

**PRE-OPERATIONAL TESTING PLAN**  
**40 CFR 146.82(a)(8), 146.87**  
**AAC 400-8-1.15(2)(d)(vi), 400-8-1-.32**  
**PINE HILLS ALABAMA REGIONAL CO<sub>2</sub> STORAGE HUB**

Prepared for

Reliant Southwest Alabama Storage, LLC



By

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**List of Abbreviations and Acronyms**

°C	degrees Celsius
°F	Degrees Fahrenheit
<sup>13</sup> C	Carbon Isotope 13
<sup>18</sup> O	Oxygen Isotope 18
<sup>2</sup> H	Hydrogen Isotope Two (deuterium)
40 CFR	Title 40 of the Code of Federal Regulations
AAC	Alabama Administrative Code
AL	Alabama
AOGB	Alabama Oil and Gas Board
AoR	Area of Review
Ar	Argon
ASTM	American Society for Testing and Materials
CALI	Caliper
CBL	Cement Bond Log
CH <sub>4</sub>	Methane
CO	Carbon Monoxide
CO <sub>2</sub>	Carbon Dioxide
Cr	Chrome
DAS	Distributed Acoustic Sensing
DIC	Dissolved Inorganic Carbon
DTS	Distributed Temperature Sensing
ECS	Elemental Capture Spectroscopy
EPA	Environmental Protection Agency
ft	feet
GR	Gamma Ray
GS	Geologic Sequestration
H <sub>2</sub>	Hydrogen
H <sub>2</sub> O	Water
H <sub>2</sub> S	Hydrogen Sulfide
He	Helium
ICP-AES	Inductively Coupled Plasma – Atomic Emission
ICP-MS	Inductively Coupled Plasma – Mass Spectrometry
ICP-OES	Inductively Coupled Plasma – Optical Emission
Kr	Krypton
MDT	Modular Formation Dynamics Tester
MIT	Mechanical Integrity Test
MMSCF	Million Standard Cubic Feet
mol	mole
n.d.	no date
N <sub>2</sub>	Nitrogen
Ne	Neon
NMR	Nuclear Magnetic Resonance
NOx	Total Nitrogen Oxides

NPHI	Neutron Porosity
O <sub>2</sub>	Oxygen
PEF	Photoelectric Factor
pH	potential of Hydrogen
PHSH	Pine Hills Sequestration Hub
PNC	Pulsed Neutron Capture
ppm	parts per million
psi	pounds per square inch
RBIL	Resistivity Borehole Image Log
RDT	Reservoir Description Tool
Reliant	Reliant Southwest Alabama Storage, LLC
RES	Resistivity
RHOB	Bulk Density
Rn	Radon
SM	Standard Methods
SP	Spontaneous Potential
TDS	Total Dissolved Solids
TMS	Tuscaloosa Marine Shale
U.S.	United States
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
USIT	Ultrasonic Imaging Tool
UV	Ultraviolet
VSP	Vertical Seismic Profile
WFT	Wireline Formation Tester
Xe	Xenon

## 5. PRE-OPERATIONAL TESTING PLAN

### 5.1. EXECUTIVE SUMMARY

This **Pre-Operational Testing Plan** describes how Reliant Southwest Alabama Storage, LLC (Reliant) will characterize each carbon dioxide (CO<sub>2</sub>) injection well and all relevant geologic formations at the Pine Hills Sequestration Hub (PHSH) site prior to injection operations under Title 40 of the Code of Federal Regulations (40 CFR) 146.87 and Alabama Administrative Code (AAC) 400-8-1-.32. Pre-injection testing will produce datasets that will be used to inform proper well construction and determine/verify the depth, thickness, porosity, permeability, mineralogy, geomechanical, and geochemical profiles of formations of interest. This **Pre-Operational Testing Plan** is organized into two sections: (1) **Pre-Operational Formation Testing Program** and (2) **Baseline Testing and Monitoring Plan**.

The **Pre-Operational Formation Testing Program**, required by 40 CFR 146.82(a)(8) and AAC 400-8-1-.15(2)(vi), describes the activities that will be performed in PHSB injection wells during drilling, construction, and completion operations to comply with the injection well construction requirements under 40 CFR 146.86 and AAC 400-8-1-.30 and the pre-operational testing requirements under 40 CFR 146.87 and AAC 400-8-1-.32. The program is designed to ensure proper well construction and to obtain data that will be used to analyze the chemical and physical characteristics of the geologic sequestration **Claimed as PBI**

**Claimed as PBI**. The **Pre-Operational Formation Testing Program** includes:

- Deviation checks (40 CFR 146.87(a)(1) and AAC 400-8-1-.32(1)(a));
- Open- and cased-hole well logging (40 CFR 146.87(a)(2), (a)(3) and AAC 400-8-1-.32(1)(b) and (1)(c));
- Mechanical integrity testing (40 CFR 146.87(a)(4) and AAC 400-8-1-.32(1)(d));
- Rock coring (40 CFR 146.87(b) and AAC 400-8-1-.32(2));
- Fluid sampling (40 CFR 146.87(b), (c), (d)(3) and AAC 400-8-1-.32(2), (3), and (4)(c));
- Formation and fracture pressure testing (40 CFR 146.87(c), (d) and AAC 400-8-1-.32(3) and (4)); and
- Hydrogeologic testing (40 CFR 146.87(e) and AAC 400-8-1-.32(5)).

The **Baseline Testing and Monitoring Plan** describes the activities to be performed in the CO<sub>2</sub> injection wells, monitoring wells, and on the surface of the PHSB site prior to injection operations according to 40 CFR 146.82, 146.87, 146.90, and AAC 400-8-1-.15, 400-8-1-.32, and 400-8-1-.34. Testing and monitoring prior to injection operations will provide baseline profiles of parameters that will be used to inform subsequent injection and post-injection phase testing and monitoring activities. Baseline testing and monitoring will include:

- Mechanical integrity testing;
- CO<sub>2</sub> stream analysis;
- Corrosion monitoring;
- Pressure fall-off testing;
- Groundwater quality and geochemical monitoring;

- Geophysical imaging and characterization; and
- Pressure monitoring.

