Evaluation of the AoR Delineation Modeling Approach in the San Joaquin Renewables (SJR) Class VI Permit Application

This area of review (AoR) delineation modeling evaluation report for the proposed San Joaquin Renewables (SJR) Class VI geologic sequestration project summarizes EPA's evaluation of the modeling performed by SJR as described in the Area of Review and Corrective Action Plan (AoR CA), and associated files submitted to the AoR and Corrective Action Module of the GSDT on October 13, 2021. This review also addresses modeling-relevant site characterization information in the permit application narrative and in the Post-Injection Site Care (PISC) and Site Closure Plan. Clarifying questions for SJR and requests for supplemental information are provided within the text below. EPA's questions about the corrective action that is described in the AoR CA will be included in the well construction and plugging evaluation.

This report describes and evaluates how site-specific data (e.g., geologic data and planned operational conditions) described in the UIC permit application narrative are incorporated into SJR's geomodel and their computational modeling approach. It is assumed, however, that planned pre-operational testing will confirm the site characterization information. Please note that modifications to the model parameters may be needed if this testing yields results that are significantly different than the model inputs. Note that EPA did not perform independent, duplicative modeling of SJR's AoR.

Evaluation of the Geomodel

To delineate the Class VI AoR, the geological layering, formation thicknesses, and petrophysical properties of the project site (as described in the permit application narrative and evaluated in the geologic site characterization report) need to be integrated into a geomodel and then into a computational model that is consistent with site-specific geologic and operational information to generate predictions of plume and pressure front movement.

Representation of Site Geologic Features

SJR plans to inject carbon dioxide (CO_2) into the Vedder Formation within the San Joaquin Valley of California. The Vedder Formation is interpreted as an east to west progradational shallow marine shelf composed of up to 5 sand units separated by shales. The confining unit above the Vedder Formation is the Freeman-Jewett Formation, a 700-foot thick shale and mudstone that is laterally continuous within the AoR. The injection zone laterally pinches out to the east in the homocline and is truncated to the west by the Pond-Poso Creek Fault Complex.

SJR explains in the AoR CA how it used geologic and hydrologic data for formations of interest (e.g., the Vedder Formation, the Pyramid Hills Sandstone, Freeman-Jewett Formation, and others) derived from multiple sources for their geomodel and computational modeling approach, including well data, seismic studies, geochemical modeling, and core laboratory analyses. The representation of site geologic features, including lithologic properties, and geomechanical behavior appears to be appropriate and is reflected in the applicant's static geomodel and computational model. However, some information was omitted from the AoR CA discussion or requires modification and is listed below.

Questions/Requests for the Applicant:

- *Please confirm and, if relevant, incorporate the following into the AoR CA discussion of the model development:*
    - *The injection zone fracture pressure derivation from Appendix G of the narrative.*
    - *The Olcese as a secondary injection zone, as referred to on page 10 of the AoR CA.*
- *To provide context for the porosity and permeability discussion, please provide a simple cross section through a static grid showing the distribution of porosity and permeability in Figure 1-5 in the AoR CA. Please also provide an index map (including the injection well location) for the cross-section line on the Figure.*

Representation of Hydrogeologic Properties and Lithology

Porosity, permeability, and rock types

The applicant describes how the porosity, permeability, and lithologic data about relevant formations are incorporated into the geomodel. Specifically, the geomodel parameters include: porosity and permeability (summarized in Tables 2-3 and 2-4 of the narrative); mineralogy for the Vedder and Freeman-Jewett Formations (from Table 2-9 of the narrative); geochemical data (summarized in Table 2-7 of the narrative); and other rock properties (in Table 2-11 of the narrative). The narrative describes the analyses used to gather these parameters, and they are evaluated in the geologic site characterization report.

The AoR CA describes (pg. 6) how various, similar, subunits of the Vedder Formation were combined for purposes of modeling and how parameter values were assigned, with homogenous porosity and permeability values that are consistent with information in the narrative. SJR submitted files with the porosity distribution to the GSDT.

The applicant asserts that Table 1-1 of the AoR CA shows that the highest permeability values exist in the Vedder 4 Sand, with alternating values throughout the Vedder stratigraphic subunits. The highest porosity values were observed within the Vedder 1 and 2 Sands. The porosity, permeability, and lithology of relevant subunits appears to be well-represented in the seismic analyses of Appendix D that serve as the basis for the geomodel. Figures 1-1 through 1-4 show that the fault, the injection well, and the pinchout are represented in the model mesh, consistent with information in the geologic narrative.

Geomechanical properties

The AoR CA describes how the geomodel incorporates geomechanical properties of the injection zone (summarized in the Geomechanical Analysis in Appendix F of the narrative). The suite of properties collected from the injection zone sample appears to be thorough and complete. Based on these properties and measured porosity, the fracture gradient for the injection zone was calculated in Appendix G of the narrative to be 0.66 psi/ft.

Geomodel – 3D model grid resolution and discretization

Appendix D of the narrative details the seismic interpretation the applicant used as the foundation for the unit grid files and fault point files that make up the geomodel. The conceptual model area examined by the full-scale geomodel is 3,200 square miles, overlain by a 200 x 200-meter grid. Seismic data and well log data were used to create a digital grid model of the area that provided the top elevation of the formations on the 200-meter grid spacing. For the purposes of the seismic interpretation, a reduced area grid was utilized. This smaller grid aligns with the larger grid, with grid nodes being a subset of the

full-scale model area. All mapped formation tops and intervals have the following grids: time, depth, isochore, isochron, and average velocity. Additional discussion of the 3D model grid is presented under "Spatial Extent" below.

Questions/Requests for the Applicant:

- *Please discuss how the average grid cell height for the 3D geomodel was selected, and how cell size could vary between vertical layers.*

Fault stability

The AoR CA discussed the relevance of the nearby Pond-Poso Creek Fault Complex to the modeling effort, including sealing properties of faults for the potential propagation of the pressure front across the fault line.

Table 1-2 of the AoR CA presents a conceptualization of the permeability of the Pond-Poso Creek Fault Complex that was generated for the computational modeling. Permeability of the fault gouge at each fault location was determined based on the shale gouge ratio (as described in the narrative) at each location for the Olcese, Upper Vedder, and Vedder 3 units. Four subcategories of horizontal and vertical permeabilities were assigned to each location and geologic formation along the fault, with horizontal permeability ranging from 0.001 to 0.5 millidarcies. See the geologic site characterization report for additional discussion and questions for the applicant about the fault complex.

Evaluation of the Computational Model Design

The applicant's discussion of computational model design includes, but is not limited to subsurface phase properties and behavior, CO_2 plume size and extent, boundary and initial conditions, timeframe and time steps, operational information, model calibration and sensitivity analysis. The applicant states that coupled hydrological-geomechanical processes are not explicitly simulated in the AoR modeling (i.e., no stress-strain calculation was performed); however, the expansion or compression of the pore space in response to changes in fluid pressures is accounted for through an elastic pore compressibility.

SJR developed a reference case model that served as the basis for their AoR delineation. The reference case model describes the general predicted system behavior based on the geological and hydrogeological conditions at the injection site, assuming injection of 1,200 tons of CO_2 per day for 15 years, followed by a 100-year post-injection period, for a total simulation time of 115 years.

It appears that the applicant's evaluation of the computational model design and associated components is appropriate and relatively complete, however there are several outstanding questions that need to be addressed in order to consider the material in this section sufficient, which are included under "Questions/Requests for the Applicant" below.

Routines for Relevant Subsurface Processes

The applicant used the general-purpose compositional reservoir simulator TOUGH2, as implemented in the iTOUGH2 simulation optimization framework, to perform the AoR delineation. The TOUGH2 model has been used in other Class VI AoR delineation applications, and SJR provided documentation as part of its GSDT submissions. The applicant used the TOUGH2 equation-of-state module ECO2N to simulate non-isothermal multiphase flow of fluid mixtures of water, CO_2, and sodium chloride (NaCl) in geologic media.

The applicant used the conceptual geomodel described in Appendix D of the narrative to develop the TOUGH2 model. They converted the 200m x 200m digital geologic grid model to a numerical modeling grid and populated the grid with initial parameter values and boundary conditions for the TOUGH2 model. The numerical model initial parameter values were assigned based on laboratory core analyses and values from available literature for the area (as described above and based on the geologic narrative). The numerical model was adapted into a 3-D mesh model created using AMESH, which serves as the final input for the TOUGH2 model grid.

Spatial Extent

The AoR CA explains the use of the AMESH mesh model, which is a 3-D, unstructured grid of Voronoi elements composed of a 2-D surface grid repeated at multiple depths to create columns. Figures 1-1 through 1-4 in the AoR CA display the surface grid, which includes an X-Y grid composed of a "background" grid that contains radial and Cartesian components, within which fault trace grid points are embedded. The AoR CA details the assignment of the radial sectors and their spacing and discretization in the X and Y directions.

Each element of the final mesh is assigned one of 38 material types, each with different property parameters. These material assignments are made one column at a time using a dataset of geologic layer data and fault trace data. The fault trace data is incorporated into the model as interpolated grid points, where lists of X-Y coordinates form fault traces, the depth ranges over which the faults are present, and fault sections receive an additional sub-category during the assignment of fault properties.

The AoR CA states that the bounding box of the final grid was chosen to be significantly large so that boundary effects would be insignificant. The spatial extent of the model excludes areas that are above the ground surface; more than 50 meters above the Olcese Formation or more than 50 meters below the Walker Formation; or south of the curved boundary on the southern and parts of the eastern borders of the model.

The applicant asserts that the mesh model is computationally efficient, while providing the resolution required to represent the hydrostratigraphic layering and fault structures, and to resolve regions where strong gradients (in pressure and saturation) are expected, specifically near the injection well and fault trace lines. The methodology SJR used to create the mesh model and make material assignments is described in further detail in the GSDT submission entitled MeshGeneration.

Questions/Requests for the Applicant:

- *Please label the fault, injection well, and pinchout on Figures 1-1 through 1-4 to provide clarity.*

Boundary Conditions

The AoR CA states that, for the purpose of generating initial static conditions, the bottom boundary and all side boundaries are hydrologically closed (pg. 11). This is consistent with discussions in the narrative about the impermeability of the Pond-Poso Creek Fault Complex to the west and the pinch out to the east. Vertically, the low permeability and high gas-entry pressure of the confining layer prevents gas from entering the Freeman-Jewett Formation, even if the injection pressure rises to relatively high values.

The AoR CA states that pressure, temperature, and salinity profiles from the initialization run were kept constant at the top boundary and along the vertical side boundaries of the three-dimensional model.

The initial pressure and temperature at the injection point are approximately 260 bar and 60°C, respectively, i.e., above the critical pressure and temperature for CO_2 of 73.82 bar and 31.04°C.

Questions/Requests for the Applicant:

- *Please plot the Pond-Poso Creek Fault Complex on Figures 1-6a and 1-8a.*

Model Timeframe

The applicant presents computational modeling results for CO_2 plume and pressure front development over a total simulated timeframe of 115 years. This includes 15 years of injection operations and a 100-year post-injection monitoring period.

Initial Conditions and Operational Information

The applicant used a steady-state calculation to generate static initial conditions for the model which include the following:

- A fully saturated system (single-phase liquid conditions) with initially no dissolved CO_2 in the aqueous phase.
- A constant pressure of 1 bar (atmospheric conditions) and a constant temperature of 18.4°C (approximate mean annual temperature) at an elevation of 360 m (the land surface elevation above the highest elevation represented in the model).
- A constant temperature of 105°C at an elevation of -5,440 m, which is the lowest elevation represented in the model. This value was imposed because of the temperature limit of the ECO2N module. The resulting geothermal gradient of 15°C/km was smaller than the gradient projected for the sequestration site. The applicant asserts that the error induced by a lower temperature at the elevation of the CO_2 plume is considered acceptable.
- Salinity is specified as a function of depth as follows: for depths less than 152 m (500 ft), NaCl concentration is 98 ppm; between 152 and 1,220 m (500 and 4,000 ft), salinity increases linearly from 98 to 25,000 ppm; and below 1,220 m, salinity is constant at 25,000 ppm. This is consistent with information in Section 2.4.2 of the narrative.

