TITAN
CARBON SEQUESTRATION

Underground Injection Control – Class VI Permit Application for

Cronos No. 1 and Rhea No. 1

Jefferson County, Texas

SECTION 4 – ENGINEERING DESIGN AND OPERATING STRATEGY

February 2024

LONQUIST SEQUESTRATION LLC

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4.1 Introduction

The following section describes the engineering design details and operational strategies employed during the planning of the Titan Carbon Sequestration Project's (Titan Project) proposed injection wells Cronos No. 1 and Rhea No. 1. The engineering design details meet the requirements of Title 16, Texas Administrative Code (16 TAC) **§5.203(e)** [Title 40, U.S. Code of Federal Regulations (40 CFR) **§146.86**].

The design, construction, and operation of injection wells fall under the jurisdiction of the EPA Underground Injection Control (UIC) program. Class VI injection wells are designed for the sole purpose of safely injecting and storing CO_2 into selected injection zones. The wells are designed to ensure protection of all Underground Sources of Drinking Water (USDWs) through the drilling, completion, injection, and plugging phases.

The two proposed injection wells of the Titan Project are centrally located near various surrounding industrial companies whose facilities produce high levels of CO_2 as a by-product. Titan Carbon Sequestration, LLC (Titan) proposes to inject CO_2 into the Lower Miocene sands. The approximately [redacted] feet (ft) of gross vertical sands are highly porous, highly permeable, saline-filled, and interbedded with shale layers to isolate each potential zone of injection. These reservoir properties make it an excellent candidate for the safe injection and containment of CO_2.

The specific requirements for the design of a carbon capture and sequestration (CCS) Class VI well are described in the following sections.

4.2 Engineering Design

The design of Titan's proposed Cronos No. 1 and Rhea No. 1 injection wells was developed to consider the volumes and rates of injection, chemical composition, and physical properties of the injectate fluid, corrosion and metallurgical evaluations, and operational requirements to maintain reservoir management for the duration of the wells.

Carbon sequestration wells are designed along parameters and considerations similar to those for acid-gas injection wells, including special metallurgies. While CO_2 is not inherently hazardous, when it is mixed with water under the right conditions, carbonic acid can form with a pH as low as 3. As with all classes of injection wells, the protection of USDWs is critically important. These wells are designed to prevent CO_2 from migrating above the upper confining zone (UCZ).

Additionally, these injection wells must ensure the protection of other subsurface natural resources. For this reason, the proposed CO_2 sequestration components of the wells, including the casing, tubing, packer, wellhead equipment, and downhole tools, are designed to withstand the corrosive environment to which they will be exposed. The cement slurries used in the wells and products selected are designed to fill the annuli from total depth to surface, create a good bond between the casing and formations, provide good compressive strengths, and withstand the nature of the corrosive fluids.

The CO_2 injectate will be sequestered in the Miocene sands, where the upper and lower confining shale zones will contain the CO_2 injectate. Intermittent layers of shales exist throughout the injection interval that will also act as additional vertical barriers to help control the migration of CO_2 plumes within each discrete injection stage. The injection interval sands are located from approximately [redacted] ft true vertical depth (TVD). The sand formations are porous, permeable, and unconsolidated—making them favorable for CO_2 injection and storage.

Once injection operations have ceased in a stage of the injection zone, that injection stage will be plugged back to isolate that stage. The next sand interval above that stage will then be perforated. The injectate will then be injected into and stored in that new stage until the predetermined amount of time—or the adjusted time—is reached. The above process will be repeated until the uppermost injection stage below the UCZ is reached. The stages and depths for this process are illustrated in Tables 4-1 and 4-2 for Cronos No. 1 and Rhea No. 1, respectively. The CO_2 plume will be monitored during and after injection to ensure that the plume follows the expectations of the model.

Table 4-1 – Cronos No. 1 Operational Strategy

Stage	Top Perf (ft)	Bottom Perf (ft)	Gross Thickness (ft)	Net Pay (ft)	Duration (yrs)
[redacted]					

Table 4-2 – Rhea No. 1 Operational Strategy

Stage	Top Perf (ft)	Bottom Perf (ft)	Gross Thickness (ft)	Net Pay (ft)	Duration (yrs)
[redacted]					

The wellbore will be designed with [redacted] inch (in.) long string casing to a depth of approximately [redacted] ft. That casing will then be crossed over to [redacted] casing at approximately [redacted] above the top of the UCZ. That casing will be run to total depth (TD) and set at approximately [redacted] ft into the lower confining zone. The injection tubing will be [redacted]

[redacted]. The tubing will be run in conjunction with a subsurface injection valve (SSIV) and a [redacted] packer with tail pipe. The packer will be located approximately [redacted] ft above the lowest stage that will be perforated. The SSIV, packer and tail pipe will be [redacted] material or equivalent.

The plugging of the lower stage and recompletion of the next highest stage will be performed using a workover rig and wireline unit. The fiber optic/electric cable lines with temperature and pressure gauges will be installed to allow for the continuous monitoring of the casing and tubing annulus. This will help to ensure that wellbore and mechanical integrity are maintained.

Figures 4-1 and 4-2 show the proposed wellbore designs for the Titan Project.

