement will be on location to perform a top job if needed.

4.3.4.3 Production Casing

The engineering and design parameters for the production casing are summarized in Tables 4-31 through 4-33.

Table 4-31 – Injection Well Production Casing Engineering Calculations, Orchard No. 4

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

Table 4-32 – Injection Well Production Casing Annular Geometries, Orchard No. 4

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

Table 4-33 – Injection Well Production Casing Cement Calculations, Orchard No. 4

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

4.3.4.4 Downhole Monitoring System

The Orchard injection wells will have a continuous downhole monitoring system in place throughout the life of the well. The system will be able to measure and record downhole temperatures and pressures in the injection interval and allow for vertical seismic profile (VSP) surveys of the CO_2

plume. The system will include fiber optic cable with an electric cable sensor package run along the backside of the production casing and cemented in place.

4.3.4.5 Centralizers

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

- Above the shoe joint
- Above the float collar
- Subsequent five joints of casing
- Every fourth joint (160 ft) to surface

[redacted] centralizers will be run on the surface casing.

Centralizer placement for the [redacted] production casing will be designed to install the fiber optic cable. Clamp and eccentric centralizers of the same alloy as the production casing will be utilized to ensure the fiber optic cable is not damaged.

- Two slide-on, eccentric centralizers will be placed across a two-joint shoe track. A cable clamp will be installed above the top eccentric centralizer for security.
- Clamp centralizers will be run every four joints (160 ft) to the surface, and cable detection clamps will be run every three to four joints.
- Fiber module protectors will be installed every five to six joints.

4.3.4.6 Injection Tubing

Table 4-34 lists the tubing specifications, design criteria, and calculated safety factors. The burst design assumes evacuated tubing with brine on the backside, and 4,000 psi applied. The collapse assumes an evacuated annulus, a full column of 12 lb/gal mud with 4,000 psi applied.

Table 4-34 – Injection Tubing Specifications, Orchard No. 4

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

4.3.5 Orchard Well No. 5 Design

Figure 4-8 provides the design schematic for Orchard No. 5.

[redacted]

Figure 4-8 – Orchard No. 5 Wellbore Schematic

4.3.5.1 Conductor Casing

[redacted]

4.3.5.2 Surface Casing

The surface hole will be drilled with a [redacted] bit with casing set approximately [redacted] which is below the lowermost USDW. A string of [redacted] casing will be run and cemented with the casing centered in the open hole using centralizers.

Summaries of engineering calculations for the surface casing are provided in the following tables (4-35 through 4-37):

Table 4-35 – Injection Well Surface Casing Engineering Calculations, Orchard No. 5

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

Table 4-36 – Injection Well Surface Casing Annular Geometries, Orchard No. 5

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

Table 4-37 – Injection Well Surface Casing Cement Calculations, Orchard No. 5

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

To ensure that cement returns to the surface are achieved, 100% excess openhole volumes will be used. The equipment and cement will be on location to perform a top job if needed.

4.3.5.3 Production Casing

The engineering and design parameters for the production casing are summarized in Tables 4-38 through 4-40.

Table 4-38 – Injection Well Production Casing Engineering Calculations, Orchard No. 5

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 – Injection Well Production Casing Annular Geometries, Orchard No. 5

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

Table 4-40 – Injection Well Production Casing Cement Calculations, Orchard No. 5

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

4.3.5.4 Downhole Monitoring System

The Orchard injection wells will have a continuous downhole monitoring system in place throughout the life of the well. The system will be able to measure and record downhole temperatures and pressures in the injection interval and allow for vertical seismic profile (VSP) surveys of the CO_2 plume. The system will include fiber optic cable with an electric cable sensor package run along the backside of the production casing and cemented in place.

4.3.5.5 Centralizers

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

- Above the shoe joint
- Above the float collar
- Subsequent five joints of casing
- Every fourth joint (160 ft) to surface

[redacted] centralizers will be run on the surface casing.

Centralizer placement for the [redacted] production casing will be designed to install the fiber optic cable. Clamp and eccentric centralizers of the same alloy as the production casing will be utilized to ensure the fiber optic cable is not damaged.

