Enclosure 2 – Area of Review Delineation Modeling
Request for Additional Information

Carbon TerraVault (CTV) VI Carbon Capture and Storage (CCS) Project
Underground Injection Control (UIC) Permit Application
Class VI Pre-Construction Permit Application Nos. R9UIC-CA6-FY24-2.1 to 2.7

Note – this document contains claimed confidential business information (CBI).

This Enclosure for the proposed CTV VI Class VI geologic sequestration project summarizes the review of the Area of Review (AoR) delineation modeling and underpinning numerical simulation. Clarifying questions or requests that require further work are provided below in ***bold, italic*** text. Text that is not ***bold, italic*** is provided to give context or is recommended for further work.

Overall Findings

1. The approach (i.e., risk-based) used for AoR delineation is not the recommended method given that the storage reservoir system is described as being at hydrostatic pressure (see Section 3.8 page B-7). We assume that this is hydrostatic relative to a relatively fresh water, which would mean that the reservoir is under-pressured with respect to the 20,700 ppm brine in the injection interval. EPA Class VI AoR and Corrective Action Guidance has a clear method (i.e., method 1 on page 39 of the EPA guidance) defining the calculation of critical pressure to delineate the AoR for under-pressured systems. ***Please update the method***.

2. Additional figures are requested to show map view pressure evolution. ***Please include additional figures to show map view pressure evolution and how pressures relate to the critical pressure for initiating leakage***.

3. The ranges in permeability explored in the uncertainty quantification need to be either better justified or expanded. ***Please provide additional justification or otherwise expand the permeability ranges***.

4. The single representation in Figure 3.9 (Page 26 of PBI_Att B) is useful but more could be done to show what was implemented in the model. ***Were multiple realizations of property distributions generated to explore uncertainty in the geostatistical model?***

5. A better description of the thermal modeling needs to be included. ***Was temperature simulated? If thermal transport was simulated, a figure showing the impact of the injection temperature on the formation should be included***.

6. Claimed as PBI [redacted] A magnetic survey would help alleviate this concern as would a review of historical photographs. ***Identify additional resources to identify undocumented wells, such as a magnetic survey***.

General Modeling

7. The conceptual model presented in Figure 2.7-5 of the report entitled "Carbon Terra Vault VI Class VI Permit Application Narrative Report" requires additional information. A "conceptual model for groundwater flow" is a simplified representation of the geological and hydrological features that control the movement of groundwater within an aquifer or aquifers and aquitard system including the location of different aquifer layers, their hydraulic properties, recharge zones, discharge points, and boundaries, providing a qualitative picture of how water flows through the subsurface system. ***Modify Figure 2.7-5 to include the features listed above. Please also include these modeling layers in the conceptual model figure or in a separate figure.***

Computational Modeling – General

8. In Attachment B, section 3.3 "Model Domain", the application states that average vertical cell height is 7.7 feet. This implies that the vertical cell height is not uniform but no description of how it varies was provided. ***Please provide a figure of a geo-cellular grid (similar to Attachment B, figure 3.3) showing the vertical direction. An average of 7.7 feet is a reasonable resolution for a model this size***.

9. Boundary conditions included in the application show that the southeast, northeast, and northwest are open boundaries. The southwest boundary pinches out and is represented as a closed boundary. Claimed as PBI [redacted] was set to a no-flow condition. The injection wells are modeled as constant rate injectors. In Section 3.7 (p. B-7) of (b), it is stated that the Injection Formations are bound Claimed as PBI [redacted] but they are not shown in the conceptual model (Attachment A: Narrative Report, Figure 2.7-5). ***The boundary conditions used in the model need to also be shown in the conceptual model. Please add the boundary conditions discussed above, including the "no-flow boundary", in the conceptual model***.

10. In both reports (a) and (b, Section 3.7, p. B-7), it is stated that the northwest boundary was modeled using Claimed as PBI [redacted] and are given in Table 1 and Table 3.2, respectively. But the table contents are different. No other information has been given in the reports regarding Claimed as PBI [redacted] approach.

