Site Characterization Evaluation of the Carbon TerraVault (CTV) Class VI A1-A2 Permit Application

This geologic site characterization evaluation report for the proposed Carbon TerraVault (CTV)-Elk Hills Class VI geologic sequestration (GS) project summarizes EPA's evaluation of the geologic narrative submitted as part of CTV's Class VI permit application (dated August 30, 2021). This review also identifies preliminary questions for the applicant. 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

The Elk Hills Oil Field (EHOF) is in Kern County, California, in the southern San Joaquin Basin (Figures 1 and 2) CTV plans to inject CO_2 at the EHOF into the Monterey Formation via 2 injection wells, 355-7R and 357-7R, over a period of 15 years. The 2 injection wells are 1,250 feet apart and will inject into the Monterey Formation A1-A2 reservoir (Monterey A1-A2) at the Northwest Stevens Anticline at ~8,500 ft depth (Figure 8 and pg. 4).

The Monterey Formation at the EHOF also contains the Miocene Reef Ridge Shale (the primary confining zone), which directly overlies the Monterey A1-A2 and has been an effective seal for 40+ years of oil and gas operations (pg. 9). Figures 4 and 5 show the spatial distribution of wells in the EHOF and data available for use in characterizing the injection zone.

The Monterey A1-A2 consists of turbidite sands bounded above and below by siliceous shale (pg. 9). The application asserts that this depositional history has resulted in minimal lateral communication of the Monterey A1-A2 outside the EHOF (Cross Section Figure 3, pg. 4; pg. 9). The reservoir is continuous across the area of review (AoR), with pinch-outs on the channel edges (pg. 9).

The Upper Tulare Formation is the lowermost underground source of drinking water (USDW). The Tulare Formation consists of poorly consolidated sandstone, conglomerate, and claystone beds, which are exposed at intervals along the west border of the San Joaquin Valley (pg. 7). It is divided into the Upper Tulare and the Lower Tulare by the Amnicola Clay (a low permeability claystone). An aquifer exemption was approved for the Lower Tulare Formation in 2018, making the Upper Tulare Formation the lowermost USDW.

In addition to the Reef Ridge Shale, the Monterey A1-A2 Sands are separated from the lowermost USDW in the Upper Tulare Formation by the Amnicola Clay (pg. 31), the Lower Tulare Formation, the San Joaquin Formation, a depleted gas reservoir directly underlying the Tulare Formation, and the Etchegoin Formation (pg. 8). The Monterey A1-A2 Sands are separated from the underlying Monterey A3-A11 reservoir by a laterally continuous 20-foot shale known as the A2 Shale (Figure 9). The application asserts that they are not in communication, as evidenced by a pressure differential (of 200-300 psi in the A1-A2 and ~1,700 psi in the A3-A11), and the need for separate pressure maintenance strategies (pg. 10). The A3-A6 reservoir is also considered a viable target for future CO_2-EOR based on its existing waterflood injector infrastructure and high reservoir pressure (pg. 11).

Tests and logs performed during drilling and prior to completion of the 357-7R injection well and the 342-7R-RD1 and 327-7R-RD1 monitoring wells (which are completed in the Monterey Formation and are located to the west and northwest of the injectors) include Array Compensated True Resistivity, SP logs, caliper logs, compensated spectral natural gamma log, spectral density dual spaced neutron log, and mud logs (Attachment G pg. 4-5). Cement bond logs and MIT tests (temperature log and SAPT) were also performed on the 357-7R injection well.

