UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105-3901

Sent electronically only

April 28, 2023

Thomas J. Paskach
San Joaquin Renewables, LLC
1521 West F Avenue
Nevada, IA 50201

Re: Technical Review of Application
San Joaquin Renewables LLC
Underground Injection Control (UIC) Permit Application
Class VI Pre-Construction Permit Application No. R9UIC-CA6-FY22-2

Dear Mr. Paskach:

The United States Environmental Protection Agency, Region 9 (EPA) has identified additional information or clarification needed for continued evaluation of the site characterization, and AoR delineation modeling approach for the subject permit application. The comments are included in three Enclosures (one on site characterization and two on modeling) to this letter.

Please submit the information requested in the Enclosures by June 9, 2023. If you have any questions about this letter and the Enclosures, please call me at (415) 972-3971, or Calvin Ho at (415) 972-3262.

Sincerely,

DAVID ALBRIGHT
Digitally signed by DAVID ALBRIGHT
Date: 2023.04.28 14:16:54 -07'00'

David Albright
Manager, Groundwater Protection Section

Enclosures: Site Characterization (1)
AoR Delineation Modeling Approach (2)

cc (via email): Gregory Schnaar, Daniel B. Stephens & Associates, Inc.
Chris Jones, CalGEM Inland District
Alex Olsen, Central Valley Regional Water Quality Control Board
Janice Zinky, CA State Water Resources Control Board

# Review of San Joaquin Renewables (SJRenew) Responses to EPA's Questions about the Site Characterization for the Class VI Permit Application

In April 2022, EPA provided questions presented in *blue italicized text* to San Joaquin Renewables (SJRenew) about the geologic narrative submitted as part of SJRenew's Class VI permit application (dated January 7, 2022) for the proposed SJRenew Class VI geologic sequestration (GS) facility. SJRenew provided an updated narrative and a document summarizing their responses to EPA on June 21, 2022 (Attachment A_SJR_Narrative_062122 & Response_062122) and September 8, 2022 (Attachment A_SJR_Narrative_090822 & Response_090822). EPA's evaluation of how the narrative addresses its questions and requests for revisions and additional information are presented in *red italicized text*.

Where specific information is lacking based on the currently available information, this evaluation identifies testing objectives that EPA recommends be incorporated into the Pre-Operational Testing Plan.

## Regional Geology and Geologic Structure

SJRenew is proposing to construct and operate a Class VI well to inject carbon dioxide ($CO_2$) generated by a biomass gasification process at a GS project located in the southern portion of the San Joaquin Basin Province near McFarland, in Kern County, CA. The southern portion of the San Joaquin Basin is described as an enclosed forearc basin with up to 30,000 feet of Cenozoic strata onlapping a west-dipping Mesozoic basement. Overlying strata thin to the east, and compressional forces from the San Andreas Fault have created a fold and thrust belt system to the west (pg. 7; Figures 2-2 to 2-5).

SJRenew plans to construct one (1) Class VI injection well (SJR-I1) to inject 1,200 tons of $CO_2$ per day into the Oligocene Vedder Formation sandstone (the injection zone) at a depth of approximately 7,780 ft below ground for a period of 15 years, for a total of 6.57 million tons of $CO_2$ (pgs. 6, 9, 29). The Vedder Formation is confined above by the Miocene Freeman-Jewett Formation shale and mudstone (the confining zone). Overlying the Freeman-Jewett are the Olcese Formation sandstone, the Round Mountain Silt, and Fruitvale Shale (Figures 2-10 and 2-23). The Vedder Formation is confined from below by a shale layer and impermeable granitic basement. The San Joaquin Basin hosts many oil and gas reservoirs, e.g., the Antelope-Stevens and Tumey-Temblor Petroleum Systems; however, none are within the defined area of review (AoR) for the project (pgs. 8, 23; Figures 2-10 to 2-13, 2-57).

The Vedder Formation is an east to west progradational shallow marine shelf filling the basin from the Sierra Nevada highlands to the east (pg. 7; Figures 2-7, 2-20). It is composed of several sand units, Vedder 1/Vedder 1a/Vedder 2/Vedder 3/Vedder 4/Cantleberry Sand, five of which are present within the AoR (the Cantleberry is not present). The sands are separated by shales and overlain locally by the Pyramid Hills sandstone and Freeman-Jewett shale and mudstone (pgs. 12-13; Figures 2-7, 2-10, 2-20). In the narrative, SJRenew states that injection will be into two of these intervals: the Pyramid Hill/Vedder 1/Vedder 2 and the Vedder 3 (pg. 31); in the AoR and Corrective Action Plan (AoR/CA) submitted with the permit application, it appears that SJRenew has not definitively determined whether the well will be perforated in both intervals. Regionally, the Vedder Formation gently dips about 4° to the west as part of a homocline structure in the forearc basin defined by the Sierran Uplift to the east and a fold and thrust belt system to the west (pgs. 7, 13; Figure 2-5). The injection reservoir laterally pinches out to the east, where Cenozoic strata onlap the granitic basement, and is truncated to the west by the Pond-Poso Creek Fault Complex (pgs. 7, 9; Figure 2-23). The application asserts that this normal fault complex is predicted to be sealing (see the discussion of "Faults and Fractures," below).

The approximate depths and relationships of each stratigraphic unit within the proposed AoR are based on seismic studies (pg. 12; Appendix D). Historical studies, e.g., Wagoner (2009) and Hewlett and Tye (2015), also characterize the stratigraphic relationships of the units (Figures 2-15, 2-16, 2-19, 2-20, 2-21).

***Questions/Requests for the Applicant:***

- *For context, please label the project AoR and well location on the seismic cross sections and maps of Appendix D, or provide a map of the seismic survey area in the application narrative. The applicant reproduced the acquired 2D seismic lines on Figure 2-22a. The response is acceptable.*
- *Please clarify the location of Cross Section 1 from Wagoner (2009) on Figure 2-14. The cross section line is obscured due to its low resolution and the well labels. Also, the legend shows Cross Section 1 as a blue line, while the figure caption says it is indicated in black. The applicant added the trace of Cross Section 1 to Figure 2-14 and updated the figure caption accordingly. The response is acceptable.*
- *The application on pg. 31, states that there will be two injection zones: the Pyramid Hill/Vedder 1/Vedder 2 and Vedder 3. Please explain how the Pyramid Hill Formation is addressed in the geologic characterization and the modeling, which focuses on the Vedder Formation. The applicant updated the Narrative with a discussion of the Pyramid Hill Formation in the new Section 2.2 "Maps and Cross Sections of the AoR." The response is acceptable.*
- *Although it is understood that no oil and gas fields are in the AoR, are there any geochemical analyses for hydrocarbons from the oil and gas wells in the region, and if so, does the compositional data indicate any type of geochemical trend (e.g., up-section/upward movement)? The applicant addresses this question in the revised Section 2.7.4 "Oil and Gas Fields." The response is acceptable.*
- *The narrative states on pg. 6 that "the Vedder Formation porosity and permeability make it ideal for production." Please revise this text to clarify that the Vedder is an injection zone. The text was updated as requested to refer to the "injection" zone.*
- *EPA requests revisions of several figures to clarify their context for the narrative: The applicant made all requested figure revisions as noted below. The response is acceptable.*
    - *Please label the Vedder Formation on Figure 2-1. The applicant updated Figure 2-1 with labels for all formations in the stratigraphic column, including the Vedder Formation.*
    - *Please label the Vedder Formation in the cross section on Figure 2-5 and the injection site in the map view in the figure. The applicant made both requested edits to Figure 2-5.*
    - *Please correct the reference to the Birkholzer (2011) table (which is in Appendix C, not Appendix D) in the last paragraph of Section 2.1.2 on page 10. The text now references Appendix C.*
    - *Please draw the AoR on Figure 2-17. The applicant indicated the AoR on Figure 2-17. The SJRenew property appears to be located outside of the study area of Hewlett & Tye (2015); however, the response is acceptable.*

   - *Please provide index maps showing the cross section lines and locations of the wells used for Figures 2-23 to 2-27. The applicant added Figure 2-28 to indicate the locations of wells used to create Figures 2-23 to 2-27.*

***Objectives for Pre-Operational Testing:***

- *Determine, based on pre-operational testing, which of the Vedder Formation intervals will ultimately be selected as the injection zone(s).*

## Faults and Fractures

Faults near the proposed injection site include the recent Pond Fault, Pond-Poso Creek Fault (Quaternary), and unnamed Quaternary faults near Rag Gulch in the Sierra Nevada Foothills (pg. 20; Figures 2-45 to 2-47). The Pond-Poso Creek Fault Complex, which consists of the Pond Deep, Pond West, and Pond East faults, marks the western structural boundary of the AoR. The Pond-Poso Creek Fault Complex runs NW-SE about 1 mile west of the injection site, dips west, has normal slip, and terminates below-ground (Appendix D, pg. 159 of the narrative PDF). Appendix D to the narrative presents a seismic interpretation of the geometry of the Pond-Poso Creek Fault Complex. Data for Appendix D is from 148 well logs and 5 seismic lines (pg. 11). Stratigraphic unit depths are shown in Appendix D, but are not clearly described in the narrative; nor is the depth of the Pond-Poso Creek Fault Complex clear within the narrative, particularly at the location of the proposed injection well.

Geophysical surveys were also conducted on 23 parallel lines one mile apart across the Pond-Poso Creek Fault Complex (and presented in Appendix E). Resultant cross sections display the stratigraphic offset between the hanging wall and footwall (pg. 16). Fault throw was estimated to range from 10 m at the fault system ends to about 395 m at Cross Section 13, where the Pyramid Hill/Vedder 1/Vedder 2 juxtapose with the Olcese (pg. 16; Appendix E Cross Section 13). Allan diagrams created from the cross sections show the juxtaposition of hanging/footwalls (pgs. 16-17; Figures 2-39 to 2-41).

These Allan diagrams serve as a basis for the applicant's assertion that the fault complex is non-transmissive via shale gouge, with possible assistance from clay smear, diagenesis, pore volume collapse, and/or grain contact dissolution (pgs. 14-16; Figure 2-36). The narrative claims that a calculated bulk shale gouge ratio of >15% in most areas and >50% in some areas demonstrates that the fault system is non-transmissive at project depth (pg. 17; Figure 2-42). Additional geochemical data, e.g., geochemical hydrocarbon analysis showing differing geochemistries across the fault, would provide further evidence of sealing across the fault.

It is unclear whether the Pond-Poso Creek Fault Complex is sealing with respect to pressure changes and what would happen if pressure were to increase to the west of the fault. If pressure changes were to occur outside of the fault boundary, this could result in a larger AoR to the west. Additional evidence of fault sealing is presented in sensitivity analyses described in the AoR/CA; EPA will provide additional evaluation and questions in the forthcoming AoR modeling report.