[redacted]

Figure 4-1 – Cronos No. 1 Wellbore Schematic

[redacted]

Figure 4-2 – Rhea No. 1 Wellbore Schematic

The drilling and completion design for Cronos No. 1 is as follows:

- Drive Pipe
  - [redacted] ft (or 200 blows/ft)
- Surface Casing
  - To be set below the lowermost USDW
    - The USDW will be determined by means of openhole logging during the drilling of the well. If necessary, the final setting depth will be adjusted.
    - The current estimated setting depth is [redacted] ft TVD. [redacted]
  - [redacted]
  - Cemented to surface
- Long string Casing
  - [redacted] in. hole size
  - [redacted] in. outer diameter (OD) casing set to TD of well
    - [redacted]
  - Cemented back to surface
    - Cement to be comprised of:
      - [redacted]
- Injection Tubing
  - [redacted]
  - Tubing annulus will be filled with a noncorrosive fluid
  - [redacted]
- Injection Packer
  - [redacted]
- Wellhead
  - [redacted]

[redacted]
- Figure 4-1 illustrates the above and additional details.

The drilling and completion design for Rhea No. 1 is as follows:

- Drive Pipe
  - [redacted] (or 200 blows/ft)
- Surface Casing
  - To be set below the lowermost USDW
  - [redacted]
  - Cemented to surface
- Long string Casing
  - [redacted] OD casing set to TD of the well
  - [redacted]
  - Cemented back to surface
    - Cement to be comprised of:
      - [redacted]
- Injection Tubing
  - [redacted]
  - Tubing annulus will be filled with a non-corrosive fluid.
  - [redacted]
- [redacted]acker [redacted] configuration
  - [redacted]
- Wel[redacted]head
  - [redacted]

[redacted]

- Figure 4-2 illustrates the above and additional details.

A detailed drilling-and-completion prognosis is included in *Appendix D*.

4.2.1 Detailed Discussion of Injection Well Design

Titan plans to inject a maximum volume of [redacted] million metric tons per year (MMT/yr) of captured CO_2 into each of the proposed wells. At standard conditions, this mass translates to a rate of approximately [redacted] million standard cubic feet per day (MMscf/D). Detailed reservoir modeling was performed by considering the properties of the injectate, rate of injection, and injection pressures to determine the size, weight, and grade of the tubing to be used in the well.

Table 4-3 shows the standard conditions of CO_2 used in the modeling and flow calculations.

Table 4-3 – CO_2 Inlet 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 | ft^3 – cubic foot

A tubing design sensitivity was run that considered calculated pipe-friction losses, exit velocities, compression requirements, and economic evaluations. Bottomhole pressures (BHPs) were calculated from detailed reservoir-engineering model runs as shown in Figures 4-3 and 4-4. The data identifies when the maximum BHP occurs during the life of the project, and the resulting maximum flowing pressure at the surface—allowing for the proper design of the casing, tubing, and wellhead configurations.

[redacted]

Figure 4-3 – Injection Pressure Plot for Cronos No. 1

[redacted]

Figure 4-4 – Injection Pressure Plot for Rhea No. 1

For the reservoir model, 100% CO_2 was used for the injectate stream. The anticipated chemical composition of the pipeline CO_2 is outlined in Table 4-4.

Table 4-4 – Injectate Parameters

Component	Value
[redacted]	

The input injection parameters from the model, for both injection wells, are shown in Table 4-5. The calculated injection parameters are shown in Table 4-6 for Cronos No. 1 and Table 4-7 for Rhea No. 1.

Table 4-5 – Input Injection Parameters for Cronos No. 1 and Rhea No. 1

Inputs	Cronos No. 1	Rhea No. 1
Maximum Injection Rate (MMT/yr)	[redacted]	
Pressure Constraint Gradient (psi/ft)		
Injection Duration (yrs)		
[redacted] Tubing Inner Diameter (ID) (in.)		
[redacted] Tubing Setting Depth (ft)		
Absolute Roughness Factor		
Wellhead Temperature (°F)		

Table 4-6 – Calculated Injection Parameters for Cronos No. 1

Stage	Year	Max Rate (MMT/yr)	Avg Rate (MMT/yr)	Max BHP (psi)	Avg BHP (psi)	Max WHP (psi)	Avg WHP (psi)
[redacted]							

Stage	Year	Max Rate (MMT/yr)	Avg Rate (MMT/yr)	Max BHP (psi)	Avg BHP (psi)	Max WHP (psi)	Avg WHP (psi)
[redacted]							

The results from running the model, using the inputs listed, indicate that [redacted] tubing is the appropriate size to inject the desired volumes of supercritical CO_2 into each well. The results also verified that the CO_2 injectate would continue to remain in a supercritical state within the wellbores.

Based on appropriate bit-size selection, pipe-clearance considerations, and recommended annular spacing for assurance of proper cementing, the following casing sizes are appropriate to accommodate the [redacted] injection tubing.

[redacted]

Drive Pipe

Because of the loose, unconsolidated nature of the sediments found immediately beneath the waterline, drive pipe will be needed to ensure that the hole integrity is maintained during the initial drilling of Cronos No. 1 and Rhea No. 1. A [redacted] drive pipe will be used in both wells and driven either to [redacted] ft or to refusal (at approximately 200 blows/ft of advancement) by a hydraulic ram.

The drive pipe size was selected to facilitate the desired bit size requirement for the drilling of the surface casing. With an ID of [redacted] bit can be used for developing the next section of the well. Once the drive pipe is installed, the inner portions of the pipe will be flushed out and cleaned, and drilling will commence.