Reliant will provide the United States (U.S.) Environmental Protection Agency (EPA) Region 4 Underground Injection Control (UIC) Program Director and the state of Alabama Oil and Gas Board (AOGB) Supervisor the opportunity to witness all injection well logging and testing, along with a schedule of the activities 30 days before commencing the first test. The UIC Program Director will be promptly notified of any updates to the testing and logging schedule upon further project development. The results of proposed testing activities discussed throughout this plan will be summarized in a report and submitted to the UIC Program Director; note that “UIC Program Director” is used throughout this document when referring to the Region 4 UIC Director and the AOGB Supervisor.

## 5.2. PRE-OPERATIONAL FORMATION TESTING PROGRAM

### 5.2.1. Overview

The **Pre-Operational Formation Testing Program**, required by 40 CFR 146.82(a)(8) and AAC 400-8-1-.15(2)(vi), describes the logging, sampling, and testing activities to be performed in the CO<sub>2</sub> injection wells prior to their operation. **Claimed as PBI**



Logging, sampling, and testing prior to injection operations will generate datasets that will be used to characterize the chemical and physical characteristics of the storage reservoirs and confining zone in compliance with 40 CFR 146.87 and AAC 400-8-1-.32. Additionally, the pre-injection testing activities performed during the drilling, construction, and completion of each CO<sub>2</sub> injection well will ensure compliance with the injection well construction requirements under 40 CFR 146.86 and AAC 400-8-1-.30; for detailed information on well construction, refer to the **Injection Well Construction Plan**. Refer to the following subsections for additional information on the logging, sampling, and testing activities to be performed within the PSHH injection wells prior to their operation.

### 5.2.2. Deviation Checks

Deviation checks, pursuant to 40 CFR 146.87(a)(1) and AAC 400-8-1-.32(1)(a), will be performed approximately every 150-300 feet (ft) during injection well construction to ensure vertical conduits for fluid movement, such as diverging holes, are not created while drilling. The frequency of deviation checks will be increased or decreased as needed based on drilling responses.

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### 5.2.3. Well Logging

Required by 40 CFR 146.87(a)(2), (a)(3), and AAC 400-8-1-.32(1)(b) and (1)(c), various open- and cased-hole well logs will be run throughout each injection well. Open-hole well logs will be run to obtain *in-situ* physical, chemical, geomechanical, and other relevant geologic information from the storage reservoirs, confining zone, and other formations of interest above the confining zone. Cased-hole well logs will be run to obtain data that will be used to evaluate injection well construction and critical baseline profiles of geologic units for future comparison.

Open-hole well logging will be performed throughout the surface and long string holes before setting each section's casing to collect data that will be used to characterize the subsurface. Meeting 40 CFR 146.87(a)(2)(i) and AAC 400-8-1-.32(1)(b)(i), caliper, spontaneous potential, and resistivity logs will be run throughout the surface hole before casing installation along with other basic wireline logging tools, if necessary, such as gamma ray and quad combo (bulk density, neutron porosity, resistivity, and acoustic logs). Basic wireline tools, including those required by 40 CFR 146.87(a)(3)(i) and AAC 400-8-1-.32(1)(c)(i) (resistivity, spontaneous potential, porosity, caliper, gamma ray, and fracture finder logs), will be run throughout the long string hole before casing installation. Additionally, advanced tools (e.g., dipole acoustic, resistivity borehole image log, nuclear magnetic resonance, elemental capture spectroscopy) may be deployed throughout select intervals within the first and deepest injection well drilled on each well pad (i.e., wells designated with a #1). The selected advanced logs will cover all four injection zones (Pilot Sand, Massive Sand, Lower Cretaceous A, and Lower Cretaceous B) and the overlying confining zone (TMS).

Cased-hole well logging will be performed throughout the surface and long string holes to evaluate injection well construction and to obtain baseline profiles of geologic units that will inform future testing and monitoring activities. Meeting 40 CFR 146.87(a)(2)(ii), (a)(3)(ii), and AAC 400-8-1-.32(1)(b)(ii) and (1)(c)(ii), cement bond, variable density, and temperature logs will be run throughout each well section upon casing installation. Additionally, advanced tools such as pulsed neutron capture (PNC) logs, fiber-optic cables with distributed temperature sensing (DTS) and distributed acoustic sensing (DAS) capabilities, may be deployed throughout each injection wellbore during and upon casing installation to collect baseline subsurface profiles.

Refer to the subsequent bullet points and/or **Table 5-2** for a summary of the open- and cased-hole well logging activities to be performed within PHS injection wells.

#### *Open-Hole Tools*

- **Caliper (CALI)** – A tool that provides information on the shape, volume, and roughness (rugosity) of the borehole. CALI logs can also be used to check the quality of the geophysical log data obtained (e.g., CALI logs indicate zones of washout where logging data may be erroneous and need correction). The CALI log will be utilized to estimate wellbore volumes and well log data quality.
- **Spontaneous Potential (SP)** – A tool that measures the natural electrical potential generated from variations in salinity between the wellbore and formation fluids. SP data will be used for subsurface correlations, salinity calculations, and to identify intervals of higher permeability relative to one another.

