APPENDIX N – PETROPHYSICAL "PLAYBOOK"

Logging Suite Discussion

Hackberry Carbon Sequestration, LLC intends to run an extensive suite of open hole logs in the stratigraphic test well to gather essential data parameters to use in the static and dynamic subsurface modeling for the Hackberry Project. Cement bond logs will also be run on each string of casing. The open hole and cased hole logging plans were generated in accordance with state regulations. The anticipated open hole and cased hole logs are detailed in Tables 1 and 2. Examples of the types of logs to be employed are outlined in the following log descriptions. The selection of the specific logging vendor will be finalized shortly to commencing well drilling operations. The ultimate choice of vendor may be influenced by commercial and supply chain considerations.

Open Hole Log Descriptions

Table 1 – Open Hole Logging Plan

CARBON SEQUESTRATION / STRATIGRAPHIC TEST WELL		
Hackberry Carbon Sequestration Well No. 001		
OPEN HOLE LOGGING PLAN		
Geophysical Logging Suite	**Logged Interval (ft)**	**Use**
Gyro Survey	Surface - 10,100'	Directional survey
Spectral Gamma Ray	Surface - 10,100'	Identification of rock properties, lithology and potassium, thorium, and uranium concentrations
Spontaneous Potential	Surface - 10,100'	Fluid identification, lithology determination and identification of permeability
Resistivity	Surface - 10,100'	Fluid identification and proportion
Bulk Density/Density Porosity	Surface - 10,100'	Rock property identification and porosity determination
Neutron Porosity	Surface - 10,100'	Rock property identification and porosity determination
Temperature	Surface - 10,100'	Geothermal gradient identification
Orientation Log	Surface - 10,100'	Orientation of wellbore, tools, sensors, and geologic formations
Sonic/Acoustic	Surface - 10,100'	Synthetic seismogram tie; identification of rock properties and geomechanics
Multi-Arm Caliper	Surface - 10,100'	Borehole/casing assessment and formation evaluation
Nuclear Magnetic Resonance	4,780' - 10,100'	Reservoir storage and deliverability; fluid content, lithology and enhanced permeability and porosity determination
Ultrasonic Borehole Imaging	4,780' - 10,100'	Geologic formation identification and wellbore integrity
Formation Lithology	4,780' - 10,100'	In-Situ minerology and lithology determination

Gyro Survey

A gyro survey is a specialized instrument used to determine the orientation of a wellbore with high precision. This log uses a gyroscope to measure the inclination (angle from vertical) and the azimuth (compass direction) of the wellbore. This logging tool assist with real time monitoring (surveying while drilling) inclination and azimuth measurements of the wellbore, post-drilling verification of wellbore trajectory, and geosteering.

Spectral Gamma Ray

The spectral gamma ray is a mineralogical characterization tool equipped with a pulsed neutron spectrometer. The tool is used in borehole logging to measure the natural gamma radiation emitted by formations surrounding a wellbore. This tool provides a detailed analysis of the gamma ray spectrum, allowing for the identification and quantification of various radioactive isotopes present in the subsurface rocks. The data obtained from a spectral gamma ray log help determine clay type and volume, lithology, stratigraphy, and mineral composition of the formations. Additionally, it helps to provide enhanced porosity determination, identify specific reservoir rock types, evaluate shale content, and assess the potential for hydrocarbon presence.

Spontaneous Potential

The spontaneous potential (SP) tool is a well logging instrument used to measure the natural electrical potential difference between a reference electrode in the borehole fluid and a surface electrode on the Earth's surface. The SP log provides information about the electrical properties of subsurface formations and fluids, aiding in the identification of different geological features. The SP log electrochemical potential difference between the borehole fluid and surrounding formation, identifies changes in formation fluid salinity, lithology changes, and formation evaluation.

Resistivity

An extended-range resistivity imaging tool is used in borehole logging to measure the electrical resistivity of formations surrounding a wellbore. The tool can provide high-resolution formation resistivity images in conductive and salt-saturated mud systems. This tool carries multiple sensors downhole to measure geologic features coupled with enhanced petrophysical reservoir evaluation. The tool also identifies structural dips, depositional environments, borehole stability, and net pay in thinly bedded sequences, reducing interpretation uncertainty and capturing detailed geological features. This imaging tool can also be used for well-to-well correlation of sedimentary and stratigraphic information.