The applicant asserts that, because the process described above yields profiles that are in static equilibrium, they are appropriate for use as initial conditions for all subsequent simulations, including the sensitivity analyses. The AoR CA states that the AoR delineation predominantly depends on changes of the system state with respect to these initial conditions rather than their absolute values, which it asserts would reduce the impact an error in the initial conditions has on the results of interest.

Regarding operational parameters, the application describes the injection rate and injection timeframe and the modeled composition of the injectate. The injection rate of 1,200 tons/day and the 15-year injection period are consistent with operating data provided in the narrative (page 29). While it is understood that determining the average daily injection pressure is pending the results of pre-operational testing, the assumed value used in the model was not provided in the AoR CA. The AoR CA (pg. 12) also describes how the well perforation within the Vedder Formation is incorporated into the model.

The composition of the CO_2 injectate reflects modeling using ASPEN process simulation software (and is summarized in Table 2-10 of the narrative). The injectate is predicted to be 98.7-percent CO_2 by mass,

with less than one percent of methane, benzene, ethane, and nitrogen comprising the composition to 99.9- percent by mass.

Questions/Requests for the Applicant:

- *Please specify the coordinate system in use for the coordinate ranges described on page 9.*
- *Please explain why SJR believes that "the error induced by a lower temperature at the elevation of the CO_2 plume is considered acceptable" (AoR CA, pg. 11).*
- *What daily average injection pressure was used in the model?*

Relative permeability and capillary pressure curves

Gas, oil, and water are all present in the Vedder Reservoir. The applicant derived contact depths from open-hole logs and history matching, and residual gas saturations assumptions are developed using the hysteretic model of Doughty (2013). The liquid phase relative permeability relationships were used in the computational model to characterize the flow. Figures 1-17 and 1-18 show, respectively, the relative permeability and capillary pressure curves for the three sets of van Genuchten parameters. Additionally, mercury-injection capillary pressure (MICP) and core data was used to determine the two-phase relative permeability relationships.

Potential Pathways for Fluid Movement

Faults

Figures 1-1 through 1-4 show the mesh plan view of the AoR delineation model; the fault boundary is depicted at a finer mesh than other areas of the model domain, indicating a finer resolution to reflect more detailed inputs to understand plume and pressure front behavior in the vicinity of the fault.

Based on the buoyant properties of CO_2, the plume is not expected to migrate down-dip towards the fault complex. However, modeling predicts that the pressure front will be impacted by the fault complex, although SJR predicts in the application narrative that through shale gouge, the Pond-Poso Creek Fault Complex will be non-transmissive of the pressure front.

SJR included relevant discussion concerning fault stability in the permit application narrative; please also see the "Representation of Site Geologic Features" and "Fault Stability" sections above, and the geologic site characterization report for discussion.

Wells in the AoR

The AoR CA states that 19 wells are present in the AoR, of which seven penetrate the Freeman-Jewett formation confining zone. These wells are tabulated in Table 2-1 of the AoR CA and presented in a map in Figure 2-1. Table 2-1 provides: API number; well lease and operator name; status; locational information (e.g., latitude/longitude and township, section, and range); whether the well was directionally drilled; dates the well was drilled and abandoned; the total depth, depths to the Freeman-Jewett and Pyramid Hills Formations, and casing and cement depths; and whether the well requires corrective action.

Six of the seven wells penetrating the confining zone require re-abandonment because they are uncased in the injection zone. One will be re-abandoned prior to injection and the remaining five will be re-abandoned within the first 3 years of injection operations. However, it is unclear if the five wells are

accounted for in the computational model. Additional discussion regarding corrective action on wells in the AoR will be provided in a separate report on well construction and plugging.

Questions/Requests for the Applicant:

- *Please clarify if, and how, the five wells that will not be re-abandoned until three years after injection commences are accounted for in the geomodel and the computational model.*
- *Please label the Pond-Poso Creek Fault Complex on the modeling output figures (e.g., Figure 1-8a).*

Calculation of critical pressure

SJR applied methods of Nicot et al. (2008), which used the following equation (Equation 1):

$$\frac{\Delta P}{g} = (z_v - z_I)\left(\frac{\lambda - \xi}{2}(z_v - z_I) + \rho_{I,\lambda} - \rho_I\right)$$

Equation 1 was applied at each TOUGH2 grid cell location based on specific parameters (specific salinity, USDW elevation, and injection-zone formation elevations at each model grid cell location). Then the resulting "threshold overpressure" at each grid cell location was plotted to produce the AoR delineation map in Figures 1-22 and 1-23.

Figure 1-8a shows the distribution of overpressures at the end of the 15-year injection period. Overpressures are highest at the injection well, from where they decline radially out. The AoR CA states that the Pond-Poso Creek Fault Complex forms a mostly impermeable barrier, which prevents pressure propagation across the fault trace line to the west. The AoR CA asserts that 25 years after injection ends the threshold overpressure will dissipate to approximately zero.

Questions/Requests for the Applicant:

- *Please clarify the point(s) within the AoR at which the threshold overpressure reaches approximately zero, as described on pg. 23.*

Representation of Fluid Properties

Relevant fluid properties for the computational modeling include viscosity, density, composition, and pore compressibility. The fluids considered in SJR's modeling include a water-rich aqueous phase containing dissolved NaCl and CO_2, along with a CO_2-rich supercritical "gas" phase. According to the applicant, solid salt may be present as well. To determine the composition of the aqueous and gaseous phases as a function of temperature, pressure, and salinity, equilibrium phase partitioning of water and CO_2 was used based on Spycher et al., 2003, along with the precipitation and dissolution of solid salt.

The applicant notes that the thermophysical properties of the two fluid phases (density and dynamic viscosity) are calculated as a function of pressure, temperature, and salinity. Brine density varies with pressure, temperature, salinity, and the concentration of dissolved CO_2. Additionally, the applicant accounts for elastic pore compressibility based on the expansion or compression of the pore space in response to changes in fluid pressures. Phase-trapping (where the gas phase may become discontinuous and get trapped in certain portions of the pore space) was accounted for using effective residual gas saturation in relative permeability functions or a fully hysteretic retention model. The pore

compressibility values in Appendix A to the AoR CA were taken from Birkholzer et al. (2011) and are reproduced below:

Formations	kh [mDarcy]	kv [mDarcy]	Φ [-]	βρ [$10^{-10}Pa^{-1}$]	α [10-5 Pa-1]	m[-]
Non-Fault Zones						
Pre-Etchegoin	3000	3000	0.35	15.5	5.0	0.457
Etchegoin	1200	1200	0.32	15.5	5.0	0.457
Macoma -Chanac	1900	1900	0.31	10.5	5.0	0.457
Santa Margarita-McLure	2000	2000	0.275	10.5	5.0	0.457
Stevens Sand	240	48	0.22	10.5	5.0	0.457
Fruitvale-Round Mountain	0.002	0.001	0.338	14.5	0.42	0.457
Olcese Sand	170	34	0.336	4.9	5.0	0.457
Temblor-Freeman	0.002	0.001	0.338	14.5	0.42	0.457
Vedder Sand (sand layers)	303	60.6	0.264	4.9	13.0	0.457
Vedder Sand (shale layers)	0.1	0.05	0.32	14.5	0.42	0.457
Tumey-Eocence	0.07	0.07	0.07	14.5	0.42	0.457
Baserock	0.0001	0.0001	0.01	22.7	0.5	0.457

Hydrogeologic properties assigned to each formation: horizontal permeability (kh), vertical permeability (kv), porosity (Φ), pore compressibility (βρ), van Genuchten parameter for entry capillary pressure (a), and the van Genuchten parameter for pore-size distribution (m).

Model Calibration and Sensitivity Analyses

The applicant performed sensitivity analyses to examine the impacts of various assumptions on the simulation results. Table 1-3, reproduced below, summarizes the sensitivity cases and notes the assumptions or parameters that were changed from the reference case. Both static (porosity/permeability) and dynamic (phase trapping/VG parameters) sensitivities were completed. The applicant notes that in most cases, only one adjustment was made at a time to unambiguously see the influence of a single parameter or assumption.

It appears that the applicant took an appropriately conservative approach in selecting the inputs for the sensitivity analyses. The Sensitivity Analyses section of the AoR CA discusses the results of the sensitivity cases listed above in detail, and Figures 1-12 through 1-21 in the AoR CA graphically represent the results. Based on the results of the sensitivity analyses, no scenarios involving changes with injection intervals, permeability, porosity, occurrences of phase trapping, and adjustments to fluid flow or fault sealing parameters appear to result in plume migration beyond the anticipated subsurface extent as predicted by the modeling.

Case	Description	Reference	Perturbation
0	Reference case		NA
A	Injection from longer interval	Injection into Upper Vedder sands	Injection into Upper Vedder and Vedder 3 sands
B	Injection from deeper interval	Injection into Upper Vedder sands	Injection into Vedder 3 sands
C	Increased permeability of Vedder sands based on 75th percentile of measured values; maintain anisotropy ratio	k_h = 254 mD k_v = 62 mD	k_h = 555 mD k_v = 136 mD
D	Decreased permeability of Vedder sands based on 25th percentile of measured values; maintain anisotropy ratio	k_h = 254 mD k_v = 62 mD	k_h = 82 mD k_v = 20 mD
E	Increased porosity of Vedder sands based on 90th percentile of measured values	f = 0.34	f = 0.39
F	Decreased porosity of Vedder sands based on 10th percentile of measured values	f = 0.34	f = 0.26
G	Reduced phase trapping by reduced residual gas saturation of Vedder sands	S_{gr} = 0.15	S_{gr} = 0.00
H	Changed van Genuchten parameters for relative permeability and capillary pressure of Vedder sands	S_{lr} = 0.0 n = 1.842 $1/a$ = 0.2 bar	S_{lr} = 0.3 n = 2.5 $1/a$ = 0.5 bar
I	Changed van Genuchten parameters for relative permeability and capillary pressure of Vedder sands	S_{lr} = 0.0 n = 1.842 $1/a$ = 0.2 bar	S_{lr} = 0.1 n = 1.5 $1/a$ = 0.1 bar
J	Sealing faults	Fault permeabilities based on Allan diagrams	All faults sealing k_h = 0.0036 mD k_v = 0.0036 mD
K	Non-sealing faults	Fault permeabilities based on Allan diagrams	All faults non-sealing k_h = 254 mD k_v = 0.0036 mD
L	Hysteretic characteristic curves	Non-hysteretic characteristic curves	Hysteretic characteristic curves from Doughty (2010)
M	Side boundary conditions	Dirichlet side boundary conditions	No-flow side boundary conditions

Of note is Case B, which models injection of the entire CO_2 mass into the Vedder Sand 3 (a potential secondary injection zone). This modeling predicts high gas saturations and relatively high overpressures; however, larger vertical spreading of the plume leads to a smaller lateral footprint after 115 years (Figures 1-11 and 1-12).

Although the plume size and injection pressures vary in some of the scenarios, the injection of CO_2 is expected to be contained within the Vedder Sand and effectively trapped by the overlying confining unit. As such, endangerment of USDWs is not anticipated under any of the alternative scenarios.

Injection Zone Storage Capacity

SJR plans to inject 1,200 tons per day of CO_2 per year for a period of 15 years, for a total of 6.57 million tons of CO_2 (narrative, pg. 29). The applicant claims that the Pyramid Hill and Vedder Formations are the thickest, most widespread potential CO_2 injection formations in the San Joaquin Basin Province (narrative, pg. 6). Therefore, due to the nature of the depositional environment and lack of structural

traps, the applicant asserts that the full capacity of the injection zone likely exceeds the total volume of CO_2 to be injected at the project.