- **Gamma Ray (GR)** – A tool that measures the natural radioactivity of a geologic formation. GR log data will be used for subsurface correlations, depth shifting and matching of other test data, and to approximate clay and/or shale volumes.
- **Bulk Density (RHOB)** – A tool that indirectly approximates the bulk density of a geologic formation. Bulk density data will be used in conjunction with other logging measurements to identify lithology and estimate the porosity (e.g., total and effective) of geologic formations.
- **Neutron Porosity (NPHI)** – A tool that indirectly approximates porosity by measuring the hydrogen content (e.g., hydrogen within water and hydrocarbons) within a geologic formation. Neutron porosity data will be used in conjunction with other logging measurements to identify lithology and estimate the porosity (e.g., total and effective) of geologic formations.
- **Photoelectric Factor (PEF)** – A tool that measures photoelectric absorption of low-energy gamma rays by a geologic formation. Because photoelectric absorption varies between elements, data obtained by the tool yields information regarding basic lithology. PEF data will be used to determine the mineralogy and lithology of geologic formations.
- **Resistivity (RES)** – A tool that measures the electrical resistance of a geologic formation (i.e., how easily current travels through the rock). RES data will be used to estimate and confirm salinity, fluid saturation, and porosity.
- **Acoustic (Monopole and Dipole)** – A tool that measures the travel time of energy waves (i.e., compressional and shear) through geologic formations. Monopole acoustic logs measure the compressional wave travel time, whereas dipole acoustic logs measure both compressional and shear wave travel times. Monopole acoustic logs will be used to characterize porosity and lithology and to generate synthetic seismograms for seismic well ties. Dipole acoustic logs will be used for geomechanical characterization (e.g., fracture and stress characterization).
- **Resistivity Borehole Image Log (RBIL)** – A tool that measures electrical resistivity radially throughout the wellbore. Measurements from this tool are processed into images of the open wellbore that are colored by contrasting resistivity values. RBIL data will be used to identify any geologic bedding planes and associated contacts, natural and induced fractures (e.g., open, healed, induced), shows of porosity, and rock textures (e.g., sedimentary structures).
- **Nuclear Magnetic Resonance (NMR)** – A tool that stimulates protons (i.e., causes hydrogen nuclei to spin) and measures their resulting magnetic signals; these signals can be processed to resolve information related to rock porosity and permeability, pore-body size, and fluid saturations independent of the rock matrix. NMR data will be used to aid in calculating petrophysical properties (e.g., porosity, permeability, saturation) of the storage complex.

- **Elemental Capture Spectroscopy (ECS)** – A tool that estimates the elemental concentration of a geologic formation. The tool uses neutron bombardment, which results in atomic nuclei releasing characteristic gamma rays that can be captured and processed to determine the geochemical makeup of a geologic formation. ECS data, if collected, will be used to estimate petrophysical properties, fluid saturations, and volumetric proportions of minerals.
- **Wireline Formation Tester (WFT)** – A tool that can be deployed to test various properties of a geologic formation. WFTs, such as the modular formation dynamics tester (MDT), reservoir description tool (RDT), or an equivalent tool, will be utilized to collect deep reservoir fluid samples, *in-situ* formation pressure measurements, and fracture pressure measurements.

#### *Cased-Hole Tools*

- **Cement Bond Log (CBL)** – A tool that uses acoustic waves to measure the integrity of a well's cement job. Acoustic transmitters and receivers measure signal attenuation to provide information on how well the casing and cement are bonded. CBLs give an indication of cement-to-formation bond in the form of a variable-density log, which will be used to interpret the integrity of the well's cement job.
- **Ultrasonic Imaging Tool (USIT)** – A tool that measures acoustic impedance within cement, which can be used to estimate well integrity and zonal isolation. USIT data, if collected, will be utilized to create maps of casing and cement integrity; identify solid (i.e., cement), liquid, or gas between the casing and formation; and identify corrosion or other damage to the casing.
- **Temperature Log** – A tool that measures temperature throughout a wellbore. Temperature logs will be utilized to collect a baseline temperature profile that supports wellbore integrity and to identify the top of the cement after cementing operations. Temperature log data may also be used to demonstrate external mechanical integrity, if necessary.
- **Pulsed Neutron Capture (PNC)** – A tool that uses neutron bombardment to measure the energy and capture of neutrons. PNC logs allow for the identification of mineralogy, lithology, fluid content, and saturations through the well's casing. PNC data will be used to estimate brine, hydrocarbon, and CO<sub>2</sub> saturations. PNC data may also be used to demonstrate external mechanical integrity, if necessary.
- **Distributed Temperature Sensing (DTS) Fiber-Optic** – DTS fiber-optic cables, which will be permanently installed on the long string casing, and their interrogators record a temperature log/profile along the wellbore in which they are deployed. DTS measurements can be used to identify temperature anomalies associated with leaks in casing or fluid movement along the wellbore to assess wellbore integrity and to identify zones taking fluid. Initial DTS measurements will establish a baseline, and subsequent analysis will be used as the primary method for demonstrating external mechanical integrity for injection wells.

- Distributed Acoustic Sensing (DAS) Fiber-Optic** – DAS fiber-optic cables, which will be permanently installed on the long string casing, and their interrogators are used to send pulses of light throughout the wellbore, which are Rayleigh-scattered. The backscattered energy provides information on strain (i.e., acoustic vibrations) throughout the subsurface, which can be used to generate a vertical seismic profile (VSP) along the wellbore in which the DAS fiber-optic is deployed. If feasibility studies show DAS as a viable option, a baseline VSP will be acquired prior to injection, and subsequent DAS VSPs will be used to image the subsurface and track the CO<sub>2</sub> plume across the PHSB site in the early phases of the project.