Bulk Density/Density Porosity

A bulk density or density porosity tool is used to measure the bulk density of subsurface formations. This tool provides information about the density of the rocks in the wellbore, which can be used to calculate porosity. To convert the bulk density of the formation to porosity, the tool must first be calibrated with the matrix and fluid density. Once this is done, the tool calculates the porosity of the formation. When used in conjunction with a neutron porosity tool, a more confident porosity is determined.

Neutron Porosity

A neutron porosity tool is used to measure the porosity of subsurface formations. This tool relies on the interaction of neutrons with the formation, providing information about the volume of pore space in the rocks. The tool operates by emitting neutrons into the formation and detecting their interactions with the surrounding nuclei. Neutrons undergo elastic scattering and inelastic scattering events, with the latter generating gamma rays that are measured by detectors. The count rate of these gamma rays is used to determine the hydrogen content of the formation,

allowing for the calculation of porosity. When used with a density porosity tool, the combination of tools provides a higher confidence estimate of porosity.

Temperature

A temperature logging tool measures temperature variations along the wellbore, providing a continuous profile of temperature changes with depth. This tool helps determine the geothermal gradient, aiding in understanding the thermal characteristics of subsurface formations. Temperature logging is crucial for assessing well integrity, monitoring drilling fluid conditions, and identifying geothermal anomalies. Additionally, the tool contributes to injection and production monitoring, offering insights into fluid behavior and reservoir dynamics.

Orientation

An orientation tool is a specialized instrument used to determine the spatial orientation of a wellbore. It measures both the inclination, indicating the deviation of the wellbore from vertical, and the azimuth, representing the compass direction of the wellbore. By utilizing gravitational and magnetic sensors, the tool provides real-time data for "Surveying While Drilling" (SWD), allowing operators to monitor and adjust the wellbore trajectory. This information is crucial for directional drilling operations, optimizing wellbore paths to reach specific targets or avoid geological obstacles.

Deep Shear-Wave Sonic/Acoustic

The deep shear-wave sonic and acoustic tool is used to measure the travel time of sound waves through the subsurface formations surrounding the wellbore. The tool utilizes both monopole and dipole measurements, ensuring high-quality compressional and shear-wave measurements in low-velocity and unconsolidated formations. This tool provides valuable information about the subsurface properties of rocks, helping to determine various geological and reservoir characteristics and when used in conjunction with other tools, can contribute to the calculation of porosity and permeability of the rock.

Multi-Arm Caliper

A multi-arm caliper tool is an instrument used to measure the diameter of a wellbore. Equipped with multiple arms or fingers, the tool makes physical contact with the wellbore wall to assess its geometry. By measuring the distance between opposing arms, it provides accurate information about the wellbore diameter at various depths. This tool is essential for casing inspection, quality control during drilling operations, and visualizing data to identify irregularities in the wellbore.

Magnetic Resonance

A magnetic resonance (MR) tool is a borehole logging instrument that utilizes nuclear magnetic resonance principles to gather information about the fluid content and porosity of subsurface formations. By applying a magnetic field and radiofrequency pulses, the MR tool can measure the response of hydrogen nuclei in the formation fluids, primarily water and hydrocarbons. The MR tool helps determine fluid content within the pore space, enhanced porosity and permeability determination, and lithology.

Ultrasonic Borehole Imaging

The ultrasonic borehole imaging tool uses a rotating acoustic transducer. This tool provides detailed images of the borehole wall and surrounding formations. This tool employs ultrasonic waves to produce high-resolution images that offer valuable information about the geological and structural characteristics of the subsurface. The ultrasonic borehole imaging tool helps determine borehole wall integrity, structural features like faults and fractures, rock type, and the stratigraphy of the formation.