***Questions/Requests for the Applicant:***

- *Please indicate the depth of the Pond-Poso Fault system within the narrative, particularly at the location of the injection well and deep monitoring wells. The applicant indicates in Section 2.3.2 that the fault is several kilometers away from the injection well at the injection depth; because the fault is outside the AoR and any pressure influences of the injection operations, this appears to present no concerns, and the response is acceptable.*
- *Will the proposed injection well intersect any identified fault planes? The applicant revised Figure 24 in Appendix D to include fault labels and the proposed injection well. The injection well appears to intersect the "Etch 1 Fault," a shallow extensional fault, separate from the Pond-Poso Creek Fault Complex, that does not reach the surface or top of the Fruitvale Shale. Because the fault is outside the AoR and any pressure influences of the injection operations, this appears to present no concerns, and the response is acceptable.*
- *Please discuss in the narrative the implications for the size of the AoR if elevated pressure were to occur to the west of the Pond-Poso Creek Fault Complex. The applicant responded that this question will be discussed in their Area of Review/Corrective Action Plan update. The updated AoR/CA appears to discuss the implications of elevated pressure on the AoR, and the response to this question is acceptable.*
- *Does any pressure data exist in wells on either side of the Pond-Poso Creek Fault Complex to demonstrate pressure containment across the fault complex? The applicant describes pressure data from Castillo and Younker (1997) in Section 2.3.2 and included a new Figure 2-45 showing regional stress data and the locations of effective stress wells. The narrative also describes pressure data from oil and gas wells west of the Pond Poso Creek fault from the Kimberlina project (south of the proposed Class VI wells); this data is presented in Figure 2-46. The wells on which the figures are based are approximately 5 miles to the south of the SJRenew facility, and likely do not provide the site-specific pressure data requested in the question.*
- *Is there any existing core data or geochemical analyses that can further confirm the sealing capacity of the Pond-Poso Creek Fault Complex, e.g., via differing geochemistries at similar depths across the fault? The applicant states in their response that there is no core data available across the fault to confirm sealing. However, the applicant further describes standard clay-smear potential and Allan Diagram techniques in Section 2.3.2 that do provide other demonstration of sealing. The applicant also references differences in porosity within the Monterey Formation across the fault. Figure 2-44 presents porosity trends in the Monterey Formation on the east and west side of the San Joaquin Basin. The figure appears to show that the Monterey Formation is overpressured to the east of the basin and normally pressured on the west of the basin. According to the figure, samples were analyzed using mercury capillary injection pressure in about 15 wells. Additional information to correlate the information in the figure to the presence and location of the fault may provide some evidence that the fault is pressure sealing at least in the Monterey Formation.*

***Follow up question for the applicant:***

- *Please provide any additional information about the representativeness of data in Figure 2-45 to the Vedder Formation at the project location.*

- *Please provide additional discussion of the relevance of the data on which Figure 2-44 is based. Where are the wells referenced in the figure located? Is there any core or other directly measured data from formations deeper than the Monterey? What evidence is there that the pressure differentials shown in that figure are representative of the Vedder Formation at the project location?*
- *Please provide available, relevant literature about the Kimberlina project.*

***Objectives for Pre-Operational Testing:***

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

## Depth, Areal Extent, and Thickness of the Injection and Confining Zones

At the injection site, the stratigraphic sequence from top to bottom consists of the alluvium and Etchegoin Formations (which contain the lowermost underground source of drinking water (USDW)), Round Mountain Silt, Fruitvale Shale, Olcese Formation, Freeman-Jewett Formation (confining zone), Vedder Formation (injection zone), and Walker Formation. All of these formations extend laterally throughout the AoR and onlap the granitic basement, wedging to the east (pg. 13; Figures 2-23 to 2-27). The cross sections from Figures 2-23 and 2-25 show lateral continuity of the Freeman-Jewett confining zone with no pinch outs along strike and a pinch out updip perpendicular to strike east of the AoR. The western end of the AoR is truncated by Pond-Poso Creek Fault Complex (see "Faults and Fractures" for additional evaluation).

The table below summarizes the depth and thickness of the formations of interest based on available data in the narrative. The data below are based on different sources (i.e., geophysical surveys, literature reviews, cross sections, etc.), but show general agreement. Some depth/thickness information for the Round Mountain Silt, Fruitvale Shale, Olcese, and Walker Formations was not provided. AoR modelling does not predict the plume to migrate above the primary confining zone, the Freeman-Jewett. Porosity and permeability data are also presented in the table below; additional discussion of these characteristics is provided under "Geomechanical and Petrophysical Characterization."

| Unit | Average Depth within the AoR | Thickness Across the AoR | Porosity | Permeability (mD) |
|---|---|---|---|---|
| Lowermost USDW | 2,100-2,900 ft bgs, 2,400 ft bgs at Facility (pg. 22). | | | |
| Round Mountain Silt/Fruitvale Shale | -5,600 to -6,600 ft msl (Figure 2-23) | 900 ft (pg. 13) | 33.8% (Appendix C, Table B-3)<br><br>20% (Table 2-4) | 0.002 horizontal, 0.001 vertical (Appendix C, Table B-3)<br><br>0.037 horizontal, 0.00073 vertical (pg. 18; Table 2-4) |
| Olcese Formation | -6,600 to -6,900 ft msl (Figure 2-23) | 430 ft Figure (2-23) | 33.6% (Appendix C, Table B-3)<br><br>28% (Table 2-4) | 170 horizontal, 34 vertical (Appendix C, Table B-3)<br><br>76.6 horizontal, 4.3 vertical (pg. 18; Table 2-4) |

| Unit | Average Depth within the AoR | Thickness Across the AoR | Porosity | Permeability (mD) |
|---|---|---|---|---|
| Freeman-Jewett Formation (Confining Zone) | -6,900 to -7,460 ft msl (Figure 2-23) | 700 ft (pg. 13)<br><br>Approx. 615 ft (Figure 2-23) | 33.8% (Appendix C, Table B-3)<br><br>20% (Table 2-4) | 0.002 horizontal, 0.001 vertical (pg. 18; Appendix C, Table B-3)<br><br>0.26 horizontal, 0.0036 vertical (pg. 18; Table 2-4) |
| Vedder Formation (Injection Zone) | 7,870 ft bgs (pg. 3); -7,460 ft to -8,000 ft msl (Figure 2-23); -7,560 to -8,200 ft msl (Figures 2-29 and 2-34) | 300-450 ft (Appendix D, Figure 9); Approx. 500 ft (Figure 2-23); Approx. 450 ft (Appendix D, Figure 8) | | |
| Vedder Sand Units | Pyramid Hills (local): 7,775 ft<br>Vedder 1: 7,789 ft<br>Vedder 2: 8,040 ft<br>Vedder 3: 8,167 ft<br>Vedder 4: 8,344 ft<br>(Figure 3-1) | | 26.4% (pg. 18; Appendix C, Table B-3)<br><br>26-34% (pg. 18; Table 2-4) | 303 horizontal, 60.6 vertical (pg. 18; Appendix C, Table B-3)<br><br>192-613 horizontal, 62-154 vertical (pg. 18; Table 2-4) |
| Vedder Shale Units | Between Vedder 2 and 3<br>Between Vedder 3 and 4<br>Base of Vedder 4<br>(pg. 13) | | 32% (Appendix C, PDF pg. 151,)<br><br>15-27% (pg. 18; Table 2-4) | 0.1 horizontal, 0.05 vertical (pg. 18; Appendix C, Table B-3)<br><br>0.11-0.91 horizontal, 0.0052-0.025 vertical (pg. 18; Table 2-4) |
| Walker Formation | -8,000 to -9,300 ft msl (Figure 2-23) | 1,100 ft (Figure 2-23) | 26% (pg. 18; Table 2-4) | 36.37 horizontal, 1.41 vertical (Table 2-4) |

***Questions/Requests for the Applicant:***

- *Please clarify the depths (particularly of the Vedder sub-units) or reference elevations in Appendix D, Figure 9. Please also label the extent/edges of the AoR within the figure. The applicant added Figure 26 to Appendix D to show the subsea depth in meters for relevant formations at the injection site and Table 2-1 to show formation thicknesses in feet and top elevations in ft -msl. The response is acceptable.*
- *Are more precise values for the thicknesses of Round Mountain/Fruitvale and Freeman-Jewett Formations than the approximations from pg. 13 available? The applicant added Table 2-1 to show formation thicknesses in feet and top elevations in ft -msl at the SJRenew property. The response is acceptable.*
- *Are any other depths and thicknesses of the relevant stratigraphic units in addition to those tabulated above available within the AoR? The new Table 2-1 gives depths and thicknesses for the surface/alluvium, Etchegoin, Miocene sediments, Santa Margarita, Round-Mountain, Olcese, Freeman-Jewett, Pyramid Hills, Vedder subunits, Walker, and basement. The response is acceptable.*
- *Please reformat the depth marks on the Y-axes of Figures 2-23 and 2-24 so that the location of the depth markers match the numbers. The applicant has updated the y-axes for Figures 2-23 and 2-24. The response is acceptable.*

## Hydrologic and Hydrogeologic Information

Groundwater data was synthesized from the Kern County Water Authority (Figures 2-50 and 2-51), California Department of Water Resources (Figures 2-52 and 2-53; Table 2-6), and a combination of data from previous studies (Figures 2-53 to 2-56).

The GS project is located in the San Joaquin Valley groundwater basin and Kern County subbasin, in which 31 water supply wells in the AoR are used for drinking water or other uses (pg. 21; Table 2-6; Figure 2-52). The static water depth of these water supply wells ranges from 70 to 400 ft bgs (pg. 21). While the testing to determine the depths is old, the data demonstrate significant separation between the base of the lowermost USDW and the confining zone and local water supply wells.

The base of the lowermost USDW is approximately 2,400 ft bgs at the project location but ranges from 2,100 ft bgs to 2,900 ft bgs across the subbasin (pg. 22; Figure 2-54). According to cross sections in Figures 2-23, 2-24, 2-25 and 2-27, the base of the lowermost USDW within the AoR is contained within surface alluvial fan deposits or the Etchegoin Formation. However, on Figure 2-24, the base of the USDW is within the Vedder Formation where the Vedder shallows, about 8 miles outside the AoR. On Figure 2-26, the base of the lowermost USDW is shown within the Freeman-Jewett Formation; however, this cross section (D-D') does not intersect the AoR. In all of the cross sections except Figure 2-24, there appears to be approximately 5,500 feet of separation between the injection zone and the base of the lowermost USDW, and the confining zone is present between these layers. Within the AoR, there are several thousand feet of separation between the USDW and the injection zone.

Figure 2-54 shows the depth of the USDW at several locations (although none are in the AoR); the depths range from 1,500 to 2,700 feet, and appear to be based on literature reviews, e.g., Gillespie et al. (2017), Kong (2016), and Metzger and Landon (2018). The depths are extrapolated to the AoR based on geostatistical kriging (pg. 22).

