CLASS VI INJECTION WELL PLUGGING PLAN

40 CFR 146.92(b)

TRILLIUM CARBON STORAGE COMPLEX (TCSC)

Facility Information

Facility Name: Trillium Carbon Storage Complex (TCSC)
TCSC-5

Facility Contact: Claimed as PBI [redacted]

Facility Address: Claimed as PBI [redacted]

Well Locations:

Well Name	Latitude	Longitude
TCSC-5	Claimed as PBI [redacted]	[redacted]

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Abbreviations and Acronyms

2D	2-Dimensional
3D	3-Dimensional
AoR	Area of Review
bbl/d	Barrels per day
BHP	Bottom Hole Pressure
BOP	Blowout Preventer
CBL	Cement Bond Log
CCS	Carbon capture, and storage
CO_2	Carbon dioxide
CMG	Computer Modelling Group
D_H	Hydraulic Diameter
DRM	Dynamic Reservoir Model
DTS	Distributed Temperature Sensing
EoS	Equation of State
EPA	Environmental Protection Agency
f_D	Darcy's Friction Factor
ft.	Feet
g	Acceleration due to Gravity
GEM	General Equation of State
KB	Kelly Bushing
$k_{r,CO2}$	CO_2 Relative Permeability
kh	Permeability-Thickness Product
k_h	Absolute Horizontal Permeability
k_v	Absolute Vertical Permeability
$k_{r,w}$	Water Relative Permeability
MD	Measured Depth
mg/L	milligrams per liter
MIP	Mercury Intrusion Porosimetry
MIT	Mechanical Integrity Test
MMt	Millions of Metric tons
MMtpa	Millions of Metric tons per annum
MR	Mobilize Rig
ΔP	Pressure Drop
ΔP_{TH}	Threshold Pressure
P&A	Plugging & Abandonment
PISC	Post-Injection Site Care
P_{grid}	Grid Block Pressure
pH	Potential Hydrogen
ppm	Parts per Million
psi	Pounds per square inch
psia	Pounds per square inch, absolute
ρ	Fluid Density

ρ_i	Injection Zone Fluid Density
ρ_u	Underground Source for Drinking Water Fluid
RCA	Routine Core Analysis
RU	Rig Up
R_e	Reynolds Number
SCA	Specialized Core Analysis
SEM	Static Earth Model
S_{grmax}	Maximum Residual Gas Saturation
SS	Subsea
S_{wconn}	Connate Water Saturation
S_{wirr}	Irreducible Water Saturation
T_{grid}	Grid Block Temperature
TIH	Trip In Hole
TD	Total Depth (MD)
TVD	True Vertical Depth
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
U.S. DOE	United States Department of Energy
U.S. EPA	United States Environmental Protection Agency
v	Fluid Velocity
z_i	Injection Zone Top Depth
z_u	Underground Source for Drinking Water Bottom

8. WELL PLUGGING AND ABANDONMENT PLAN

8.1. EXECUTIVE SUMMARY

Trillium will conduct injection well plugging and abandonment for TCSC-5 according to the procedures below. In accordance 40 CFR §146.92, Trillium. will comply with this plugging plan for the TCSC-5 CO_2 injection well, in addition to maintaining and updating the plan as required throughout the operational phase of TCSC project. Trillium will send a written notice documenting the intent to plug the TCSC-5 well at least 60 days prior to plugging the well. Any proposed revisions to this plugging plan will only be incorporated into this plan and/or implemented in the field, upon approval from the Region V UIC Director and will be incorporated into the permit, subject to the permit modification requirements of 40 CFR §144.39 or §144.41. After plugging operations are complete for the TCSC-5 well, a plugging report will be submitted to the Region V Underground injection control(UIC) Director within 60 days of plugging, and Trillium will retain the well plugging report for 10 years following site closure.