Questions/Requests for the Applicant:

- ***Please label the injection wells or the injection well site on Figure 2.***
- ***Was any data collected or testing performed during drilling of the 355-7R injection well? If so, please characterize this data.***
- ***The AoR and Corrective Action Plan (on pg. 3) states that, the "Monterey Formation sands are bound above by the regional Reef Ridge Shale, and below by the Lower Antelope Shale Member of the Monterey Formation." Please clarify the difference between the A2 Shale and the Lower Antelope Shale.***
- ***Does the Antelope Shale provide confinement? If so, please provide additional discussion of the confining properties.***
- ***What is the source of the statement about the pressure differential between the Monterey A1-A2 Sands and the Monterey A3-A11 Sands described on pg. 10?***
- ***Please provide pressure build-up test results for the 357-7R injection well.***
- ***Several of the figures in the narrative that contain data are difficult to read (e.g., Figures 14 and 15); please provide higher resolution versions of this information.***
- ***Please provide a map of the Elk Hills Oil Field that shows the 355-7R and 357-7R injection wells, along with the wells planned for the Elk Hills 26R Storage Project (with a scale that shows distances).***

Objectives for Pre-Operational Testing:

- ***Confirm hydraulic separation of the Monterey A1-A2 Sands and the Monterey Formation A3-A11 reservoir.***
- ***If no pressure build-up test results exist for the 357-7R injection well, perform pressure build-up testing as part of the Pre-Operational Testing Plan.***

Faults and Fractures

The 31S and Northwest Stevens (NWS) anticlines in the EHOF are separated by mid-Miocene thrust faults (pg. 12). The application states that the Reef Ridge Shale and Monterey Formation are well resolved based on seismic data, and there is no evidence of faults penetrating the Reef Ridge Shale or transecting the Monterey Formation (pg. 13). Figure 10 shows reverse faults in seismic profiles, however the resolution is too low to discern formation labels (pg.12). These reverse faults, oriented NW-SE, offset the NWS anticline (pg. 12).

Evidence for confinement includes 3D seismic and well data confirming the absence of faults penetrating the Reef Ridge Shale, 40+ years of previous waterflooding and gas injection operation, pressure differentials across formations (i.e., 230 psi in the Monterey A1-A2 Sands and 1,500 psi in the Etchegoin Formation for a 0.43 psi/ft pressure gradient at 3,600 ft depth), and geochemical analysis of 66 oil samples (Zumberge, 2005; Figure 12).

Questions/Requests for the Applicant:

- ***Please update Figure 10 to clearly label the formations in which the thrust faults terminate.***
- ***Where were the 66 oil samples collected within the EHOF described on pp 13-14, relative to faults within the field?***

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

At the site of the injection wells, the stratigraphic sequence from top to bottom consists of the Tulare Formation, the San Joaquin and Etchegoin Formations, the Reef Ridge Shale confining zone, and the Monterey Formation injection zone (pg. 4, 7). The depths and thicknesses of the injection and confining zones were determined based on wireline logs and 3D seismic data and are presented in Table 1 of the application narrative. In the AoR, the Reef Ridge Shale thickness is controlled by the Monterey Formation deposition patterns and minimum thickness corresponds to a highpoint in the Monterey Formation Sand thickness (pg. 15).

The table below summarizes the depth and thickness of the formations of interest according to available data in the permit application narrative. Some depth/thickness information for the San Joaquin or Etchegoin Formations was not provided; however, this is not critical for the purposes of the application evaluation. Porosity and permeability data are presented as well; additional discussion of these characteristics is provided under “Geomechanical and Petrophysical Characterization.”

Unit	**Average Depth within the AoR**	**Thickness Across the AoR**	**Porosity**	**Permeability**
Tulare Formation	600-2,500 ft (pg. 31)	1,200-1,500 ft (pg. 31)	34-40% (pg. 7)	1,410-8,150 mD (pg. 7)
San Joaquin Formation	Not given	Not Given	28%-45% (pg. 8)	64-6,810 mD (pg. 8)
Etchegoin Formation	1,500-4,000 ft (pg. 8)	Not Given	29-37% (pg. 9)	32-826 mD (pg. 9)
Reef Ridge Shale (Confining Zone)	6,929 ft-7,962 ft TVD (Table 1, Figure 13)	1,122-1,892 ft (Table 1, Figure 13)	7.7% (pg. 6); 7% (pg.9); 4 to 14% (Table 2)	0.01 mD (pg. 9); 0.00003 to 0.0917 mD (Table 2)
Monterey Formation A1-A2 Sands (Injection Zone)	8,403 ft – 9,598 ft TVD (Table 1, Figure 13)	27-548 ft (Table 1, Figure 13)	11%-27% (Figures 16 and 17); 16% (pg. 9)	0.1-1,300 mD (Figures 16 and 17); 60 mD (pg. 9)