The Vedder Formation is described as a saline aquifer with an estimated TDS of about 25,000 mg/L (pg. 22, 24). These measurements indicate a relationship between water salinity and depth, which is quantified in Figure 2-55. Two groundwater samples from the Vedder Formation (taken in 1960 and 1968) from the Rio Bravo Oil Field (Table 2-7; Figures 2-54 and 2-56), have a TDS of 21,982 and 24,757 mg/L, based on United States Geological Survey (USGS) data. While these samples are old (and a baseline sample will be taken as part of the pre-operational testing), this appears to provide sufficient documentation that the Vedder Formation is not a USDW in the AoR. Portions of the Vedder Formation are an exempted aquifer within the Jasmin Oil Field (for the Cantleberry Sand) and in the Mount Poso Oil Field.

***Questions/Requests for the Applicant:***

- *When were the samples from Gillespie et al. (2017), Kong (2016), and Metzger and Landon (2018) taken, i.e., are they recent to the dates of the studies? The revised Section 2.7.2 "Depth to USDWs and Base of Fresh Water" states that the samples in the referenced studies were sourced from the California Division of Oil, Gas, and Geothermal Resources and date from 1910-2015. The response is acceptable at this point in the permitting process (sampling will be performed as part of pre-operational testing).*
- *Is any direct data on the depth of the lowermost USDW within the AoR available? The applicant responded that all information they are aware of on the depth of the lowermost USDW within the AoR is included within the narrative. Pending the results of pre-operational testing, the response is acceptable.*
- *How far is the SJRenew project's AoR from the exempted portions of the Vedder Formation in the Jasmin and Mount Poso Oil Fields? The applicant responded that the exempt portion of the Vedder in the Jasmin Oil Field is 11.8 miles from the AoR, and the Mount Poso Oil Fields' exempted portion is 14.4 miles from the AoR. The response is acceptable.*

***Objectives for Pre-Operational Testing:***

- *Establish the depth of the lowermost USDW within the AoR.*
- *Sample all formations during drilling of the injection well and deep monitoring wells to confirm that no other formations are USDWs.*

## Geochemistry/Geochemical Data

Freshwater aquifer geochemical data comes from the Southern San Joaquin Municipality Utility District Management Area Plan (pg. 23). The data indicates concerns with salinity, arsenic, nitrate, and trichloropropane levels in some water wells (pg. 23); however, since these shallow wells will not be affected by $CO_2$ injection, any maximum contamination level (MCL) exceedances are outside the purview of this UIC permit. Baseline chemistry for any shallow wells to be used as part of the Class VI Testing and Monitoring Plan will be established.

Historical geochemical data for the Vedder Formation comes from the USGS Produced Waters Database for the Rio Bravo Oil Field (shown in Figures 2-54 and 2-56), which is approximately 10 miles south of the AoR (pgs. 23-24). Two samples from the USGS database were used to create Table 2-7, which shows baseline geochemistry of the Vedder Formation and is reproduced below.

| Analyte | Concentration (ppm) at Rio Bravo Field | |
|---|---|---|
| | 4/6/1960 | 4/2/1968 |
| Bicarbonate | 961 | 671 |
| Calcium | 433 | 283 |
| Chloride | 13,788 | 12,340 |
| Magnesium | 68 | 42 |
| pH (standard units) | 7.25 | 7.6 |
| Potassium | 187 | — |
| Sodium | 8,799 | 8,211 |
| Sulfate | 354 | — |
| Total Dissolved Solids (TDS) | 24,757 | 21,982 |
| Data Source | USGS 4001271 | USGS 4000447 |

Both samples match the Vedder Formation TDS predicted by the salinity curve of Figure 2-55 and the isohaline map of Figure 2-56. The lower TDS value for sample 4000447 is explained by the lack of testing for potassium and sulfate. It is unclear how the TDS value was derived (i.e., measured vs. calculated); however, it should be noted that it appears that other parameters that are required to use the anion/cation balance to calculate TDS were not run, i.e., perchlorate, nitrate, and fluoride. Given the dates of the Vedder Formation samples (i.e., in 1960 and 1968), and the applicant's reliance on them for geochemical modeling, the geochemistry of the Vedder Formation will need to be confirmed during pre-operational testing, and the geochemical modeling revised as needed if newer testing provides significantly different results.

PHREEQC (pH-REdox-Equilibrium) geochemical modeling software was used to calculate the behavior of minerals and aqueous chemistry in the Vedder and Freeman-Jewett formations from the onset of $CO_2$ injection until chemical equilibrium conditions are reached (pgs. 23, 25). Four samples were used for geochemical modeling: Vedder at 4,308-4,333 ft depth, Vedder at 8,350-8,360 ft depth, Freeman-Jewett at 4,369-4,379 ft depth, and Freeman-Jewett at 4,801-4,805 ft depth. Table 2-2 summarizes the source wells from which core samples were collected and the laboratory tests that were performed. Figure 2-43 shows the locations of these wells; of the four samples used for the modeling, three are outside the AoR within 1-2 km to the east; the other is from the southwestern part of the AoR.

The application describes the sources of parameters for the PHREEQC modeling. Known thermodynamic parameters are from USGS and Lawrence Livermore National Laboratory (pg. 26) databases. Injectate chemistry, modeled using ASPEN process simulation software, is given in Table 2-10 (pg. 25; Appendix B). The geochemical inputs (in Table 2-7), geomechanical inputs (in Table 2-11), and mineralogy (from four samples shown in Table 2-12), are discussed elsewhere in this site characterization evaluation.

Modeling the Vedder Formation involved equilibrating the Vedder groundwater sample with the Vedder mineralogy samples and $CO_2$. Freeman-Jewett modeling involved using the Vedder modeling results at 4,308-4,333 ft depth and equilibrating that with Freeman-Jewett mineralogy and $CO_2$. Results of mineralogical changes are shown in Table 2-13 and equilibrium aqueous concentrations in Table 2-14 (pg. 28). The results indicate that mineral dissolution and precipitation will occur and affect the volume of the injection zone by an approximately 1% increase; however, the porosity of the injection and confining zones is not significantly affected by $CO_2$ injection activities. $CO_2$ injection is therefore not expected to cause chemical reactions that would affect the injection or containment of the $CO_2$ (pgs. 28-29). Trace concentrations of ferrous iron ($Fe^{2+}$) were detected in solution in samples with reducing conditions. See "$CO_2$ Stream Compatibility with Subsurface Fluids and Minerals" for more detail on specific chemical reactions.

***Questions/Requests for the Applicant:***

- *Have there been any significant changes in local geochemistry of the Vedder Formation since the 1960's, when the two Vedder Formation geochemical samples were taken? What evidence is there that they are still representative of the geochemistry of the Vedder Formation within the AoR? Did they come from wells that are still operating? The applicant explains in their response that all information they are aware of regarding geochemistry within the AoR is included within the narrative, and they have no reason to suspect formation geochemistry has changed since the collection of the cited samples. Pending the results of pre-operational testing, the response is acceptable.*
- *Is any information available about fluoride, nitrate, or perchlorate concentrations in the Vedder Formation from past analyses? The applicant's response cites Rivas, 2016 as containing data on nitrate and fluoride, and they are not aware of any data on perchlorate. However, they did not provide the cited report.*
- *Is any TDS data for the Vedder Formation available from the wells that provided the four samples that were used for geochemical modeling? The applicant states that TDS data used in geochemical modeling is listed in Table 2-8. The response is acceptable.*
- *What are the implications for reactions with $CO_2$ of ferrous iron in solution? The applicant clarified that ferrous iron in solution acts as an indicator of reducing (negative pH) conditions in the revised Section 2.8.4 "Equilibrium Geochemical Modeling." The response is acceptable.*
- *Please add references to the ASPEN modeling/Appendix B to Section 2.6.3 on pg. 25 and Section 3.1, if appropriate. The applicant added the references to the revised Sections 2.8.3 and 7.2. The response is acceptable.*
- *Please indicate whether applicable cations in the Vedder Formation samples from the Rio Bravo Oil Field are dissolved or total. The applicant responded that the database from which data was obtained did not specify dissolved or total. Pending the results of pre-operational testing, the response is acceptable.*

***Follow-up Questions/Requests for the Applicant:***

- *Please provide a copy of the 2016 Rivas report and update the narrative to include the information cited from the report about fluoride, nitrate, or perchlorate concentrations in the Vedder Formation.*

***Objectives for Pre-Operational Testing:***

- *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.*

## Geomechanical and Petrophysical Characterization

SJRenew performed geomechanical tests on archival core samples supplied by CalGEM (pg. 17), including triaxial compressive strength testing (TXC) and mercury-injection capillary pressure analyses

(MICP). Table 2-2 identifies which tests were applied to cores, and the source wells. MICP porosity and permeability results are presented for each core in Table 2-3 and summarized in Table 2-4. Laboratory reports are provided in Appendix F, and a fracture gradient calculation is provided in Appendix G.

### *Geomechanics*

Appendix F, Geomechanical Analysis, contains TXC laboratory test results for one sample from the Vedder Formation at 8,499 ft bgs and one sample from the Olcese Formation at 6,194 ft bgs (pg. 19). These results are reproduced below.

| Geomechanical Properties | Vedder Sample 3 (Shell KCL-A 83-85) | Olcese Sample 5 (General Petroleum KCL 25#1) |
|---|---|---|
| Bulk Density (g/cc) | 2.476 | 2.450 |
| Confining Stress (psi) | 2,850 | 2,050 |
| Peak Strength (psi) | 11,413 | 16,061 |
| Compressive Wave Vp (ft/sec) | 13,082 | 14,690 |
| Shear Wave Vs (ft/sec) | 5,667 | 6,319 |
| Vp:Vs Ratio | 2.31 | 2.32 |
| Static Poisson's Ratio | 0.129 | 0.338 |
| Static Young's Modulus (psi) | 8.61E+05 | 1.85E+06 |
| Dynamic Young's Modulus (psi) | 1.78E+06 | 3.72E+06 |

Below is a summary of the fracture gradient of the injection zone, as calculated in Appendix G.

| Stress | Gradient (psi/ft) |
|---|---|
| Calculated Fracture Gradient | 0.51 |
| Assumed Tectonic Stress Gradient | 0.15 |
| Total Fracture Gradient | 0.66 |

Two core samples from shale units failed during loading into the testing apparatus, therefore, there is no geomechanical TXC information for the confining zone (pg. 19).