8.2. PLUGGING AND ABANDONMENT STRATEGY

A generalized summary of plugging and abandonment (P&A) approach and operations for the TCSC-5 Injection well is as follows:

- Trillium will submit a written notice of intent to plug to the Region V UIC Director at least 60 days prior to the intended commencement of plugging and abandonment operations [40 CFR §146.91 (e) and §146.92 (c)].
- After the life cycle of the well is complete, bottom hole measurements will be made from downhole gauges to determine bottomhole reservoir pressure, necessary fluid density, and the well will then be flushed with a kill weight brine fluid [40 CFR §146.92]. A minimum of three tubing volumes will be injected without exceeding fracture pressure.
- The well will undergo mechanical integrity testing (MIT) to ensure external mechanical integrity prior to commencement of P&A operations [40 CFR §146.89, 40 CFR §146.92]. If a mechanical integrity issue is encountered, remedial activities will be completed prior to proceeding with P&A activities.
- All casing in the wells will be cemented to the surface during construction [40 CFR §146.86] and will not be retrievable at abandonment.
- Upon permanent conclusion of the lifecycle of wells, the tubing and packer will be removed.
- A bridge plug will be set within 50 to 100 ft above the shallowest (ft MD) perforation with a cement plug on top [ODNR 1501:9-11-08 (B) (1)].
- After removal of the tubing and packer, the balanced-plug placement method will be used to plug the well. If, after flushing, the tubing and packer cannot be released, an electric line with tubing cutter will be used to cut off the tubing above the packer and the packer will be left in the well, and the cement retainer method will be used for plugging the injection formation below the abandoned packer.
- All of the casing strings will be cut off at least 3 feet below the surface, below the plow line. A blanking plate with the required permit information will be welded to the top of the cutoff casing.

- All surface features associated with the plugged well and well-pad will be removed.
- A plugging report will be submitted within 60 days after plugging operations are completed to the Director [40 CFR §146.92].

8.3. PLANNED TESTS OR MEASURES TO DETERMINE BOTTOMHOLE RESERVOIR PRESSURE

Trillium will record bottom hole pressure measurements from a down hole pressure gauge and calculate kill fluid density prior to flushing the well [40 CFR §146.92].

8.4. PLANNED EXTERNAL MIT(S)

Trillium will conduct at least one of the tests listed in **Table 8-1** to verify external mechanical integrity prior to plugging the injection well as required by 40 CFR 146.92(a).

Table 8-1. Planned MITs.

Test Description	Location
DTS or Equivalent	Distributive Temperature Sensing (DTS) measurement across wellbore
CBL Log	Wireline well log

External mechanical Integrity tests must be completed pursuant to 40 CFR 146.89.

A DTS or equivalent test will be run and continuously monitoring temperature throughout the wells' entire depth or an equivalent test like a temperature log will be run through the entire depth of the wellbore after injection before plugging the well. The temperature curve data obtained from the DTS, or equivalent test will be evaluated for anomalies in temperatures, signaling potential fluid migration beyond the injection zone. A comparison will then be made between this data and the baseline temperature data conducted prior to the CO_2 injection into the well. If disparities are observed in the temperature curve before and after CO_2 injection, the wells casing or cement integrity may be insufficient, so immediate attention will be given to address the issue.

A Cement Bond Log (CBL) will also be run through the entire length of the well via wireline. The tool measures the amplitude and attenuation of waves traveling axially within a casing. The amplitude of the initial arrival wave at the receiver signals the existence of cement encasing the casing. A diminished amplitude suggests the presence of cement, while an elevated amplitude suggests unrestricted pipe. This log provides insights into the compressive strength and distribution of cement surrounding the casing. This log will pass if all the important intervals of the well have a good bond log isolating the region. These intervals include the Underground Sources of Drinking Water (USDW), weak or troublesome formations, our injection zones, and our confining layers. If these formations are not isolated adequately with good plugs, then a well workover like a squeeze job may be necessary.