Questions/Requests for the Applicant:

- ***The depths listed in Table 1 for the Monterey A1-A2 Sands are inconsistent with the logs in Figure 9. It appears, based on the log, that the depth to the Monterey A1-A2 Sands is ~8,500 feet MD or ~7,700 feet TVD at the 357-7R injection well, not 8,403 feet TVD as stated in Table 1. The mean depth to the Monterey Formation is also listed as 5,907 ft when the low and high depths are listed as 8,403 ft and 9,589 ft respectively. Please clarify the discrepancy or revise Table 1.***

- ***There is a typo on Figure 16, “Capitally” for Mercury Injection <u>Capillary</u>*** **Pressure. Please fix this when the application is updated.**
- ***Please characterize, name, and provide depth and permeability data for the underlying confining unit, if one exists.***

Hydrologic and Hydrogeologic Information

The Lower Tulare Formation, which conformably overlies the shallow marine deposits of the San Joaquin Formation, was approved as an exempt aquifer in 2018. The Upper Tulare Formation is the only USDW in the AoR (pg. 7). The regional extent of the exempted portions of the Lower Tulare Formation is shown in Figures 7, 26, and 29. It extends well beyond the AoR in the southern direction but closely borders the AoR to the north. The depth to the lowest USDW in the Upper Tulare is shown in Figure 28; however, the figure is difficult to read.

The San Joaquin Basin has no appreciable surface or subsurface outflow (pg. 35). The primary source of surface water and fresh groundwater is the Kern River, which drains to the southeast and terminates near the EHOF (pg. 35). Low precipitation rates and high evaporation rates result in almost no groundwater recharge from precipitation, leading to high salinity and TDS concentrations (pg. 35). CTV did not find any water supply wells within the AoR after a search of CALGEM, USGS, Kern County Water Agency (KCWA), West Kern Water District, and the GeoTracker Groundwater Ambient Monitoring and Assessment online database (pg. 36). CTV owns the surface area of the EHOF (pg.35).

Questions/Requests for the Applicant:

- ***It appears that Figure 26 provides information on the depth and regional extent of the area shown in cross section with wireline logs for TDS content, however the resolution is low (pg. 31). Please provide a higher resolution version of Figure 26.***
- ***What is the depth of the Upper Tulare Formation and the separation of this lowermost USDW from the injection zone and the confining zone within the AoR?***
- ***Is the Upper Tulare USDW present within the modeled AoR of the injection wells?***

Geochemistry/Geochemical Data

Limited baseline geochemical data for the Upper Tulare Formation (USDW) and Monterey Formation (injection zone) are provided in the application.

Figure 30 shows the results of water analysis performed on waters from the Upper and Lower Tulare Formations. The produced fluid has been collected during previous operations to establish a baseline and characterize the region. Hydrocarbon content in the injection zone was determined through fractional distillation and chromatography (pg. 37). Figure 30 is difficult to read, but it appears that the analysis is from 1995, and the analytes include some, but not all, of those planned as part of injection and post-injection phase monitoring. The TDS values of the Upper Tulare Formation appear to be 4,800-4,900 mg/L.

