

Review of Carbon TerraVault (CTV) Responses to EPA's Site Characterization Questions about the Class VI A1-A2 Permit Application

In December 2021, EPA provided questions presented in *blue, bold, and italic text* to CTV about the geologic narrative submitted as part of CTV's Class VI permit application (dated August 30, 2021) for the proposed Carbon TerraVault (CTV)-Elk Hills Class VI geologic sequestration (GS) project. CTV provided an updated narrative and a table summarizing their responses to EPA on March 2, 2022. EPA's May 2022 evaluation of how the narrative addressed its questions is presented in *red, bold and italic* text. CTV submitted an updated narrative (Attachment A Site Evaluation v3) to EPA on June 20, 2022. This document evaluates how the updated narrative addresses EPA's May 5, 2022 questions (in *purple* text). Requests for revisions and additional information are presented in *purple, bold and italic* text. Previous responses that require no further information are not included in this enclosure.

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 CO₂ 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 CO₂-EOR based on its existing

waterflood injector infrastructure and high reservoir pressure (pg. 11).¹

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.

- ***Please provide pressure build-up test results for the 357-7R injection well. CTV requested technical discussion prior to inclusion in the pre-operational testing plan. The response is acceptable at this stage of the permit application review. EPA will schedule a technical discussion.***

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.***

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 now 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

¹ Note: CA SB905 now prohibits enhanced oil recovery with CO₂.

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.** The revised figures (now Figures 33 and 34) are legible. The TDS of the four samples in the Upper Tulare Formation ranges from 4,800 to 4,900 mg/L. EPA has no further questions.
- **Where is Well 381-17R?** CTV referenced page 40; however a revised Figure 34 on page 39 shows the well, which is just outside the eastern edge of the AoR. EPA has no further questions.
- **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.** CTV referenced page 40; however Figure 34 on page 39 shows the requested water quality information. EPA has no further questions.
- **Is any water quality data available for the Etchegoin Formation? If so, please provide this.** CTV responded that this is included in the pre-operational testing plan. It is assumed that no current water quality data exist. The response is acceptable at this point in the permit application review. No further questions.
- **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.** CTV responded that it will drill a new monitoring well and baseline results will be included in pre-operational testing. However, they did not provide any specific information about the location or construction of the well (which has ramifications for the testing and monitoring and financial responsibility evaluations).

Follow-up Questions/Requests for the Applicant:

- **Where will the new Tulare Formation monitoring well that CTV references above be located?** CTV responded that the USDW monitoring well will be located on the pad for 61WS-8R (it is shown on Figure 1 of the Testing and Monitoring Plan and its construction is shown in Appendix 1_TM Monitoring Well Schematics). Data will be gathered on the new USDW monitoring well and provided as part of pre-operational testing. No further questions in the context of the geology evaluation.
 - **Is this well in addition to the existing well 61WS-8R?** CTV responded that it reviewed the 61WS-8R well and determined that it was not an adequate monitoring well; therefore, the new well will replace that well.
 - **CTV should provide specific information about the construction of this well and include this well in the Testing and Monitoring Plan and PISC and Site Closure Plan, and address it in the financial responsibility cost estimates.** CTV responded that it will update the Testing and Monitoring Plan, PISC and Site Closure Plan, provide well construction details, and address this in the financial responsibility cost estimates.
 - **Please update the modules listed above to reflect the construction of the new monitoring well.**

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.*