According to the literature, Claimed as PBI [redacted] is based on the Van Everdingen and Hurst aquifer influence functions for radial flow from an outer aquifer region employed (e.g., Van Everdingen, A.F., and W. Hurst, "The Application of the Laplace Transformation to flow Problems in Reservoirs, " Trans. Soc. Pet. Eng. AIME, Vol. 186, pp. 305-324, 1949; Kipp, K.L., Jr., Claimed as PBI [redacted] ***Describe what kind of influence functions are included in the GEM software. Specifically, which one was used for this project? Has any evaluation been done for different influence functions during the modeling study?***

11. In the third bullet of a, AoR Delineation CTV VI in AoR and AoR Supporting Documentation and in the third bullet of b, Attachment B, Aection 3.7 reports, it is stated that the southwest boundary is closed due to the stratigraphic pinchout, thinning, and faulting associated with the uplift on the western margin. It looks like this a no-flow boundary (a special case of the Neuman boundary condition). ***If the area noted above is in fact interpreted to be a no-flow boundary, please state that it is considered a no-flow boundary***.

12. No information on time stepping was provided in the application, however, it's likely standard Computational Molecular Dynamics (CMG) time-stepping schemes were incorporated. The CO_2 plume is delineated in Figure 4.1 at 1, 5, 10, 30, 50, and 100 years. The average reservoir pressure within the plume is provided in Figure 4.3. The pressure near the injection wells is provided in Figure 3.16 and the bottom-hole pressure in 3.15. It is stated in the risk-based AoR calculation that the pressure increase in the plume does not exceed 500 pounds per square inch (psi). This is true on an average basis as shown in Figure 4.3 but it is unclear if it's true near the injection wells as shown in Figure 3.16 and unclear overall since no map of the pressure results is provided. The appropriateness of the time steps is determined with the Courant number (e.g., Huyakorn and Pinder, 1983, p. 206). No information is given in the reports regarding the values of time steps and their appropriateness. Therefore, an evaluation could not be made. ***Include some discussion of Courant number related to transport of CO_2***.

Computational Modeling Parameters

13. In Section 3.8 of Attachment B (p. B-7), it is stated that the temperature is set as variable with depth using a fixed surface temperature 72.5°F. ***What are the reasons for selecting this surface value?***

14. In Table 3.3 of Attachment B, temperature values are given at four elevations. ***Please describe what these temperature values at each elevation represent. Was temperature simulated?***

15. Section 3.9 states an anticipated injection temperature of 90°F; ***was this simulated? Please describe the rationale behind this value***.

16. According to Table 3.2 of Attachment B, the four formations have significant thicknesses between Claimed as PBI In Section 3.8, it is stated that a geothermal gradient $0.012^oF/ft$ was determined from Figure 3.12 of Attachment B. With this gradient, the following temperature differences between top and bottom of the formations can be calculated: Claimed as PBI [redacted] ^oF [redacted] ^oF [redacted] ^oF [redacted] ft [redacted] ^oF [redacted] ***Have the effects of these temperature differences for the formations been evaluated by sensitivity runs or other means? Please explain and provide the results.***

17. In Section 3.8 of Attachment B, it is stated that the initial reservoir pressure was determined to be hydrostatic with a pressure gradient of roughly 0.439 psi/ft. Where are the details in determining this value? With this pressure gradient, the following pressure differences between top and bottom of the formations can be calculated: Claimed as PBI [redacted] psi [redacted] psi [redacted] psi [redacted] ft [redacted] psi [redacted] ft [redacted] psi [redacted] psi [redacted] psi [redacted] ft [redacted] ***These are significantly high values. Have the effects of these pressure differences for the formations been evaluated by sensitivity runs or other means? Please explain and provide the results.***

18. In Section 3.8 of Attachment B, it is stated that the salinity concentrated values in Table 3.3 of Attachment B were approximated from water analysis in the area as discussed in Section 2.8.2 of Attachment A used. In Section 2.8.2.5 of Attachment A (p. 24), it is stated that the measured Total Dissolved Solids (TDS) concentration in Claimed as PBI [redacted] is 20,700 ppm. ***20,700 ppm is reported as the salinity concentration for several Formations in Table 3.3 of Attachment B. Please clarify where the salinity values in this table originate from***.