Surface Casing

The surface hole will be drilled t [redacted] casing will be run and cemented with the casing centered using centralizers in the open hole. The selected hole size and centralizers will provide a consistent thickness of cement between the casing and the open hole. Cement returns will be circulated to surface. [redacted] This process provides a good cement bond from the surface-casing setting depth to the surface, protecting the USDW. After cementing, a cement bond log will be run to evaluate and verify good bonding throughout the surface hole.

Summaries of engineering calculations for the surface casing are displayed in Tables 4-8 to 4-10. The engineering calculations for both injection wells in this project were performed assuming identical wellbore conditions and setting depth for surface casing.

Table 4-8 – Surface Casing Engineering Calculations for Cronos No. 1 and Rhea No. 1

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)	Thermal Conductivity (W/m / °C)
[redacted]									

Table 4-9 – Surface Casing Annular Geometries for Cronos No. 1 and Rhea No. 1

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

Table 4-10 – Surface Casing Volume Calculations for Cronos No. 1 and Rhea No. 1

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

To ensure that cement returns to surface are achieved, 100% excess of openhole volumes were used to calculate cement volume.

Long String Casing

Due to the unconsolidated nature of the Miocene sands targeted for injection in these wells, the long string casing will be run all the way to each well's TD. The long string casing will be cemented from the casing-shoe setting depth back to surface.

The following are key design criteria to be used for the long string of casing:

- [redacted]
- Integration of tools such as float equipment, and centralizers

- CO_2-compatible cement systems from [redacted]
- [redacted]

A detailed metallurgical analysis was performed that considered the chemical composition of the injectate and downhole conditions as shown in Table 4-3 (*Section 4.2.1*) and included in *Appendix E*. The injectate stream is made up of [redacted] Based on the analysis of the injectate stream and downhole conditions, the long string casing will be [redacted] material to prevent corrosion and downhole failures, should any fluids enter the wellbore from the reservoir.

The long string will be cemented with CO_2-compatible cement from [redacted] above the UCZ—to provide a good barrier across the UCZ and the top of the injection level, to prevent CO_2 migration out of the injection interval. Above the CO_2-compatible cement, the well will be cemented from that point to the surface with a high-quality blended Portland cement.

The Miocene sand for Cronos No. 1 and Rhea No. 1 is approximately [redacted] ft thick. The sand is interbedded with layers of shale above each sand layer that will act as barriers to confine the CO_2 injectate below the UCZ. The completion strategy for both wells will be designed to start injecting at the lowest stage selected. The CO_2 injectate will be injected for a predetermined amount of time derived from the reservoir-injection plume modeling. Once that stage has reached its maximum injection time, that stage will be plugged. The plugging of the lower stage and recompletion of the next highest stage will be performed using a workover rig and wireline unit.

Each stage will be permanently plugged by setting a corrosion-resistant bridge plug [redacted] plug of CO_2-compatible cement will then be placed on top of the bridge plug. The [redacted] in. casing will be perforated into the next stage above the bridge plug and cement. The [redacted] This process will be repeated throughout the life of each well until the uppermost stage is completed. [redacted] injection stages are planned for Cronos No. 1 and [redacted] for Rhea No. 1, as determined from type logs and injection-modeling results.

Throughout the life of both wells, a FOC, TEC and sensor package will be installed behind the long string casing and cemented into place. This equipment will be used to perform vertical seismic profile (VSP) surveys of the plume and record formation temperatures and pressures in each injection interval. This ability is considered part of the overall long-term monitoring system of the wells. As the life of the wells progresses, the installed system can monitor data from the plugged zones as well as each new injection zone that will be completed.

The engineering and design parameters for the long string casing are summarized in Tables 4-11 through 4-16.

Table 4-11 – Long String Casing Engineering Calculations for Cronos No. 1

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)	Thermal Conductivity (W/m / °C)
[redacted]									

Table 4-12 – Long String Casing Engineering Calculations for Rhea No. 1

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)	Thermal Conductivity (W/m / °C)
[redacted]									

Table 4-13 – Long String Casing Annular Geometries for Cronos No. 1

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

Table 4-14 – Long String Casing Annular Geometries for Rhea Well No. 1

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

Table 4-15 – Long String Casing Volume Calculations for Cronos No. 1

Section – Long string	Footage (ft)	Capacity (ft^3)	Excess (%)	Cement Volume (ft^3)
[redacted]				

*An excess of 30% of openhole volumes was used to calculate cement volum

Table 4-16 – Long String Casing Volume Calculations for Rhea No. 1

Section – Long String	Footage (ft)	Capacity (ft^3)	Excess (%)	Cement Volume (ft^3)
[redacted]				

*An excess of 30% of openhole volumes was used to calculate cement volume.

<u>Centralizers</u>

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

[redacted]

[redacted]

Centralizer placement for the [redacted] in. long string casing is designed for the installation of the FOC and TEC. Clamped centralizers and eccentric centralizers will both be utilized to ensure the FOC and TEC are not damaged. The recommended procedure is as follows:

[redacted]

<u>Injection Tubing</u>

The [redacted] in. injection tubing size and material were selected for use in both wells based on modeling results from planned injection volumes, rates, and injectate composition. [redacted]. A complete summary of the metallurgical analysis is included in *Appendix E*. Tables 4-17 and 4-18 provide the design calculations for Cronos No. 1 and Rhea No. 1, respectively.