- Two slide-on, eccentric centralizers will be placed across a two-joint shoe track. A cable clamp will be installed above the top eccentric centralizer for security.
- Clamp centralizers will be run every four joints (160 ft) to the surface, and cable detection clamps will be run every three to four joints.
- Fiber module protectors will be installed every five to six joints.

4.3.5.6 Injection Tubing

Table 4-41 lists the tubing specifications, design criteria, and calculated safety factors. The burst design assumes evacuated tubing with brine on the backside, and 4,000 psi applied. The collapse assumes an evacuated annulus, a full column of 12 lb/gal mud with 4,000 psi applied.

Table 4-41 – Injection Tubing Specifications, Orchard No. 5

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

4.3.6 Orchard Well No. 6 Design

Figure 4-9 provides the design schematic for Orchard No. 6.

[redacted]

Figure 4-9 – Orchard No. 6 Wellbore Schematic

4.3.6.1 Conductor Casing

[redacted]

4.3.6.2 Surface Casing

The surface hole will be drilled with a [redacted] bit with casing set approximately [redacted] which is below the lowermost USDW. A string of [redacted] casing will be run and cemented with the casing centered in the open hole using centralizers.

Summaries of engineering calculations for the surface casing are provided in Table 4-42 through 4-44.

Table 4-42 – Injection Well Surface Casing Engineering Calculations, Orchard No. 6

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

Table 4-43 – Injection Well Surface Casing Annular Geometries, Orchard No. 6

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

Table 4-44 – Injection Well Surface Casing Cement Calculations, Orchard No. 6

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

To ensure that cement returns to the surface are achieved, 100% excess openhole volumes will be used. The equipment and cement will be on location to perform a top job if needed.

4.3.6.3 Production Casing

The engineering and design parameters for the production casing are summarized in Tables 4-45 through 4-47.

Table 4-45 – Injection Well Production Casing Engineering Calculations, Orchard No. 6

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

Table 4-46 – Injection Well Production Casing Annular Geometries, Orchard No. 6

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

Table 4-47 – Injection Well Production Casing Cement Calculations, Orchard No. 6

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

4.3.6.4 Downhole Monitoring System

The Orchard injection wells will have a continuous downhole monitoring system in place throughout the life of the well. The system will be able to measure and record downhole temperatures and pressures in the injection interval and allow for vertical seismic profile (VSP) surveys of the CO_2 plume. The system will include fiber optic cable with an electric cable sensor package run along the backside of the production casing and cemented in place.

4.3.6.5 Centralizers

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

- Above the shoe joint
- Above the float collar
- Subsequent five joints of casing
- Every fourth joint (160 ft) to surface

[redacted] centralizers will be run on the surface casing.

Centralizer placement for the [redacted] production casing will be designed to install the fiber optic cable. Clamp and eccentric centralizers of the same alloy as the production casing will be utilized to ensure the fiber optic cable is not damaged.

- Two slide-on, eccentric centralizers will be placed across a two-joint shoe track. A cable clamp will be installed above the top eccentric centralizer for security.
- Clamp centralizers will be run every four joints (160 ft) to the surface, and cable detection clamps will be run every three to four joints.
- Fiber module protectors will be installed every five to six joints.

4.3.6.6 Injection Tubing

Table 4-48 lists the tubing specifications, design criteria, and calculated safety factors. The burst design assumes evacuated tubing with brine on the backside, and 4,000 psi applied. The collapse assumes an evacuated annulus, a full column of 12 pounds per gallon mud with 4,000 psi applied.

Table 4-48 – Injection Tubing Specifications, Orchard No. 6

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

4.3.7 Orchard Well No.7 Design

Figure 4-10 provides the design schematic for Orchard No. 7

[redacted]

Figure 4-10 – Orchard No. 7 Wellbore Schematic

4.3.7.1 Conductor Casing

[redacted]

4.3.7.2 Surface Casing

The surface hole will be drilled with a [redacted] bit with casing set approximately [redacted], which is below the lowermost USDW. A string of [redacted] casing will be run and cemented with the casing centered in the open hole using centralizers.

Summaries of engineering calculations for the surface casing are provided in Tables 4-49 through 4-51.