The application states that water sampling was not performed in the Monterey A1-A2 Sands because reservoir depletion has reduced water saturation to residual levels. However, geochemical analysis was performed using fluid produced during oil and gas operations (pg.37). CTV provides an example of the water geochemistry analysis taken from well 381-17R from a sand underlying the Monterey A1-A2 Sands (Figure 31). Figure 33 presents a 2021 analysis from nearby Well 353-7R. The figure is difficult to read, so it is unclear what analytes were measured, and if all the analytes planned during operational testing are addressed. It appears that the TDS of the Monterey A1-A2 Sands is about 24,000 mg/L.

CTV's Testing and Monitoring Plan (Attachment C) includes monitoring the overlying Etchegoin/San Joaquin Formations and the Tulare Formation for groundwater quality and geochemical changes and the Monterey Formation as part of direct plume tracking activities. Water quality will need to be established in each of these formations prior to injection operations to provide a baseline for comparison to future monitoring results.

Questions/Requests for the Applicant:

- ***Please provide clear/legible versions of the sample analyses in Figures 30 and 31 to allow a review of the sampling performed.***
- ***Where is Well 381-17R?***
- ***What is the total dissolved solids (TDS) content of the Monterey Formation? Please indicate how many data points or measurements are available to support this measurement (i.e., based on past field operations) and, if they are not from throughout the AoR, please provide information to support a determination that the Monterey Formation is not a USDW.***
- ***Is any water quality data available for the Etchegoin Formation? If so, please provide this.***
- ***In the Testing and Monitoring Plan, CTV states that they obtained a baseline analysis for the 61WS-8R well (apparently for the Tulare Formation). Please provide this analysis if it is not the same as is provided in Figure 30.***

Objectives for Pre-Operational Testing:

- ***Establish baseline geochemistry for the Monterey Formation, as well as the Tulare and Etchegoin Formations for all analytes to be monitored during injection operations, per the Testing and Monitoring Plan.***

Geomechanical and Petrophysical Characterization

Capillary pressure was determined using mercury injection capillary pressure analysis from 18 wells. The average rock strength of the confining zone is 2,452 psi according to brittleness calculations and the average ductility of the confining zone is 1.24 as derived from compressional sonic data from 18 wells with 59,214 data points using a calculation methodology from Ingram and Urai (1999) and Ingram et al. (1997) (pg.23). The applicant concludes that brittleness of less than 2 is evidence that the confining layer is sufficiently ductile to "anneal" discontinuities and that there are no fractures for fluid migration (Figure 19). The application states that this conclusion is further supported by historical water and gas injection data at the site in addition to millions of years of confinement of oil and gas in the Monterey Formation by the Reef Ridge Shale (pg. 23).

In the EHOF, the maximum principal stress direction is northeast-southwest as determined by a study of EHOF fracture gradients and borehole breakout (Castillo, 1997; Figure 21) Table 3 of the application narrative is reproduced below.

Stress	Reef Ridge Shale Confining Layer (Well: 374A-7R-RD1)	Monterey Formation A1-A2 Reservoir (Well: 372-7R-RD1)
Pore Pressure Gradient (psi/foot)	0.433	0.2
Overburden Gradient (psi/foot)	0.93	0.94
Minimum Horizontal Stress Gradient (psi/foot)	0.73	0.97

The GEOMECH geomechanical model, along with the GEM equation of state compositional reservoir simulator, were used to determine failure pressures under a base case and three additional scenarios; this modeling is described on pages 25-28 of the application narrative. Descriptions of variations from the base case for other scenarios are given below:

- Reduced Young's Modulus: to model uncertainty in the cap rock Young's Modulus, a second case was run with a value of 8E05 psi.
- Reduced Injection Rate: sensitivity to injection rate was studied by reducing the injection rate to 20 million cbf per day.
- Thinner cap rock: the impact of a thinner cap rock was modeled by assigning a confining layer of 795 feet.

Table 4 of the application narrative, which presents the results of the modeling, is reproduced below:

Geomechanical Scenario Results	
Scenario	**Failure pressure (psi)**
Base Case	8,306
Reduced Young's Modulus	8,388
Reduced Injection Rate	8,340
Thinner Cap Rock	7,600

Figure 23 shows the change in normal fracture effective stress in the bottom cap rock layer and the pressure in the top layer of the reservoir with time for each scenario. See also the evaluation of the AoR CA (Attachment B) for additional information.