Questions/Requests for the Applicant:

- *Did SJR use any type of volumetric approach (e.g., using the number and sizes of cells in the geomodel along with the effective porosity assigned to each cell) to estimate the storage capacity of the injection formation? If so, please describe this in the AoR CA.*
- *If possible, please provide maps illustrating the extent of the plume and/or pressure front under each of the scenarios contemplated in the sensitivity analysis to provide clarity about the impact of each scenario on resources within the AoR.*

Presentation of Model Results

TOUGH2 modeling predicts that the CO_2 plume will expand laterally up-dip to the east until the cessation of injection activity; at its maximum, the plume is predicted to be an elliptical area with a horizontal radius of about 850 m and a thickness of about 100 m. The simulated maximum pressure front extends radially north, south, and east from the injection site; the overpressure increases during the injection phase reaching a maximum of 265 bar at year 15, and generally decreases after injection ends.

Map and cross-sectional views of the spatial extent of the simulated CO_2 plume and pressure front were provided in the AoR CA. Figure 1-6b shows the predicted position of the plume at years 15 (corresponding to the end of the 15-year injection period), and 40, 75, and 115 (100 years after the cessation of injection); Figure 1-8b depicts the position of the pressure front at years 15, 20, 40, 65, 75, 100, and 115. The resulting AoR delineation (a 73 square-mile area that encompasses the outermost threshold overpressure at 15 and 20 years) is presented in Figures 1-22 and 1-23.

Detailed discussions of the predicted evolution of the CO_2 plume and pressure front are presented in the AoR CA, and summarized below.

Predictions of CO_2 Plume Movement

TOUGH2 modeling predicts that the CO_2 plume will expand laterally outwards updip due to buoyancy effects until its arrest by physical forces. The gas plume is expected to migrate up-dip to the east, until the cessation of injection activity at Year 15. Following the injection phase, the CO_2 plume is gradually arrested due to injection pressure subsiding, capillary pressure gradients reducing, and the buoyancy forces weakening over time. Finally, at Year 80, modeling predicts that the gas phase may become discontinuous and trapped within the pore space or dissolved into the brine, and the advance of the gas pockets will be stopped (AoR CA, pg. 13). The differences in the predicted positions of the plume and pressure front between the cessation of injection, 15 years, and 100 years post-injection were fairly minor; the applicant asserts that this suggests that the plume movement may remain stable after injection ceases.

Figures 1-6a and 1-6b show the size and shape of the CO_2 plume at various time-steps, which at maximum is approximately an elliptical area with a horizontal radius of about 850 m and a thickness of about 100 m. The AoR CA describes that, after 15 years of injection, the supercritical CO_2 ($scCO_2$) plume is approximately elliptical, with the slightly longer axis oriented in the north-south direction due to the strike of the Vedder Formation. The AoR CA notes that deviations from the elliptical shape occur due to

spatial variability in layer thicknesses, dip, and pressure distribution. The center of the plume is slightly to the east of the injection well, mainly because of the dip of the layers, which generally incline from west to east.

The application states that at the end of injection period (Year 15), about 80% of the total injected mass of 6.57 million tons of CO_2 is present in the CO_2-rich gas phase; the remaining 20% is dissolved in brine. The plume will have a gas volume of 6.51 million cubic meters with an average $scCO_2$ density of 811 kg/m^3. According to the average plume extent shown in graph (b) of Figure 1-7, evolution of the CO_2 plume ceases after about 80 years and is essentially stable towards the end of the modeled timeframe of 115 years. At the end of the 115-year performance period, approximately 64% of the total injected mass of CO_2 is present in the CO_2-rich gas phase; the remaining 36% is dissolved in brine. The final plume has a gas volume of 6.27 million cubic meters with an average $scCO_2$ density of 804 kg/m^3.

Predictions of Pressure Front Movement

Figure 1-8b shows the spatial extent of the overpressures at different time-steps. The simulated maximum overpressure extends radially north, south, and east from the injection site. The applicant asserts that the Pond-Poso Creek Fault Complex blocks pressure dissipation to the west, due to its sealing properties.

TOUGH2 modeling predicts that, after one year of injection, the formation pressure will be slightly above 264 bar, steadily increasing to reach its maximum value of 265 bar at year 15 (the end of the injection phase). After CO_2 injection stops, the pressure front will continue to expand until it reaches its final maximum extent around year 40. At year 40, the threshold overpressure is nearly zero, and the pressure front begins to retreat towards the injection site. At the end of the 100-year monitoring period, the model predicts that the formation will remain slightly overpressured (by about 0.3 bars) because of the CO_2 volume added to the storage formation. The intersection between the Vedder Formation and the lowermost USDW in the eastern domain was assumed to have negligible overpressure. Figure 1-9 shows the formation pore pressure vs. time for the full 115-year project duration.

Questions/Requests for the Applicant:

- *Please provide additional maps reflecting the positions of the plume and pressure front at additional time steps of 2, 5, and 10 years to provide a basis for comparison following the planned 3D seismic surveys described in the Testing and Monitoring Plan.*
- *Please provide a graphic depiction of the cumulative storage for each of the phases of CO_2 over time.*
- *Please add more discussion within the AoR CA narrative of the plume movement over time as depicted on Figure 1-6b.*
- *Please add units for simulated CO_2 saturation on Figure 1-6b.*
- *The TOUGH2 model (based on Equation 1) indicates that pressures could rise after the end of the injection period while the reference case model predicts that pressure reaches maximum at the end of the injection period.*
    - *Please clarify the discrepancy and discuss the specific time at which the CO_2 plume and pressure front are expected to reach their maximum vertical and lateral extent.*
    - *Additionally, please discuss the boundaries at which this extent is defined.*

- *Please clarify the predicted pressure increases "in areas distant from the injection well after injection ends" referenced on page 22 of the AoR CA, and the length of time over which these increases are predicted to persist.*
- *For what depth does Figure 1-9 show pressure measurements?*
- *Please add figures to represent comparisons of $scCO_2$ saturation profiles for Years 5, 10, 40, and 75 (similar to Figures 1-10 and 1-11).*
- *Please clarify in the AoR and Corrective Action Plan what is meant by the terms "5-year AoR," "15-year AoR," and "20-year AoR."*

AoR Reevaluation Schedule

SJR described the procedures and timing for AoR reevaluations to be performed during the injection and post-injection phases, and the information that will be considered in the AoR reevaluations. At this point in the permit application review, the five-year default reevaluation schedule in the Class VI Rule that SJR proposes appears to be appropriate.

SJR also outlines the process for performing AoR reevaluations, including adjusting model parameters based on any newly obtained information and observed pressure and CO_2 saturation data. SJR says that it will provide the revised AoR to EPA and describe the revised model attributes; input parameter values; comparisons of observed and modeled CO_2 migration and fluid pressure values; model results/maps; and model calibration statistics.

Questions/Requests for the Applicant:

- *On page 24, the AoR CA states that "EPA recommends that the model calibration process and final AoR delineation results be presented in detail as part of the submission with…" EPA requests that SJR explicitly state that it will take these steps as part of the model calibration.*
- *Please also explain that SJR will report to EPA if it determines that no updates to any of the project plans are needed based on the results of an AoR reevaluation, and the basis for such a determination.*
- *Please identify at what frequency the AoR will be reevaluated in the post-injection timeframe.*
- *EPA also recommends that SJR reference the evaluations and interpretations of monitoring results in the Testing and Monitoring Plan (e.g., the seismic and pressure data collected as part of plume and pressure front tracking) as part of the AoR reevaluation process.*

Triggers for AoR Reevaluations Prior to the Next Scheduled Reevaluation

On pages 23-24, the AoR CA says that an unscheduled reevaluation of the AoR will take place if any of the following scenarios occur:

- After injection well construction and pre-injection testing and logging, to incorporate additional geologic information obtained from core analyses and additional injection well tests;
- If the anticipated injection rate changes;
- Following any switch from injection in the upper Vedder units (assumed in the baseline modeling scenarios) to the Vedder 3 unit;
- If monitoring results for the injected CO_2 plume and/or the associated pressure front differ significantly from model predictions; or

- If new site characterization data is obtained that may significantly change model predictions and the delineated AoR.

Questions/Requests for the Applicant:

- *Please clarify the timing for conducting an unscheduled AoR reevaluation (i.e., within 6 months) if any of the triggering events occur and that SJR will perform unscheduled reevaluations using the same procedures described in the AoR and Corrective Action Plan.*
- *EPA recommends the following clarifications/enhancements to the triggers for AoR reevaluation SJR identified:*
    - *Identify the specific changes (e.g., in injection rates, pressures or exceeding fracture pressure conditions), and explain how such an increase would not involve an exceedance of permit limits.*
    - *Specify what qualifies as a significant change in monitoring results, e.g., values of 3 standard deviations from average fluid concentrations of monitored parameters/CO_2 saturation in the injection zone or above the confining zone, or changes in pressure/temperature.*
    - *Clarify that new site data (e.g., the presence of a fault or fracture) may be identified in the course of seismic surveys/monitoring.*
- *EPA recommends that the following events be added to the triggers for an AoR reevaluation:*
    - *Initiation of competing injection projects within the same injection formation within a 1-mile radius of the injection well;*
    - *Significant land-use changes that would impact site access;*
    - *A compromise in injection well mechanical integrity;*
    - *Any seismic event greater than M 3.5 within a specified vicinity (e.g., 5 miles) of the injection well; and*
    - *Any other activity prompting a model recalibration.*

Post-Injection Site Care Plan

Certain elements of the applicant's PISC and Site Closure Plan are based on the modeling effort and the results and are evaluated below. See also the Testing and Monitoring report (for an evaluation of SJR's post-injection monitoring plan).

As required in 40 CFR 146.93(a)(2)(i) and (ii), the applicant presented the pre- and post-injection pressure differentials and the predicted position of the CO_2 plume and pressure front at site closure. This information is consistent with the AoR and Corrective Action Plan.

Post-Injection Site Care Time Frame

SJR proposed a 15-year post injection site care time frame. EPA evaluated the information SJR provided to support the proposed timeframe based on the criteria at 40 CFR 146.93(c) and in the context of the site characterization and AoR modeling evaluations, as described below.

- The results of computational modeling for delineation of the AoR [40 CFR 146.93(c)(1)(i)]. SJR references the AoR delineation modeling methods, results, and sensitivity analyses, as

presented in the AoR CA. The AoR delineation modeling approach appears to be acceptable (i.e., using an established model and extensive site data), provided that EPA's questions above are addressed and pre-operational testing confirms the site data on which the modeling is based.