Table 4-49 – Injection Well Surface Casing Engineering Calculations, Orchard No. 7

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

Table 4-50 – Injection Well Surface Casing Annular Geometries, Orchard No. 7

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

Table 4-51 – Injection Well Surface Casing Cement Calculations, Orchard No. 7

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

To ensure that cement returns to the surface are achieved, 100% excess openhole volumes will be used. The equipment and cement will be on location to perform a top job if needed.

4.3.7.3 Production Casing

The engineering and design parameters for the production casing are summarized in Tables 4-52 through 4-54.

Table 4-52 – Injection Well Production Casing Engineering Calculations, Orchard No. 7

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

Table 4-53 – Injection Well Production Casing Annular Geometries, Orchard No. 7

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

Table 4-54 – Injection Well Production Casing Cement Calculations, Orchard No. 7

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

4.3.7.4 Downhole Monitoring System

The Orchard injection wells will have a continuous downhole monitoring system in place throughout the life of the well. The system will be able to measure and record downhole temperatures and pressures in the injection interval and allow for vertical seismic profile (VSP) surveys of the CO_2

plume. The system will include fiber optic cable with an electric cable sensor package run along the backside of the production casing and cemented in place.

4.3.7.5 Centralizers

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

- Above the shoe joint
- Above the float collar
- Subsequent five joints of casing
- Every fourth joint (160 ft) to surface

[redacted] centralizers will be run on the surface casing.

Centralizer placement for the [redacted] production casing will be designed to install the fiber optic cable. Clamp and eccentric centralizers of the same alloy as the production casing will be utilized to ensure the fiber optic cable is not damaged.

- Two slide-on, eccentric centralizers will be placed across a two-joint shoe track. A cable clamp will be installed above the top eccentric centralizer for security.
- Clamp centralizers will be run every four joints (160 ft) to the surface, and cable detection clamps will be run every three to four joints.
- Fiber module protectors will be installed every five to six joints.

4.3.7.6 Injection Tubing

Table 4-55 lists the tubing specifications, design criteria, and calculated safety factors. The burst design assumes evacuated tubing with brine on the backside, and 4,000 psi applied. The collapse assumes an evacuated annulus, a full column of 12 pounds per gallon mud with 4,000 psi applied.

Table 4-55 – Injection Tubing Specifications, Orchard No. 7

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

4.3.8 Wellhead Discussion

The wellheads are designed to accommodate anticipated working pressures and eliminate corrosion complications. The wellhead equipment will be manufactured from a combination of stainless-steel components across the hanger and casing spool. Inconel lining will be placed across trims, stems, gates, valves, etc. The final pressure rating will be confirmed before beginning the manufacturing process. The wellheads for each of the Orchard No. 1 to No.7 injection wells will be configured as shown in Figure 4-11 (note: the manufacturer of the wellhead may differ).

Figure 4-12 illustrates the control valves and monitoring equipment that will be installed at Orchard No. 1 to No. 7. As described in Section 5.5.1, the injection stream will be continuously monitored to meet 16 TAC **§5.203 (j)(2)(B)** [40 CFR **§146.90(b)]** requirements. A Supervisory Control and Data Acquisition (SCADA) system will be installed at the Project Orchard site to facilitate the operational data collection, monitoring, and reporting. In accordance with 16 TAC **§5.206 (d)(2)(B)**, the total volume of CO_2 injected into the Orchard Project facility will be metered through either a master meter or a series of master meters. The volume or mass of CO_2 injected into Orchard wells No. 1 through No. 7 will be metered through individual well meters.

Continuous monitoring of the injected CO_2 stream pressure and temperature will be performed using digital pressure and temperature gauges installed at individual well sites. A flowmeter will also be installed on each of the injection wells and connected to the SCADA system at the CO_2 storage site, to ensure continuous monitoring and control of the CO_2 injection rate.

The wellhead (wellhead and tree assembly) will accommodate continuous annular pressure measurement and injection pressure (tubing pressure) measurement. As described in Section 5.4.7, injection wells, the tree and well injection skid will be continuously monitored via the SCADA system and will be equipped with automated shutdown systems. These systems include, at a minimum, an actuated master valve and an actuated wing valve to automatically shut down flow in the event of an emergency.