**Table 5-2. Summary of the pre-injection open- and cased-hole well logging activities for Pine Hills Sequestration Hub injection wells.**

Zone	Logging Activity	Purpose/Additional Comment
<i>Open-Hole</i>		
Surface Hole	<i>Basic wireline logs: caliper<sup>[A]</sup>, spontaneous potential<sup>[A]</sup>, resistivity<sup>[A]</sup>, gamma ray<sup>[B]</sup>, bulk density<sup>[B]</sup>, neutron porosity<sup>[B]</sup>, photoelectric factor<sup>[B]</sup></i>	Characterize geology and determine formation tops  Obtain baseline characteristic data from shallow formations
	Acoustic monopole <sup>[B]</sup>	Seismic well tie  Acoustic porosity
Long String Hole	<i>Basic wireline logs: caliper<sup>[A]</sup>, spontaneous potential<sup>[A]</sup>, resistivity<sup>[A]</sup>, gamma ray<sup>[A]</sup>, bulk density<sup>[B]</sup>, neutron and/or density porosity<sup>[A]</sup>, photoelectric factor<sup>[B]</sup></i>	Characterize geology and determine formation tops  Formation evaluation
	Acoustic dipole <sup>[B]</sup>	Seismic well tie  Acoustic porosity  Geomechanical analysis  Fracture characterization
	Resistivity borehole image log <sup>[A]</sup>	Fracture characterization  Sedimentological and geological interpretation
	Nuclear magnetic resonance <sup>[B]</sup>	Formation evaluation
	Elemental capture spectroscopy <sup>[B]</sup>	Mineral model  Formation evaluation
	Wireline formation tester <sup>[A]</sup>	Collection of fluid samples, <i>in-situ</i> formation pressures, and fracture pressure information

Zone	Logging Activity	Purpose/Additional Comment
<i>Cased-Hole</i>		
Surface Hole	Cement bond log <sup>[A]</sup>	Cement and wellbore integrity
	Temperature log <sup>[A]</sup>	
Long String Hole	Cement bond log <sup>[A]</sup>	Cement and wellbore integrity
	Ultrasonic imaging tool <sup>[B]</sup>	
	Temperature log <sup>[A]</sup>	
	Pulsed neutron capture log <sup>[B]</sup>	Baseline fluid content and saturations
	Distributed temperature sensing fiber-optic <sup>[B]</sup>	Baseline temperature profile and external mechanical integrity demonstration
	Distributed acoustic sensing fiber-optic <sup>[B]</sup>	Baseline vertical seismic profile, if included in the testing and monitoring program

<sup>[A]</sup>Logs or tests required by 40 CFR 146.87(a) through (d) and AAC 400-8-1-.32(1)(a) through (1)(4).

<sup>[B]</sup>Additional logs and/or fiber-optic that may be run throughout select intervals and wells.

#### 5.2.4. Mechanical Integrity Testing

Mechanical integrity testing will be performed in all injection wells throughout the lifespan of the PHSB project. A well has mechanical integrity if:

- There is no significant leak in the casing, tubing, or packer (40 CFR 146.89(a)(1) and AAC 400-8-1-.31(1)(a)); and
- There is no significant fluid movement into an underground source of drinking water (USDW) through channels adjacent to the injection well bore (40 CFR 146.89(a)(2) and AAC 400-8-1-.31(1)(b)).

Various tools and tests will be utilized to ensure each injection well has internal and external mechanical integrity prior to its operation. During injection well drilling and after casing is set and cemented, a casing pressure test along with cement bond and temperature logging will be performed to verify the cement job and general well integrity under 40 CFR 146.87(a)(2)(ii), (a)(3)(ii), and AAC 400-8-1-.32(1)(b)(ii) and (1)(c)(ii). Upon injection well completion and prior to operation, internal and external mechanical integrity, pursuant to 40 CFR 146.87(a)(4) and AAC 400-8-1-.32(1)(d), will be demonstrated with a standard annulus pressure test and DTS fiber-optic measurements, respectively. Refer to **Table 5-3** for a summary of the mechanical integrity tests (MIT) to be performed in all injection wells prior to injection operations.

**Table 5-3. Summary of the pre-injection mechanical integrity tests to be performed on Pine Hills Sequestration Hub injection wells.**

Mechanical Integrity Test Type	Testing Method	Location	Frequency
General Well Integrity	Casing pressure test	Each casing section (surface and long string)	Once after casing installation and prior to drilling the next wellbore section
Internal	Annulus pressure test <sup>[A]</sup>	Long string/tubing-annulus	Once after well completion, prior to injection operations
General Well Integrity	Cement bond log	Each casing section (surface and long string)	Once after casing installation
External and General Well Integrity	Temperature log	Each casing section (surface and long string)	Once after casing installation
External	Distributed temperature sensing fiber-optic measurements <sup>[B]</sup>	Long string	Once after well completion, prior to injection operations

<sup>[A]</sup>Testing method to demonstrate internal mechanical integrity prior to injection pursuant to 40 CFR 146.87(a)(4)(i) and AAC 400-8-1-.32(1)(d)(i).

<sup>[B]</sup>Testing method to demonstrate external mechanical integrity prior to injection pursuant to 40 CFR 146.87(a)(4)(iii) and AAC 400-8-1-.32(1)(d)(iii).

#### 5.2.4.1. Internal Mechanical Integrity

Prior to injection operations, internal mechanical integrity will be demonstrated in all injection wells with a standard annulus pressure test pursuant to 40 CFR 146.87(a)(4)(i) and AAC 400-8-1-.30(14)(a) and 400-8-1-.32(1)(d)(i). Required by AAC 400-8-1-.30(14)(a), the initial annulus pressure test will include pressurizing the tubing-casing annulus to a specified level for a testing period of 30 minutes. The annulus and tubing pressures will then be monitored and recorded periodically throughout the test period. Once the test period ends, a final pressure will be recorded to identify any significant pressure changes. If the pressure remains within 10% of the initial starting test pressure, the well demonstrates internal mechanical integrity.