Table 4-17 – Tubing Engineering Design Calculations – Cronos No. 1

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)	Thermal Conductivity (W/m / °C)
[redacted]									

Table 4-18 – Tubing Engineering Design Calculations – Rhea No. 1

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)	Thermal Conductivity (W/m / °C)
[redacted]									

<u>Packer Discussion</u>

The [redacted] in. injection tubing will engage a [redacted] packer. A subsurface injection valve will be placed [redacted]. Several joints of [redacted]ail pipe will be run directly below the packer. Once the packer and tubing are installed, the tubing/casing annulus will be pressure tested for verification.

Figure 4-5 provides a schematic of the planned packer assembly.

[redacted]

Figure 4-5 – [redacted] Packer Illustration

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

Safety Injection Valve

In accordance with TAC **§5.206(d)(2)(F)(i)** [40 CFR **§146.88(e)(2)**], an SSIV will be installed in the [redacted] in. tubing just above the packer.

Pressure Gauge Array

Pressure and temperature gauges will be installed across the active injection interval to provide continuous data in real time for reservoir monitoring purposes. A TEC will be installed on the exterior of the long string casing to power the gauges and provide communication to the surface for both wells. A FOC will be installed on the exterior of the long string casing to provide temperature measurement, acoustic measurement and VSP survey capability for both wells.

Wellhead Discussion

The wellhead is designed to control working pressures and corrosion complications. The wellhead equipment will be manufactured to be National Association of Corrosion Engineers (NACE) and American Petroleum Institute (API) compliant using a combination of stainless-steel components and Inconel lining across the tubing hanger, casing adapter spool and lower master valve. The final pressure rating will be confirmed prior to the beginning of the manufacturing process. The wellhead will be configured as illustrated in Figure 4-6. The wellhead design and manufacturer shown may change based on well and commercial factors determined before drilling.

[redacted]

Figure 4-6 – Titan Injection Wells Cronos No. 1 and Rhea No. 1 Preliminary Wellhead Design

4.2.2 Completion/Stimulation Plans

Titan's proposed injection wells, Cronos No. 1 and Rhea No. 1, may be stimulated during completion operations, to clean up the well after drilling and/or to improve injection performance. Final stimulation designs will be determined based on the conditions met during drilling. Titan will submit proposed stimulation procedures to the UIC Director at least 30 days prior to beginning such operations. Such procedures may include the following activities:

[redacted]

4.3 <u>Testing and Logging During Drilling and Completion Operations</u>

In accordance with 16 TAC **§5.206(i)** [40 CFR **§146.87(f)**], Titan will submit a proposed schedule to the UIC Director for any planned testing and logging at least 30 days prior to conducting the first such activity. Titan will submit notice at least 48 hours in advance of any actual activity.

4.3.1 Coring Plan

[redacted] Core samples will be collected using [redacted] core barrels and engineering best practices, to attempt to recover high quality samples in the unconsolidated formations. If needed, sidewall cores may be collected during the drilling and testing of the injection wells to supplement the whole core analysis.

4.3.2 Logging Plan

An extensive suite of electric logs will be run in both the openhole and cased-hole sections of Cronos No. 1 and Rhea No. 1. The openhole logging plan is detailed in Table 4-19. The cased-hole logging plan is detailed in Table 4-20.

Table 4-19 – Openhole Logging Plan

Trip	Hole Section	Logging Suite	Openhole Diameter (in.)	Cronos No. 1 Depths (ft)	Rhea No. 1 Depths (ft)
[redacted]					

Table 4-20 – Cased-Hole Logging Plan

Trip	Hole Section	Logging Suite	Casing Dimension (in.)	Use	Cronos No. 1 Depths (ft)	Rhea No. 1 Depths (ft)
[redacted]						

Deviation checks will also be performed 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.

4.3.3 Formation Fluid Testing

Prior to setting the long string casing string, samples of the formation fluid will be obtained by running an openhole fluid recovery tool (MDT). Recovery sections will be determined based on openhole evaluations. Parameters to be measured include formation fluid temperature, pH, conductivity, reservoir pressure, and static fluid level of the injection zone as required by 16 TAC **§5.203(f)(3)(A)** [40 CFR **§146.87(c)**].

4.3.4 Step-Rate Test

Prior to the commencement of CO_2 injection, Titan will conduct a step-rate injectivity test to attempt to measure the fracture gradient of the proposed injection wells in compliance with 16 TAC **§5.203(f)(2)(A)** [40 CFR **§146.87(d)(1)**] and 16 TAC **§5.203(f)(2)(C)** [40 CFR **§146.87(e)(3)**]. A bottomhole pressure gauge and temperature gauge will be run to the bottom of the wellbore. A surface gauge with continuous readout will also be installed. All gauges will be calibrated prior to the test. Initial bottomhole pressure and temperature readings must be taken prior to beginning injection.