### *Porosity and Permeability*

The Vedder Formation sand units have porosities ranging from 26% to 34% and permeabilities from 192 to 613 mD horizontally, and 62 to 154 mD vertically (pg. 18; Table 2-4). Vedder shale units have porosities ranging from 15% to 27% and permeabilities from 0.11 to 0.91 mD horizontal, 0.0052 to 0.025 mD vertical (pg. 18; Table 2-4). The Freeman-Jewett (confining zone) shale and mudstone has an approximate porosity of 20% and permeabilities of 0.26 mD horizontal, 0.0036 mD vertical (pg. 18; Table 2-4). It appears that these results are consistent with the lithological characteristics of the formations and support the assertion that the Vedder Formation will serve as a sufficient injection zone and the Freeman-Jewett an effective confining zone. Data is also provided for the overlying Olcese sandstone and Round Mountain Silt/Fruitvale Shale units. See the table under "Depth, Areal Extent, and Thickness of the Injection and Confining Zones."

The results from archival core laboratory testing compare well with historical porosity and permeability values given in Appendix C, Table B-3 from Birkholzer et al. (2011) (pg. 19). Historical data shows the porosity of the entire Vedder Formation to be 26.4% and the permeability as 303 mD horizontal, 60.6

mD vertical (pg. 18; Appendix C, Table B-3). The Freeman-Jewett historical porosity is given as 33.8% and permeability as 0.002 mD horizontal, 0.001 mD vertical, showing a slight divergence between the historical data and laboratory results (pg. 18; Appendix C, Table B-3). However, this is not expected to affect the confining ability of the Freeman-Jewett Formation, which depends on consistently low permeability (pg. 19).

Table 2-11, which shows geomechanical and petrophysical parameters used for PHREEQC geochemical modeling, is reproduced below.

| **Formation** | **Rock Density (kg/L)** | **Modeled Porosity (%)** | **Modeled Porosity** | **Bulk Density (kg/L)** |
|---|---|---|---|---|
| Freeman-Jewett | 2.2 | 20 | 0.2 | 1.76 |
| Vedder | 2.65 | 34 | 0.34 | 1.749 |

***Questions/Requests for the Applicant:***

- *Is any data available on in situ stress within the AoR? Where are the principal stress directions? The applicant added a discussion of in situ stress, including the directions of principal stress, within the AoR to Section 2.3.2. The response is acceptable.*
- *Where are the Shell KCL-A 83-85 and General Petroleum KCL 25#1 wells (the sources of the geomechanical data)? If they are not within the AoR, please explain how they are representative of the geomechanical properties of the injection and confining zones within the AoR and at the injection well location. The applicant included API references for the wells Shell KCL-A 83-85 (402930606) and General Petroleum KCL 25#1 (402930604) in Section 2.5. These API references correlate to wells on Figure 2-47. The applicant states that these wells are the nearest locations to the AoR with available TXC data. The response is acceptable.*
- *Please provide evidence for the statement on page 19 that sample 5 from the Olcese Sand is representative of the Vedder Formation at the injection depth. Also, please explain how the sample at 8,499 feet in the Vedder Formation represents the injection zone depth at 7,780 ft. The applicant explains in Section 2.5 that the Olcese and Vedder Formations are comparable due to their similar depositional settings and porosities. However, their permeabilities differ at different depths by one or more orders of magnitude. Pending results from pre-operational testing, this response is acceptable.*
- *How will SJRenew identify any heterogeneities between the zones updip and zones proximal to the fault system that could affect $CO_2$ storage? The revised Sections 2.1.2 and 2.4.2 acceptably answer the original question.*
- *The depth of Sample 3 in the Geomechanical Analysis is stated as 8,400 ft bgs on page 19 of the narrative, but is listed as 8,499 ft bgs in the Triaxial Compressive Strength table of the Appendix F Geomechanical Report. Please correct the discrepancy. The discrepancy has been corrected.*
- *What is the basis of the assumed tectonic stress from Appendix G? The applicant explains the source of the assumption in Section 2.5 as derived from the recommendation of production engineers experienced with the San Joaquin Basin. Pending results of pre-operational testing, the response is acceptable.*
- *Why do several core samples from Table 2-3 (e.g., in 410720206) have no formation identified? The applicant explains that the core samples without an identified formation did not have*

*porosity and permeability data and/or were too far from the project site to be relevant for the statistical analysis. The applicant removed these rows from Table 2-4 (formerly Table 2-3). The response is acceptable.*

- *Please explain why the permeability value for the KCL-25-1 Olcese sample at 6,131 feet bgs on Table 2-4 is considered to be an outlier and is excluded. The applicant explains that this value was assumed to be representative of a shale unit within the Olcese due to its low permeability value. Pending results from pre-operational testing, the response is acceptable.*

***Objectives for Pre-Operational Testing:***

- *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.*
- *Confirm/characterize the geomechanical and petrophysical properties (including porosity and permeability) of the Vedder and Freeman-Jewett Formations and other relevant formations based on analyses of core samples taken during drilling of the injection and monitoring wells to confirm the representativeness of the available data from nearby oil fields.*

## Mineralogy of the Injection and Confining Zones

Baseline mineralogy of the injection and confining zones is based on studies by Nguyen and others (2014). The Vedder Formation consists of arkosic arenites and graywacke sandstones and is predominantly composed of quartz and feldspar minerals. The Freeman-Jewett Formation consists of siltstones and shales and has a high clay content, which varies from 5-30% and is primarily smectite (pg. 24), which is consistent with the depositional environment (pg. 10; Figure 2-20).

Table 2-9 shows the results of core sample analyses, which are described in detail in Appendix F. The samples analyzed include the four samples used in the PHREEQC geochemical modeling (including three from 1-2 km to the east of the AoR and one from the southwestern part of the AoR). The laboratory tests conducted include X-Ray diffraction (XRD), scanning electron microscopy (SEM), and micro-computed tomography (Micro-CT). This information is summarized in Table 2-2, and XRD results, thin section images, SEM images, and Micro-CT images are provided in Appendix F. The application asserts that these tests confirm the findings of Nguyen and others (2014).

The Freeman-Jewett Formation consists of shale and siltstones and is predominantly smectite clay, quartz, and plagioclase feldspars. About half of the Freeman-Jewett consists of clay minerals (pg. 25; Table 2-9).

Table 2-12, reproduced in part below, shows the mineralogical parameters used from the four samples for PHREEQC geochemical modeling.

| Mineral | Molar Mass (g/mol) | Freeman-Jewett 4,801-4,805 ft | | Freeman-Jewett 4,369-4,379 | | Vedder 4,308-4,333 ft | | Vedder 8,350-8,360 ft | |
|---|---|---|---|---|---|---|---|---|---|
| | | Relative Abundance (%) | moles/L | Relative Abundance (%) | moles/L | Relative Abundance (%) | moles/L | Relative Abundance (%) | moles/L |
| Albite (for plagioclase) | 262.223 | 21 | 7.05 | 23 | 7.72 | 31 | 6.08 | 29 | 5.69 |
| Smectite-low-Fe-Mg | 549.07 | 51 | 8.17 | 32 | 5.13 | 2 | 0.19 | 27 | 2.53 |
| K-Feldspar (orthoclase) | 278.33 | 2 | 0.63 | 5 | 1.58 | 18.5 | 3.42 | 6 | 1.11 |
| Calcite | 100.09 | 0 | 0 | 6 | 5.28 | 0.5 | 0.26 | 0 | 0 |
| Dolomite | 184.4 | 0 | 0 | 5 | 2.39 | 3 | 0.84 | 0 | 0 |
| Illite | 389.34 | 4 | 0.90 | 6 | 1.36 | 0.5 | 0.07 | 2 | 0.26 |
| Kaolinite | 258.16 | 0.5 | 0.17 | 0 | 0 | 2 | 0.40 | 1 | 0.20 |
| Gypsum | 172.17 | 0.5 | 0.26 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pyrite | 119.98 | 1 | 0.73 | 2 | 1.47 | 0.5 | 0.21 | 0 | 0 |
| Fluorapatite | 486.82 | 0 | 0 | 7 | 1.27 | 0 | 0 | 0 | 0 |
| Quartz (+ opal) | 60.08 | 20 | 29.29 | 14 | 20.51 | 41 | 35.10 | 34 | 29.11 |

The application asserts that quartz, feldspars, and clays in the injection and confining zones are not expected to be highly reactive with the injectate due to their relative stability and low reactivity. However, mineral dissolution and precipitation, especially for carbonate minerals, is still expected to occur in small amounts (pg. 28). Additionally, trace concentrations of ferrous iron ($Fe^{2+}$) were detected in solution at equilibrium. Table 2-13 shows a summary of mineralogical changes based on equilibrium modeling, and Table 2-14 shows the final equilibrium aqueous chemistry. See "$CO_2$ Stream Compatibility with Subsurface Fluids and Minerals" for more discussion on predicted changes in mineralogy and aqueous concentrations resulting from $CO_2$ injection.

***Questions/Requests for the Applicant:***

- *Page 24 of the narrative lists minerals formed as a result of reactions that have occurred due to dissolution in groundwater. Please identify what groundwater parameters may be in solution after leaching, erosion, or other reactions that occur from the minerals formed, i.e., pyrite reacts with oxygen to produce the ferrous iron in solution. The applicant expanded Section 2.8 to further discuss expected reactions as well as the aqueous chemistry results from geochemical modeling. The response is acceptable.*
- *Please make the following clarifications in Section 2.6.2: The applicant made all requested changes in Section 2.8.2. The response is acceptable.*
    - *Reference Table 2-9, rather than Table 2-8. The narrative now references Table 2-10.*
    - *Based on the XRD analyses and Clay Subtotal of Table 2-9, clay content for the Vedder Formation ranges from 4.5% to 30%, not 10% to 30% as stated in the second paragraph. The values are now correct.*
    - *Add a reference to the XRD data in Appendix F. This reference is now included.*
- *Section 2.6.4.3 refers to Table 2-9 as the mineralogical input for PHREEQC and Table 2-12 as the calculated values for mineralogy, while the title of Table 2-12 is, "Mineralogy Input for PHREEQC." Please clarify the following: The applicant clarified the mineralogical inputs for PHREEQC modeling in the revised text of Section 2.8.4. The response is acceptable.*

- *Do the “calculated values” described in the text refer to values that are calculated as results of modeling, or values that were derived from the conversion to mol/L? This has been clarified.*
- *Table 2-12 shows the mol/L converted data, rather than “calculated values.” This has been clarified.*
- *Which table is the source of the values that were used in the PHREEQC equilibrium modeling? This has been clarified.*

***Objectives for Pre-Operational Testing:***

- *Perform a mineralogic analysis of the injection zone and confining zone solids that represents the project site during drilling of the injection well and the injection zone monitoring well.*

## Seismic History and Seismic Risk

Seismic data for the Southern San Joaquin Basin Province was compiled from USGS and California Geological Survey (CGS) databases (pg. 20; Table 2-5).