Porosity and Permeability

As shown in the table under "Depth, Areal Extent, and Thickness of the Injection and Confining Zones," above, porosity values for the Reef Ridge Shale are approximately 7-14% and reported porosities of the Monterey A1-A2 Sands range from 11%-27%. The permeability of the Reef Ridge Shale is about 0.01 mD, and Monterey Formation permeability ranges from 0.1-1,300 mD. Permeability and porosity for the Reef Ridge Shale in the 355X-30R well are presented in Table 2 of the application.

Formation porosity and permeability used as inputs for the geomodel were determined using wireline log data, including SP logs, gamma ray, borehole caliper, resistivity, neutron porosity, and bulk density (pg. 17). Porosity is determined from bulk density using a 2.65 matrix density calibrated from particle density (Figure 15) and porosity data. Clay volume is determined from neutron-density separation and is calibrated to core data. A permeability function was calculated using mercury injection capillary pressure porosity and clay values (Figure 16). The application states (on pg. 17) that core data from 13 wells with 175 data points were used to calibrate log porosity and to develop a permeability transform. However, it is unclear which wells are the source of this data.

Questions/Requests for the Applicant:

- ***Please update Figure 23 to include base case pressure.***
- ***Please discuss the selection of the base case parameter values (i.e., Young's Modulus, thickness, etc.) in the geomechanical modeling.***
- ***Please explain what is meant by "anneal discontinuities" in the discussion on page 23.***
- ***The application references core data from 13 wells on page 17.***
    - ***To which wells does this refer and where are they located?***
    - ***If they are not distributed throughout the AoR, please describe how they are representative of the entire area that will be affected by injection.***
- ***Where are the 18 wells that are the source of ductility data referred to on pg. 23 located?***
- ***The application states that, "The final/maximum values for surface and downhole injection pressures are far below (~2,000 psi) those associated with the Class II permitted fracture gradients of .8 psi/foot," and that, "the final reservoir pressure target of 4,000 PSI is significantly below the Reef Ridge confining shale estimated minimum geomechanical failure pressure of ~7,500 PSI" (pg. 46). Please clarify the sources of data used to determine failure pressure, fracture pressure, and fracture gradient.***

Mineralogy of the Injection and Confining Zones

X-ray diffraction (XRD) data from 108 data points in 9 wells was analyzed to determine injection zone mineralogy. Fourier Transform Infrared Spectroscopy from 36 points in 1 well located outside the AoR but within the EHOF was used to characterize confining zone mineralogy (pg. 16-17). Figure 14 presents an example XRD analysis from well 367-7R located within the AoR. The applicant addresses the use of a single well for characterizing the mineralogy of the confining zone, citing that it is representative of the formation because of depositional continuity and consistency of facies and properties within the EHOF (Figure 15).

The Monterey A1-A2 Sand intervals consist of 43% quartz, 38% potassium feldspar, albite, and oligoclase as well as 7% total clay. The Reef Ridge Shale consists of 47.1% silica polymorphs (Opal-CT, chert, and cristobalite), 29.5% total clay, 14.5% potassium feldspar, albite, and oligoclase, and 3.7% quartz (pg.16).

Questions/Requests for the Applicant:

- ***Please provide a map of the 9 well locations used for XRD described on pages 16-17.***
- ***What evidence is there for depositional continuity and facies consistency within the EHOF, as described on page 17?***

Seismic History and Seismic Risk

The application notes that the "EHOF is in a seismically active region, but no active faults have been identified by the State Geologist of the California Division of Mines and Geology (CDMG) for the Elk Hills area (DOE, 1997)" (pg.29). Seismic activity in the region stems from the San Andreas Fault (12 miles west of the project site) and the White Wolf fault (25 miles southeast of the site) (pg. 29). Regional seismic data dating back to 1932 was gathered from the Southern California Earthquake Data Center (SCEDC) and USGS databases (Pg.29).