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

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

Equation 1:

(Eq. 1.0) $$Qm = \frac{Qv*\rho BH}{\rho \mathrm{SC}}$$

(Eq. 1.1) $\rho_{\mathrm{BH}}=(T_{\mathrm{BH}},P_{\mathrm{BH}},Fluid\ Composition) \leftarrow$ from $REFPROP\ software$

(Eq. 1.2) $\rho_{SC}=(T_{BH},P_{BH},Fluid\ Composition) \leftarrow$ from $REFPROP\ software$

Where:

Qv = Volumetric flow rate (bbl/day)

Qm = Mass flow rate (SCF/day)

T_{BH} = Temperature at bottomhole (°F)

ρ_{BH} = Pressure at bottomhole (°F)

ρ_{BH} = CO_2 density at bottomhole conditions pound per cubic foot (lb/ft^3)

ρ_{SC} = CO_2 density at standard conditions (lb/ft^3)

Testing Method

Specific wellbore and injection zone properties will define the final test parameters. The following test method outlines the expected test injection rates and times. [redacted] (Table 4-21, which also shows barrels per hour (bph) and per day (bpd)). The injection rates will be stepped up in increments until at least three measurements are taken both below and above the estimated formation fracture initiation pressure, [redacted] *Each stage duration will be based on the time required for the bottomhole pressure for the initial step to stabilize*.

Table 4-21 – Proposed Step-Rate Injection Test

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

4.4 Injection Well Operating Strategy

Titan plans to inject [redacted]/yr of CO_2 into each of the proposed injection wells, Cronos No. 1 and Rhea No. 1. This equates to an injection rate of [redacted]/D per well at standard atmospheric conditions. The gas will be compressed at the surface to around [redacted] pounds prior to injection. This pressure will be sufficient to move the gas into the formation and ensure that the gas achieves a supercritical phase or state of being. Because of the injection interval depths, the CO_2 will remain in liquified form until it is either absorbed into the connate fluid of the formation or is chemically bound to the existing geochemistry.

The BHP is calculated to increase by [redacted] psi, which will occur during the initial stages of injection, with the pressure dropping over time. The formation pressure at the extent of the plume migration is expected to rise by [redacted] psi. This relatively low buildup of pressure within the reservoir is a result of the injection intervals having such high porosities and permeabilities. These reservoir properties allow for the formation pressure to balance out and relieve itself much more readily than more restrictive geologies. The operating parameters for the proposed injection wells are provided in Table 4-22.

Table 4-22 – Injection Parameters

Parameter	Cronos No. 1	Rhea No. 1
Gross Injection Interval (ft)	[redacted]	
Average Injection Volume (MMT/yr)		
Average Injection Rate (MMscf/D)		
Maximum Surface Injection Pressure (psi)		
Expected Surface Injection Pressure (psi)		
Maximum Annular Pressure (psi)		

Surface injection pressures will be limited so that the BHP does not exceed 90% of the fracture pressure of the injection reservoir. The anticipated surface and bottomhole injection pressures and injection rates over time for the wells are shown in Tables 4-23 and 4-24.

Table 4-23 – Injection Pressures and Volumes by Stage, Cronos No. 1

Completion Stage	Completion Date	Top Depth (ft)	Fracture Pressure (psi)	Maximum Allowable Bottomhole Pressure (psi)
[redacted]				

Table 4-24 – Injection Pressures and Volumes by Stage, Rhea No. 1

Completion Stage	Completion Date	Top Depth (ft)	Fracture Pressure (psi)	Maximum Allowable Bottomhole Pressure (psi)
[redacted]				

To maximize the use of the available pore space, multiple injection intervals will be used. Each discrete injection interval was selected to maximize the utilization of the pore space and collectively maximize the usage of the acreage position for CO_2 sequestration. A summary of the planned injection strategy is listed in Table 4-25 for Cronos No. 1 and Table 4-26 for Rhea No. 1.

Table 4-25 – Injection Intervals – Cronos No. 1

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

Table 4-26 – Injection Intervals – Rhea No. 1

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

The operating plan was devised to optimize reservoir pore space and plume expansion management. The loosely consolidated Miocene sands, while ideal for carbon sequestration due to their significant thicknesses and high porosities and permeabilities, also pose complications to operational considerations. Miocene sands require substantial reservoir management practices to facilitate a controlled injection operation. Unlike typical injection wells, the plume growth will be controlled by a complex series of injection operations over multiple intervals over time.

Because of the differences in physical properties between CO_2 and the connate brine in the formation, plume modeling indicates that the injectate will rush to the shallowest portions of the opened sand packages first, with the small amounts of supercritical fluid migrating upward, to the uppermost portion of the injection interval. This effect is because the CO_2 is less dense than brine. Typical densities for the injectate range from [redacted]

The result is a significant "mushroom cap" effect, with the top of the mushroom expanding outward in a nearly uncontrolled fashion (Figure 4-7).