19. The modeled grid adequately represents hydrogeologic properties through detailed characterization of porosity, permeability, and capillary entry pressure. Porosity is derived from bulk density and sonic log data, calibrated using core grain density,

porosity, and depth-dependent shale travel time. Permeability is determined through a core-based transform utilizing capillary pressure, porosity, and clay volume, supported by XRD or FTIR analysis. Data from 16 regional wells inform these transforms, with porosity and permeability distributions simulated using sequential Gaussian kriging in the static model. ***Please explain if multiple realizations of property distributions were generated to explore uncertainty in the geostatistical model. The single representation in Figure 3.9 (Page 26 of PBI_Att B) is useful but please include more detail about the implementation of the model***.

20. In Section 3.5 of Attachment B (p. B-5), equations (1) and (2) are given under the title "Constitutive Relationships and Other Rock Properties" and they are identified as "Gas-water Corey model Gas" and "Gas-water Corey model Water", respectively. But the references are not given. The well-known reference is: "Brooks, R.H., and A.T. Corey. 1964. Hydraulic properties of porous media. Hydrology Paper No. 3, Civil Engineering Dept., Colorado State University, Fort Collins, Colorado." ***As the paper indicates, the term "Brooks-Corey" is used in the literature. Equations (1) and (2) of Attachment B are not included in their form in the aforementioned Brooks and Corey (1964) reference. Please include the correct references for the form of "Brooks-Corey" used in Attachment B***.

21. On page B-6 of Attachment B (section 3.5), it is stated that Figure 3.10 shows the relative permeability curves used in the Base Case and sensitivity cases (Base case, Case G, and Case H). ***Please provide additional explanation for these cases***.

22. On page B-6 of Attachment B (section 3.5), it is stated that Figure 3.11 shows the capillary pressure curve used in the computational model. ***Please describe how it is justified to use one curve for formations having widespread variabilities***.

23. On page B-6 of Attachment B (Section 3.5), the term "J-function" is not defined. ***On page B-6 of Attachment B (Section 3.5), please define the term "J-function".***

24. On page B-6 of Attachment B (section 3.5), it is stated that there are two facies defined in the model (sand and shale) and only one curve of relative permeability and capillary pressure was used for each facies. ***Please justify this approach***.

25. No faults or fractures are included in the model. It is stated that none are present. The subsurface structure is included in the model. ***A better description needs to be added on how bounding faults were implemented in the static model and upscaled to the simulations. Also, on page 8, Section 2.3, the last paragraph needs clarification on how the fault boundary condition was modified***.

26. In Attachment A (Section 2.3, page 8, second paragraph), it is stated that the faults are used to flex the structural model for the Injection Zones but not with discrete offsets due to the lack of sealing. ***This statement is not clear. Please clarify the meaning of this statement and add additional explanation***.

27. In Table 3.4 of Attachment B, the operational details are presented in accordance 40 CFR 146.84(c)(1)(i). Information, especially the last four lines, are critically important. ***Please cite related documentation where the last four lines of this table (modeled injection period, modeled injection duration, modeled injection rate, and modeled CO_2 injected) were gathered from***.

Operational Procedures

Many of the comments that follow pertain to Appendix 4 and apply to all wells. If the comment appears to apply to all wells, it is additionally indicated by the phrase "(Please answer for all wells)" below. If preferred, a short section at the beginning of Appendix 4 could be added to answer many of the following questions should the information be relevant for all proposed wells.