- The USGS database indicates that nine M 2.5 - M 3.09 earthquake events occurred between 1970 and 2021 within a 25 km x 18 km box centered on McFarland. All of the events originated in the granite basement at depths of 4.76 km to 28.58 km and none were associated with Quaternary or recent faults. 152 seismic events were recorded from 1970 to 2021 within a 65 km x 75 km box centered around the nearby town of Shafter (pgs. 20, 21; Figures 2-48 and 2-49).
- CGS's database catalogues events greater than M 5.0. There are two periods of seismicity with earthquakes greater than M 5.0 for a total of five earthquake events: 2 earthquakes in 1905 and 3 earthquakes in 1952. All events occurred far from the SJRenew property, south and east of Bakersfield (pg. 20; Figures 2-48 and 2-49).

Figure 2-46 and Figure 2-47 show some creep that was previously associated with groundwater withdrawal (Smith, 1983). This is associated with the Pond-Poso Creek Fault, but there have been no earthquakes associated with this feature (Figure 2-46).

Of all known historical earthquakes of significant magnitude near McFarland, the application asserts that none are associated with the faults in the McFarland area or within the AoR (pg. 21). Further, none originated above the granitic basement, and none are associated with recent/Quaternary faults (pg. 21). Given overall concerns about seismicity in California and the presence of the fault system to the west, a baseline microseismicity study may support further characterization of the AoR.

The applicant asserts that fault reactivation due to $CO_2$ injection activities is unlikely. The AoR/CA details modeled overpressuring of the Pond-Poso Creek Fault Complex due to injection on the order of 3 bars. According to Renaldi et al. (2015), a typical fault reactivation pressure is 20 bars (AoR/CA, pg. 16).

The evaluation of seismic risk also reflects other elements of the comprehensive permit application review (described elsewhere in this report), including porosity and permeability of the injection and confining zones; regional structural features; information on faults in the vicinity of the project site; formation pressure; and the geomechanical properties of the injection and confining zones.

Seismic risk and risk mitigation will also be considered in the review of the following aspects of the permit application:

- Predictions of plume and pressure front behavior over time, including pressure build-up over time, and pressure dissipation following cessation of injection.
- The ability of the injection well to maintain mechanical integrity under stress.
- Wells within the project area and the status of well corrective action.
- Planned injection pressures.
- Emergency and remedial response planning.

Based on the information provided, it appears that the risk of an induced seismic event associated with the injection project is low, if injection pressure and volume limits are met.

***Questions/Requests for the Applicant:***

- *Please explain how the project will be monitored such that, in the unlikely event of an induced seismic event, risks will be quickly addressed and mitigated. The applicant states in their response that the Testing and Monitoring Plan will be updated with information on planned seismic monitoring. The updated Testing and Monitoring Plan, dated September 7, 2022, states that seismic monitoring will be conducted via existing state- or USGS-operated seismic monitoring networks. The response is acceptable, pending a forthcoming review of the updated Testing and Monitoring Plan.*
- *Please revise Section 2.3 to remove duplicate information that appears on pages 20 and 21, including: The applicant made both requested revisions in Section 2.6. The response is acceptable.*
    - *"CGS maintains a database of earthquakes … none in the McFarland vicinity." This revision was completed.*
    - *Information on the 9 seismic events from USGS. This revision was completed.*
- *Please add a legend to Figure 2-48 to explain the magnitude represented by differently sized circles. The applicant added a legend to (now) Figure 2-53 explaining the magnitude of mapped earthquakes, as well as the delineated AoR and SJRenew property. The response is acceptable.*
- *Please show the AoR and injection site on Figures 2-45 to 2-49 (the SJRenew Property is already labeled on Figure 2-48). The applicant updated Figures 2-50 to 2-53 to include the delineated AoR and SJRenew property. Figure 2-49 from the original submission appears to have been removed; however, this has no impact and the response is acceptable.*

***Objectives for Pre-Operational Testing:***

- *Establish pressure in the injection zone.*
- *Establish baseline seismicity.*

## Surface Air and/or Soil Gas Monitoring Data

No soil gas or surface air data were submitted with the permit application. At this point, we do not believe this will be necessary; however, if the results of future reviews necessitate surface air and/or soil gas monitoring, we would request baseline data.

## Facies Changes in the Injection or Confining Zones

Based on seismic profile interpretations from Appendix D, the Vedder Formation is a progradational shallow marine shelf deposit with sand layers separated by various shale layers: Vedder 1/1A/2/3/4/Cantleberry Sand (pg. 13). The Cantleberry Sand layer is limited in lateral extent and is not present in the AoR (Figures 2-28 and 2-33). Shale layers exist between layers 2/3 and 3/4, and the Vedder 4 has a basal shale (pgs. 6, 13; Table 2-4; Appendix D). Section 3.3 of the narrative (the injection well description) indicates that the well will have a dual completion of two intervals within the Vedder Formation: Pyramid Hill/Vedder 1/Vedder 2 and Vedder 3 (pg. 31; Figure 3-1). The interpretation from Appendix D is consistent with the wireline log interpretation of the depositional environment from Hewlett and Tye (2015; pgs. 9-10; Figures 2-17 to 2-21) and wireline logs from Wagoner (2009; pg. 9; Figures 2-15 and 2-16), which are in turn consistent with the proposed depositional setting of a progradational shallow marine shelf (pg. 13; Figure 2-7). The plume migration modeling described in the AoR/CA takes the heterogeneity of the Vedder Formation injection zone into account, where some internal layers may assist in $CO_2$ confinement (AoR/CA: pgs. 17-18).

The Freeman-Jewett confining zone is interpreted as a transgressive-systems tract (Jewett Shale) transitioning to a highstand-systems tract (Freeman Silt) that forms an overlying seal above the Vedder Formation (pg. 10, Figure 2-20). From this depositional interpretation, the Freeman-Jewett is expected to form a thick and continuous overlying seal (shown in well log-derived cross sections in Figures 2-23 to 2-27). According to MICP data from core samples (identified in Table 2-3), there are no appreciable heterogeneities in the Freeman-Jewett with regards to permeability that might adversely affect the containment of $CO_2$. The Freeman Jewett formation horizontal permeability is calculated to be 0.26 mD, and vertical permeability is 0.0036 mD through the core sample MICP analyses in Appendix F (pg. 18; Table 2-4). See "Confining Zone Integrity" for more details on the efficacy of the confining zone.

***Questions/Requests for the Applicant:***

- *What does the facies succession look like within the Vedder Formation? Are there any depositional features within the Vedder Formation that may affect containment or fluid flow? The applicant added a discussion of the facies succession in Section 2.4.2. Based on the discussion, there were no concerns presented about facies changes that could affect injection or confinement. The response is acceptable.*
- *Are there any potential fluid flow pathways associated with facies changes within the Freeman-Jewett or Vedder Formation? What evidence supports this finding? The applicant states in Section 2.4.2 that fluid flow pathways have not been reported in the Freeman-Jewett, nor have pathways been observed in well logs or 2-D seismic surveys of the Vedder in the McFarland region. The response is acceptable.*
- *Please provide additional detail about the thicknesses of the various layers of the Vedder Formation, including how they may vary within the AoR. The applicant added Table 2-1 to clarify formation thicknesses, including thicknesses of the Vedder subunits. The applicant provided the entire static geomodel to the GSDT to show layer variability within the AoR, and the geomodel is consistent with the AoR CA Plan. The response is acceptable.*
- *On page 13, the Vedder 4 is listed twice in the sentence listing the different Vedder Formation layers. Please revise the sentence. The typo was corrected.*

***Objectives for Pre-Operational Testing:***

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

## Structure of the Injection and Confining Zones

Based on the wireline logs, cross sections, and interpreted 2D seismic images provided in Appendix D, the Vedder Formation appears to be a laterally continuous and thick reservoir unit suited for injection activities. It is covered by the Freeman-Jewett shale and mudstone, a laterally continuous and thick confining layer (schematically shown in Figures 2-23 to 2-27). The primary structural features within the AoR are the homocline and the Pond-Poso Creek Fault System.

The injection zone is contained wholly within the regional homocline structure, gently dipping about 4° west (pg. 7; Figure 2-5). See "Regional Geology and Geologic Structure" for more details on the structure of the injection and confining zones, "Facies Changes in the Injection or Confining Zones" for details on internal structure due to facies changes, and "$CO_2$ Stream Compatibility with Subsurface Fluids and Minerals" for details on updip fluid migration.

The Pond-Poso Creek Fault Complex serves as the western boundary of the delineated AoR (pg. 20; Appendix D; AoR/CA: Figure 1-22). The $CO_2$ plume is not expected to migrate far enough downdip to encounter the Pond-Poso Creek Fault (AoR/CA: Figure 1-6a). However, the pressure front will reach and be arrested by the Pond-Poso Fault. See "Faults and Fractures" and the AoR modeling evaluation for more discussion on the effects of the fault system on pressure front migration.

## $CO_2$ Stream Compatibility with Subsurface Fluids and Minerals

Appendix B presents the results of injectate chemistry modeling using the UNIQUAC equation of state and UNIFAC method within ASPEN Plus process modelling software (Appendix B: pg. 2). The injectate will be in liquid phase at the surface, and become supercritical at about 2,400 ft below surface (pg. 4; Appendix B). The modeled composition of the injectate is: 98.7% $CO_2$, with less than 1% methane/benzene/ethane/nitrogen (pg. 29). The specific modeled composition of the injectate is given in Table 3-1. The injectate composition used for PHREEQC geochemical modeling is given in Table 2-10, which is reproduced below.

| Gas | Mass Fraction | Mass % |
|---|---|---|
| Carbon dioxide | 0.9866 | 98.7% |
| Methane | 0.0047 | 0.5% |
| Benzene | 0.0036 | 0.4% |
| Ethane | 0.0024 | 0.2% |
| Nitrogen | 0.0014 | 0.1% |
| Total | | 99.9% |

PHREEQC geochemical modeling results are presented in Tables 2-13 and 2-14, and are described in the narrative on pages 28 and 29. The modeling predicts the following reactions to occur between the fluids and minerals of the injection zone and the injectate:

- Dissolution of calcite (when present), then precipitation of dolomite;
- Illite dissolution (which will contribute magnesium to dolomite precipitation);
- Dolomite, kaolinite, quartz, k-feldspar precipitation (shown in all models due to their stability); and
- Gypsum dissolution when initially present (due to mineral instability).

The following equilibrium aqueous chemistry results are expected to occur:

- $CO_2$ will dissolve into solution, which is included in the Total Inorganic Carbon (TIC);
- Ferrous iron ($Fe^{2+}$) is in solution in samples with a reducing environment (negative pE);
- pH ranges from 6.5 to 7.5; and
- Low calcium concentrations due to precipitation of minerals like dolomite.