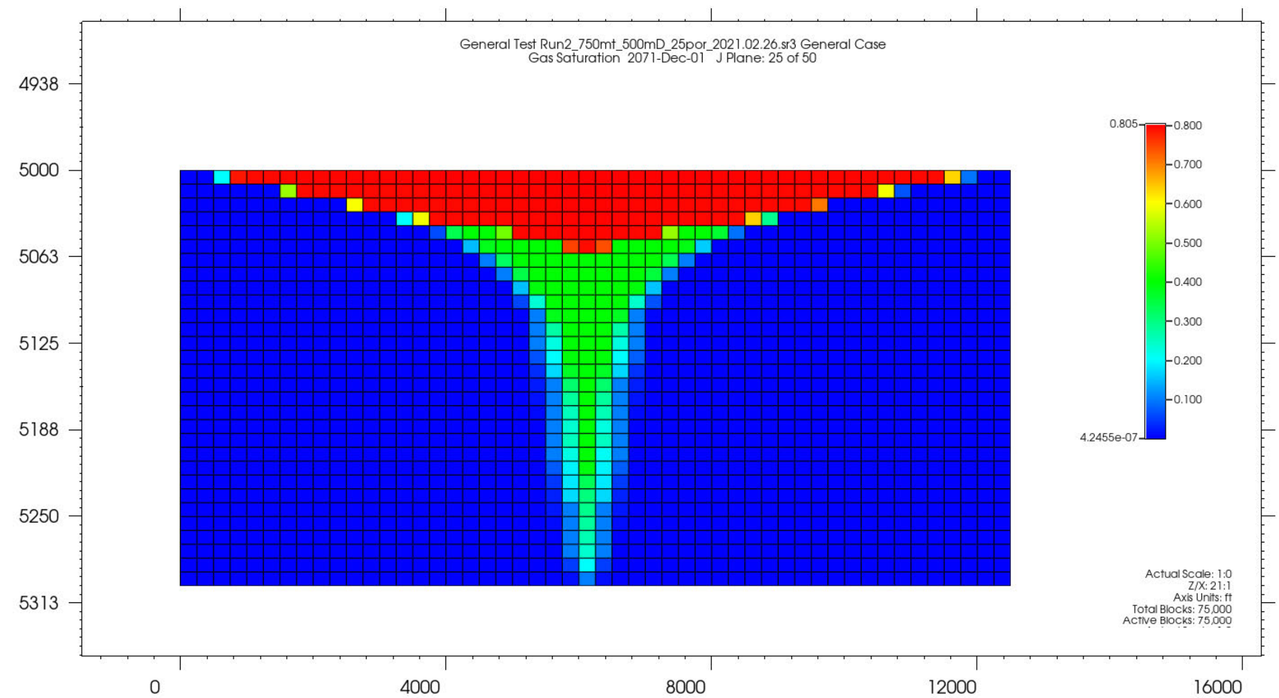

Figure 4-7 – Typical Plume Profile in High Permeability Formations

Figure 4-7 shows that injected fluids occupy only approximately 5%–10% of the total pore space—an inefficient use of available formation pore space. Also, since pore space rights for carbon sequestration wells are determined by the lateral extent of the farthest-reaching portion of the plume, this result is not desirable.

As such, reservoir management is important for injection wells in thick, loose sand formations. The operating strategy for the proposed injection wells Cronos No. 1 and Rhea No. 1 is as follows:

- The gross injection zone is broken into several discrete injection stages.
- These injection stages are then divided into discrete completion intervals.
- The initial completion stages for each well are perforated.
- The injectate fluids are injected into the discrete stages for a relatively short period of time–no less than 1 year–no greater than 5 years (estimated).
- Plume migration surveys are conducted annually in Years 1 and 5 after injection begins, then every 5 years thereafter to contrast actual plume development with the simulated plume model.
- Once the surveyed plume has reached the model results or caused a sufficient change to cease injection, the stage is isolated and a recompletion to the next stage is performed.
- The completed stage is then plugged with a duplex stainless steel (or equivalent) bridge plug, with [redacted] corrosion-resistant cement on top of it. The bridge plug with cement plug and casing are then tested.
- The abandoned stage remains open below the bridge plug to allow for continual

monitoring of BHPs and temperatures in the abandoned stages.
- This process is repeated until the entire gross injection zone has been completed.

Figure 4-8 depicts this process in a general form.

Figure 4-8 – Operational Completion Strategy

The actual injection intervals, injection time frame, injection rate, and injection volume for both wells were displayed in Tables 4-25 and 4-26 (page 30).

4.5 Injection Well Construction and Operation Summary

The proposed well design is engineered to address the potential hazards and risks associated with Class VI wells, including protection of the USDW. Casing setting points, materials, and cement meet and exceed the requirements for this classification of injection well. All requirements and regulations are satisfied by the well design. Additionally, the completion strategy efficiently maximizes the use of the available pore space and mitigates issues with sand control while still allowing pressure monitoring throughout the injection interval.

The gross injection interval will be subdivided into stages, which are established based on the designed injection rate. Each stage is then completed in discrete injection intervals, into which CO_2 will be injected for periods of time so that the plume buildup and migration do not exceed modeled limits.

A VSP survey will initially be performed one year after injection begins, then in year five after the start of injection and every 5 years thereafter to measure actual plume growth within the active injection interval. Once the measured plume reaches modeled extents, the next shallowest sand package will be opened with perforations. The new interval will then be injected into, following the same practices as previously described. Due to the density difference between the injected fluids and connate fluids of the formation, the injected carbon stream will favor the shallowest perforations, with minimal further influence on the deeper sands. Once all the discrete packages within a stage have reached modeled plume extents, the stage will be plugged and abandoned. The next stage will be completed, developed, and operated in the same fashion until all stages have been exploited. Once all stages have been completed, the well will be plugged and abandoned.

This completion and operating strategy is employed to achieve maximum use of available pore space while maintaining control of plume growth and migration. Without this strategy, it is estimated that less than 10% of the entire gross injection interval would be used and the maximum extent of the injection plume would be approximately three times larger than the maximum extent modeled for these wells. As previously discussed, the location for this project is ideally situated for carbon sequestration purposes. Combining the best engineering practices in the design of the well with a state-of-the-art monitoring system and a robust reservoir management strategy, these wells will serve the State of Texas for years to come.