- The predicted timeframe for pressure decline within the injection zone [40 CFR 146.93(c)(1)(ii)]. SJR asserts that pressure at the location of the injection well prior to injection is predicted to be approximately 259.5 bars; will increase to 265.25 bars at the end of the injection period; and then rapidly decline after injection ceases. Modeling predicts that pressure at the injection well will be 261 bars 5 years after the end of injection and 260.25 bars by 15 years after the end of injection, after which pressure decreases asymptotically, approaching the initial pre-injection pressure. SJR predicts similar pressure declines at the injection zone (IZ) monitoring well to below the threshold overpressure 6 years after the end of injection. Thus, it appears that pressure within the AoR declines to near pre-injection conditions within 5 years of cessation of injection and given the separation of the injection zone and USDWs, the presence of a competent confining layer, and the lack of conduits for fluid movement, the relatively low pressure increase by 15 years post-injection does not appear to be a concern. The TOUGH2 model predicts minor pressure increases in areas distant from the injection well after injection ends (AoR CA, pg. 22); however, no clarification or discussion is provided regarding the extent of pressure increase or how long these would persist (see EPA's questions under "Presentation of Model Results," above).
- The predicted rate of CO_2 plume migration within the injection zone, and the predicted timeframe for the cessation of migration [40 CFR 146.93(c)(1)(iii)]. SJR states that the separate-phase CO_2 plume is predicted to move very slowly (23 feet per year) after the injection period, with a maximum lateral expansion of 2,300 feet by 100 years post-injection; from 15 to 40 years, the rate of plume movement is less than 51 feet per year. Further, SJR asserts that the plume will migrate at a negligible rate as compared to the location of sensitive receptors (including abandoned wells in the AoR) and not pose an endangerment to USDWs. The AoR CA and PISC and Site Closure plans provide varying estimates of the rate of plume movement over the model timeframe:
    - Page 15 of the AoR CA predicts that the plume will move 150 m (about 492 feet) during the injection period (i.e., years 1-15), or approximately 33 feet/year.
    - According to the PISC and Site Closure Plan, from 15 to 40 years the rate of plume movement is less than 51 feet per year (which would equate to a total extent of about 1,275 feet). This would equate to approximately 31 feet per year between years 15 and 40 (when the plume expands from 492 to 1,275 feet).
    - SJR also states that the plume will expand to a maximum lateral extent of 2,300 feet by 100 years post-injection. This would equate to the plume moving approximately 17 feet per year in years 40 through 100 (as the plume extent expands from 1,275 to 2,300 feet).

  Given the lack of receptors and if corrective action is accomplished as described in the AoR CA, the rate of plume migration appears to be negligible.
- The site-specific processes that will result in CO_2 trapping [40 CFR 146.93(c)(1)(iv)], the predicted rate of CO_2 trapping [40 CFR 146.93(c)(1)(v)], and the results of analyses, research, and/or field studies to verify this information [40 CFR 146.93(c)(1)(vi)]. SJR predicts that CO_2

trapping occurs primarily by capillary trapping and CO_2 dissolution in the brine, as described in the narrative. The modeling predicts that at the end of injection, about 80% of the total injected mass of CO_2 are present in the CO_2-rich gas phase and 20% are dissolved in brine. At 100 years after the end of injection, about 64% of the CO_2 will be present in the gas phase and 36% dissolved in brine. Minor CO_2 mineralization is supported by the equilibrium geochemical modeling presented in the narrative and the low reactivity of the minerals in the Vedder and Freeman-Jewett Formations (e.g., quartz, feldspar and kaolinite). This is consistent with descriptions of CO_2 trapping in the AoR CA. As described in the geologic site characterization report, SJR performed geochemical modeling PHREEQC geochemical modeling software and, while the modeling approach appears to be acceptable, updated modeling using newer data acquired during pre-operational testing is needed to confirm that chemical concentrations used for the modeling are appropriate. SJR did not provide references to the results of analyses, research, and/or field studies to verify this information in the PISC and Site Closure Plan; however, these are included in the AoR CA and the permit application narrative.

- Confining zone thickness, permeability, and integrity [40 CFR 146.93(c)(1)(vii)]. SJR references the discussions of the Freeman-Jewett Formation confining zone in the permit application narrative. The Freeman-Jewett Formation is approximately 625 feet thick, with horizontal permeability of 0.26 mD and vertical permeability of 0.0036 mD, and contains no transmissive faults. Geochemical modeling indicates that the Freeman-Jewett Formation will not be significantly reactive with CO_2. The information about the confining zone is documented in the narrative, and is considered to meet this criterion, if EPA's questions in the site characterization evaluation are adequately addressed and pending the results of pre-operational testing, e.g., triaxial compressive strength tests.
- The presence of potential conduits for fluid movement, including injection wells and monitoring wells near the CO_2 plume and pressure front [40 CFR 146.93(c)(1)(viii)] and the quality of plugs of all abandoned wells within the AoR [40 CFR 146.93(c)(1)(ix)]. In the AoR CA, SJR explains that six of the seven identified wells that penetrate the Freeman-Jewett in the AoR will require corrective action based on casing and plugging records review. SJR did not describe the injection and monitoring well construction (per 40 CFR 146.93(c)(1)(viii)). However, SJR describes these wells in the permit application package (including a schematic of the injection well in the narrative). EPA will request schematics of the IZ monitoring well in its evaluation of testing and monitoring activities. EPA finds this information to be acceptable, pending receipt of the final as-built schematics of the injection and monitoring wells.
- The distance between the injection zone and the nearest USDWs [40 CFR 146.93(c)(1)(x)]. SJR states that the distance between the injection zone and the lowermost USDW ranges from 1,774 to 6,907 feet in the AoR, and is 5,284 feet at the location of the injection well. This is depicted in Figure 4 and discussed in the permit application narrative. Information about the depths of the injection zone and the lowermost USDW submitted to the AoR module of the GSDT also describe a separation of 1,612 meters, or 5,289 feet. While there are differences in the unit references in the narrative, AoR CA, and PISC and Site Closure Plan (i.e., bgs vs. msl), there appears to be significant and sufficient vertical separation distance (on the order of thousands of feet) between the injection zone and the USDWs, and this is acceptable as long as questions about confinement in the site characterization evaluation are addressed.

- Any additional site-specific factors required by the Director [40 CFR 146.93(c)(1)(xi)]. EPA has no specific requests at the current stage of the permit application review.

SJR did not directly address the items at 40 CFR 146.93(c)(2) regarding testing protocols/reproducibility of testing results, appropriateness of the model and inputs, QA/QC procedures, etc., in its alternative PISC timeframe demonstration. However, EPA has reviewed the testing performed for site characterization (as described in the geologic evaluation) and the modeling approach (as described above), and considers these criteria to be met. Any pre-operational testing that confirms the information above, and all post-injection monitoring, would be pursuant to the QA/QC procedures described in the QASP that SJR submitted in January 2022.

Based on the information available, EPA conditionally approves the alternative PISC timeframe (assuming that EPA's questions about the geologic and modeling bases of the proposed time frame are addressed). Note that all predictions on which the alternative PISC timeframe are based must be verified by post-injection monitoring and a non-endangerment demonstration.

Questions/Requests for the Applicant:

- *Based on information in the AoR CA and the PISC and Site Closure Plan, it appears that the plume will move 33 feet/year during the 15-year injection phase, approximately 31 feet per year between years 15 and 40, and approximately 17 feet per year in years 40 through 100. Please confirm.*
- *Please describe or reference the construction of the injection and the IZ monitoring wells (per 40 CFR 146.93(c)(1)(viii)) in the alternative PISC timeframe demonstration of the PISC and Site Closure Plan.*
- *Please reference, within the PISC and Site Closure Plan, the specific analyses, research, and/or field studies that provide evidence to support CO_2 trapping as required by 40 CFR 146.93(c)(1)(vi).*

Non-Endangerment Demonstration Criteria

Consistent with EPA guidance recommendations, the AoR CA describes the information and procedures criteria that it will use to demonstrate non-endangerment prior to gaining authorization for site closure, including: operational and monitoring data; status of conduits for fluid movement; modeling results from AoR evaluations; evaluation of reservoir pressure; and evaluation of the CO_2 plume based on monitoring data. For additional information on EPA's expectations for the non-endangerment demonstration criteria, see the PISC and Site Closure Plan template in the GSDT.

Questions/Requests for the Applicant:

- *EPA recommends the following clarifications/enhancements to the non-endangerment demonstration information that SJR identified:*
    - *Please reference the specific monitoring data, e.g., water quality monitoring, seismic survey results, downhole pressure data, that will support the evaluation of the CO_2 plume and specifically reference the monitoring strategies in the Testing and Monitoring Plan and PISC and Site Closure Plan.*

- *The criteria should specify that the same delineation model that supported the initial AoR delineation will be used in AoR reevaluations and to make the non-endangerment demonstration. This will facilitate verification and/or model calibration using actual monitoring and operational data.*
- *The non-endangerment criteria should also include a summary of any emergencies or other unanticipated events that may occur during the injection and post-injection phases. This may be presented in a table that shows (1) examples of unanticipated events that might occur, and (2) the types of data that might be used to demonstrate that any associated issues have been resolved such that they will no longer endanger USDWs.*

Evaluation of Proposed Testing and Monitoring Activities at the San Joaquin Renewables Class VI Project

This testing and monitoring evaluation report for the San Joaquin Renewables (SJR) proposed Class VI geologic sequestration (GS) project summarizes EPA's evaluation of the testing and monitoring that the applicant proposes to conduct during and following injection operations into the Vedder Formation. Due to the similarities of certain monitoring activities (e.g., groundwater monitoring and plume and pressure front tracking) to be performed in the injection and post-injection phases, these activities (as described in the Testing and Monitoring Plan and PISC and Site Closure Plans, dated October 13, 2021) are evaluated in a single report. EPA also reviewed SJR's Quality Assurance Surveillance Plan (QASP), dated December 22, 2021. This review identifies preliminary questions for the applicant, includes requests for supplemental information, and provides some considerations for future testing/analytical requirements. Note that, because of the interdependencies between the testing and monitoring strategy and other aspects of the permit application, additional questions may arise as other reviews proceed.

SJR says that it will report the results of all injection-phase testing (including supporting data) semi-annually or within 30 days of the completion of each mechanical integrity test/pressure fall-off test. SJR will submit all post-injection monitoring results to EPA in annual reports within 60 days following the anniversary of the date on which it ceases injection. These reporting schedules are consistent with the requirements of 40 CFR 146.91.

Questions/Requests for the Applicant:

- *When SJR submits its updated Testing and Monitoring Plan, please clarify that CO_2 stream analysis, corrosion monitoring, plume and pressure front tracking results will be submitted in an electronic format.*

Carbon Dioxide Stream Analysis

To meet the requirements of 40 CFR 146.90(a), SJR plans to analyze the carbon dioxide (CO_2) stream for the following parameters using the methods listed below:

- CO_2 purity (ASTM E1747);
- Total sulfur (ISBT 14.0);
- Hydrogen sulfide (ISBT 14.0);
- Nitrogen (ISBT 4.0);
- Total Hydrocarbons (ISBT 10.0); and
- Methane (ISBT 10.1).

These analytes are consistent with information in the permit application narrative, which states that 99.9 percent by mass of the stream will be CO_2, methane, benzene, ethane, and nitrogen (narrative, pg. 30 and Table 2-10). Table 3-1 of the narrative presents the modeled composition of the injectate and includes a wider range of parameters, primarily hydrocarbons, many of which are predicted to be present in extremely low concentrations, i.e., in concentrations of 10^{-5} or less. Table 3-1 also includes carbon monoxide and water, which EPA recommends be included in the analytes for completeness.

There are no EPA-approved analytical methods for CO_2 injection streams. The majority of the analytical methods SJR proposes to use are from the International Society of Beverage Technologists, and have been employed for other CO_2 GS projects, so there is EPA precedent for their use in EPA Class VI permits. In the QASP, SJR mentions the use of ASTM methods for CO_2 stream analysis (including ASTM D1945, D3246, and D6228) in addition to the methods listed above.

Questions/Requests for the Applicant:

- *For completeness and consistency with the preliminary injectate information and other Class VI permits, EPA requests that injectate analysis also include water, ammonia, oxygen, carbon monoxide, and oxides of nitrogen.*
- *Please clarify the discrepancy with the QASP, where SJR describes ASTM methods for CO_2 stream analysis or revise the Testing and Monitoring Plan to include these methods. (Including these methods in the Testing and Monitoring Plan would avoid the need for future approval prior to their use during project operations.)*

Considerations based on the results of Pre-Operational Testing/Modeling Updates:

- *EPA will require that a baseline injectate sample be analyzed for the same parameters as in the Testing and Monitoring Plan prior to commencement of injection.*
- *If this sample or any updated information about injection formation fluids indicates that any injectate constituents may lead to geochemical reactions that could affect operations or change formation properties, additional analytical parameters for the injectate analysis may be requested.*

Injection Well Testing

The subsections below describe: the planned corrosion monitoring; continuous recording of injection pressure, rate, and volume to evaluate internal mechanical integrity; and annual external MITs for the SJR-I1 injection well that will meet the requirements at 40 CFR 146.90(b), (c), and (e).