According to the applicant, the changes in mineralogy and aqueous chemistry due to $CO_2$ injection will not affect the injection or containment of $CO_2$ in the Vedder Formation (pg. 29). The volume of minerals in the confining zone is expected to increase by only about 1%, and the porosity of the Vedder and Freeman-Jewett Formations is not expected to be sustainably impacted (pg. 28). These expectations are based on the mineralogy of the Vedder and Freeman-Jewett Formations, which consists primarily of stable silicates such as quartz, feldspars, and clays. The precipitation of carbonates is predicted to assist in the sequestration of $CO_2$ through the incorporation of the carbon into mineral phases (pg. 29).

For the AoR delineation, the TOUGH2 equation-of-state (EOS) module ECO2N (Pruess, 2005) is used to simulate non-isothermal multiphase flow of fluid mixtures of water, $CO_2$, and sodium chloride (NaCl) in geologic media (AoR/CA: pgs. 1-2).

***Questions/Requests for the Applicant:***

- *Page 29 states that the aqueous chemistry results are presented in Table 2-13; however, this information is in Table 2-14. Please clarify the discrepancy. The applicant updated the table reference. The response is acceptable.*

***Objectives for Pre-Operational Testing:***

- *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.*
- *Generate fluid chemistry and mineralogic data, pressure, temperature, and pH conditions at depth via core sampling and formation testing in the injection and monitoring wells to confirm the inputs to the geochemical modeling.*

## Injection Zone Storage Capacity

SJRenew plans on generating and injecting 1,200 tons per day of $CO_2$ per year into one injection well (SJR-I1) for a period of 15 years (pg. 3) for a total of 6.57 million tons of $CO_2$ (pg. 29). This total volume is based on SJRenew's energy and material balance analyses. Due to the nature of the depositional environment and lack of structural traps, the full capacity of the injection zone likely exceeds the total volume of $CO_2$ to be injected at the project. The applicant claims that, according to the stratigraphic sections in Figures 2-1 and 2-10, Pyramid Hill and Vedder Formations are the thickest, most widespread potential $CO_2$ injection formations in the San Joaquin Basin Province (pg. 6). Based on the TOUGH2 AoR delineation modeling, the $CO_2$ plume will expand laterally outwards updip until its arrest by physical forces. The gas plume is expected to migrate up-dip to the east, until the cessation of injection activity. Then, the $CO_2$ plume is gradually arrested due to injection pressure subsidizing, capillary pressure gradients reducing, and the buoyancy forces weakening over time. Finally, 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). Sensitivity Case M (described on page 21 of the AoR/CA) states that "there are no hydrogeological features (such as sealing faults or water divides) that would impose [no-flow] boundary conditions." Therefore, the plume will migration updip and gradually decline until it rests at the boundaries modeled by TOUGH2 (AoR/CA: Figure 1-6a/b).

## Confining Zone Integrity

According to Section 3 of the permit application narrative, predicted pressure distributions throughout the AoR will remain below the fracture pressure of the Vedder Formation. The fracture gradient given for the Vedder Formation in Appendix G is 0.66 psi/ft, giving a fracture pressure of 5,132 psi (35,384,000 Pa, or 353.8 bar) at the planned injection depth of 7,775 ft bgs. The maximum predicted pressure from TOUGH2 modeling is 480,000 Pa (69.6 psi, or 4.8 bar) (pg. 30). The initial static pressure of the injection zone is 259.5 bar (AoR/CA: pg. 16). Adding the predicted pressure to the initial static pressure gives a final maximum predicted pressure at the cessation of injection operations of about 265 bar. This is approximately 75% of the fracture pressure for the Vedder Formation, which is below the 90% threshold in the Class VI Rule.

Variations in parameters that affect the maximum injection pressure are explored in the sensitivity cases of the AoR/CA (pgs. 16-21; Table 1-3). Additional evaluation of the sensitivity analyses will be provided in the AoR modeling evaluation report. The narrative (pg. 30) identifies testing SJRenew plans to confirm the fracture pressure and calibrate calculated results (these are listed under the objectives for pre-operational testing, below).

The Pond-Poso Creek Fault Complex does not appear to compromise the integrity of the confining zone. See "Faults and Fractures" for more details on the Pond-Poso Fault.

***Questions/Requests for the Applicant:***

- *Please discuss in the narrative whether the maximum predicted pressure falls below the capillary entry pressure for the confining zone. The applicant added a discussion to Section 7.1 (Operating Procedures), stating that the maximum predicted pressure is significantly below the capillary entry pressure of the Freeman-Jewett, as shown by the TOUGH2 modeling. The response is acceptable.*
- *Is a figure available for capillary pressure versus wetting phase saturation for MICP core data? The applicant added the requested figure to Section 7.1. The response is acceptable.*

***Objectives for Pre-Operational Testing:***

- *Determine the maximum allowable injection pressure, based on the results of 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.*
    - *Step test rate test or leak-off test to determine fracture pressure after the well has been perforated.*

# Review of San Joaquin Renewables (SJRenew) Responses to EPA's Questions about the AoR Delineation Modeling Approach in the Class VI Permit Application

In June 2022, EPA provided questions presented in *blue italicized text* to San Joaquin Renewables (SJRenew) about the Area of Review and Corrective Action Plan (AoR/CA) and Post Injection Site Care (PISC) and Closure Plan submitted as part of SJRenew's Class VI permit application (dated October 13, 2021) for the proposed SJRenew Class VI geologic sequestration (GS) facility. SJRenew provided an updated AoR/CA (Attachment B_SJR_AoR_081622) and a document summarizing their responses (SJR_Response_081622) to EPA on August 16, 2022. EPA's evaluation of how the AoR/CA addresses its questions and requests for revisions and additional information are presented in *red italicized text* below.

This area of review (AoR) delineation modeling evaluation report for the proposed San Joaquin Renewables (SJRenew) Class VI geologic sequestration project summarizes EPA's evaluation of the modeling performed by SJRenew 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 SJRenew 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 SJRenew'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 SJRenew'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

SJRenew 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.

SJRenew 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.* *SJRenew added a new section (Section 2.9) to the AoR CA plan detailing the fracture pressure and fracture gradient, including data pertaining to how these parameters interact with the maximum pressure as predicted from injection phase modeling. The response is acceptable.*
    - *The Olcese as a secondary injection zone, as referred to on page 10 of the AoR CA.* *SJRenew removed references to the Olcese Formation as a secondary injection zone from the application. The response states that the Olcese was considered a potential secondary injection zone based on its known characteristics and storage capacity; however, because the deeper Vedder Formation is identified as the main injection zone, the Olcese is not listed for consideration within the application. SJRenew states that, since the Olcese does have the capacity to sequester $CO_2$, it was included in their assessment model as an additional layer of protection of USDW. The response is acceptable.*
- *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.*
  *Figure 1-5 has been replaced with Figure 2-5, which presents cross-sectional depictions of materials (formation units), permeability, and porosity. The cross-sections correspond to transect C-C' which is shown on Figure 2-6a. The AoR CA text has also been updated to reference these figures in Sections 2.3 and 2.4. The response is acceptable.*

## 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. SJRenew 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.*
  *The applicant responded that the vertical grid spacing was selected to be 5 meters, uniformly spaced over the entire model depth, as stated in Section 2.3 of the AoR CA. This spacing is stated to provide sufficient resolution within the Vedder Shale layers and the dipping layers over the entire model depth. Additionally, this grid height resolves other factors such as vertical saturation changes. The response is acceptable.*

*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.

SJRenew 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 SJRenew 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 SJRenew 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.*
  *The injection well and fault call outs have been added to these figures, which are now Figures 2-1 through 2-4. Information about pinchouts was provided within various figures in the narrative. The response is acceptable.*

## 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.*
  *The Pond-Poso Creek Fault Complex has been added to these figures, which are now Figures 2-6a and 3-2a. Although visually depicted, the fault system is not labeled on the figure nor is it called out in the legend. However, the response is acceptable.*

## 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.*
  *The coordinate system (NAD27/UTM Zone 11N) has been added to Table 2-1 of the AoR CA. Note that there is also another Table 2-1 within the Tables section that follows the Figures section.*
- *Please explain why SJRenew believes that "the error induced by a lower temperature at the elevation of the $CO_2$ plume is considered acceptable" (AoR CA, pg. 11).*
  *SJRenew's responded that the initial temperature of 60°C at the injection depth in the modeling is appropriate to represent the 80°C temperature of the injection site at the planned injection depth because the difference in hydraulic conductivity between 60°C and 80°C is only about 9%. SJRenew added this explanation as a footnote to page 10 in Section 2.7. The footnote is difficult to read, as it appears that the value of 80°C is used erroneously three times: to refer to the difference between the model and actual site (this should be 20°C); to refer to the assumed temperature in the model (this should be 60°C); and to refer to the limitations of ECO2N (this should be 105°C).*
- *What daily average injection pressure was used in the model?*
  *SJRenew responded that the average injection pressure is not constant but time-dependent. The $CO_2$ is injected at a constant mass rate of 1,200 tons per day as specified in Section 2.8. Based on Figure 3-3 referenced in the response, the average injection pressure appears to be around 259.5 bar to 265 bar. This is also detailed in Section 3.1.3 of the AoR CA. This response is acceptable.*

***Follow-up Questions/Requests for the Applicant:***

- *Please revise the numbering of the table at the end of Section 2.3 on page 8 to avoid duplicate numbering.*
- *Please revise the footnote on page 10 to reference the correct temperature values as noted above.*

## 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 SJRenew predicts in the application narrative that through shale gouge, the Pond-Poso Creek Fault Complex will be non-transmissive of the pressure front.