Figure 24 shows the eight (8) magnitude 5.0 or greater earthquakes that have occurred within a 30-mile radius of the EHOF. These earthquakes have an average depth of 6.3 miles, well below the Monterey Formation (pg.29). It is stated that there have been no earthquakes within the EHOF greater than magnitude 3.0. Site characteristics, including low factor amplification due to thin sediment, high density soil, and soft rock, based on shear-wave velocity (V_S) are asserted to further reduce seismic risk. The largest known earthquake in the region was a 7.5 magnitude 1952 earthquake in nearby Kern County which did not affect reservoir containment (pg. 30).

CTV will install borehole and surface seismometers to establish a baseline and assess natural and induced seismicity (pg. 29).

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.
- Seismic monitoring and emergency and remedial response planning.

Questions/Requests for the Applicant:

- ***Please include all earthquakes of magnitude 3.0 and above in Figure 24.***
- ***To inform an evaluation and documentation that there is no significant seismic risk, EPA recommends that CTV describe how the project:***
    - ***has a geologic system free of known faults and fractures and capable of receiving and containing the volumes of CO_2 proposed to be injected.***
    - ***will be operated and monitored in a manner that will limit risk of endangerment to USDWs, including risks associated with induced seismic events;***
    - ***will be operated and monitored in a way that in the unlikely event of an induced event, risks will be quickly addressed and mitigated; and***
    - ***poses a low risk of inducing a felt seismic event.***

Objectives for Pre-Operational Testing:

- ***Establish baseline seismicity after borehole and surface seismometers are installed.***

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

Depths to the confining and injection zones are presented on structural and isopach maps based on 3D seismic and wireline log data (Figure 13). However, the locations and number of wells used to characterize formation depths was not provided.

Figure 3 of the application shows a cross section of formations across the San Joaquin Basin and Figure 6 shows a stratigraphic cross section with well types for the Northwest Stevens anticline. Figure 12 shows a stratigraphic column with oil samples grouped into families. There appear to be logs on the figure used to correlate formations laterally, but they could not be distinguished.

Page 41 of the application describes the development of a geo-cellular model as part of the A1-A2 reservoir characterization and plume modeling. This is supported by cross sections in Figures 34 and 35 (which appear to be outputs of the AoR delineation model) that the applicant asserts also demonstrate the lateral continuity of the sand facies within the reservoir. Sand continuity and lack of internal baffles and barriers also supports predictable plume development. The application states that the modeled plume migration (Figures 34 and 35) is consistent with the structure of the anticline.

Figure 4 identifies “data coverage” for the Reef Ridge Shale and per Figures 5 and 8, several wells have core data in the Reef Ridge Shale and the Monterey Formation; however, it is unclear what information is available from the wells on the map and how it informed the application.

On page 11, the application concludes that the Northwest Stevens Monterey depositional framework and sand continuity have been established by static data that includes open-hole well logs and core data, as well as 3D seismic data. Discussion and questions for the applicant regarding lateral continuity of the Confining Zone are discussed above in the section on “Mineralogy of the Injection and Confining Zones.”

Questions/Requests for the Applicant:

- ***Please clarify what data sources were used to determine inputs for the geomodel where applicable, e.g., the inputs for sand vs. shale facies as discussed on pg. 40.***
- ***Please also discuss how a sufficient number and distribution of formation characterization data are available to demonstrate a lack of local heterogeneities that could affect storage or confinement of CO_2.***
- ***Please specify the names, number, and locations of wells used to characterize formation thicknesses for the maps in Figure 13.***

Objectives for Pre-Operational Testing:

- ***Determine if there are any heterogeneities within the Monterey A1-A2 Sands that could affect its suitability for injection, including facies changes that could facilitate preferential flow.***

Structure of the Injection and Confining Zones

Regional structure of the injection and confining zones is controlled by San Andreas Fault development resulting in mid-Miocene anticlines (pg. 3). The application describes the anticlines that form the Elk Hills Oil Field, which CTV asserts will contribute to confinement. See the discussions of "Regional Geology and Geologic Structure" and "Faults and Fractures," above.