Corrosion Monitoring

SJR proposes to conduct corrosion monitoring using the coupon method and by conducting casing inspection logs.

SJR will perform quarterly monitoring of corrosion coupons. SJR states that coupons made of materials that are representative of the long-string casing, injection tubing, and wellhead will be installed in a flow-through pipe arrangement directly upstream of the wellhead, but does not describe the coupons. SJR states that coupon corrosion will be evaluated based on ASTM method G1-03 including photography, dimensional measurement, and weighing.

SJR will also monitor for corrosion by performing semi-annual casing inspection logs using one or more of the following methods: ultrasonic imaging log, multi-finger caliper log, electromagnetic flux log, or downhole video. The logging procedures are not described; however, EPA recommends including logging descriptions to provide for a complete plan and to facilitate their use, especially if they are ever to be used as a substitute for the use of coupons.

Questions/Requests for the Applicant:

- *Please describe the corrosion coupons in the Testing and Monitoring Plan, i.e., based on the materials for the injection well as described in the narrative.*
- *The QASP also mentions the possible use of corrosion coupons by National Association of Engineers (NACE) International TM-01-69. EPA recommends adding this to the Testing and Monitoring Plan for completeness and to facilitate their use during project operations.*
- *What level/rate (e.g., 0.3 mils/year) of observed corrosion of the coupons would indicate an integrity concern?*
- *Please describe casing inspection logging procedures to facilitate their use if they are to be used as a substitute for the use of corrosion coupons.*

Continuous Monitoring to Evaluate Internal Mechanical Integrity

SJR describes continuous recording devices to monitor: injection pressure, rate, and volume; the pressure on the annulus between the tubing and the long string casing; and the temperature of the CO_2 stream, as required by 40 CFR 146.88(e)(1), 146.89(b), and 146.90(b). However, the Testing and Monitoring Plan does not describe methods to measure the annulus fluid volume added, which is also required at 146.90(b).

According to the permit application narrative, SJR plans to perform formation testing to determine the fracture pressure of the injection zone. It is presumed that, at that point, SJR will calculate an appropriate injection pressure, and SJR will need to install pressure gauges that will ensure the maximum allowable surface and downhole injection pressures are not exceeded. SJR will also need to indicate the annular pressure needed to signify a mechanical integrity issue based on the final construction of the well.

Questions/Requests for the Applicant:

- *Please clarify the location/depths of the downhole gauges described in the Testing and Monitoring Plan. These should also be depicted on the injection well schematics when they are submitted.*
- *Please add monitoring of the annulus fluid volume to match the activities required at 40 CFR 146.90(b).*
- *Please explicitly define the annular pressure deviation that would warrant a mechanical integrity investigation.*
- *Please describe the minimum measuring and recording frequencies (e.g., measuring every 10 seconds, recording every 2 minutes) for each continuous monitoring device described in the Testing and Monitoring Plan.*
- *EPA recommends that information about continuous monitoring be provided in a table that describes each device, its location (i.e., surface vs. downhole), and the sampling and recording frequencies. See, e.g., the table in the Testing and Monitoring Plan template, which is available in the GSDT.*

Considerations based on the results of Pre-Operational Testing/Modeling Updates:

- *The maximum pressure thresholds identified for continuous monitoring and the annulus pressure will need to be incorporated into the Testing and Monitoring Plan based on formation testing and the final permit conditions related to injection pressure.*
- *The final injection well schematics will need to reflect all downhole gauges.*

External MITs

To verify external mechanical integrity as required at 40 CFR 146.89(c) and 146.90, SJR plans to perform temperature and/or oxygen activation logs annually. SJR also plans to perform the same MITs prior to commencing injection.

SJR states that temperature logs (TL) and/or oxygen activation logs (OALs) will be conducted according to the specifications in EPA's Class VI Testing and Monitoring Guidance. That guidance does not provide specific procedures for MITs; however, the TL procedures are described in guidance from EPA Region 9. SJR outlines the basic procedure for conducting temperature logs, including descriptions of shut-in times and temperature logging times.

SJR states that it will conduct OALs only if necessary to resolve temperature logging results or if temperature logging results indicate potential failure. No OAL procedures are provided. If SJR plans to perform an OAL, it would need to provide a detailed description of the MIT testing procedures to EPA prior to performing the test.

SJR's financial responsibility demonstration includes costs for post-injection MITs in the Vedder Formation monitoring well, which is consistent with EPA guidance; however, this testing is not described in the Testing and Monitoring or PISC and Site Closure plans. EPA recommends that SJR include MITs of both of the deep monitoring wells in the Testing and Monitoring Plan.

Questions/Requests for the Applicant:

- *Please provide more extensive temperature logging procedures, e.g., in accordance with the document, "Appendix E – Temperature Logging Procedures – U.S.E.P.A. Region IX," which is available online at: https://archive.epa.gov/region9/water/archive/web/pdf/appendixetemplogreqs.pdf.*
- *EPA recommends that SJR describe OAL procedures in the Testing and Monitoring Plan to facilitate their use during project operations.*
- *Please provide procedures and plans for performing MITs in the Vedder Formation and ACZ monitoring wells in the Testing and Monitoring Plan.*

Pressure Fall-Off Testing (PFOT)

SJR states that it will perform PFOTs every five years during the injection phase to meet the requirements of 40 CFR 146.90(f). SJR will also perform a PFOT after initial completion of the injection well. The Testing and Monitoring Plan provides a brief description of the test procedures and information to be submitted to EPA.

Questions/Requests for the Applicant:

- *Please provide more detailed PFOT procedures, e.g., in accordance with the document, "EPA Region 9 UIC Pressure Falloff Requirements," which is available online at: https://archive.epa.gov/region9/water/archive/web/pdf/falloff-testing-guidlines.pdf.*

Groundwater Quality Monitoring

To meet the requirements of 40 CFR 146.90(d), SJR plans to perform the following direct and indirect monitoring above the confining zone:

- Quarterly injection-phase water quality monitoring and continuous pressure monitoring in one above confining zone (ACZ) monitoring well that SJR plans to install immediately southeast of the injection well (per Figure 1). The well will be completed in the Olcese Formation, which is the formation immediately above the Freeman-Jewett confining zone and occurs from approximately 6,625 to 7,095 feet below ground surface. During the post-injection phase, SJR plans to perform annual water quality sampling and continuous pressure monitoring.
- Semi-annual water quality monitoring in eleven (11) publicly- and privately-owned wells that are currently monitored by the Southern San Joaquin Municipal Utility District (SSJMUD). The wells are screened within USDWs overlying the SJR project site. Six of the wells (Delano Well 14, McFarland Taylor Well, SSJMUD-23, SSJMUD-42, SSJMUD-53 and SSJMUD-14) are located within the delineated AoR; the others are just outside of the AoR. According to Figure 2, the wells are between 6 and 329 feet deep.

SJR says that it will seek to enter into a memorandum of understanding (MOU) with SSJMUD to (1) gain access to water quality data from each of the monitoring wells within the AoR, and (2) if needed, obtain access to the wells for periodic sampling. The permit application narrative states that the deepest USDW is over 1,000 feet, and would therefore not be monitored. However, monitoring in the shallow formation that likely serves as the drinking water source is appropriate.

If an MOU with SSJMUD is in place for the duration of the injection and post injection time frames, this should provide the necessary access to water quality data. However, any change in ownership of the USDW monitoring wells, particularly those within the AoR, could affect the applicant's ability to perform all of the monitoring. Any change in SJR's ability to access these wells could necessitate an update to the injection or post-injection monitoring plan.

SJR proposes to monitor water quality in the USDW and the ACZ wells for the same set of parameters using the same analytical methods. The table below identifies these parameters and provides EPA's evaluation notes and questions for SJR.

Parameter (Method)	Evaluation Notes/Questions
Carbon dioxide (ASTM D513 or similar)	Please clarify the year of the ASTM method.
Dissolved metals (EPA 200.8/200.9/7010 or similar)	EPA Methods 200.7, 200.8 and 200.9 are likely more appropriate options. EPA Method 7010 does not appear to be an approved EPA wastewater analytical method. Please specify the following revision numbers: 200.7, Rev. 4.4; 200.8, Rev. 5.4; 200.9, Rev. 2.2.
Total dissolved solids (ASTM D5907 or similar)	Please clarify the year of the ASTM method.
Major anions (EPA 300.1 or similar)	Please list the specific anions (e.g., Br, Ca, F, NO3, SO4, and Cl).
Major cations (EPA 6020A/6020C/700B or similar)	Please list the specific cations (e.g., Al, Ba, Mn, As, Cd, Cr, Cu, Pb, Se, Tl, Sb, Ca, Fe, K, Mg, Na, and Si). Please provide additional information about EPA Method 6020C, which is not an EPA-approved wastewater analytical method. Please edit "EPA Method 700B" to be "EPA Method 7000B." Please clarify that EPA Method 6020A is the February 2007 version.
pH, temperature, specific conductivity (calibrated field meter)	Please provide documentation that meter calibration is using standards that are not out of date.

The parameters appear to be generally appropriate for groundwater quality monitoring needs for GS projects, and are consistent with other Class VI monitoring programs, except as noted in the table above and the questions below. As the permit application narrative describes (on pg. 28), the Vedder and Freeman-Jewett formations are composed predominantly of silicate minerals like quartz, feldspar, and clays that are not expected to be highly reactive during CO_2 sequestration. The graywacke sandstones in the Vedder Formation indicate iron and/or magnesium presence with potential manganese when dissolution/oxidation occurs; thus, dissolved metals and cations of manganese are appropriate analytes. Note that, as additional information is gathered based on the reviews of other parts of the permit application or pre-operational data collection, recommendations or requirements for additional analytical parameters may be provided.

Many of the methods SJR proposes are used in other UIC permits (including Class VI permits), and are considered acceptable as part of the Testing and Monitoring Plan. Most of the methods are EPA-approved wastewater analytical methods or ASTM methods; while no information was provided about the ASTM methods, they are generally considered to be acceptable testing methods and approvable in EPA permits. For several analytes, SJR indicates they may use a "similar" method to the one listed; this could introduce some uncertainty about the method to be used, and EPA recommends that SJR explicitly describe all methods they may potentially use in the plan.

EPA recommends in Class VI guidance that monitoring well construction and planned plugging procedures be reviewed as part of the permit application evaluation to confirm that these wells will not provide conduits for fluid movement that could endanger USDWs. No monitoring well construction or plugging information was provided in the permit application materials. Verification of the depth and

construction of the ACZ well will be needed prior to authorization of injection. EPA will also need to review schematics, including the pressure gauges, for the ACZ well.

SJR's QASP describes similar analytes and methods to the Testing and Monitoring Plan. However, it also mentions analysis of dissolved oxygen (DO), which EPA recommends including in the Testing and Monitoring Plan.

SJR should note that the Central Valley Water Board indicated in its consultations with EPA on a prior Class VI project that any newly drilled monitoring wells must be approved by the Water Board and, while existing wells would not need to be approved, the Water Board expressed interest in any plans to use existing wells as monitoring wells.