28. In the first paragraph of Section 2.2, it is stated that [redacted] and assuming a 100 percent CO_2 stream, bottom-hole and surface pressures have been estimated using results from the reservoir simulation. ***Please include the calculation details, and explain the rationale for assuming 100 percent CO_2 stream.***

29. In the second paragraph of Section 2.1, it is stated that the average bottom-hole and surface injection pressures required for the injector over the course of the project are expected to be 2,343 psi and 1,137 psi, respectively. ***What does the word "expected" mean? Are there any calculation details for these values? Please provide an explanation. (Please answer for all wells and their representative psi values)***

30. In Section 2.1.1 of Appendix 4 (second and third paragraphs), it is stated that the minimum applied annular surface pressure will be maintained at or greater than 100 psi during injection. ***Where does this value come from? Please provide an explanation***.

31. In Section 2.1.2 of Appendix 4 (second paragraph), it is stated that injection well [redacted] expects a maximum injection rate [redacted] and a maximum [redacted] (calculated at the top of perforation using a 0.8 psi/ft fracture gradient and 10 percent safety factor). ***Where are the***

calculation details? Please state the basis for the selection of the 10 percent safety factor.

32. In Section 2.1.3 of Appendix 4, it is stated that CTV will reduce CO_2 injection at a rate of [redacted] over a 6-day period to ensure protection of health, safety, and the environment. ***Where do these numbers come from? Please provide a more detailed explanation of the reduced rate, and associated drop in pressure, and how this was calculated to protect health, safety and the environment. (Please answer for all wells)***

Model Outcomes

33. A map of the pressure results (e.g., pressure front) is not provided. It is assumed that the near injector and bottom hole pressures (Figure 3.15 and Figure 3.16) are the highest pressures. ***Please add pressure contour evolution maps across the entire project area that show the lateral pressure increases through time***.

34. In Section 4.1 of Attachment B (page B-8, first paragraph), it is stated that the plume boundary is defined by a 0.01 CO_2 global mole fraction cutoff at 100 years post-injection. ***What is the basis of this defined value? Please include a citation to where this cut-off value came from***.

35. In Section 4.1 of Attachment B (page B-8, second paragraph), it states that Figure 4.1 shows that the CO_2 extent is largely defined 20 years post-injection for the different Injection Zones. ***Figure 4.1 does not include a 20-yr CO_2 plume. Please update the figure accordingly***.

36. In Section 4.1 of Attachment B (page B-8, second paragraph), it is stated that the majority of the CO_2 injectate (74 percent) remains as supercritical CO_2 at the end of the simulation, with the remaining portion of the CO_2 dissolving in the formation brine over the simulated 100 years post-injection. ***Please briefly describe how the 74 percent value was determined***.

37. In Section 4.1 of Attachment B (page B-8, second paragraph), it is stated that Figure 4.4 shows the cumulative storage for each of the mechanisms. [redacted] ***Please briefly discuss the sharp change in the curves in the text of the application***.

38. In Section 4.2 of Attachment B (Model Calibration and Validation, page B-9, first paragraph), the following statements are made:" In addition to the plume modeling, CTV performed a volumetric estimate of the storage capacity of our plume footprint using U.S. Department of Energy (DOE) methodology (Goodman et al., 2011), using

distributions from our geomodel for the storage reservoir and CO_2 properties, and storage efficiency coefficients for a deltaic sandstone reservoir using the widely applicable storage efficiency coefficients from Gorecki et al. (2009). The P50 estimate from this volumetric approach was Claimed as PBI [redacted] which is well over the estimate from our dynamic modeling, which gives us further confidence that our storage capacity estimate from the dynamic modeling is appropriate." ***Please (a) provide the details of the volumetric estimate of the storage capacity; (b) Define what P50 means; and (c) Provide the location for the dynamic model documentation***.

39. The title of Section 4.2 in Attachment B implies that the model was calibrated. ***Please present the calibrated model results and describe what is meant by calibration***.

40. The title of Section 4.2 implies that the model was validated. The AoR Review Team interprets groundwater model validation as " the process of assessing how accurately a computer model representing a groundwater system reflects real-world conditions by comparing its predicted results with independently collected field data, essentially verifying that the model is reliable for making predictions about the groundwater system under study". ***Was the model validated similar to this definition? If so, please provide the validation results. If this is not how the model was validated, please update the language in Attachment B, Section 4.2***.