4.6 <u>Discussion of Above-Zone Monitoring Wells</u>

Titan plans to drill and complete two above-zone monitoring (AZM) wells, Atlas No. 1 and Andes No. 1. The AZM wells' surface location will be located [redacted]. The AZM wells will be vertically drilled and are intended to monitor the Middle Miocene sand formation. This formation is the first permeable zone above the UCZ of the injection zone. Continuous measurements will be taken with a pressure and temperature sensor run in the wells and hung off in the wellheads, or other conveyance methods as necessary. The long string casings will be perforated in the Middle Miocene, just above the UCZ, to enable fluid samples to be taken. Atlas No. 1 and Andes No. 1 will monitor for indications of CO_2 leaking out of the confining zone. These wells will not penetrate the confining zone and therefore will not need to consider corrosion resistant materials in their construction. Figures 4-9 and 4-10 illustrate the proposed designs for Atlas No. 1 and Andes No. 1, respectively.

[redacted]

Figure 4-9 – Atlas No. 1 Monitoring Wellbore Schematic

[redacted]

Figure 4-10 – Andes No. 1 Monitoring Wellbore Schematic

4.6.1 General Outline of Atlas No. 1 Well Design

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

- Drive Pipe
    - [redacted] (or 200 blows/ft)
- Surface Casing
    - To be set below the lowermost USDW
        - The USDW will be determined by means of openhole logging during the drilling of the wells. If necessary, the final setting depth will be adjusted.
        - [redacted]
    - [redacted]
    - Cemented back to surface
- Long String Casing
    - [redacted] (top of lower confining layer)
    - [redacted]
    - Cemented back to surface

The Andes No. 1 well was designed with the following specifications (as illustrated in Figure 4-10):

- Drive Pipe
    - [redacted] (or 200 blows/ft)
- Surface Casing
    - To be set below the lowermost USDW
        - The USDW will be determined by means of openhole logging during the drilling of the wells. If necessary, the final setting depth will be adjusted.
        - [redacted]
    - [redacted]
    - Cemented back to surface
- Long String Casing
    - [redacted] (top of lower confining layer)
    - [redacted]
    - Cemented back to surface

Detailed drilling-and-completion prognoses for Atlas No. 1 and Andes No. 1 are included in *Appendix D*.

<u>Surface Casing</u>

The AZM wells will be drilled vertically from the Cronos No. 1 and Rhea No. 1 injection well pads. The surface holes will be drilled vertically below the lowermost USDW with a [redacted] bit, to casing set [redacted] ft. A string of [redacted] in. casing will be run and cemented, with the casing centered using centralizers in the open hole. The selected hole size and centralizers will provide a consistent thickness of cement between the casing and the open hole. Cement returns will be circulated to the surface. If the cement level falls after it is circulated to the surface, a top-job will be performed to ensure cement at surface—to provide a good cement bond from the surface casing setting depth to the surface, protecting the lowermost USDW. After cementing, a cement bond log will be run to evaluate and verify good bonding throughout the surface hole.

Summaries of engineering calculations for the surface casing are displayed in Tables 4-27 through 4-29.

Table 4-27 – Atlas No. 1 and Andes No. 1 Surface Casing Engineering Calculations

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)	Thermal Conductivity (W/m / °C)
[redacted]									

Table 4-28 – Atlas No. 1 and Andes No. 1 Surface Casing Annular Geometries

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

Table 4-29 – Atlas No. 1 and Andes No. 1 Surface Casing Cement Calculations

Section – Surface	Footag e (ft)	Capacit y (ft^3/ft)	Excess (%)	Cement Volume (ft^3)
[redacted]				

To ensure that cement returns to surface are achieved, 100% excess of openhole volumes were used to calculate cement volume.

Long String Casing

The long string holes will be drilled vertically with a [redacted] in. casing string centered using centralizers in the hole. The long string casing is the final, permanently cemented string of casing installed in the wells, to be run from the surface to the top of the UCZ TD—then cemented back to the surface. As these wells do not penetrate the UCZ, corrosion resistant cements and tubulars were not considered.

The engineering and design parameters for the long string casings are summarized in Tables 4-30 through 4-35.

Table 4-30 – Atlas No. 1 Long String Casing Engineering Calculations

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)	Thermal Conductivity (W/m / °C)
[redacted]									

Table 4-31 – Andes No. 1 Long String Casing Engineering Calculations

Description	Casing Wt. (lb/ft)	Depth (ft)	Tensile (psi)	Collapse (psi)	Burst (psi)	Capacity (bbl/ft)	ID (in.)	Drift ID (in.)	Thermal Conductivity (W/m / °C)
[redacted]									

Table 4-32 – Atlas No. 1 Long String Casing Annular Geometries

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

Table 4-33 – Andes No. 1 Long string Casing Annular Geometries

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

Table 4-34– Atlas No. 1 Long String Casing Cement Calculations

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

Table 4-35 – Andes No. 1 Long String Casing Cement Calculations

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

<u>Centralizers</u>

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

[redacted]

The solid body centralizer design for the [redacted] in. long string casing is designed to protect all shallow aquifer zones per state regulations. The specific placement ensures that a continuous, uniform column of cement is present throughout the [redacted] in. annular void. The recommended locations are as follows:

[redacted]

[redacted]

Tubing
There will be no tubing run in this well as discussed in *Section 4.6*.