[redacted]

Figure 4-11 –Preliminary Wellhead Design, Orchard No. 1 to No. 7

[redacted]

Figure 4-12 – Typical Injection Well and Injection Skid Flow Schematic

4.3.9 Testing and Logging During Drilling and Completion Operations

4.3.9.1 Deviation Surveys

Deviation checks will be taken every 100 ft during drilling operations. The overall maximum allowable deviation of the wellbore is 3 degrees, and the maximum allowable deviation for any 100-ft segment is 1 degree.

4.3.9.2 Coring Plan

As discussed in the drilling procedures in *Appendix C-1 and C-2*, core samples will be collected during the drilling of the Orchard wells. Specifically, Orchard intends to obtain whole core in well Nos. 1, 3, 6, 7 and MW No. 1. The core sampling will target the UCZ, the injection interval, and the lower confining zone. The estimated depths for each core section are provided in Table 4-56. In addition, Table 4-56 specifies whole core to be acquired in the Orchard MW No. 1 in the Queen formation, the first permeable zone above the UCZ. Decisions regarding rotary side wall cores will be determined based on each openhole log and, if obtained, the whole core recovery will supplement the necessary analysis as needed.

Whole core will be acquired, preserved as necessary, and transported to lab facilities for further analysis. Whole core will be subjected to routine whole core analysis including spectral gamma, photography, CT scan and then slabbed and will be plugged in selected intervals. Core plugs will be further analyzed for the relevant reservoir properties. Orchard intends to conduct special core analysis (SCAL) on selected samples to measure mechanical properties, capillary pressure and other reservoir properties. Table 4-57 provides additional specifics of anticipated core analysis.

Table 4-56 – Core Plan Summary Table

[redacted]

Table 4-57 – Proposed Core Analysis

[redacted]

1. Entire core
2. Plugs selections based on core recovery and openhole logs
3. If possible

4.3.9.3 Logging Plan

An extensive suite of electric logs (detailed in Tables 4-58 and 4-59) will be run in the openhole sections and each casing string. Orchard Storage will provide a schedule of all logging plans to the Director at least 30 days prior to conducting the first test. Notice will be provided at least 48 hours in advance of such activity.

Table 4-58 – Injection Well Openhole Logging Plan

Trip	Hole Section	Logging Suite	Target Data Acquisition	Open Hole Diameter	Depths of Survey
1	Surface Casing	Triple Combo (Gamma Ray (GR), Spontaneous Potential (SP), Photoelectric (PE), Resistivity, Neutron, Density)	Identification of Rock Properties	[redacted]	
2		Sonic (Dipole)			
3		Openhole Caliper			
4	Production Casing	Triple Combo (GR, SP, PE, Resistivity, Neutron, Density)	Identification of Rock and Fluid Properties		
5		Sonic (Dipole)			
6		Openhole Caliper			
7		Fullbore Formation Microimager (FMI)			
8		Sidewall Cores (as needed)			
9		Repeat Formation Tester (RFT)/ Modular Formation Dynamics Tester (MDT)			
10		Spectral GR			

The RFT/MDT highlighted in the openhole logging plan will be used to collect representative baseline samples of the injection zone formation fluids prior to the start of injection. These samples will be collected, transferred to appropriate shipping containers for transport to a lab to perform the necessary testing to characterize the formation fluids for baseline chemistry and composition. The detailed parameters to be collected are provided in Table 17 in the Quality Assurance and Surveillance Plan provided in Appendix E.

Table 4-59 – Injection Well Cased-Hole Logging Plan

Trip	Hole Section	Logging Suite	Target Data Acquisition	Casing Dimension	Depths of Survey
1	Surface Casing	Ultrasonic, Casing Collar Locator (CCL), Cement Bond Log (CBL), Cement Mapping Tool (CMT), GR, Temperature, VDL	Cement Investigation	[redacted]	[redacted]
2	Production Casing	Ultrasonic, CCL, CBL, CMT, GR, Temp (Bond Log), VDL	Cement Investigation	[redacted]	[redacted]
3		Pulsed Neutron Log – Baseline		[redacted]	[redacted]

4.3.9.4 Formation Fluid Testing

Before setting the production casing string, samples of the formation fluid will be obtained by running an openhole fluid recovery tool. Recovery sections will be determined based on openhole evaluations. Multiple samples will be taken per section based upon results of the openhole logs. Data collected during testing and logging will include formation fluid temperature, pH, conductivity, reservoir pressure and static fluid level. Additionally, drawdown and buildup tests, as described in *Section 5 – Testing and Monitoring Plan*, will be performed to further quantify reservoir properties.