A description of the annulus pressure test to be performed and the opportunity to witness the test will be provided to EPA Region 4 and the AOGB at least 30 days in advance of the internal mechanical integrity demonstration in compliance with 40 CFR 146.87(f) and AAC 400-8-1-.32(6). The results of each initial annulus pressure test will be reported to the UIC Program Director within 30 days of testing according to 40 CFR 146.91(b)(1) and AAC 400-8-1-.45(8)(a). Following the initial annulus pressure test, injection pressure, rate, and volume, along with annulus pressure and its fluid volume, will be continuously monitored throughout the injection phase to demonstrate internal mechanical integrity in accordance with 40 CFR 146.89(b) and AAC 400-8-1-.31(2). For additional information on internal mechanical integrity throughout the injection phase, refer to section **7.3.2 Internal Mechanical Integrity** of the **Testing and Monitoring Plan**.

#### 5.2.4.2. External Mechanical Integrity

Prior to injection operations, external mechanical integrity will be demonstrated through the interpretation and reporting of temperature data, pursuant to 40 CFR 146.87(a)(4)(iii) and AAC 400-8-1-.32(1)(d)(iii), collected via DTS fiber-optic. DTS fiber-optic cables permanently deployed on the long string casing of each injection well will record a temperature log/profile throughout the wellbore, which can be used to detect temperature anomalies resulting from leaking fluids. DTS fiber-optic cables provide various advantages over standard wireline temperature logging, such as reliability in hostile environments and high spatial, time, and temperature resolution (Buecker & Grosswig, 2017) based on the system's configuration. While DTS fiber-optic cables and their interrogators can record temperature continuously, official external mechanical integrity tests will involve shutting in the injection well for a sufficient period of time to allow temperature to change toward static geothermal conditions (U.S. EPA, 2013). DTS measurements will then be analyzed for temperature anomalies indicative of leaks in casing and fluid movement along the wellbore. Baseline DTS measurements will be used to define specific threshold values that are to be classified as temperature anomalies and leaks in and around the wellbore. Prior to injection, DTS systems will be calibrated with the geothermal gradient, and calibration checks will be performed with the downhole pressure/temperature gauges throughout the project to ensure the collection of accurate and precise temperature measurements.

A description of the test to be performed and the opportunity to witness the test will be provided to EPA Region 4 and the AOGB at least 30 days in advance of the external mechanical integrity test per 40 CFR 146.87(f) and AAC 400-8-1-.32(6). The results of baseline external mechanical integrity tests will be reported to the UIC Program Director within 30 days of testing pursuant to 40 CFR 146.91(b)(1) and AAC 400-8-1-.45(8)(a). For additional information on external mechanical integrity testing, refer to section **7.3.3 External Mechanical Integrity** of the **Testing and Monitoring Plan**.

#### 5.2.5. Rock Coring

To meet the requirements of 40 CFR 146.87(b) and AAC 400-8-1-.32(2), rock cores (i.e., whole and/or sidewall) will be collected from the first and deepest CO<sub>2</sub> injection well drilled on each well pad (i.e., injection wells designated with a #1). Approximately 30-90 feet of core will be collected from each zone of interest (i.e., TMS confining zone and the Pilot Sand, Massive Sand, Lower Cretaceous A, and Lower Cretaceous B storage reservoirs) in each well that is to be cored.

Analytical tests planned to be performed on cores collected from the injection wells will include routine core analysis (i.e., porosity, permeability, grain density, lithology, fluid saturation, and fluorescence), geologic and mineralogic analysis (i.e., core/thin section descriptions and x-ray diffraction), and special core analysis (i.e., geomechanics and capillary pressure testing, specifically meeting the requirements under 40 CFR 146.82(a)(3) and AAC 400-8-1-.15(2)(d)(ii), relative permeability, threshold entry pressure, and geochemical compatibility testing).

Refer to **Table 5-4** for a summary of the whole core acquisition plan and **Table 5-5** for a summary of the whole core testing and analysis plan. For additional information on sidewall core, which may be used to supplement the whole core collection, refer to **Table 5-6**.

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## 5.2.6. Fluid Sampling

Pursuant to 40 CFR 146.87(b), (c), (d)(3), and AAC 400-8-1-.32(2), (3), and (4)(c), fluid samples from the [redacted] will be collected prior to injection operations during either construction or completion operations of each injection well. Fluid samples will either be collected in open-hole conditions via a wireline formation tester or during completion operations via a slickline sampling tool or swabbing the well. Any fluids introduced into the wellbore environment throughout the drilling, conditioning, cementing, or testing process will be removed before fluid sampling to ensure representative samples of the subsurface system are collected. Storage reservoir fluid samples will be collected, stored, and transported to an appropriate analytical laboratory as discussed in the **Quality Assurance and Surveillance Plan (QASP)**. Refer to **Table 5-12** for the preliminary parameters and analytical methods proposed for fluid samples collected at PHS.

## 5.2.7. Formation and Fracture Pressure Testing

In accordance with 40 CFR 146.87(c), (d), and AAC 400-8-1-.32(3) and (4), **Claimed as PBI** [redacted] Wireline formation testers, such as an MDT, RDT, or an equivalent tool, will be utilized in the first and deepest CO<sub>2</sub> injection well drilled on each of the nine well pads to measure *in-situ* formation pressure and to perform wireline stress tests within each formation of interest. Wireline stress testing involves a tool string with a packer arrangement, pump, and pressure gauges that locally press up against and isolate a several-foot interval along the wellbore. The selected interval is then pressurized to obtain data that can be used to determine each formation's fracture pressure to meet the requirements of 40 CFR 146.87(d)(1) and AAC 400-8-1-.32(4)(a). Depending on the condition of the borehole, a step-rate test, which can be used to determine fracture pressure over a larger interval, may be performed in place of the wireline-based test and/or to supplement wireline-based test results. Fracture pressure measurements from the first and deepest CO<sub>2</sub> injection well drilled on each well pad will be used to verify, calibrate, and supplement well log-based (e.g., acoustic logging) or core analysis-based estimates of fracture pressure made in subsequent wells drilled and from core collected, respectively. Refer to **Table 5-7** for a summary of the pre-injection formation and fracture pressure testing activities.