41. In Section 4.2.1 of Attachment B (page B-9, second paragraph), the following statements are used: "The Injection Zones CO_2 plume for Injectate 1 and Injectate 2 is consistent with the plume outline for 100 percent CO_2 injectate (Figure 4.5), with negligible difference among the three cases. The CO_2 plume outline was defined by a 0.01 global CO_2 mole fraction cutoff at 100 years post-injection for all three cases. The 100-year post end of injection plumes for the three cases are shown in Figure 4.5. The wells that fall within the CO_2 plume are the same for all three cases." ***Please include the exact composition of injectate 1 and injectate 2 in this section of Attachment B. Perhaps the language from Section 7.2 of Attachment A could be repeated here also for completeness***.

42. CO_2 plume results were presented along with their lateral and vertical extents, however the associated pressure front results were not included. ***In alignment with comment No. 33, please include the location in the application of the associated pressure front discussion, or if it was not included, please include one***.

Model Calibration and Sensitivity Analyses

43. In Report B (p. B-10, second paragraph), the following statement is included for permeability: "There are only two cases with a plume size change greater than 10 percent compared to the base case. Case C results in a +34.7 percent plume size change, corresponding to increasing the permeability transform by a multiplier of 3, which is a high-end increase in the system permeability." ***What are the reasons for selecting the multiplier of 3 for permeability? Is it a high-end value of the measured permeabilities? Since the permeability is the most sensitive parameter, its sensitivity on the plume shape needs to be discussed further by using multipliers greater than 3***.
    a. ***The reasons of the multipliers for the rest of cases need to be discussed further in Section 4.2 of Attachment B***.
    b. For all parameters in Table 4.1 of Attachment B, ***the uncertainties, especially for permeability, need to be discussed further***.
    c. As displayed in Figure 4.7 of Attachment B, minimal difference exists in plume boundaries for most scenarios except for Case C with extreme parameters which are related to the permeability. This situation clearly emphasizes the importance of permeability and here the need to simulate higher permeability cases or provide firm justification for not doing so is reiterated.

44. Areas of high uncertainty/risk within the target formation warrant additional data collection. ***Core logs should be taken, and new measurements used to further constrain the simulated range of permeability. This can be done once site-specific boreholes are drilled. The uncertainty analysis will need to be revised using site-specific data***.

45. The sensitivity analysis of the increased and decreased porosity, permeability, residual saturation, capillary pressure, and adjusting the relative permeability shape is a start but ***more justification for the multipliers needs to be given, and higher permeability should be explored or the lack of a need for higher bounds needs to be justified***.

46. Results of sensitivity runs regarding mesh refinement are not presented in the application. No mesh analysis was performed. ***Please discuss why no mesh analysis was performed***.

47. As mentioned previously, the model grid has been refined in the project area and around the seven (7) proposed injectors. The Grid Description report as well as the report entitled "Carbon Terra Vault VI Class VI Permit Application Narrative Report"

do not present the ranges of Peclet number for grid spacings regarding numerically stable results for solute transport (e.g., Pinder and Gray, 1977, pp. 150-169; Huyakorn and Pinder, 1983, pp. 206-207). ***Please discuss Peclet number as related to CO_2 transport***.

48. The model described in Attachment B (Section 3, pp. B-1 – B-8) and Figure 3.3 of Attachment B indicate that the model uses finite-difference methods. The appropriateness of the time steps is determined with the Courant number (e.g., Huyakorn and Pinder, 1983, p. 206). No information is given regarding the appropriateness of the time steps. Therefore, evaluation could not be made. ***In alignment with comment No. 12, please present information on time steps, if available***.

Additional Items

49. Additional simulations for geostatistical variability and permeability uncertainty are requested. ***Simulations showing that the mesh is appropriate for the CO_2 transport are also needed unless previous studies of mesh resolution can be cited to show how the current mesh spacing is appropriate.***