4.3.9.5 Fracture Pressure Determination, Injection Zone - Step-Rate Test and Core Analyses

After the initial injection interval is perforated, a step-rate test will be performed in the injection zone prior to any stimulation work, as discussed in *Section 5*. The purpose of this test is to quantify the injectivity potential and the fracture pressure of the injection zone. Additionally, the special core analysis from the injection zone will be used to further determine the fracture pressure of this zone.

4.3.9.6 Fracture Pressure Determination, Upper Confining Zone – Core Analyses

Fracture pressure determination for the confining zone will be obtained as part of the special core analysis of the samples from the confining zone. No step-rate test will be performed in the confining zone to avoid fracturing of the confining zone.

4.3.10 Completion/Stimulation Plans

Following the approval to inject, the injection zone will be stimulated to create fractures with a half-length on the order of 25 ft. This fracture half-length will limit vertical growth of the fractures.

Actual stimulation design will be determined based on log analysis and core results. This stimulation design is expected to yield a completion [redacted]. The fracture stimulation will serve two purposes, the first of which is that the stimulation will create a negative completion skin that will reduce injection pressure vs. an unstimulated case. Second, stimulation of the perforated intervals throughout the injection zone will ensure good injection conformance, distributing injected CO_2 throughout the injection interval.

Orchard anticipates that the stimulation fluid would be a slickwater fracture fluid designed appropriately to generate the desired response in the injection formation once fully defined from drilling operations. Final fluid composition will be determined and identified based on log and core analysis.

4.3.11 Orchard Injection Well Operating Strategy

The Orchard Project injection wells will be operated per the following parameters provided in Table 4-60. The BHP output from the dynamic simulation model is calculated at the reference layer (for this model, the shallowest perforated layer) and corrected internally by the simulator to the defined BHP reference depth (presented in the "Depth for BHP Value" field in Table 4-5), using a gradient of 0.39 psi/ft defined as a model input. In the cases where the BHP reference depth is a few feet from the top perforation depth, a correction has been applied based on the difference in elevation between the BHP reference depth and the top perforation depth using the same 0.39 psi/ft gradient, as shown in the following example for Orchard No. 6. This well has the largest difference between the simulator BHP reference depth and top perforation depth.

BHP Reference Depth	*1,893 ft subsea*
Top Perforation Depth	*1,881 ft subsea*
Elevation difference to top perforation (ft)	*-12 ft*
Wellbore gradient (defined in model)	*0.39 psi/ft*
Maximum BHP at reference depth	*2,722.4 psi*
Correction to top perforation	*-4.8 psi*
Maximum BHP at top perforation	*2,717.6 psi*

Under downhole wellbore and reservoir conditions, the CO_2 will stay in the supercritical phase throughout the project life. Figures 4-13 through 4-19 show the plots of the maximum pressure increase vs. time at the Orchard injection well locations. These plots represent the maximum of all grid blocks penetrated by the injection well at any given time.

The maximum annular pressure will be 200 psi over the maximum injection pressure.

Table 4-60 – Orchard Injection Well Operating Parameters

Parameter	Orchard No. 1	Orchard No. 2	Orchard No. 3	Orchard No. 4	Orchard No. 5	Orchard No. 6	Orchard No. 7
[redacted]							

Surface and bottomhole injection pressures will be continuously monitored during injection, with surface injection rates and pressures adjusted as necessary, to ensure that bottomhole pressures remain below maximum pressure limits. The maximum injection pressure limits will be set to 90% of the formation fracture pressure, as determined from step-rate and/or microfracture tests. These tests will be performed during the early stages of project development, prior to commencement of injection. In the current simulation case, the maximum injection bottomhole gradient was set to 0.6 psi/foot, which corresponds to 90% of an estimated 0.67 psi/foot fracture gradient. The fracture pressure gradient is calculated using the equation developed by Eaton (Eaton, 1969) using typical values, as shown in the example below:

$$FG = \frac{\nu}{1-\nu}(OBG - PG) + PG$$

$$FG = \frac{0.31}{1-0.31}(1.0 - 0.40) + 0.40$$

$$FG = 0.67\ psi/ft$$

Where	*FG*	=	Fracture gradient, psi/foot
	OBG	=	Overburden gradient
	PG	=	Pore pressure gradient
and	ν	=	Poisson's Ratio

It should be noted that the calculation above is an example. Fracture pressure and injection pressure limits will be updated once step-rate and/or microfracture tests have been completed during project development.