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## **5.2.8. Hydrogeologic Testing**

Upon well completion and prior to injection operations, pressure fall-off testing will be performed in each CO<sub>2</sub> injection well to verify the hydrogeologic characteristics of **Claimed as PBI** meeting 40 CFR 146.87(e) and AAC 400-8-1-.32(5). Pressure fall-off tests are designed to measure formation properties, such as transmissivity, in the vicinity of the injection wellbore to verify injectivity and to identify flow boundaries or other changes in the near-wellbore environment that could impact injectivity. Refer to **Table 5-8** for a summary of the hydrogeologic testing activities to be performed in each CO<sub>2</sub> injection well prior to injection operations.

Best practices for pressure fall-off testing will be followed, such as those discussed in U.S. EPA (2002) or equivalent guidance. The pressure fall-off tests performed will include a period of injection followed by a period of no injection or shut-in. Prior to the shut-in period of the fall-off test, a constant injection rate will be maintained for a suitable amount of time (commonly one hour), which ideally results in a stable pressure response. Following the injection period, the well being tested will be shut in at the wellhead to reduce wellbore storage effects. The shut-in period of the fall-off test will last long enough for adequate pressure transient data to be collected and to calculate the average pressure. The shut-in period will be approximately three to five times the length of the buildup period (U.S. EPA, 2013).

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## 5.3. BASELINE TESTING AND MONITORING PLAN

### 5.3.1. Overview

Prior to injection operations, various testing and monitoring activities will be performed within each CO<sub>2</sub> injection well, monitoring well, and on the surface of the PHS site to meet 40 CFR 146.82, 146.87, 146.90, and AAC 400-8-1-.15, 400-8-1-.32, and 400-8-1-.34. Baseline testing and monitoring will include the following activities, as applicable:

- Mechanical integrity testing;
- CO<sub>2</sub> stream analysis;
- Corrosion monitoring;
- Pressure fall-off testing;
- Groundwater quality and geochemical monitoring; and
- CO<sub>2</sub> plume and pressure front tracking.

Baseline data collected prior to injection will inform subsequent injection and post-injection phase testing and monitoring activities to help identify any changes in wellbore integrity, composition of the injectate stream, potential corrosion of well components, properties of the storage complex, properties of the above confining zone monitoring formations, and CO<sub>2</sub> plume/pressure front migration. Refer to **Table 5-9** for a summary of all baseline testing and monitoring methods, locations, and frequencies, and **Figure 5-1** for a map view of the PHS site displaying the location of all injection and monitoring wells relative to project elements. For detailed information on testing and monitoring activities and their equipment, refer to the **Testing and Monitoring Plan** and its **Quality Assurance and Surveillance Plan**.

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### **5.3.2. Mechanical Integrity Testing**

Pursuant to 40 CFR 146.87(a)(4) and AAC 400-8-1-.32(1)(d), internal and external mechanical integrity will be demonstrated in all CO<sub>2</sub> injection wells prior to injection operations. Mechanical integrity testing (i.e., internal and external) is a key component of the baseline testing and monitoring program that will ensure each injection well is constructed such that there is no endangerment of USDWs from leakage or unpermitted fluid movement in and around the wellbore.

Prior to injection, internal mechanical integrity will be demonstrated with a standard annulus pressure test, pursuant to 40 CFR 146.87(a)(4)(i) and AAC 400-8-1-.32(1)(d)(i). For additional information on the initial annulus pressure test, refer to section **5.2.4.1. Internal Mechanical Integrity**. Once the initial pressure test is performed in each CO<sub>2</sub> injection well, internal mechanical integrity will be continuously monitored throughout the injection phase as described in sections **7.3.2. Internal Mechanical Integrity** and **7.4.3. Continuous Monitoring of Annulus Pressure and Fluid Volume of the Testing and Monitoring Plan**.

External mechanical integrity, prior to injection, will be demonstrated in all CO<sub>2</sub> injection wells through the analysis of DTS fiber-optic measurements to meet the requirements of 40 CFR 146.87(a)(4)(iii) and AAC 400-8-1-.32(1)(d)(iii). The baseline temperature log/profile collected for the initial external MIT will be used to define threshold values for temperature anomalies indicative of leaks in casing and fluid movement along the injection wellbore and will inform subsequent injection and post-injection phase external MITs. For additional information on DTS measurements and external mechanical integrity testing, refer to section **5.2.4.2. External Mechanical Integrity** of this plan and section **7.3.3 External Mechanical Integrity of the Testing and Monitoring Plan**.

### **5.3.3. Carbon Dioxide Stream Analysis**

Prior to injection operations, an analysis of the CO<sub>2</sub> injectate stream will be provided to the UIC Program Director pursuant to 40 CFR 146.82(a)(7)(iv). Understanding the chemical and physical characteristics of the CO<sub>2</sub> stream prior to injection operations is a key component of the baseline testing and monitoring program, as it will provide the chemical and physical profiles for which the injectate stream will be monitored at the surface throughout the injection phase. The chemical and physical characteristics of the CO<sub>2</sub> stream will be used to understand potential reactions with formation solids, fluids, and well components (e.g., casing, tubing, packer).

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For a summary of the expected physical and chemical characteristics of the CO<sub>2</sub> stream to be injected at the PHS site, refer to **Table 5-10. Section 7.4.1 Carbon Dioxide Stream Analysis of the Testing and Monitoring Plan** provides additional information on the proposed CO<sub>2</sub> injectate stream and its respective testing and monitoring strategy.