8.5. INFORMATION ON PLUGS

Trillium will use the plugging materials, details and methods noted in **Table 8-2** to plug the TCSC-5 CO_2 injection well. The volume and depth of the plug or plugs will depend on the final geology and downhole conditions of the well as assessed during construction; this plan will be updated after well construction to determine the type and number of plugs to be used.

The cement(s) formulated for plugging wells which penetrate the CO_2 storage complex will be compatible with the carbon dioxide stream and will consist of CO_2 resistant cement. Wells which do not penetrate the storage complex will be plugged with class A or H cement. The cement formulation and required certification documents will be submitted to the agency with the well plugging plan. The owner or operator will report the wet density and will retain duplicate samples of the cement used for each plug.

Table 8-2. Injection Well TCSC-5 Plugging Details

Plug Information	Plug #1	Plug #2	Plug #3	Plug #4	Plug #5	Plug #6	Plug #7	Plug #8	Plug #9
Diameter of boring in which plug will be placed (Inches)	Claimed as PBI								
Depth to bottom of tubing or drill pipe (MD ft)									
Sacks of cement to be used									
Slurry volume to be pumped (ft3)									
Slurry weight (lb./gal)									
Calculated top of plug (MD ft)									
Bottom of plug (MD ft)									
Type of cement or other material	CO_2 Resistant Bridge Plug	CO_2 Resistant	CO_2 Resistant	CO_2 Resistant	CO_2 Resistant	CO_2 Resistant	Class A	Class A	Class A

8.6. CASING AND TUBING RECORD AFTER PLUGGING

Table 8-3. Casing and Tubing Specifications After Well Plugging for for Injection Well TCSC-5

Tubular OD	Weight (lb/ft)	To be put in well (ft)	To be left in well (ft)	Diameter of boring

Claimed as PBI

8.7. DESCRIPTION OF PLUGGING PROCEDURES

8.7.1. Notifications, Permits, and Inspections

In compliance with 40 CFR 146.92(c), Trillium will notify the regulatory agency at least 60 days before plugging the well and provide updated Injection Well Plugging Plan, if applicable.

8.7.2. Plugging Procedures

1. Upon receiving approval from the Director, if plan updates are required, well plugging and abandonment operations will commence.
2. Mobilize Rig (MR) and field staff to the TCSC Site and rig up (RU). All CO_2 pipelines will be marked and noted with rig supervisor prior.
3. Conduct and document a safety meeting to identify site specific occupational hazards.
4. Record bottom hole pressure from down hole gauge and calculate kill fluid density.
5. Open up all valves on the vertical run of the tree and check pressures.
6. Test the pump and line to 2,500 psi. Fill tubing with kill weight brine (9 ppg or determined by bottom hole pressure measurement). Bleeding off occasionally may be necessary to remove all air from the system. Test casing annulus to 1000 psi and monitor as in annual Mechanical Integrity Test (MIT). If there is pressure remaining on tubing rig to pump down tubing and inject three tubing volumes of kill weight brine. Monitor tubing and casing pressure for 1 hour. If both casing and tubing are dead, then nipple up blowout preventers (NU BOP's). Monitor casing and tubing pressures.
7. If the well is not dead or the pressure cannot be bled off of tubing, rig up slickline and set plug in lower profile nipple below packer. Circulate tubing and annulus with kill weight fluid until well is dead. After well is dead, nipple down tree, nipple up blow-out preventers , and perform a function test. BOPs should have appropriately sized single pipe rams on top and blind rams in the bottom ram for tubing. Test pipe rams and blind rams to 250 psi low, 3,000 psi high. Test annular preventer to 250 psi low and 3,000 psi high. Test all Texas Iron Works (pressure valve), BOP choke and kill lines, and choke manifold to 250 psi low and 3,000 psi high. NOTE: Make sure casing valve is open during all BOP tests. After testing BOPs pick up tubing string and unlatch seal assembly from seal

bore. Rig slick line and lubricator back to well and remove plug from well. Rig to pump via lubricator and circulate until well is dead.