Testing and Logging of Monitoring Well During Drilling and Completion Operations
A basic suite of electric logs will be run in the openhole sections and each casing string. The logging plan is detailed in Tables 4-36 and 4-37. Titan will provide a schedule of all logging plans to the UIC Director at least 30 days prior to conducting the first test. Notice will be provided at least 48 hours in advance of such activity.

Table 4-36 – Openhole Logging Plan, Atlas No. 1 and Andes No. 1

Trip	Hole Section	Logging Suite	Target Data Acquisition	Openhole Diameter (in.)	Depths of Survey (ft)
[redacted]					

Table 4-37 – Cased-Hole Logging Plan, Atlas No. 1 and Andes No. 1

Trip	Hole Section	Logging Suite	Target Data Acquisition	Casing Dimension (in.)	Depths of Survey (ft)
[redacted]					

<u>Overview of Atlas No. 1 and Andes No. 1 Completion Program</u>
The completion program includes the following:

- Make bit and scraper run to TD.
- Run cased-hole logs as described in Table 4-44.
- Test the casing.
- Perforate the casing approximately in the Middle Miocene, just above the UCZ; specific depths to be determined with openhole logs.
- Perform pump-in test to ensure fluid and pressure communication with the formation.
- [redacted] weight or similar options.

<u>Monitoring Well Operational Strategy Summary</u>
The Atlas No. 1 and Andes No. 1 monitoring wells are designed to be above-zone monitoring wells. Continuous monitoring will be implemented with the use of a Supervisory Control and Data Acquisition (SCADA) system to monitor the casing pressure. The Middle Miocene formation is the first porous interval above the UCZ. Temperature and pressure anomalies within the Middle Miocene are potential early warning signs of injectate from the proposed Titan Project injection wells moving out of the injection zone. If pressure or temperature anomalies consistent with loss of containment are observed, injection will be stopped, and the incident will be assessed as described in *Section 8 – Emergency and Remedial Response Plan*. After injection ceases in Cronos No. 1 and Rhea No. 1, the monitoring wells will be plugged as discussed in *Section 6 – Injection Well Plugging Plan*.

4.7 Discussion of USDW Monitoring Wells

Titan plans to drill and complete two USDW monitoring wells, TCS WM No. 1 and TCS WM No. 2. The USDW monitoring wells will be located on the planned injection well pads. Long string casing will be set, gravel packed and cemented back to surface with 20 ft of screen/slotted pipe just above the TD of the well to enable the taking of fluid samples. These wells will monitor for indications of CO_2 leaking out of the confining zone. These wells will not penetrate the confining zone; therefore, corrosion resistant materials will not need to be considered in their construction. The specific depths will be updated for each well after the stratigraphic test well is drilled and the aquifer depths better identified.

Representative aquifer water samples will be obtained two times each year and compared against baseline sampling and fluid testing results, to verify that injectate is not leaking into the USDW. If fluid sample anomalies are detected, injection will be stopped, and the incident will be assessed as described in *Section 8 – Emergency and Remedial Response Plan*. After injection ceases in Cronos No. 1 and Rhea No. 1, the monitoring wells will be plugged as discussed in

Section 6 – Injection Well Plugging Plan. Figure 4-11 shows the proposed design for TCS WM No. 1.

[redacted]

Figure 4-11 – TCS WM No. 1 Wellbore Schematic

4.7.1 General Outline of USDW Monitoring Wells Design

The Titan USDW monitoring wells are designed with the following specifications (as illustrated in Figure 4-11):

<u>Conductor Casing</u>
The conductor casing will be run from the surface to [redacted] then cemented back to the surface with Portland Cement.

- Conductor Casing
    - [redacted]
    - Cemented back to surface

<u>Long String Casing</u>
Casing to be run from the surface to [redacted] ft below the USDW at [redacted] then cemented back to the surface. As these wells do not penetrate the UCZ, corrosion resistant cements and tubulars were not considered.

- Long string Casing
    - [redacted]
    - Gravel packed and cemented back to surface

<u>Long string Centralizers</u>
The bow-spring centralizer design for the [redacted] in. long string casing is designed to protect all shallow aquifer zones per state regulations. The specific placement ensures that a continuous, uniform column of cement is present throughout the [redacted] in. annular void. The recommended locations are as follows:

[redacted]

[redacted]

<u>Tubing</u>

[redacted]

Overview of USDW Well Completion Program

After setting and cementing the long string casing, the completion program includes the following:

- Perform pump-in test to ensure fluid and pressure communication with the formation.
- Install tubing and electric pump
- Install wellhead.

4.8 Engineering Design and Operations Summary

The Titan Project site is ideally situated for carbon sequestration and monitoring purposes. By combining the best engineering practices in each well design with a state-of-the-art monitoring system and robust reservoir management strategy, these proposed injection wells will safely permanently sequester CO_2.

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

Appendix D – Well Construction Schematics and Procedures:

- Appendix D-1 Injection Wellbore Schematics
- Appendix D-2 Injection Well Drilling and Completion Prognoses
- Appendix D-3 Monitoring Wellbore Schematics
- Appendix D-4 Monitoring Well Drilling and Completion Prognoses
- Appendix D-5 USDW Monitoring Wellbore Schematics
- Appendix D-6 Supporting Well Construction Programs