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#### **5.3.4. Corrosion Monitoring**

Throughout the injection phase, well components that are to be in contact with the CO<sub>2</sub> injectate stream will be monitored for loss of mass, thickness, cracking, pitting, and any other signs of corrosion pursuant to 40 CFR 146.90(c) and AAC 400-8-1-.34(1)(c). Corrosion coupons of materials used in the construction of CO<sub>2</sub> injection wells that are to be exposed to CO<sub>2</sub> will be sampled and analyzed (**Table 5-11**). Prior to injection operations and initial CO<sub>2</sub> exposure, corrosion coupons will be photographed, visually inspected, dimensionally measured, and weighed for baseline measurements. Coupons will then be sampled and evaluated throughout the injection phase to ensure well components meet the minimum standards for material strength and performance in accordance with 40 CFR 146.86(b) and AAC 400-8-1-.30. For additional information on corrosion monitoring, refer to section **7.4.4 Corrosion Monitoring** of the **Testing and Monitoring Plan**.

**Table 5-11. Summary of the well components to be monitored for corrosion prior to injection at Pine Hills Sequestration Hub.**

Equipment Coupon	Material of Construction	Location	Frequency
Long String Casing	22 Chrome (22Cr)	After baseline measurements, coupons will be placed immediately upstream of each CO <sub>2</sub> injection well on the well pad	Once prior to injection
Injection Tubing	22 Chrome (22Cr)		
Wellhead	Inconel 718		
Packer	22 Chrome (22Cr)		

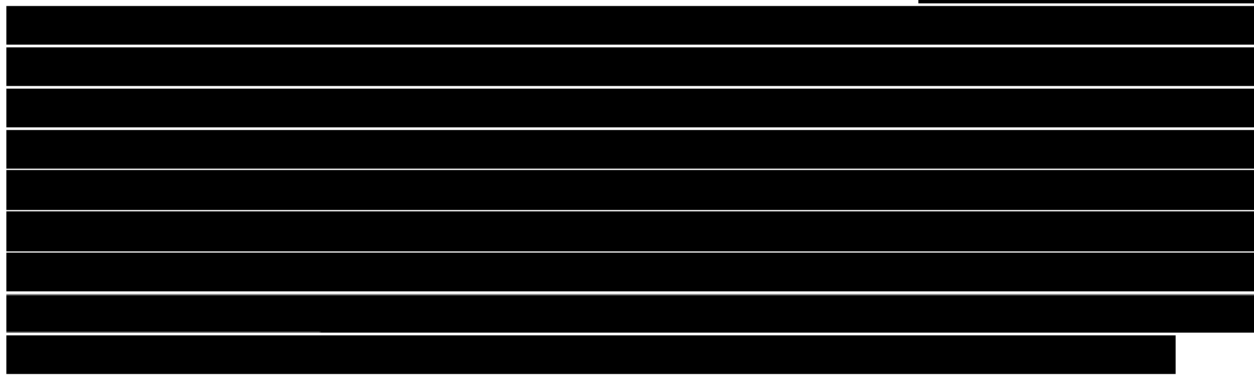
Cr = chrome, CO<sub>2</sub> = carbon dioxide.

**5.3.5. Pressure Fall-Off Testing**

Required by 40 CFR 146.87(e)(1) and AAC 400-8-1-.32(5)(a), the hydrogeologic characteristics of the Pilot Sand, Massive Sand, and Lower Cretaceous A and B storage reservoirs will be tested in each of their respective CO<sub>2</sub> injection wells prior to injection operations via a pressure fall-off test. Data from baseline pressure fall-off tests and those performed throughout the lifespan of the project will be used to verify injectivity, ensure operating parameters are appropriate for downhole conditions, inform AoR reevaluations, and better understand any reservoir changes throughout time. For additional information on hydrogeologic testing details, refer to section 5.2.8. Hydrogeologic Testing of this plan and 7.4.5 Pressure Fall-Off Testing of the Testing and Monitoring Plan.

**5.3.6. Groundwater Quality and Geochemical Monitoring**

To meet the requirements of 40 CFR 146.82(a)(6) and AAC 400-8-1-.15(2)(iii)(g), groundwater quality and geochemical baseline measurements will be taken prior to injection operations. Baseline fluid samples will be collected before the commencement of injection operations from both (a) **Claimed as PBI**



Baseline sampling and analysis events will target the proposed parameters summarized in **Table 5-12**, which will define a baseline profile that can be referenced throughout the injection and post-injection testing and monitoring phases. The parameters listed in **Table 5-12** will be used as water quality indicators and geochemical tracers to determine whether out-of-zone fluids have been introduced into the above confining zone monitoring formations. Baseline results will be used to assess parameter threshold values and will define the injection and post-injection phase sampling suites. Any parameters observed to be absent or insignificant to the project during baseline analyses will be removed from the fluid sampling and analysis

program. If baseline results indicate additional parameters should be monitored, they will be added to the fluid sampling and analysis program for the injection and post-injection phases.

To supplement the geochemical fluid samples, baseline downhole pressure measurements from the Upper Tuscaloosa will be obtained via the downhole pressure gauges deployed within the nine above-zone monitoring wells. In the unlikely event that there is a loss of containment from the storage complex, pressure perturbations within the first permeable zone above the confining zone are expected to be the earliest detectable signal. Accordingly, the baseline and subsequent pressure measurements from the Upper Tuscaloosa can be used as an indirect water quality indicator, allowing for early detection of any out-of-zone storage reservoir fluids prior to them potentially reaching and endangering overlying USDWs. For detailed information on the groundwater quality and geochemical monitoring program, refer to section 7.5 **Groundwater Quality and Geochemical Monitoring** of the **Testing and Monitoring Plan**.