Questions/Requests for the Applicant:

- *Please update the discussion of water quality monitoring parameters to address the comments in the table above.*
- *In addition, please include the following groundwater quality parameters to support a robust monitoring program, as follows:*
    - *Dissolved O_2 and H_2S. Dissolved O_2 is a primary indicator of water quality (and is mentioned in SJR's QASP). H_2S occurs in the subsurface and has the potential to be mobilized, and is listed as a toxic substance by the CDC.*
    - *EPA also recommends SJR analyze groundwater for alkalinity (e.g., using SM 2320 B) and dissolved methane (e.g., via RSK-175/Gas Chromatography).*
- *EPA requests that, where SJR mentions the use of analytical methods that are "similar" to the EPA methods listed, SJR should describe these methods in the plan; otherwise, SJR will need to gain EPA's approval before using any of them.*
- *What is SJR's plan for conducting USDW monitoring if any of the wells that are owned by municipalities or private entities were to be closed?*
    - *EPA recommends that SJR include in the Testing and Monitoring and PISC and Site Closure Plans that, should any of the USDW wells be plugged by their owners, SJR will notify EPA and identify whether additional monitoring wells are needed and revise the plan if necessary.*
    - *The Testing and Monitoring Plan says that SJR plans to gain access to water-quality data obtained from each of the SSJMUD monitoring wells "within the AoR." Please clarify in the plan if SJR also plans to gain water quality data from the wells outside the delineated AoR.*
- *Please provide schematics of all the wells to be used for monitoring that depict the sampling equipment/gauges to be used and their depths.*
- *Please also provide plugging and abandonment plans for the ACZ monitoring well.*

Considerations based on the results of Pre-Operational Testing/Modeling Updates:

- *Confirm the depth and diameter of the ACZ well after it is constructed for consistency with other permit attachments, e.g., the financial responsibility demonstration.*
- *Confirm the appropriateness of the water quality analytes based on formation water quality analyses during drilling of the injection and monitoring wells.*

CO_2 Plume and Pressure Front Tracking

SJR describes planned CO_2 plume and pressure front tracking that includes the use of direct and indirect methods for tracking the extent of the CO_2 plume and pressure front during the injection and post-injection phases, per the requirements of 40 CFR 146.90(g)(1),(2). Specifically, SJR proposes to track the plume and pressure front using the following methods:

- **Indirect monitoring of the CO_2 plume** using time-lapse three-dimensional surface seismic surveys within the AoR.
- **Direct pressure monitoring** within the injection zone via the injection well and a monitoring well completed in the injection zone.

CO_2 Plume Monitoring

SJR proposes to monitor the CO_2 plume using time-lapse three-dimensional (3D) surface seismic surveys within the AoR. The 3D seismic surveys will be conducted prior to injection (baseline), and at Years 2, 5, and 10 during the injection phase. According to the PISC and Site Closure Plan, seismic surveys will be performed at the cessation of injection and in Year 15 of the post-injection phase.

SJR states that plume monitoring will cover the entire extent of the area anticipated to be subject to CO_2 migration. On Figure 1, it appears that the area covered by the seismic survey is a 6-square mile area that extends beyond the areas depicted where CO_2 plume saturation will be greater than 5%. SJR also states that surface-seismic results will provide an indication of whether supercritical-phase CO_2 is present in any given location and that it plans to compare the results of the seismic surveys to the predicted extent of the CO_2 plume; however, it does not explain how this correlation between seismic survey data and CO_2 plume saturation will be made.

In their financial responsibility demonstration, SJR describes fluid sampling in the Injection-Zone (IZ) monitoring well; however, this sampling is not described in the Testing and Monitoring Plan. EPA recommends in guidance that permittees perform fluid sampling in the injection zone with similar analytes as in the above confining zone monitoring to gather data to demonstrate that USDWs are not endangered and to support AoR reevaluations and the non-endangerment demonstration required at 40 CFR 146.93(b).

Questions/Requests for the Applicant:

- *Please clarify in the Testing and Monitoring Plan that updating of the computational modeling is not a plume tracking method, but is a verification process.*
- *EPA recommends that SJR perform fluid sampling in the IZ monitoring well (at least until the CO_2 plume reaches the well) with similar analytes as in the ACZ monitoring to demonstrate that*

USDWs are not endangered and to gather data to support AoR reevaluations and the non-endangerment demonstration.

- *EPA recommends that SJR ensure that the second seismic survey (i.e., at 5 years of injection), be timed to allow collection of this data prior to the initial AoR revaluation.*
- *Please explain how SJR plans to use the seismic and pressure data collected as part of plume and pressure front tracking to estimate CO_2 saturation and characterize any changes that might occur.*
- *EPA recommends that SJR include monitoring for seismic events (e.g., via existing state- or USGS-operated seismic monitoring networks) to afford an opportunity to respond to any events that could affect the injection/monitoring wells.*

Considerations based on the results of Pre-Operational Testing/Modeling Updates:

- *Gather baseline seismic data via a 3D seismic survey.*

Pressure Front Monitoring

SJR proposes to perform direct pressure monitoring within the injection zone via the Class VI injection well and in a monitoring well to be installed within the Vedder Formation (the IZ well). SJR states that the injection well will be fitted with downhole fiber optics for monitoring pressure within the injection zone, and the IZ monitoring well will be fitted with a downhole transducer for continuous pressure measurement. This monitoring well is depicted on Figure 1 in the Testing and Monitoring Plan, and is approximately two miles to the east of the injection well, and within the area where pressures are expected to increase, as shown in the AoR and Corrective Action Plan (i.e., on Figure 1-8a which shows the distribution of overpressures at the end of the 15-year injection period). However, it is unclear based on Figure 1 when the pressure front will reach the location of the IZ monitoring well. Pressure monitoring in the injection zone monitoring well will continue in the post-injection timeframe, according to the PISC and Site Closure Plan.

No pressure monitoring is planned to the west of AoR, where the Pond-Poso Creek Fault Complex forms the western structural boundary of the AoR. As described in EPA's geologic evaluation report, there is no definitive pressure data that would indicate that the fault complex is sealing to pressure. Depending on SJR's responses to questions in that report about the sealing nature of the fault, pressure monitoring to the west of the Pond-Poso Creek Fault Complex may be appropriate.

Verification of the depth and construction of the Vedder Formation monitoring well will be needed prior to authorization of injection.

Questions/Requests for the Applicant:

- *When is the pressure front expected to intersect the location of the IZ monitoring well?*
- *EPA recommends adding a map to the Testing and Monitoring Plan that shows the IZ monitoring well along with the pressure contours shown on Figure 1-8a of the AoR and Corrective Action Plan to provide context for the location of the IZ monitoring well.*
- *On page 9, the Testing and Monitoring Plan states that the planned location of the IZ monitoring well is on Figure 2; however, the well is on Figure 1. Please clarify the reference.*
- *Please provide schematics of the IZ well that depict the sampling equipment/gauges to be used, and their depths.*
- *Please provide a plugging and abandonment plan for the IZ monitoring well.*

Considerations based on the results of Pre-Operational Testing/Modeling Updates:

- *Confirm the depth and diameter of the IZ well after it is constructed for consistency with other permit attachments, e.g., the financial responsibility demonstration.*
- *Determine whether pressure monitoring west of the Pond-Poso Creek Fault Complex is needed.*

Air/Soil or Other Testing and Monitoring

No monitoring of CO_2 levels in air or soils is described in the Testing and Monitoring Plan.

Questions/Requests for the Applicant:

- *The Emergency and Remedial Response Plan scenarios include elevated CO_2 in indoor air. How does SJR plan to monitor and detect this?*

Considerations based on the results of Pre-Operational Testing/Modeling Updates:

- *If uncertainties about the geologic setting or other concerns are identified based on the results of planned pre-operational testing, the need for air and/or soil gas monitoring or other monitoring will be reconsidered.*

Quality Assurance Procedures

EPA reviewed the QASP to verify that the testing activities, analytes, etc., included in the QASP are consistent with proposed injection and post-injection phase testing and monitoring. The QASP outlines QA procedures (e.g., for laboratories, field instruments/field sampling methods, analytical methods, and sample handling) for all of the activities described in the Testing and Monitoring Plan. The methods described are similar to those in the Testing and Monitoring Plan, except as described in EPA's evaluation notes above.

Questions/Requests for the Applicant:

- *The Testing and Monitoring Plan refers to quality assurance and quality control procedures. EPA recommends that it specifically reference the QASP document.*
- *Water quality sampling methods in the above confining zone well are described in the QASP. EPA requests that SJR indicate that any water quality sampling/analysis in the USDW or injection zone wells that is performed by SJR will be performed with the same QA protocols.*

Evaluation of Operating Procedures in the San Joaquin Renewables Class VI Permit Application

This evaluation for San Joaquin Renewables' (SJR) proposed Class VI geologic sequestration project summarizes EPA's review of proposed operating procedures for the SJR-I1 injection well, per 40 CFR 146.82(a)(7), (9), (10) and 146.88. SJR submitted information regarding operation of the injection well in their Class VI permit application narrative dated January 7, 2022. This review identifies preliminary questions and includes requests for supplemental information from the applicant. This evaluation of the proposed operating conditions, particularly injection rates and pressures, was performed in conjunction with EPA's evaluation of SJR's Area of Review (AoR) delineation modeling (which is documented in a separate report).

The proposed operational procedures for SJR-I1 are summarized in the table below from EPA's Summary of Requirements template:

Parameter/Condition	Limitation or Permitted Value
Maximum Injection Pressure - Surface	Not provided
Maximum Injection Pressure - Bottomhole	Not provided
Annulus Pressure	Pressure at packer depth not provided
Annulus Pressure/Tubing Differential	Pressure at packer depth at average injection conditions not provided
Maximum CO_2 Injection Rate (daily)	1,200 tons/day
Maximum CO_2 Injection Rate (annual)	438,000 tons/year

Injection Pressure

The basis for the maximum injection pressure in relation to the Vedder Formation fracture pressure is described in the permit application Narrative. The total fracture gradient for the Vedder Formation (given in Appendix G of the Narrative) is 0.66 psi/ft. Based on this gradient calculation, the fracture pressure for the Vedder Formation at project depth of ~7,775 ft bgs is 5,132 psi (Narrative, pg. 30), which is equivalent to 353.8 bar. However, SJR did not provide an estimate of the surface or down-hole injection pressure.

Questions/Requests for the Applicant:

- *Please provide an estimate of the surface and/or bottomhole injection pressures.*

Objectives for Pre-Operational Testing:

- *Determine maximum surface and downhole injection pressures based on pre-operational testing.*

Annulus Pressure and Annulus/Tubing Pressure Differential

The applicant does not discuss annulus pressure and annulus/tubing pressure differential in the description of injection well design in Section 3.3 of the Narrative.

Questions/Requests for the Applicant:

- *Please provide the annulus pressure and the annulus/tubing pressure differential.*

Maximum CO_2 Injection Rate

SJR plans to inject 1,200 tons of carbon dioxide per day into well SJR-I1 for a period of 15 years, for a yearly rate of 438,000 tons/year and a total of 6.57 million tons (Narrative, pg. 29).

Questions/Requests for the Applicant:

- *Please describe standard operating procedures to ensure that the permitted maximum daily injection rate will not be exceeded.*
- *Does SJR expect that the injection rate will be consistently 1,200 tons/day for the entire duration of the project, or are fluctuations in this rate anticipated? If fluctuations are anticipated, please describe.*

Shutdown Procedures

Section 6 of SJR's Emergency and Remedial Response Plan (ERR) states that a step-by-step shutdown procedure will be added to the document following the construction of the SJR-I1 well (ERR, pg. 7). Describing procedures for shutting down the well, either for routine workovers or in response to emergency events (other than those that warrant an immediate shutdown) will ensure that procedures are in place to shut down the well in a manner that will not damage the well and cause a mechanical integrity issue.