Figures 4-13 through 4-19 show the injection rates and bottomhole pressures for the Orchard injection wells and the anticipated maximum injection pressure limits. The maximum injection pressure limit has been determined by applying the 0.6 psi (90% of 0.67 psi estimated fracture pressure) limit to the depth of the shallowest perforations. At no time does the modeled injection pressure exceed this injection pressure limit.

[redacted]

Figure 4-13 – Injection Pressure Plot, Orchard No. 1

[redacted]

Figure 4-14 – Injection Pressure Plot, Orchard No. 2

[redacted]

Figure 4-15 – Injection Pressure Plot, Orchard No. 3

[redacted]

Figure 4-16 – Injection Pressure Plot, Orchard No. 4

[redacted]

Figure 4-17 – Injection Pressure Plot, Orchard No. 5

[redacted]

Figure 4-18 – Injection Pressure Plot, Orchard No. 6

[redacted]

Figure 4-19 – Injection Pressure Plot, Orchard No. 7

The completion and operating strategy for all seven injection wells is as follows:

- The gross injection interval will be perforated at the initial completion.
- The injectate fluids will be injected throughout the entire injection interval.
- Plume migration surveys will be conducted every five years to contrast actual plume development with the simulated plume model.
- The wellbore will have continual monitoring of bottomhole pressures and temperatures throughout the life of the well.

4.3.12 Orchard Injection Wells Operational Summary

Orchard No. 1 through No. 7 are designed to maximize the available pore space and safely sequester CO_2. Formation pressures and temperatures will be measured within each wellbore and used to update the plume model and refine future injection strategies. This process will provide accurate evaluation and 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 wells will be plugged as discussed in *Section 6 – Injection Well Plugging Plan*.

4.4 Above Confining Zone Monitoring Wells

Orchard Storage plans to drill and complete two above confining zone monitoring wells, Orchard MW No. 1 and Orchard MW No. 3. These wells are intended to monitor the first permeable zone above the confining interval, [redacted]. The monitoring wells will be located in the expected critical pressure front and will monitor for indications of CO_2 leaking out of the confining zone. Temperature and pressure anomalies within [redacted] are an early warning of injectate from Orchard No. 1–No. 7 moving out of the injection zone. These wells will not penetrate the confining zone and therefore will not need to consider acid-resistant materials in their construction.

4.4.1 General Outline of Monitoring Well Design, Orchard MW No. 1 and MW No. 3

The Orchard MW No. 1 and MW No. 3 wells were designed with the following specifications (as shown in Figures 4-20 and 4-21):

- Conductor
  - [redacted]
- Surface Casing
  - To be set below the lowermost USDW, per the GAU (estimated setting depth is [redacted] ft).
  - [redacted]
  - Cemented back to surface
- Production Casing
  - [redacted]
- Tubing – [redacted]
- Wellhead
  - [redacted]

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

[redacted]

Figure 4-20 – Orchard MW No. 1 Monitoring Wellbore Schematic

[redacted]

Figure 4-21 – Orchard MW No. 3 Monitoring Wellbore Schematic

4.4.1.1 Conductor Casing

To ensure that hole integrity can be maintained during the initial drilling of the well, [redacted]

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

4.4.1.2 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. This will help to ensure a quality cement bond and create two barriers between the USDW formation and wellbore during the remaining drilling operations. Cement will be circulated to the surface, and a top job will be provided, if needed, should the cement level fall after the cement has been circulated to the surface. After cementing, a cement bond log will be run to evaluate and verify good bonding throughout the surface hole. Once the production casing has been run and cemented to the surface, there will be four barriers between the USDW formation and the wellbore.

