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Proposed Work Plan
U.S. EPA Request for Additional Information
[GCS Hackberry (R06-LA-0007)] – Notice of Deficiency - Item 9

Collier Consulting, Inc. is proposing this outline of our work plan to prepare an independent study, including a cost estimate for potential groundwater remediation, at the planned Hackberry Carbon Sequestration, LLC (Hackberry) CO_2 sequestration project. This outlined work plan is specific to the U.S. EPA request for additional information for Underground Injection Control – Class VI Permit Application for Hackberry Carbon Sequestration Well.

A comprehensive understanding of the geological framework, the CO_2 storage system design, a determination of the potential storage system failure scenarios, and specific cost estimates for groundwater remediation provided in Hackberry's EPA permit application are required to complete this element of the project permitting application. Our proposed work plan outline is based on our review of a redacted copy of Hackberry's EPA permit application.

Proposed Work Plan Outline

Task 1. Review of Existing Key Project Documents
- a. Hackberry's EPA permit application
- b. Geological Publications for the Hackberry Project Area
- c. Hackberry's Principal Consultant's Itemized Remediation Cost Estimates

Task 2. Evaluate Storage System Failure Scenarios
- a. Well Casing Failure
- b. Integrity Failure of CO_2 Reservoir
- c. Predictive modeling of brine and CO_2 migration
- d. Identify potential receptors

Task 3. Develop monitoring plan

Task 4. Prepare Groundwater Remediation Plan
- a. Eliminate Source of CO_2 Leak
- b. Point Source Well Capture System
- c. CO_2 Dispersion Modeling
- d. Water Well (Point Source) CO_2 Capture

Task 5. Itemized Remediation Cost Estimate

a. Repair of CO_2 injection well
b. Installation of Point Source Well Capture System
c. CO_2 Dispersion Modeling
    i. Drill & Complete CO_2 Capture Well(s)
    ii. Groundwater Reinjection System
d. Water Well (Point Source) CO_2 Capture
    i. Well Chemical Sampling Program
    ii. Individual Wellhead CO_2 Separators

Analog Fluid Storage Groundwater Remediation Experience

The design and operation of an underground fluid storage system is based first on the concept of multiple barriers to fluid (natural gas/ CO_2) migration, and second on reservoir engineering hydraulic principles. An additional principle is that stored fluid pressures must not compromise the stability or integrity of the vessel by creating potential pathways (fractures) for fluid migration, and/or the loss of storage space due to collapse or chemical reactions.

Natural gas has been stored successfully in underground aquifers and depleted natural gas fields and solution mined salt caverns since the early 1950s, unlike CO_2. Approximately 78 new carbon sequestration projects have been announced in the United States since 2021. We do not have an actual carbon sequestration project in an aquifer/depleted gas storage medium that have been developed, then failed, and required groundwater remediated.

A small number of aquifer gas storage fields experience natural gas leakage during the early development of the fields, and more recently due to corrosion of well tubing/casings that resulted in groundwater remediation program. We believe the Herscher and Manlove Illinois natural gas storage fields are good analog storage systems to evaluate potential impacts and remediation plan that could be expected from the Hackberry CO_2 sequestration reservoir.

Natural gas leaked from the Herscher gas storage field during the initial gas injection into the storage formations. It turned out the caprock for the storage system was not adequate to contain the over pressured gas reservoir. Gas leak from Herscher gas storage through the caprock and collected in a higher permeable formation with an adequate caprock. The Herscher gas storage operation successfully captured the leak gas and reinjected it into the primary gas storage reservoir. *Note that Michael King with Hydrodynamics was a gas storage engineering that worked on the Herscher gas storage field from 1975 to 1978.*

Natural gas leaked from the Manlove gas storage field during the initial gas injection into the St. Peter formations with the gas never collecting in an upper permeable gas storage zone. A tracer gas was injected into the St. Peter to provide a tracer to identify the source of the gas. The leaked gas was detected in the shallow groundwater aquifers some 40 years later. The concentrations of the leak gas in the shallow aquifers are in the non-detect range, and had no impact of the quality of the local water supply wells.

Both the Manlove (Mahomet) and Herscher initial gas storage field leaks are described in the Illinois State Geological Survey publication:

> *Bushbach, T., Bond, D., 1967, Underground Storage of Natural Gas in Illinois-1967: Illinois State Geological Survey, Illinois Petroleum 86, pages 32-36 and pages 38-40.*

A single Manlove gas storage injection well experienced a well tubing/casing failure resulting in gas leaking into the shallow groundwater aquifer. The leaked gas impacted multiple local water supply wells. A groundwater remediation program was approved through the Illinois EPA, as described in:

Circuit Court for the Sixth Judicial District, Champaign County Illinois, Consent Order No. 17-CH-218, 6/21/2022, People of the State of Illinois vs. The Peoples Gas Light and Coke Company.

Peoples Gas Light and Coke Company submittal to the Illinois Environmental Protection Agency, Letter of July 31, 2019, Groundwater Management Zone Application for the Gas Storage Field.

Mahomet Aquifer Protection Task Force: Findings and Recommendations, Published December 21, 2018.

This program is a good analog to what may be required for the Hackberry sequestration project should groundwater remediation be required.