Questions/Requests for the Applicant:

- *Please describe the shutdown procedures that would be implemented as part of an emergency response, i.e., the rate of injection volume reduction over a specified number of days.*
- *Please also describe routine well shutdown procedures (e.g., for well workovers), and if these would be the same as the gradual shutdown procedures requested above.*

Automated Shutdown System

Section 6 of SJR's Emergency and Remedial Response Plan states that information on emergency shutoff controls and instrumentation will be added to the document following the construction of the SJR-I1 well (ERR, pg. 7).

Questions/Requests for the Applicant:

- *Please include standard operating procedures (including routine tests/checks and any failsafe mechanisms) to support the automated shutdown system when details about the system are provided.*

Well Stimulation

SJR submitted a well stimulation program on January 7, 2022. The plan describes potential procedures for acid and fracture stimulation techniques, which SJR indicated that they may employ. This generic stimulation program meets the requirement at 40 CFR 146.88(a) that stimulation programs be approved by the EPA Director as part of the permit application and incorporated into the permit. EPA anticipates

that, if SJR determines that stimulation is needed at a later date, they would provide updated procedures for EPA review and approval.

Evaluation of Construction and Plugging Procedures for the San Joaquin Renewables Class VI Project

This well construction and plugging evaluation report for the proposed San Joaquin Renewables (SJR) Class VI geologic sequestration (GS) project summarizes EPA's evaluation of several related activities associated with construction and plugging of the injection well (SJR-I1) and monitoring wells associated with the planned GS project and corrective action in the area of review. Due to the similarities of these activities, they are evaluated in a single report. These activities are described in Attachments 2-7 of the permit application. This review also identifies preliminary questions for SJR.

Injection Well Construction

SJR did not submit a separate well construction plan, but Section 3 of the permit application narrative describes the proposed injection well construction design. The proposed injection well design schematic is presented in Figure 3-1 of the narrative. The figure shows the position of the various casing strings, tubing, packers, and perforations to be implemented in the SJR-I1 injection well.

The proposed injection well will be a new vertical well. SJR will determine the final perforation intervals based on the results of pre-operational well logs and formation sampling (see additional evaluation under "Injection Well Pre-Operational Testing," below). However, the perforations are preliminarily anticipated to be as follows (based on the cement casing details on the proposed wellbore schematic):

- From 7,775 to 7,789 feet below ground surface (bgs) in the Pyramid Hills Formation (PH),
- From 7,789 to 7,900 feet bgs in the Vedder 1 (V1) Sands,
- From 8,040 to 8,132 feet bgs in the Vedder 2 (V2) Sands, and
- From 8,167 feet to 8,255 feet bgs in the Vedder 3 (V3) Sands.

While, as the application notes, the final perforation depths will be determined based on pre-operational testing, the well schematic appears to be consistent with information about the depth of the Pyramid Hills and Vedder Formations in the narrative.

The narrative states that well materials will be compatible with the CO_2 injectate and will limit corrosion, including the use of standard J55 and N80 steels for surface and intermediate casing. According to the narrative, the injection casing may be able to be installed using standard L80 or lower specifications, assuming the estimated purity of the carbon dioxide injection stream is accurate. Another option would be to place 13Cr casing across the injection sands below the intermediate pipe, and non-chrome inside the intermediate section. All casing strings will be cemented to the surface, and a dual completion will enable two injection zones. SJR did not describe the pre-operational testing plan to confirm the composition, properties, and corrosiveness of the injectate and its compatibility with well construction materials. This will be needed prior to operation of Well SJR-I1.

The narrative states that "intermediate casing will be placed across fresh water and USDW zones, with a shoe at 2,600 ft bgs" (p. 30); per the Class VI Rule, the surface casing must be set and cemented to the depth of the lowermost USDW. The proposed depth of the casing shoe appears to be appropriate based on information in the narrative about the depth to the USDW.

Proposed Wellbore Schematic

CO2 Injection Well
Two Injection Zones, Two Strings
Short String: Pyramid Hill + Vedder 1 + Vedder 2
Long String: Vedder 3

San Joaquin Renewables

Geo Marker	INCL/TVD	Hole		Casing & Perf	Details
				Depths are MD	
		26"		20" 94# J-55 BTC Csg @ 250'	20" Csg cmt'd @ 250'-Surf w/ 489 CF cmt
		17-1/2"			
BFW @ ~1750'					
USDW @ ~2495'				13-3/8" 61# J-55 BTC Csg @ 2600'	13-3/" Csg cmt'd @ 2600'-Surf w/ 2377 CF cmt
		12-1/4"			
				9-5/8" 53.5# N-80 LTC Csg @ 7700'	9-5/8" Csg cmt'd @ 7700'-Surf w/ 3207 CF cmt
Pyramid Hills @ 7775' Vedder 1 @ 7789' Vedder 2 @ 8040'				Perforated @ 7775'-7789' (PH), 7789'-7900' (V1), 8040'-8132' (V2)	Hydraulic set packer @ 7725' 2-3/8" IC Cr13 tbg @ 7750'
		8-1/2"			2-3/8" IC Cr13 tbg @ 7725' Wireline set packer @ 8120' 2-3/8" IC/EC Cr13 tbg @ 8150'
Vedder 3 @ 8167' Vedder 4 @ 8344'				Perforated @ 8167'-8255' (V3)	
		TD @ 8700'		7" 29# L-80 Cr13 LTC Csg @ 8700'	7" Csg cmt'd @ 8700'-Surf w/ 1166 CF cmt w/ latex additive in tail

Creator & Date: JM 5/26/2021

SAN JOAQUIN RENEWABLES
Injection Well Design

K:\Projects\Environmental Services\Private\Frontline Bioenergy\Final Documents\Permit Application\Figures\docx\ Fig_3-1_Injection Well Design.docx

10/4/2021 DB19.1252

Figure 3-1

The applicant states that conventional Class G cement will be adequate for the surface and intermediate casings, and a latex additive in the tail cement for the injection casing will help eliminate potential gas migration. The narrative also states that all casing strings will be cemented to surface.

The permit application narrative (on pg. 14) notes that the "The eastern homocline of the San Joaquin Basin Province overlies the granite basement. The nature of the prograding, agrading, and retrograding stratigraphy indicates that the basin formed at a variable but increasing subsidence rate." The effects of subsidence on the mechanical integrity of injection wells have been cited as a concern in other California oil fields, and some operators have developed mitigation measures to relieve stress on the surface casing (e.g., via wellhead design that allows differential movement between the casings). Any design modifications to address the subsidence concern will need to meet the requirement that Class VI wells have cementing of the surface casing that extends to the surface.

Questions/Requests for the applicant:

- *The narrative (pg. 31) states that "The dual injection string design … using 2 3/8" tubing may restrict certain logging options to special smaller diameter logging tools." Please confirm that SJR will be able to perform the required mechanical integrity tests (MITs), or other tests given the small tubing diameter.*
- *Please include the continuous recording devices that will be installed to monitor injection pressure, rate, and volume (as described in the Testing and Monitoring Plan) on the injection well schematic.*
- *Please provide a description of the safety valves and shut-off devices required at 40 CFR 146.88(e)(2) and how they will be linked to the continuous injection and annulus monitoring system.*
- *Please describe in the well construction procedures that the annulus between the tubing and the long string casing will be filled with a non-corrosive fluid, as required by 40 CFR 146.88(c), and describe the fluid.*
- *Please confirm that the surface casing extends to through the base of the lowermost USDW, as required per 40 CFR 146.86(b)(2).*
- *Please clarify that the surface (not intermediate) casing will be set and cemented to the depth of the lowermost USDW.*
- *Please provide well construction details in table form (i.e., using the "Construction Details" template that is available in the GSDT) for the following:*
    - *Open Hole Diameters and Intervals;*
    - *Casing Specifications;*
    - *Tubing Specifications (including tensile, burst, and collapse strengths); and*
    - *Packer Specifications.*
- *Please explain how the injection well's design will mitigate shallow compression that has been shown to occur in California oil fields.*

Objectives for Pre-Operational Testing:

- *Confirm the composition of the CO_2 injectate as part of baseline sampling and provide verification that it is compatible with the well materials and cement.*
- *Confirm the depth to the lowermost USDW to ensure the proper depth and cementing of the surface casing.*

Injection Well Pre-Operational Testing

The proposed pre-operational formation and well testing program required at 40 CFR 146.82(a)(8) and 146.87 is described in Section 3 of the permit application narrative and the "Recommended Pre-Injection Logging and Testing Program" (Attachment 2) of the application package. The document describes tests and logs to be performed: at the surface hole location, intermediate hole section, injection hole section, surface casing, intermediate casing, and injection casing. Additionally, SJR states that several 30' whole cores will be taken to evaluate fluid and rock properties to calibrate against open hole logs. The recommended testing and logging is considered comprehensive and acceptable with the exception of the comments/questions listed below and should be incorporated into a final proposed pre-operational testing plan.

SJR states in the Quality Assurance and Surveillance Plan (Data Management and Reporting) that project data and records will be compiled and maintained as they are generated. Additionally, laboratory tests will be reviewed for accuracy and completeness before data is submitted.

Questions/Requests for the applicant:

- *Please clarify which of the logging procedures described for the surface casing, intermediate casing, etc. will be performed during vs. after casing installation (i.e., per 40 CFR 146.87(a)(2) and (3)).*
- *Please provide testing methods and procedures for the tests to be performed on the new injector.*
- *Please add the following to the pre-operational testing plan to be consistent with 40 CFR 146.87 and meet the pre-operational testing objectives as described in the site characterization evaluation (see below):*
    - *Deviation checks (including the frequency of deviation checks to be performed during drilling).*
    - *Caliper logs before the surface, intermediate, and long string casing are installed.*
    - *Standard annulus pressure test (SAPT).*
    - *Testing to determine the geochemistry of the formation fluids and confirm the inputs to the geochemical modeling, determine the depth of the lowermost USDW, and confirm that no other formations are USDWs, and establish the baseline geochemistry of the USDW and the Vedder Formation in all monitoring wells.*
    - *Leak-off test or step rate test to determine fracture pressure after the well has been perforated, as described in the narrative (pg. 30).*
    - *Pressure fall-off, pump test, or injectivity tests to determine the injection zone hydrogeologic characteristics.*

    - *Testing to provide evidence of fault sealing within the Pond-Poso Creek Fault Complex.*
    - *Testing to establish baseline seismicity.*
- *Please update the "Recommended Pre-Injection Logging and Testing Program" document to clarify that these are the pre-operational tests that SJR intends to perform (i.e., that they are not merely recommendations).*
- *Please clarify that SJR will notify the Director at least 30 days prior to conducting any testing.*

Objectives for Pre-Operational Testing

Based on the site characterization, AoR delineation modeling, and testing and monitoring evaluations, EPA has identified the following objectives for the planned pre-operational testing to address data gaps identified during these reviews. This information is summarized below (along with the planned tests that will address each data need) for reference and to clarify EPA's expectations for the updated materials that SJR must submit pursuant to 40 CFR 146.82(c).

Regional Geology and Geologic Structure

- Determine, based on pre-operational testing, which of the Vedder Formation intervals will ultimately be selected as the injection zones (anticipated testing methods: whole core analyses).

Faults and Fractures

- Collect data (i.e., geochemical and pressure) to provide evidence of fault sealing within the Pond-Poso Creek Fault Complex (anticipated testing methods: TBD).

Hydrologic and Hydrogeologic Information

- Establish the depth of the lowermost USDW within the AoR (anticipated testing methods: TBD).
- Sample all formations during drilling of the injection well and deep monitoring wells to confirm that no other formations are USDWs (anticipated testing methods: TBD).

Geochemistry/Geochemical Data

- Characterize the baseline geochemistry of the USDW and the Vedder Formation and in all wells to be monitored for all parameters described in the Testing and Monitoring Plan to: (1) confirm the inputs to the geochemical modeling, and (2) establish a baseline for monitoring (anticipated testing methods: TBD).