SJRenew 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.*
  *SJRenew responded that the revised AoR CA was updated to reflect that no wells are located within the area simulated to exhibit pressure greater than admissible levels; therefore, negating the need for corrective action. The response also details their technical opinion regarding incorporating abandoned wells in the model. They assert that this would result in a smaller AoR, but argue that not including this would reduce the potential for underestimating other effects such as fracturing, induced seismicity and fault reactivation. The response is acceptable, pending discussion below.*
- *Please label the Pond-Poso Creek Fault Complex on the modeling output figures (e.g., Figure 1-8a).*
  *The applicant responded that the Pond-Poso Creek Fault has been added to Figures 2-6a, 3-2a, and 4-1. The fault is included on Figures 2-6a and 3-2a, but not labeled or called out in the Legend. The fault is included and labeled on Figure 4-1.*

*Follow-up Questions/Requests for the Applicant:*

- *Please label the Pond-Poso Creek Fault on Figures 2-6a and 3-2a.*

## Calculation of critical pressure

SJRenew 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.*
  *The applicant responded that Section 4.1 of the AoR has been updated with pressure calculations for the AoR delineation that consider sustained admissible overpressure, critical pressure to drive formation fluids and drilling muds, and admissible pressure increases. It appears that the reference to threshold overpressures dissipating to approximately zero has been removed. In place of this, Figure 4-1 (the delineated AoR) has been added to show areas where simulated pressure exceeds the admissible pressure (which is limited to an area 0.5 miles from the injection well). A longer duration of overpressure over time is illustrated on Figure 3-3 showing no areas greater than the admissible pressure (~20 and 40 years).*
  *The revised AoR CA now considers the pressure to overcome gel strength of the water-based drilling muds in wells within the AoR in the critical pressure calculations. The AoR CA provides a new calculation (Equation-2 or EQ-2) that factors in gel strength, borehole diameter, and formation depth which, the applicant asserts, is consistent with methods referenced within the document [e.g., Nicot et al. (2008), Barker (1981), and Johnston and Knape (1986)], and is allowed by other EPA regional UIC programs, which SJRenew asserts have allowed accounting for gel strength when calculating the allowable pressure buildup that defines the AoR. The overpressure calculations provided in Appendix B now include the gel strength, with final allowable overpressure being the sum of the admissible overpressure (ΔP from Equation 1 or EQ-1) and the gel strength ($P_g$ from EQ-2).*

*There are several concerns about this approach:*

- *The computational modeling assumed a gel strength value of 25 lbs/100 ft2 within the AoR wells in the critical pressure calculations. The application asserts that this value is based on a study by Nicot et al. (2008), which is also cited in the Class VI AoR Delineation Guidance. However, other aspects of that paper were referenced in the Guidance, and the use of the assumed gel strength is not recommended in the Guidance. Although this gel strength value is considered to be a conservative estimate, it is an assumption and not empirical data about the current condition of the wells. EPA has expressed similar concerns in other permit application reviews, noting that the estimated gel strength value does not represent a site- or well-specific value.*
- *The information presented in the permit application does not provide empirical data that drilling muds in the abandoned wells in the AoR have retained the ability to suppress fluid movement between zones after decades of inactivity and in the presence of CO2, which is buoyant. The*

*wells were plugged between 1942 and 1995 (most before 1955), and no information on their current condition was provided. EPA has previously expressed concerns about how older wells in the AoR defined for other permit applications have held up over time. For example, studies cited in the Response to Comments for a Class I permit application (including Barker, 1981; and Johnston and Knape 1986, which SJR references) caution that gel strength measured early after plugging will not be representative of downhole conditions in old, abandoned wells. Regarding Johnston and Knape (1986), summaries of reference literature and personal communications provided in the appendix to the paper are inconsistent in their support for reliance on mud properties to contain injection zone pressures in improperly abandoned wellbores, and the authors acknowledge that they are not aware of any field studies in abandoned boreholes directly related to this topic.*

*Without definitive information about the current condition of the mud in abandoned wells and the quality of plugs in the wells, the impact of injection zone pressure increases on potential fluid movement cannot be ascertained to a level that ensures USDW protection. Therefore, EPA would not accept, in this case,* considering *the pressure to overcome gel strength of the water-based drilling muds in the critical pressure calculations used to define the AoR.*

## Representation of Fluid Properties

Relevant fluid properties for the computational modeling include viscosity, density, composition, and pore compressibility. The fluids considered in SJRenew'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 ($\Phi$), pore compressibility ($\beta_\rho$), 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<br>$k_v$ = 62 mD | $k_h$ = 555 mD<br>$k_v$ = 136 mD |
| D | Decreased permeability of Vedder sands based on 25th percentile of measured values; maintain anisotropy ratio | $k_h$ = 254 mD<br>$k_v$ = 62 mD | $k_h$ = 82 mD<br>$k_v$ = 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<br>$n$ = 1.842<br>$1/a$ = 0.2 bar | $S_{lr}$ = 0.3<br>$n$ = 2.5<br>$1/a$ = 0.5 bar |
| I | Changed van Genuchten parameters for relative permeability and capillary pressure of Vedder sands | $S_{lr}$ = 0.0<br>$n$ = 1.842<br>$1/a$ = 0.2 bar | $S_{lr}$ = 0.1<br>$n$ = 1.5<br>$1/a$ = 0.1 bar |
| J | Sealing faults | Fault permeabilities based on Allan diagrams | All faults sealing<br>$k_h$ = 0.0036 mD<br>$k_v$ = 0.0036 mD |
| K | Non-sealing faults | Fault permeabilities based on Allan diagrams | All faults non-sealing<br>$k_h$ = 254 mD<br>$k_v$ = 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

SJRenew 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 SJRenew 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.*
  *SJRenew described the approach they used to determine storage capacity. Additional information was added to Section 3.1 of the updated AoR CA indicating that the storage capacity was dependent on relative permeability and capillary pressure functions as depicted on Figures 2-7 and 2-8. The model simulations indicate that the available pore volume is far greater than the volume of the supercritical $CO_2$ plume. The response is acceptable.*
- *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.*
  *The applicant provided $CO_2$ plume mapping based on various modeling scenarios. The extent of the plume appears to be relatively consistent under the various modeled scenarios, except for Case G, which does not account for any phase trapping. Under the Case G scenario, the plume appears to extend further to the east; however, this scenario is a conservative assumption designed to consider no phase trapping. The response is acceptable.*

## 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.*
  *The $CO_2$ plume extents for time steps of 2, 5, 10 years have been added to the TOUGH2 simulated maximum $CO_2$ saturation base case figure (formerly Figure 1-6b, now Figure 2-6b in*

*the updated AoR CA). The pressure front extent is depicted for 15 years on Figure 4-1. This response is acceptable.*

- *Please provide a graphic depiction of the cumulative storage for each of the phases of $CO_2$ over time.*
  *The applicant added Figure 3-4, which is a graphic illustration of the cumulative amounts of $CO_2$ in the storage formation, separated for each phase (dissolved $CO_2$, $scCO_2$, and total $CO_2$). Additional information explaining the data from Figure 3-4 was added to Section 3.1 of the updated AoR CA. The response is acceptable.*
- *Please add more discussion within the AoR CA narrative of the plume movement over time as depicted on Figure 1-6b.*
  *SJRenew provided additional discussion in Section 3.1.1 of the updated AoR CA, explaining the evolution of the $scCO_2$ plume through the injection and redistribution period as depicted on Figure 2-6b (formerly Figure 1-6b). The response is acceptable.*
- *Please add units for simulated $CO_2$ saturation on Figure 1-6b.*
  *The applicant added a note to Figure 2-6b (formerly Figure 1-6b) of the updated AoR CA indicating the contour line saturation units and that they are dimensionless. This response is acceptable.*
- *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.*
    *The applicant responded that pressure near the injection well reaches its maximum at the end of the injection period, while pressures in other parts of the modeled domain will slightly increase post-injection. They also state that Equation 1 and Equation 2 are used for comparison to the overpressure as determined by TOUGH2 model. This response is acceptable, pending additional discussion on the gel strength as described above.*
  - *Additionally, please discuss the boundaries at which this extent is defined.*
    *The applicant provided additional details within Section 4.1 of the updated AoR CA to include critical pressure calculations and the migration behavior of the $CO_2$ plume. Figure 4-1 was provided to show the outer limits of the $CO_2$ storage complex in relation to the injection well, and areas where simulated pressure exceeds the calculated admissible pressure over 15 years. Section 4.2 of the AoR CA states that the predicted plume footprint is 1.49 square miles. The applicant also states that the injection project will not cause pressure increases sufficient to endanger USDWs outside of the $CO_2$ plume footprint based on the updated pressure calculations. This response is acceptable, pending additional discussion on the gel strength as described above.*
- *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.*

  *The applicant indicated that the predicted pressure increases will not increase indefinitely due to asymptotic decline in the pore pressures, continuous equilibrium of the saturation distribution, and $CO_2$ dissolution. As stated previously, the outer limits of the predicted pressure increases are shown in Figure 4-1. Section 4.1 of the AoR CA states that the predicted pressure increases are* *limited to a distance of approximately 0.5 miles from the injection well over a duration of 15 years. This response is acceptable.*

- *For what depth does Figure 1-9 show pressure measurements?*
  *The applicant clarifies the depth of the pressure measurements, as detailed on Figure 1-9, where the injection well intersects the Vedder-Freeman-Jewett contact (at a depth of ~2,355 mbgs/elevation of ~2,255 masl). These details have been included in Section 3.1.3 of the updated AoR CA. Figure 1-9 has been relabeled as Figure 3-3 in the updated AoR CA. This response is acceptable.*
- *Please add figures to represent comparisons of sc$CO_2$ saturation profiles for Years 5, 10, 40, and 75 (similar to Figures 1-10 and 1-11).*
  *The applicant added Figures 3-6a through 3-6f to the updated AoR CA; the figures compare sc$CO_2$ saturation profiles for years 5, 10, 15, 40, 75, and 115. These figures also show side-by-side profiles for west-east and south-north directions for each year. The response is acceptable.*
- *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."*
  *SJRenew indicated that the terms are no longer used and have been removed from the updated AoR CA. The response is acceptable.*

## AoR Reevaluation Schedule

SJRenew 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 SJRenew proposes appears to be appropriate.

SJRenew 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. SJRenew 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 SJRenew explicitly state that it will take these steps as part of the model calibration.*
  *Section 6 of the updated AoR CA includes this edit. The response is acceptable.*
- *Please also explain that SJRenew 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.*
  *Section 6 of the updated AoR CA includes this reference. The response is acceptable.*

- *Please identify at what frequency the AoR will be reevaluated in the post-injection timeframe.*
  *Section 6 of the updated AoR CA has been updated to indicate an AoR reevaluation fixed frequency of every 5 years, including during the post-injection timeframe. The applicant also requested that EPA consider less frequent reevaluations during the post-injection phase. However, the Class VI Rule, at 146.84(e) states that the minimum fixed frequency is not to exceed 5 years. It is noted that, should the site perform as predicted after injection ceases, the applicant may make a demonstration using monitoring data and modeling results that no amendment to the AoR and corrective action plan is needed, per 146.84 (e)(4).*
- *EPA also recommends that SJRenew 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.*
  *Section 6 of the updated AoR CA includes this reference. The response is acceptable.*

## 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 SJRenew will perform unscheduled reevaluations using the same procedures described in the AoR and Corrective Action Plan.*
  *Section 6 of the updated AoR CA includes this reference. The response is acceptable.*
- *EPA recommends the following clarifications/enhancements to the triggers for AoR reevaluation SJRenew 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.*
    *The requested information about the specific triggers was added to Section 6, page 21 of the updated AoR CA. However, the applicant did not explain how these increases would not exceed permit limits. EPA expects that the applicant will adhere to the permit-defined limits on injection rates and pressures for the duration of the permit.*
  - *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.*
*The requested information was added to Section 6, pages 21 and 22, fourth bullet of the updated AoR CA. The response is acceptable.*

- *Clarify that new site data (e.g., the presence of a fault or fracture) may be identified in the course of seismic surveys/monitoring.*
  *The requested information was added to Section 6, pages 21 and 22, second bullet of the updated AoR CA. The response is acceptable.*

- *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.*
- *Section 6 of the updated AoR CA includes the requested information. The response is acceptable.*
-

# 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 SJRenew'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

SJRenew proposed a 15-year post injection site care time frame. EPA evaluated the information SJRenew 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)]. SJRenew 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)]. SJRenew 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. SJRenew 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)]. SJRenew 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, SJRenew 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).
  - SJRenew 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)]. SJRenew 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, SJRenew 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. SJRenew 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)]. SJRenew 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, SJRenew 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. SJRenew did not describe the injection and monitoring well construction (per 40 CFR 146.93(c)(1)(viii)). However, SJRenew 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)]. SJRenew 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.