Summaries of engineering calculations for the surface casing are provided in Table 4-61 through 4-63.

Table 4-61 – Monitoring Well Surface Casing Engineering Calculations, Orchard MW No. 1 and MW No. 3

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

Table 4-62 – Monitoring Well Surface Casing Annular Geometries, Orchard MW No. 1 and MW No. 3

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

Table 4-63 – Monitoring Well Surface Casing Cement Calculations, Orchard MW No. 1 and MW No. 3

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

To ensure that cement returns to the surface are achieved, 100% excess openhole volumes were used. The equipment and cement will be on location to perform a top job if needed.

4.4.1.3 Production Casing

The production (i.e., long-string) casing is the final, permanently cemented string of casing installed in the well, to be run from the surface to TD then cemented back to the surface. As this well does not penetrate the UCZ, acid-resistant cements and tubulars were not considered.

The engineering and design parameters for the production casing for Orchard MW No. 1 are summarized in Tables 4-64 through 4-66.

Table 4-64 – Monitoring Well Production Casing Engineering Calculations, Orchard MW 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 4-65 – Monitoring Well Production Casing Annular Geometries, Orchard MW No. 1

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

Table 4-66 – Monitoring Well Production Casing Cement Calculations, Orchard MW No. 1

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

The engineering and design parameters for the production casing for Orchard MW No. 3 are summarized in the following tables (4-67 through 4-69):

Table 4-67 – Monitoring Well Production Casing Engineering Calculations, Orchard MW No. 3

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

Table 4-68 – Monitoring Well Production Casing Annular Geometries, Orchard MW No. 3

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

Table 4-69 – Monitoring Well Production Casing Cement Calculations, Orchard MW No. 3

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

4.4.1.4 Centralizers

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

- Above the shoe joint
- Above the float collar
- Subsequent five joints of casing
- Every fourth joint (160 ft) to surface

[redacted] centralizers will be run on the surface casing.

The bow-spring centralizer placement for the [redacted] production casing strings is designed to ensure a continuous, uniform column of cement throughout [redacted] The recommended locations will be as follows:

- Above the shoe joint
- Above the float collar
- Subsequent five joints of casing
- Every fourth joint (160 ft) to surface

[redacted] total centralizers will be run on the production casing.

4.4.1.5 Tubing

The tubing strings will consist of [redacted] tubing and a permanent packer assembly. The tubing string will be used to collect fluid samples above the UCZ.

Tables 4-70 and 4-71 list the tubing specifications, design criteria, and calculated safety factors. Since there will be no injection in this well, the burst design assumes evacuated tubing with brine on the backside, with 500 psi applied on the annulus. The collapse assumes an evacuated annulus, a full column of 11 pounds per gallon mud with 1,000 psi applied.

Table 4-70 – Monitoring Well Tubing Engineering Calculations- Orchard MW 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 4-71 – Monitoring Well Tubing Engineering Calculations- Orchard MW No. 3

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

4.4.1.6 Packer

The production tubing will be run in the well with a [redacted] permanent packer, with a latch-in seal assembly as shown in Figure 4-22.

[redacted]

Figure 4-22 – [redacted] Seal Assembly & Permanent Packer

4.4.1.7 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 shown in Figure 4-23 (note: the manufacturer may differ from the one shown).

[redacted]

Figure 4-23 – Orchard Monitoring Wells Preliminary Wellhead Design

4.4.2 Testing and Logging of Orchard MW No. 1 and MW No. 3 During Drilling and Completion Operations

A suite of electric logs will be run in the openhole sections and each casing string for Orchard MW No. 1 and MW No. 3. The logging plan is detailed in Tables 4-72 and 4-73. Orchard Storage will provide a schedule of all logging plans to the Director at least 30 days prior to conducting the first test. Notice will be provided at least 48 hours in advance of such activity.