Geomechanical and Petrophysical Characterization

- Gather site-specific measurements during drilling of the injection well and deep monitoring well of: capillary pressure; information on fractures, stress, ductility, rock strength, elastic properties; and in situ fluid pressures within the confining zone to support an evaluation of confining zone integrity (anticipated testing methods: logging and core analyses, e.g., tri-axial tests, pore compressibility, etc.).
- Confirm/characterize the geomechanical and petrophysical properties (including porosity and permeability) of the Vedder and Freeman-Jewett Formations and other relevant formations to confirm the representativeness of data from nearby oil fields (anticipated testing methods: core analyses, e.g., porosity/permeability analyses, core descriptions, saturations, etc.).

Mineralogy of the Injection and Confining Zones

- Perform a mineralogic analysis of the injection zone and confining zone solids that represents the project site (anticipated testing methods: core analyses, e.g., porosity/permeability analyses, core descriptions, saturations, etc.).

Seismic History and Seismic Risk

- Establish pressure in the injection zone (anticipated testing methods: geomechanical measurements of the injection and confining zones).
- Establish baseline seismicity (anticipated testing methods: TBD).

Facies Changes in the Injection or Confining Zones

- Confirm the thickness of the Vedder Formation sands at the location of the injection and monitoring wells to provide additional information on their suitability for injection, including facies changes that could facilitate preferential flow (anticipated testing methods: cores and well logging data).

CO_2 Stream Compatibility with Subsurface Fluids and Minerals

- Confirm the composition of the CO_2 injectate as part of baseline sampling and provide verification that it will not react with the formation matrix (anticipated testing methods: injectate analysis and core sampling).
- Generate fluid chemistry and mineralogic data, pressure, temperature, and pH conditions at depth to confirm the inputs to the geochemical modeling (anticipated testing methods: core sampling and formation testing in the injection and monitoring wells).

Confining Zone Integrity

- Determine the maximum allowable injection pressure (anticipated testing methods: fall-off testing and injectivity testing).
- Confirm the fracture pressure of the injection zone via one or more of the following methods:
    - Triaxial stress test for rock mechanics for a static measurement from the rock core.
    - Dipole full wave sonic log, to provide a dynamic result that can be calibrated back to the static triaxial test.
    - Leak-off test or step rate test to determine fracture pressure after the well has been perforated.

Monitoring Well Construction

EPA recommends in Class VI guidance that monitoring well construction be reviewed in a manner that is similar to the injection well review (especially for the deep ground water monitoring wells). SJR describes plans to construct two deep monitoring wells in the Testing and Monitoring Plan:

- One well to be installed above the confining zone (the ACZ well). SJR indicates that the location and design of the ACZ well will be finalized at a later phase but will be in the vicinity of the injection well.
- An injection zone (IZ) monitoring well will be installed for plume and pressure front tracking within the Vedder Formation. The IZ well will be located updip of the project and will be perforated within the Vedder Formation. The IZ monitoring well will be fitted with a downhole transducer deployed for continuous pressure measurement.

Additionally, SJR describes planned monitoring in six shallow production wells that are routinely monitored by the Southern San Joaquin Municipal Utility District (SSJMUD). These are existing wells, completed above the confining zone.

Note, EPA understands that the California Regional Water Quality Control Board will need to approve the construction of any new monitoring well. While this will not be a UIC permit condition, it is relevant to SJR's planning of its monitoring well network and is being shared for informational purposes.

Questions/Requests for the applicant:

- Please provide schematics for the above confining zone and injection formation monitoring wells that are described in the Testing and Monitoring Plan for EPA to review prior to their installation and construction. The schematics should include the sampling equipment and downhole pressure monitoring gauges needed to perform all monitoring described.
- If construction schematics for the six USDW monitoring wells are available, please include them in the permit application.

Injection Well Plugging Plan

Plugging details for Well SJR-I1 are provided in an attachment titled, "Recommended Injection Well Plugging and Abandonment Plan," dated July 8, 2021. Before plugging the injection well, SJR will determine the bottom-hole pressure needed to successfully squeeze cement for plugging operations as referenced in the Injection Well Plugging Plan. Procedures for plugging the injection well are described in the Injection Well Plugging Plan, which include the following:

- Squeeze cement into the perforations through a cement retainer.
- A coiled tubing unit (CTU) will be used to place cement at intervals from plugged back total depth (PBTD) to surface to conform with applicable U.S. EPA standards for a Class VI well.
- Move in and rig up (MIRU) equipment on location including blowout prevention equipment (BOPE).
- Run wireline survey to measure bottomhole pressure and confirm PBTD.
- Kill well with brine of appropriate density to prevent flowback.
- Pull completion tubing and packers.
- Land corrosion resistant cement retainer at 7700'.
- Rig up (RU) cementers. Down squeeze cement through tubing and retainer until pressure increases but remains below formation fracture gradient. Calculate maximum allowable injection pressure based on bottomhole pressure data.
- Un-sting tubing from retainer and pull out of hole (POOH).
- RU CTU and place continuous cement plug from top of retainer at 7700' to surface.
- Rig down CTU and cementers.
- Nipple down (ND) BOPE. Rig down move out (RDMO).
- Dig out cellar, cut casing ten feet below ground level (GL) and flush with outer casings.
- Weld steel plate on top of casing marked with well API and injection permit number.
- Survey final well location.
- Backfill cellar, clean location, and remove all debris. RDMO all equipment and commence applicable surface reclamation efforts.

The plan does not describe a final mechanical integrity test or include a plugging schematic. The plugging procedures appear to be acceptable, provided responses to the questions below are adequate.

The plan also explains that a site closure report will be submitted to EPA within 90 days of monitoring well plugging and the documentation it will contain. However, the plan does not describe the procedures for closing the site.

Questions/Requests for the applicant:

- *Please provide a table with plugging details (e.g., about plugs, cement types/volumes) in table form (i.e., using the "Injection Well Plugging" template that is available in the GSDT or at https://www.epa.gov/uic/class-vi-permit-application-templates).*
- *Please include "flushing" among the steps to be completed prior to injection well plugging, in accordance with 40 CFR 146.92(a).*
- *Please also include planned MITs to be performed in accordance with 40 CFR 146.92(b)(2).*
- *Please provide a plugging schematic for Well SJR-I1 and label the USDW and other relevant formations (i.e., the injection and confining zones) and perforations on the plugging diagram. The diagram should demonstrate the following:*
  - *That plugs will extend at least 100 feet below the lowermost USDW and*
  - *That the plugs will cover all perforations and the extent above the uppermost perforations, as determined based on pre-operational logging and testing (estimated range of 7,775' to 8,255' bgs).*
- *Please describe the cement to be used. Specifically provide information to demonstrate that the cement:*
  - *Meets Class D, G, or H standards and is CO_2-resistant;*
  - *Is the same as or compatible with the cement used in the well's construction; and*
  - *Has adequate permeability and compressive strength.*
- *Please specify in the Well Plugging Plan that SJR will submit required closure documentation within the timeframes specified in 40 CFR 146.92, including a notice of intent to plug (at least 60 days prior to plugging the well) and a well plugging report (60 days following plugging completion).*
- *Please describe the procedures SJR will perform to close the site, e.g., landscaping material and equipment to be removed or staged onsite.*
- *Please update the "Recommended Injection Well Plugging and Abandonment Plan" document to clarify that these are the plugging procedures that SJR intends to perform (i.e., that they are not merely recommendations).*

Monitoring Well Plugging Plan

The proposed plugging and abandonment procedures for the monitoring wells are described in Section 7 of the Post-Injection Site Care (PISC) and Site Closure Plan. The document describes the general procedures SJR will use to plug the monitoring wells, which are identical to those described for plugging the injection well. This section of the plan does not include any plugging schematics, which likely reflects

the fact that plans for the monitoring wells have not been developed. However, they will be needed prior to EPA's approval of the PISC and Site Closure Plan.

Questions/Requests for the applicant:

- *Please ensure that the final monitoring well plugging procedures are specific to the construction and depth of each monitoring well.*
- *Please include plugging schematics for the monitoring wells in the PISC and Site Closure Plan.*
- *Please clarify that the monitoring well procedures described will be performed on each of the deep monitoring wells, i.e., the ACZ and IZ wells.*
- *Please describe the procedures SJR will perform to close the site, e.g., landscaping material and equipment to be removed or staged onsite.*
- *Please describe the external MIT to be performed on the monitoring wells prior to abandonment.*

Corrective Action on Wells in the AoR

The Corrective Action Plan (Attachment 3 of the application package) lists oil and gas wells that are located within the delineated AoR based on CalGEM records. Nineteen (19) wells are located within the AoR, and each is a plugged and abandoned well; of these wells, seven (7) penetrate the confining zone. SJR submitted plugging records for each of the 19 wells to the GSDT, and a spreadsheet containing all of the information required at 40 CFR 146.82(a)(4).

According to the Corrective Action Plan, re-abandonment will be necessary for any well that penetrates the Freeman-Jewett if the well is uncased in the injection zone and the cement plug is not within the confining zone. Six of the seven wells within the AoR meet the aforementioned criteria and will require re-abandonment: Chevron 32-5, Curry 1, Del Fortuna, Ingram 13-73, KCL 87-25, and Tenneco 11x-31. The proposed plugging procedures and schematics are provided in Appendix C of the AoR and Corrective Action Plan.

Information about the seven wells in the AoR that penetrate the confining zone is presented in Table 2-1 of the Corrective Action Plan. The table contains all of the information required at 40 CFR 146.82(a)(4), except their types; the diameter of all but one of the wells were available on well schematics in Appendix C to the AoR CA.

SJR plans to implement corrective action on a phased basis. One well (Ingram 13-73, API #402980729) will be re-abandoned prior to commencing injection, and SJR proposes to re-plug the remaining five wells within three years of commencing injection activities.

Questions/Requests for the Applicant:

- *Please provide additional details for well re-abandonment, specifically approximate wait times for cement curing, in Appendix C.*
- *Please add to Table 2-1 of the Corrective Action Plan a column for well type.*
- *Consistent with 40 CFR 146.84(b)(2)(iv), please describe how corrective action will be adjusted if there are changes in the AoR and how site access will be guaranteed for future corrective action.*
    - *EPA also recommends that SJR describe that it will notify EPA prior to plugging the five wells for which corrective action will be performed on a phased basis.*

Evaluation of the Biological Assessment for the San Joaquin Renewables Class VI Project

EPA reviewed the biological assessment (BA) included in a response report prepared by TSS Consultants (TSS) for the San Joaquin Renewables (SJR) Class VI project, dated December 30, 2021. EPA has the following requests and recommendations in blue for the applicant.

- TSS's BA is insufficient. TSS focused on the California species for their BA (*see* Table 1), not the federal species. There is some overlap (3 species), but there are 5 federally listed species for which there is no analysis. TSS's analysis relies on the fact that there is no 'critical habitat' in the project area—an analysis legally and factually separate from whether there is suitable habitat or if the species may be present on-site. TSS needs to update their analysis in a Table (like they did for the California species), but with more detailed information. For example, for nearly every species in their table, TSS simply says "Not expected: Suitable habitat on project site not present." TSS needs to add a "because" and describe why it's not suitable. It doesn't have to be a long description, but EPA needs more detail/information for the "Habitat Requirements" and the "Potential On-site Occurrence" columns in order to have a defensible record.

- There is recommendation in the BA for SJR to do a Kit Fox field survey 14-30 days before construction. EPA needs something in writing from SJR indicating that SJR will do this field survey. EPA recommends SJR have TSS update their BA first, and then send us a letter (with the updated BA as an appendix) in which SJR identifies the TSS's recommendation and commits in writing to conducting the mitigation measures as written in the report. This will become part of SJR's permit application that EPA can reference in our request for concurrence to the U.S. Fish and Wildlife Service (USFWS).