8. Pull out of hole with tubing laying it down. NOTE: Ensure that the well is over-balanced so there is no backflow due to formation pressure and there are at least two well control barriers in place at all times.

9. Pull seal assembly, pick up work string, and trip in hole (TIH) with the packer retrieving tools. Latch onto the packer and pull out of hole laying down same. Next, confirm the well's mechanical integrity by performing one of the permitted external mechanical integrity tests listed in **Table 8-1**.

    a. ***Contingency:*** If unable to pull seal assembly, RU electric line and make cut on tubing string just above packer. Note: Cut must be made above packer at least 5-10 ft measured depth (MD). If unable to pull the packer, pull the work string out of hole and proceed to next step. If problems are noted, update cement remediation plan (if needed) and execute prior to plugging operations.

10. TIH with work string to total depth (TD). Keep the hole full at all times. Circulate the well and prepare for cement plugging operations.

11. It is then anticipated that it is necessary for TCSC-5 to need 9 plugs total of various lengths for. No more than two plugs will be set before cement is allowed to set and plugs verified by setting work string weight down onto the plug.

12. Complete a scraper run and then set the bridge plug at a depth of [redacted] ft. Circulate the well to condition the wellbore and trip in the hole to 10-ft above the bridge plug. Mix and spot a 400 ft balanced plug in [redacted] with a CO_2 resistant cement slurry. Pull out of plug and reverse circulate out tubing. Wait on cement to 500 psi compressive strength.

13. Trip in hole and tag cement top to insure placement and consistency. Reverse circulate the tubing to clean up. Mix and spot additional balanced plugs in [redacted] to the top of the caprock using a CO_2 Resistant cement with a density of [redacted] ppg and yield of [redacted] ft^3/sk. Plugs shallower than the caprock will use a Class-A cement blend with a density of [redacted] ppg and a yield of [redacted] ft^3/sk. (*Example Calculations for TCSC-5 CO_2 Injection Well:* Assume [redacted] casing for this interval [redacted]). When pulling out of the plugs trip 10 stands above and reverse circulate the tubing to clean up. Repeat this operation for 7 further plugs (9 plugs in total) in TCSC-5. A 9 ppg viscous bentonite pill will be spaced between the cement plugs to maintain pressure inside the casing to mitigate casing collapse. After the last plug is set, trip out of the hole laying down the work string. Nipple down BOPs and cut all casing strings below plow line (min 3 feet below ground level or per local policies/standards). Rig down equipment and move out. Clean cellar to where a plate can be welded with well name onto lowest casing string at 3 feet, or as per permitting agency directive.

14. The procedures described above are subject to modification during execution as necessary to ensure a plugging operation that protects worker safety and is effective to protect USDWs, and any significant modifications due to unforeseen circumstances will be described in the Plugging report.

Complete plugging forms and send in with charts and all lab information to the regulatory agency as required by permit. Plugging report shall be certified as accurate by Trillium and plugging contractor and shall be submitted to the Region V UIC Director within 60 days after plugging is completed in accordance with 40 CFR §146.92. A reference schematic for the plugging protocol mentioned above is shown in **Figure 8-2.**

8.8. WELL DESIGN AND PLUGGING SCHEMATICS

Figure 8-1. Well construction schematic detailing design specifications of TCSC-5 injection well.

Figure 8-2. Plugging schematic detailing plug specifications for the TCSC-5 injection well.

8.9. REPORT RETENTION

A copy of this injection well plugging report will be retained by Trillium for 10 years following the date of site closure.

8.10. CERTIFICATION

The plugging report will be certified by an authorized individual with certification language such as presented below:

Certification		
I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations. (Ref. 40 CFR 144.32)		
Name and Official Title (please type or print)	**Signature**	**Date Signed**