Table 4-72 – Openhole Logging Plan

Trip	Hole Section	Logging Suite	Target Data Acquisition	Open Hole Diameter	MW No. 1	MW No. 3
1	Surface Casing	Triple Combo (GR, SP, PE, Resistivity, Neutron, Density)	Identification of Rock Properties	[redacted]		
2		Sonic (Dipole)				
3	Production Casing	Triple Combo (GR, SP, PE, Resistivity, Neutron, Density)	Identification of Rock Properties			
4		Sonic (Dipole)				
5		Spectral GR				

Table 4-73 – Cased-Hole Logging Plan

Trip	Hole Section	Logging Suite	Target Data Acquisition	Casing Dimension	Depths of Survey	
1	Surface Casing	Ultrasonic, CCL, CBL, CMT, GR, Temp (Bond Log)	Cement Investigation	[redacted]		
2	Production Casing	Ultrasonic, CCL, CBL, CMT, GR, Temp (Bond Log)	Cement Investigation			
3		Pulsed Neutron Log – Baseline				

4.4.3 Overview of Well Completion Program

After setting and cementing the production casing, the production tubing string will be run. The completion program includes the following:

- Make bit and scraper run to TD.
- Run cased hole logs as described in Table 4-70.
- Test the casing.
- Perforate the Queen formation, specific depths to be determined with openhole logs.
- Pump-in test to ensure fluid and pressure communication with the formation.
- Displace the hole with corrosion-resistant packer fluid.
- Run tubing and packer to depth, set and test the same.

4.5 In-Zone Monitoring Well

Orchard Storage is proposing to use an existing well, the [redacted] as an in-zone monitoring well. This well will be in the pressure front AOR and used to not only monitor pressures and temperatures of the injection interval, but also determine the extent of the CO_2 plume from the Orchard No. 1–No. 7 injection wells. Because this well is not in the CO_2 plume, it will not require specialty metallurgy considerations.

4.5.1 Orchard MW No. 2 Conversion

The [redacted] is currently classified by the TRRC as a [redacted] Orchard Storage proposes to recomplete this well as an in-zone monitoring well. Orchard is in negotiations to acquire this wellbore and has had no access to open hole log information. Publicly available data indicates that a full suite of open hole logs were run along with extensive side wall cores in 2019. Once this data is received it will be incorporated into the Orchard subsurface analysis. Orchard has received a copy of the [redacted] Pressure and temperature gauges will be installed on the tubing in the final completion.

4.5.1.1 Recompletion Program

Orchard Storage proposes the following steps to recomplete this well:

- Move in and rig up workover unit.
- Install the wellhead or other pressure-control equipment.
- Unseat packer and pull tubing out of hole.
- [redacted]

- [redacted]

Figure 4-24 shows the current schematic for the existing wellbore. Figure 4-25 shows the proposed recompletion design.

[redacted]

Figure 4-24 – [redacted] Current Wellbore Schematic

[redacted]

Figure 4-25 – Orchard MW No. 2 Proposed Wellbore Schematic

4.5.1.2 Tubing

The tubing strings will consist of [redacted] tubing and a permanent packer assembly. The tubing string will be used to collect fluid samples above the UCZ.

Table 4-74 lists the tubing specifications, design criteria, and calculated safety factors for Orchard MW No. 2. Since there will be no injection in this well, the burst design assumes evacuated tubing with brine on the backside, with 500 psi applied on the annulus. The collapse assumes an evacuated annulus, a full column of 11 pounds per gallon mud with 1,000 psi applied.

Table 4-74 – Monitoring Well Tubing Engineering Calculations – Orchard MW No. 2

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

4.5.1.3 Packer

The production tubing will be run in the well with a [redacted] permanent packer, with a latch-in seal assembly as shown in Figure 4-22 (in *Section 4.4.1.6*).

4.5.2 Monitoring Well Operational Strategy Summary

Continuous monitoring will be implemented with the use of SCADA to monitor the tubing pressure as well as the tubing and casing annulus pressure. If pressure or temperature anomalies are observed, injection will be stopped, and the incident will be assessed.

The location for this project is ideally situated for carbon sequestration monitoring purposes. Combining the best engineering practices in the design of the well with a state-of-the-art monitoring system and robust reservoir management strategy, this monitoring well will help to safely store CO_2 for years to come.

Detailed drilling and completion procedures are provided in *Appendix C.*

Appendix C – Well Construction Schematics and Procedures:

- Appendix C-1 Injection Well Drilling and Completion Prognoses
- Appendix C-2 Monitoring Well Drilling and Completion Prognoses

4.6 References

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