Key Personnel

Collier Consulting, Inc. (Collier) is a geoscience and engineering consulting firm specializing in water resources engineering and studies. We are a high-end specialty consulting firm focused on hydrogeology and subsurface characterization. Our experts include engineers, hydrogeologists, advisors, technicians, environmental specialists, as well as other design, project, and construction management professionals.

We also have an informal partnership with The Hydrodynamics Group, LLC. Hydrodynamics is a team of principal-level expert consultants experienced in the development of groundwater resources and deep geological storage projects. They specialize in the application of advanced subsurface geological characterization technology to solve complex groundwater supply and fluid/petroleum storage problems. Our Team includes:

Michael King, R.G., C.E.G., C.HG.

Michael King is a Registered Geologist and Certified Engineering Geologist and Hydrogeologist with over 47 years of experience in the field of gas storage engineering, hydrogeology and environmental engineering. Mr. King is involved in natural gas and air storage in aquifer storage structures throughout the United States and overseas. Mr. King's natural gas storage engineering experience started with the Natural Gas Pipeline Company with responsibility for gas storage operations at four natural gas fields in the Midwest. He continued his work as a natural gas storage engineer consultant for energy storage projects in the U.S.A., Republic of Georgia, and Republic of Trinidad & Tabago. He applied his gas storage expertise to the study and development of 17 CAES projects in solution mined salt caverns, depleted gas fields, aquifer structures, and mine storage systems.

King, M.J., McGill, M.J., 2009, Compressed Air Energy Storage, Encyclopedia of Energy Engineering, Taylor & Francis Group, New York, New York.

King, M.J., Moridis, G., 2022, Compressed Air Energy Storage in Aquifer and Depleted Gas Storage Reservoirs: Chapter in Handbook of Energy Storage, Wiley Press, London, UK.

George Moridis, Ph.D.

Dr. George Moridis has over 43 years of experience as a research reservoir engineer. He has had a distinguished career with Lawrence Berkeley National Laboratory, University of California at Berkeley. Dr. Moridis is a professor and holder of the Robert L. Whiting Chair of Petroleum Engineering in the Harold Vance Department of Petroleum Engineering at Texas A&M University. He is responsible for development of reservoir energy storage system performance models for CAES, natural gas, and hydrogen storage projects in solution mined salt caverns, depleted gas reservoirs, performed gas storage simulation design models for depleted gas storage fields, and is unique in having developed the latest version of the TOUGH2 modeling code. This allows the capability to modify the source code to better represent unique storage reservoir conditions.

Huang, T, Moridis, G., Blasingame, T: 2023, Feasibility Analysis of Hydrogen Storage in Depleted Natural Reservoirs Through a Multi-Phase Reservoir Simulator, Society of Petroleum Engineers SPE-212701-MS.

John Jansen, Ph.D., P.G.

Dr. John Jansen is a registered Professional Geologist with over 35 years of experience in the field of surface and borehole geophysics, and groundwater hydrogeology. His experience concentrates on the efficient development and management of groundwater resources, which includes the exploration and development, use, treatment, and protection of groundwater-based water supply systems. Dr. Jansen's specialty is the strategic identification of well sites in fractured controlled aquifers, and the testing and isolation of vertical zones of aquifers with water quality problems. His additional areas of expertise include environmental investigations, well design and well rehabilitation.

Gretchen Miller, Ph.D., P.E., P.G.

Dr. Miller is a Senior Groundwater Engineer with Collier Consulting who has been working in environmental and water resources engineering for nearly 20 years. Prior to joining Collier, she was an associate professor at Texas A&M University, where she taught fluid dynamics and groundwater engineering. She is an experienced project and program manager and has developed and led major projects involving numerical modeling of groundwater flow and transport, unsaturated zone hydrology, and managed aquifer recharge. She is well versed in multiple programs for modeling subsurface flow and transport in both the saturated and unsaturated zones (e.g., MODFLOW, PARFLOW, HYDRUS, MT3D, MIN3P). She has published 36 journal articles and book chapters and given more than 145 conference and seminar presentations. Dr. Miller is a sought-after technical reviewer; she has reviewed reports, proposals, and technical

papers for the US Environmental Protection Agency, US Department of Energy, California Department of Water Resources, California Environmental Protection Agency, and numerous academic journals. In 2015, she was recognized with an Editors' Citation for Excellence in Refereeing from the American Geophysical Union journal Water Resources Research.

Brad Cross, P.G.

Brad Cross is a Registered Professional Geologist in Louisiana and Texas and has over 40 years of experience in the fields of underground injection control, groundwater resource evaluation and management, hydrogeologic studies, environmental management, public water supply, peer review, and project management. Throughout his 15 years at the Texas Commission on Environmental Quality and contract work with the U. S. Environmental Protection Agency, Mr. Cross gained extensive experience and knowledge on the development of rules, regulations, and guidelines associated with the Underground Injection Control, Public Drinking Water, and Waste Management programs. He is considered the architect of Texas' statewide Source Water Protection Program and directed the program for years. He was responsible for developing site-specific groundwater protection strategies, development of public education strategies, and coordination of local, regional, state, and federal representatives to assure comprehensive program coordination.