SJRenew 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 SJRenew 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.*
- *The applicant responded that the TOUGH modeled plume migration is measured to be approximately 3,000 feet updip from the injection well in an easterly direction from the 0 to 15-year timeframe (200 ft/yr). There is a gradual decrease in plume migration over subsequent year timeframes, with a maximum extent of 5,300 ft to the east by year 115. This information is depicted in Figure 2-6b of the updated AoR CA, and Figure 2 in the updated PISC. These figures illustrate the simulated maximum CO2 saturation contours for each year of the simulation period. The applicant also notes that plume migration is discussed further within Section 6.3 of the updated PISC and Site Closure Plan. The response is acceptable.*
- *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.*
  *The applicant responded that the construction of the injection and monitoring wells is referenced in Section 6 of the updated PISC and Site Closure Plan. The response is acceptable, pending forthcoming evaluation of plugging information.*
- *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).*
  *The applicant responded that the $CO_2$ trapping mechanisms are described in the updated AoR CA. The requested edit is included within Section 6.4 of the updated PISC, and includes a reference to Krevor et al., 2015 regarding capillary trapping at the project site being consistent with key storage processes in saline reservoirs. Phase trapping is discussed in detail within the updated AoR CA, e.g., in Section 2.2.1, 3.1.1, and within various model sensitivity cases in Section 3.2. The response is acceptable.*

## 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 SJRenew 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.*
    *Section 7 of the PISC and Site Closure Plan was updated to include these references and is now consistent with the EPA template. The response is acceptable.*
  - *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.*
    *Section 7 of the updated PISC and Site Closure Plan (specifically the AoR evaluation section) contains the requested information. The response is acceptable.*
  - *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.*
    *Section 7 of the updated PISC and Site Closure Plan contains the requested information (specifically under the Evaluation of Emergencies section). The response is acceptable.*

# Comments on SJR Computational Modeling
# Class VI Pre-Construction Permit Application No. R9UIC-CA6-FY22-2

## General Modeling Comments

- The incorrect definition of saturation index (SI) has been used in the Narrative Eq. (1) on Page 24. It should be in a logarithm form as $SI = \log(IAP/K_{sp})$ where $SI = 0$ represents the equilibrium condition. Please correct Eq. (1) or explain the reasoning behind the equation. *(Narrative, Section 2.8 Geochemistry)*

## Model Suitability

- Please explain why SJRenew chose to do isothermal $CO_2$ injection, when the simulator is capable of modeling thermal impacts and the model is initially populated with a thermal gradient. *(AoR and Corrective Action Plan, Section 2.7 Initial Conditions)*
- Has SJRenew confirmed that TOUGH2 is using appropriate formulations or connections for unstructured grids, and that the appropriate input settings are set? Please document this. *(AoR and Corrective Action Plan, Section 2.3 Model Domain)*
- Mineral dissolution-precipitation using chemical equilibrium is not realistic, as well-known primary mineral dissolution-precipitation involving dolomite, kaolinite, quartz, and k-feldspar are controlled kinetically. Why was mineral dissolution-precipitation modeled using chemical equilibrium? Please perform 1D kinetic transport sensitivity analysis using a range of kinetic rates in the literature. *(Narrative, Section 2.8.4 Equilibrium Geochemical Modeling)*
- It is not clear how $CO_2$ injection wells have been modeled. Is a special well function used in the TOUGH2 simulation or as a source term?
- The maximum overpressure was estimated from the simulation result, but it is not clearly described how the overpressure is computed. Is the overpressure computed as the bottom-hole pressure at the injection well? *(Narrative, Section 7.1 Operational Procedures; AoR and Corrective Action Plan, Section 2.9 Fracture Pressure and Fracture Gradient)*
- What is the Kelly Bushing for proper conversion of various metrics?

## Model Design

- Please clearly identify the injection well perforation lengths and depths along with the model domain summary information. *(AoR and Corrective Action Plan, Section 2.3 Model Domain)*
- Is any skin factor or productivity index assumed in the well model or is it open hole?
- Please clarify if each formation was modeled as a "single model layer" or if the units were subdivided in the TOUGH2 simulation model.
- It appears that each rock material type is assumed to be homogeneous. Was each unit assigned a constant permeability and porosity, or was some geostatistical distribution assigned? (*AoR and Corrective Action Plan, Section 2.4 Porosity and Permeability; AoR and Corrective Action Plan, Figure 2-5 Materials, Permeability, and Porosity Cross Sections, TOUGH2 Model*)
- Please include a summary table of the modeled rock properties and parameters by simulation model "rock type". *(AoR and Corrective Action Plan, Section 2.2 Site Geology and Hydrology)*
- Faults/fault reactivation:
    - Please provide $scCO_2$ plume central moment plots for the transmissive potential of the fault complexes to be verified. *(AoR and Corrective Action Plan, Section 3.1.2 First and Second Central Moments)*

  - Since the faults are dipping, their XY map-view location is depth-dependent. What depth was used in determining the XY locations of the faults in the model grid? *(AoR and Corrective Action Plan, Section 2.3 Model Domain)*
  - Please provide a description of fault locations within the model domain with respect to the injection well. Please also clarify what type of properties were assigned to the faults and whether any pressure increase reaches to the nearest fault from the injection activity. *(AoR and Corrective Action Plan, Section 2.3 Model Domain; AoR and Corrective Action Plan, Section 3.1.1 Plume Distribution)*
- Please provide a clear description of the numerical timesteps used for the overpressure map.

## Model Calibration and Sensitivity Analyses

- Since the average pressure within a 10-m radius of the injection well is used to report the maximum overpressure, the boundary condition around the $CO_2$ injection well needs to be described and justified. Please provide justification for the 10-m averaging around the injection well. *(AoR and Corrective Action Plan, Section 3.1.3 Pressure Distribution)*
- Residual water saturation is not reported. Since residual water saturation has the similar effect on effective porosity for $CO_2$ storage, both reduced porosity and inclusion of residual water saturation will have an increasing impact on the $CO_2$ plume size. Please include this case in the sensitivity analysis. *(AoR and Corrective Action Plan, Section 3.1.4 Carbon Dioxide Phase Distribution)*
- Please perform model sensitivity analyses for permeability and cap rock dip angles. If permeability turns out to be significantly higher and/or porosity significantly lower than anticipated, the 2022 AoR will increase. If the cap rock has steeper dip, or dips in a different direction, then the plume could go further or in a different direction. *(AoR and Corrective Action Plan, Section 3.2 Model Sensitivity Analyses)*
- Was a maximum bottomhole injection pressure assigned and was it ever reached (for all simulation cases)? *(AoR and Corrective Action Plan, Section 3.2 Model Sensitivity Analyses)*
- In the permeability sensitivity cases and porosity sensitivity cases, was the capillary pressure also scaled? *(AoR and Corrective Action Plan, Section 3.2.2-3.2.3 Sensitivity Cases)*
- The description of the reference case relative permeability and capillary pressure models and assumptions is not adequate to interpret the results of the phase trapping and van Genuchten parameters sensitivity cases. Please also refer to the third bullet point under "Formation conditions" below. *(AoR and Corrective Action Plan, Section 3.2.4-3.2.5 Sensitivity Cases)*
- The associated pressure front is not well reported for the phase trapping, Vedder permeability, Vedder porosity, injection interval, fault sealing, and boundary condition sensitivity analyses. Please report the results more appropriately. *(AoR and Corrective Action Plan, Section 3.2 Model Sensitivity Analyses)*
- The anisotropy ratio has been fixed to a constant. Please expand the anisotropy ratio to at least a factor of 10 from the reference case to represent the local heterogeneity since heterogeneous features are not accounted for. *(AoR and Corrective Action Plan, Section 3.2 Model Sensitivity Analyses)*

## Input Parameters vs. Site-Specific Conditions

- Initial conditions:
  - Please provide model input files to facilitate a more complete evaluation of the modeling effort including an evaluation of the initial conditions. *(AoR and Corrective Action Plan, Section 2.7 Initial Conditions)*

  - What site-specific information was used to determine the initial surface and reservoir temperatures? *(AoR and Corrective Action Plan, Section 2.7 Initial Conditions)*
- Hydrologic properties:
  - Please clarify what residual water saturation was used. *(AoR and Corrective Action Plan, Section 2.7 Initial Conditions)*
  - Was $CO_2$ available in excess in the PHREEQC model? Also, please provide units in Narrative Table 2-14. *(Narrative, Section 2.8.4 Equilibrium Geochemical Modeling)*
- Formation conditions:
  - Is the model considered completely saturated up to the land surface? Please support the assumption about the saturation level with data. *(AoR and Corrective Action Plan, Section 2.7 Initial Conditions)*
  - Please support the temperature and temperature gradient with appropriate data or literature values. *(AoR and Corrective Action Plan, Section 2.7 Initial Conditions)*
  - In the constitutive relationships description, please describe the relative permeability and capillary pressure models used, the residual aqueous and gas saturations (and their justifications), critical gas saturations, if/why/why-not separate curves/parameters were included for drainage and imbibition, and any particular trapping and/or hysteresis models used. *(AoR and Corrective Action Plan, Section 2.5 Constitutive Relationships and Other Rock Properties)*
  - Please describe the differences and implications for the models/parameters used for the injection zone vs. seal zone. *(AoR and Corrective Action Plan, Section 2.5 Constitutive Relationships and Other Rock Properties)*
- Geomechanical properties:
  - The fracture gradient was determined using the Eaton's method. While the method gives an estimate of the fracture gradient, this method is not accurate. Please provide an alternative method for calculating the fracture gradient. *(Narrative, Section 2.5 Geomechanical and Petrophysical Information)*
  - Is the injection pressure only 5.5 bar above the initial reservoir pressure? *(Narrative, Section 2.5 Geomechanical and Petrophysical Information)*

## Description of Computational Modeling Results

- Please report the injection pressures at the well. *(AoR and Corrective Action Plan, Section 3.1.3)*
- For Figure 3-2a (maximum overpressure base case), please label the contours and contour interval, so it is possible to fully interpret the modeling results shown on the map. *(AoR and Corrective Action Plan, Figure 3-2a)*
- There is only overpressure prediction from 15 years to the end of the injection period. Please include how the pressure front changes during the injection period (at 1, 5, 10 years). *(AoR and Corrective Action Plan, Section 3.1.3 Pressure Distribution)*