Formation Lithology

A formation lithology logging tool is an instrument used to identify and characterize the lithology or rock composition of subsurface formations. This logging tool employs various sensors and measurements to assess the physical and chemical properties of the rocks surrounding the wellbore. By analyzing data such as natural gamma radiation, elemental composition, and other formation responses, the tool provides insights into the types of rocks present, aiding in the determination of lithological boundaries and stratigraphic variations. Formation lithology logging is crucial for reservoir evaluation, wellbore stability assessment, and overall geological understanding in hydrocarbon exploration and production.

Cased Hole Log Descriptions

Table 2 – Cased Hole Logging Plan

CARBON SEQUESTRATION / STRATIGRAPHIC TEST WELL		
Hackberry Carbon Sequestration Well No. 001		
CASED HOLE LOGGING PLAN		
Geophysical Logging Suite	**Logged Interval (ft)**	**Use**
Cement Bond Log	Surface - 10,100'	Cement investigation
Gamma Ray	Surface - 10,100'	Identification of rock properties, lithology and potassium, thorium, and uranium concentrations
Casing Collar Locator	Surface - 10,100'	Casing investigation
Imaging Caliper	Surface - 10,100'	Borehole/casing assessment and formation evaluation
Electromagnetic Casing Inspection	Surface - 10,100'	Corrosion and Fiber Optic determination
Pulse Neutron	Surface - 10,100'	Gas movement behind pipe
Casing Wall Thickness	Surface - 4,780'	Wall thickness - through tubing

Cement Bond Log

A cement bond log (CBL) tool is equipped with sonic instruments. The tool is utilized in well logging to assess the integrity and quality of cement bonding between the casing and the wellbore wall in the well. This tool helps determine the effectiveness of the cement sheath in isolating different zones within the wellbore. The tool helps identify cement bond quality, casing failures, zonal isolation, detection of formation fluids, and wellbore integrity.

Gamma Ray

See *Spectral Gamma Ray* in *Open Hole Logging* Section.

Casing Collar Locator (CCL)

The Casing Collar Locator (CCL) tool is an instrument used to identify and locate casing collars in a wellbore. This tool operates on electromagnetic principles, emitting signals that interact with the casing. The tool detects variations in the electromagnetic response caused by the presence of thicker casing collars, allowing it to accurately pinpoint the depth and spacing of these collars. CCL logs are essential for wellbore correlation, depth determination, and provide valuable information for subsequent logging tools and operations.

Imaging Caliper

See *Multi-Arm Caliper* in *Open Hole Logging* Section.

Electromagnetic Casing Inspection

The electromagnetic casing inspection tool is an instrument used for evaluating the integrity of well casing. Operating on electromagnetic principles, the tool emits signals that interact with the casing, providing insights into the condition of the metal structure. By measuring changes in the electromagnetic response, the tool can detect potential issues such as corrosion, casing thickness variations, or the presence of anomalies. Electromagnetic casing inspection tools are essential for ensuring the structural integrity of the wellbore, preventing fluid migration, and guiding maintenance or remediation efforts when casing issues are identified.

Pulse Neutron

The pulse neutron logging tool is an instrument used in the oil and gas industry for well logging purposes. The tool operates by emitting short bursts or pulses of neutrons into the formation surrounding the wellbore. The tool measures the responses of the formation, including the interactions between the neutrons and the atomic nuclei of the subsurface materials. By analyzing these responses, the pulse neutron logging tool provides valuable information about formation porosity, lithology, and the presence of certain elements. In injection wells, the pulse neutron logging tool is used to assess the effectiveness of fluid injection and monitor the distribution of injected fluids in the subsurface. The tool helps evaluate the zonal isolation and containment of injected fluids within the target formation. By measuring the responses of the formation to pulsed neutron interactions, the tool provides information about porosity, fluid saturation, and potential fluid movement.

Casing Wall Thickness

A casing wall thickness tool is used to measure the thickness of well casing or tubing walls in a borehole. Employing electromagnetic or ultrasonic principles, the tool assesses the structural integrity of the casing, identifying potential issues such as corrosion, erosion, or thinning. By providing accurate thickness measurements, it helps ensure zonal isolation, prevent fluid migration, and maintain the stability of the wellbore. Regular use of casing wall thickness logging tools is a critical aspect of well integrity management and contributes to the safety and reliability of oil and gas wells.