CO_2 Stream Compatibility with Subsurface Fluids and Minerals

The proposed injectate will consist of at least 95% CO_2 with mixtures of water and oxygen that will be controlled for corrosion mitigation (pg. 46). The applicant states that corrosiveness of the stream will be "very low as long as the entrained water is kept in solution with the CO_2" which will be accomplished by limiting its water content (pg. 46).

Existing subsurface fluid information is based on extensive and ongoing CO_2 injection activity in the EHOF region. CTV has injected 6.3 billion cubic feet of gas containing up to 44% CO_2 into the Monterey A1-A2 Sands since 2011 without any changes to injectivity (pg. 38-39). A 2021 analysis from an oil sample in the 353-7R well showed a 6.5 mole % CO_2 content (pg. 38). The applicant states that low water volume in the formation (15% saturation in the gas cap and 85% in the thin oil band) and low residual oil saturation (15%) will also dissolve only a small amount of CO_2. Furthermore, the Monterey A1-A2 Sands is dominated by quartz and feldspar which are stable in the presence of CO_2 and carbonic acid (pg. 39).

There is no geochemical analysis of water samples from the Reef Ridge Shale because the shale will only provide fluid for analysis if stimulated (pg. 39). The CO_2 composition used for the geomodel and its interaction/solubility is established by the Peng-Robinson Equation of State (AoR and CA Plan, pg. 2).

Questions/Requests for the Applicant:

- ***Please provideevidence for the statement in the Application on page 39 that the quartz and feldspar in the Monterey A1-A2 Sands are stable in the presence of CO_2 and carbonic acid?***
- ***Please elaborate on why use of the Peng-Robinson Equation of State supports compatibility of the CO_2 with any fluid which may be contained within the Reef Ridge Shale.***

Objectives for Pre-Operational Testing:

- ***Confirm the composition and water content of the CO_2 injectate as part of baseline sampling and provide verification that it will not react with the formation matrix.***

Injection Zone Storage Capacity

Modeled storage capacity of the Monterey Formation A1-A2 reservoir was 8-10 million tons of CO_2 (pg. 41). The forecasted/proposed injection rate is 0.25 - 0.75 million tons per year for 15 years; according to

Table 8 (Proposed operational procedures); an average estimate of 8 million tonnes and a maximum of 10 million tonnes will be injected.

Injection zone storage capacity is discussed in the Evaluation of the AoR CA and above in the "Structure of the Injection Zone and Confining Zone" section. Any additional follow up questions/requests for the applicant will be provided in the AoR modeling evaluation.

Confining Zone Integrity

Fluid confinement is supported by 3D seismic data (pg. 12) and historic operating experience in addition to core data (pg. 20) and geochemical analysis (pg. 13). The capillary entry pressure of the Reef Ridge Shale is 4,220 psi in a CO_2-brine system, reducing the likelihood of deformation (pg. 20). There are no faults extending into the Reef Ridge Shale. See additional discussion and questions for the applicant above.

Questions/Requests for the Applicant:

- ***Were any other tests performed to corroborate pressure measurements in the Reef Ridge Shale?***
- ***The application, on pg. 14, states that there is a pressure differential of 1,300 psi between the overlying Etchegoin Formation and Monterey Formation due to the sealing nature of the Reef Ridge Shale. What is the source of the pressure data for this statement?***

Objectives for Pre-Operational Testing:

- ***Test for changes in capillary entry pressure of the Reef Ridge Shale due to reaction of the shale with the injectate via laboratory experiments.***
- ***A step rate test should be performed to establish the fracture pressure of the confining zone.***