**Table 5-12. Summary of the analytical parameters and methods for baseline fluid samples at Pine Hills Sequestration Hub.**

Parameters <sup>[A]</sup>	Analytical Methods <sup>[B]</sup>
<i>Formations: Predominant local source of drinking water, Upper Tuscaloosa (above-zone), and Pilot Sand, Massive Sand, Lower Cretaceous A, and Lower Cretaceous B (storage reservoirs)<sup>[C]</sup></i>	
Major Cations	ICP-AES, ICP-OES, ICP-MS, or equivalent (EPA [n.d.], EPA [1994], or equivalent)
Major Anions	Ion Chromatography, Spectroscopy, or equivalent (EPA [1993], EPA [1999], SM [n.d.], or equivalent)
Dissolved CO <sub>2</sub>	Coulometric Titration, Gas Sensing Electrode, or equivalent (ASTM [2016] or equivalent)
TDS	Gravimetry or equivalent (EPA [1971], SM [2015], ASTM [2018a], or equivalent)
Alkalinity	pH Meter or equivalent (SM [2005], ASTM [2017], or equivalent)
pH	pH Meter or equivalent (EPA [1982a], SM [2011], ASTM [2018b], or equivalent)
Temperature	Thermocouple or equivalent (SM [2010] or equivalent)
Conductivity	Conductivity Meter or equivalent (EPA [1982b], SM [2021], ASTM [2023], or equivalent)
Density	Pycnometer, Hydrometer, Density Meter, or equivalent (ASTM [2013], ASTM [2021], ASTM [2022], or equivalent)
Noble Gases <sup>[D]</sup> : He, Ne, Ar, Kr, Xe, Rn	Mass Spectrometry or equivalent
<sup>13</sup> C of DIC and CO <sub>2</sub> <sup>[D]</sup>	Isotope Ratio Mass Spectrometry or equivalent
<sup>2</sup> H of H <sub>2</sub> O <sup>[D]</sup>	Isotope Ratio Mass Spectrometry or equivalent
<sup>18</sup> O of H <sub>2</sub> O <sup>[D]</sup>	Isotope Ratio Mass Spectrometry or equivalent

<sup>[A]</sup>Parameters may be added to or subtracted from the sampling and analysis list depending on baseline results.

<sup>[B]</sup>Specific analytical methods will be selected in collaboration with the laboratory to perform the fluid testing and analysis to ensure parameters are appropriately analyzed. The methods and procedures selected will be provided to the UIC Program Director.

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<sup>[D]</sup>Noble gases and carbon, hydrogen, and oxygen isotopes will be analyzed prior to injection operations. Noble gas and isotopic monitoring will be reduced or excluded during operations once initial baseline profiles are defined. Should the simplified injection phase sampling suite indicate out-of-zone fluids, noble gases and carbon, hydrogen, and oxygen isotopes can be analyzed and compared to baseline results to verify the presence or absence of out-of-zone fluids within the groundwater monitoring formations.

ICP = Inductively Coupled Plasma, AES = Atomic Emission Spectrometry, OES = Optical Emission Spectrometry, MS = Mass Spectrometry, EPA = Environmental Protection Agency, SM = Standard Methods, n.d. = no date, ASTM = American Society for Testing and Materials, CO<sub>2</sub> = carbon dioxide, TDS = total dissolved solids, pH = potential of hydrogen, He = helium, Ne = neon, Ar = argon, Kr = Krypton, Xe = xenon, Rn = radon, <sup>13</sup>C = carbon isotope 13, DIC = dissolved inorganic carbon, <sup>2</sup>H = hydrogen isotope two (deuterium), H<sub>2</sub>O = water, <sup>18</sup>O = oxygen isotope 18.

### **5.3.7. Carbon Dioxide Plume and Pressure Front Tracking**

As part of the **Testing and Monitoring Plan** and in accordance with 40 CFR 146.90(g) and AAC 400-8-1-.34(1)(g), indirect and direct methods will be used to (1) monitor the free-phase CO<sub>2</sub> plume location, thickness, and saturation, (2) track the pressure front development within the storage complex, (3) validate the computational model and inform AoR reevaluations, (4) guide post-injection site care and site closure procedures, and (5) confirm USDW non-endangerment by demonstrating that the CO<sub>2</sub> injectate is appropriately stored and is moving throughout the reservoirs as predicted. Therefore, subsurface imaging and characterization are required prior to injection to obtain baseline profiles that can be compared to subsequent injection and post-injection phase data.

In compliance with 40 CFR 146.90(g)(2) and AAC 400-8-1-.34(1)(g)(ii), seismic surveys will be used to indirectly image the CO<sub>2</sub> plume across the PHSB site throughout the injection and post-injection phases. Prior to injection operations, a surface seismic survey will be acquired across the PHSB site and will act as the baseline for subsequent time-lapse surveys throughout the injection and post-injection phases. Additionally, a baseline well-based seismic survey (i.e., DAS VSP) may be obtained from select wells to be used in the early phase of injection if feasibility modeling demonstrates DAS VSPs are capable of CO<sub>2</sub> plume imaging. To supplement seismic imaging, baseline PNC logging profiles will be obtained in each injection well, in-zone monitoring well, and above-zone monitoring well prior to injection operations. Baseline profiles and subsequent PNC logging can be utilized in select wells on an as needed basis throughout the lifespan of the PHSB project to (1) verify the presence and extent of CO<sub>2</sub> within the storage reservoirs and (2) verify the vertical location and saturation of CO<sub>2</sub> and/or storage reservoir fluids in formations above the confining zone in the unlikely event of loss of containment from the storage complex. For additional information on CO<sub>2</sub> plume tracking, refer to section **7.6.2 Carbon Dioxide Plume Tracking** of the **Testing and Monitoring Plan**.

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pressure measurements will be used to inform subsequent injection and post-injection phase monitoring to track the elevated pressure front throughout the storage reservoirs over time. Additionally, in-zone pressure measurements will be used to inform operational parameters and verify and/or update the computational model to ensure the PSHH is operating as permitted and that models are accurately predicting CO<sub>2</sub> plume and pressure front migration. For additional information on direct pressure front tracking, refer to section **7.6.3 Pressure Front Tracking** of the **Testing and Monitoring Plan**.

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#### 5.4. REFERENCES

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