PRE-OPERATIONAL TESTING PROGRAM

SUTTER DECARBONIZATION PROJECT

1.0 Facility Information

Facility name: Sutter Energy Center
[redacted]

Facility contact: [redacted]

Well location: Robbins, Sutter County, CA
[redacted]

2.0 Introduction

The testing activities at the Sutter Decarbonization project described in this attachment are restricted to the pre-injection phase. Testing and monitoring activities during the injection and post-injection phases are described in the Testing and Monitoring Plan, along with other non-well related pre-injection baseline activities such as geochemical monitoring.

A series of [redacted] injection wells are proposed for the project site. The well and the testing results are described in the permit application Narrative.-The pre-operational formation testing program will be implemented at each injection well to verify the chemical and physical characteristics of the injection zone and confining zone(s).

The program is developed to meet the testing requirements of 40 CFR 146.87 and well construction requirements of 40 CFR 146.86. The pre-operational testing program will include a combination of wireline logging and side-wall coring. In addition, formation geohydrologic testing will be completed to verify injectivity of the storage formation.

The pre-operational testing program will determine or verify the depth, thickness, mineralogy, lithology, porosity, permeability, and geomechanical information of the Winters Shale (basal confining zone), the Starkey Clean Sand (CO_2 injection zone), the overlying Capay Shale (confining zone), and other relevant geologic formations. In addition, formation fluid characteristics will be obtained from the Starkey Clean Sand to establish baseline data against which future measurements may be compared. A stratigraphic test well is planned to the south of the proposed injectors as part of CarbonSAFE Phase II project. The pre-operational testing plan will be re-evaluated upon completion and testing of this well if new data obtained from the well significantly change model predictions and the delineated AoR. The results of the testing activities will be documented in a "Pre-operational Testing Narrative" report and submitted to the EPA after the well drilling and testing activities have been completed, and before the start of CO_2 injection operations.

After completing the characterization and testing, the borehole will be completed as an injection well. Mechanical integrity tests (e.g., wireline and pressure tests) will verify well construction and integrity.

3.0 Pre-Injection Testing Plan – Injection Wells

The following tests and logs will be conducted during drilling, casing installation and after casing installation in accordance with the testing required under 40 CFR 146.87(a), (b), (c), and (d). The tests and procedures are described below and in the proposed Injection Well Construction Information section of the permit application Narrative.

3.1 Well Deviation Checks

During drilling, the wellbore trajectory will be tracked and surveyed by running appropriate survey tools on a wireline or alternatively, as part of the drilling program (MWD tool). The hole deviation will be maintained to within ±5 degrees of the planned wellbore trajectory. This will be achieved with the downhole rotary steerable system added to the BHA (Well Construction Plan). Should there be significant deviation off the planned trajectory, remedial actions will be taken up as necessary to bring the well back within specification.

3.2 Tests and Logs

Open-borehole logs will be run to obtain densely spaced, in situ, structural, stratigraphic, physical, chemical, and geomechanical information for Winters Shale, the Starkey Clean Sand, the Capay Shale, and other relevant geologic formations. Open-borehole characterization logs will be obtained at the surface casing point, the intermediate casing point, and at the long-string casing point (i.e., total borehole depth). No open-borehole wireline logs are planned to be run in the conductor casing borehole. Open-borehole logs may include caliper, gamma, spontaneous potential (or brine formation equivalent), resistivity, neutron, density, photoelectric cross-section, sonic (full waveform), nuclear magnetic resonance, resistivity-based and/or acoustic-based micro-image, and gamma spectroscopy logs. Fluid temperature, pH, conductivity, reservoir pressure and static fluid level of the injection zone will be measured prior to injection.

3.3 Coring

An extensive coring program is planned for the pre-injection stratigraphic test well. Additional cores will be collected at the injection wells as required based on results from the stratigraphic well. Specifically, full core and side wall core samples will be collected from the Starkey sand CO_2 injection zone and the basal Sacramento confining zone as well as the overlying Capay confining zone. The preliminary coring program as planned is outlined in Table 1. Further changed to the plan will be communicated to the UIC program Director for approval.

Additional core will be collected if the stratigraphic test well data indicates that additional data is needed to meet the Class VI permit requirements or as required by the UIC Program Director. The cores will be run through various standard and special tests to better understand relevant confining zone and injection zone properties as deemed necessary for the program. Table 2 provides a summary of potential core analysis and associated parameters. The plan is preliminary and will be updated with additional information and as any new data gaps are identified. All potential proposed tests will be subject to material availability and suitability from the core collection program.

Table 1. Proposed coring program for [redacted] wells.

[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]

Table 2. Summary of Potential Core Analysis and Associated Parameters

[redacted]

3.4 Demonstration of mechanical integrity

Tests and logs will be conducted as needed (per 40 CFR § 146.8(c)) to demonstrate the internal and external mechanical integrity of the injection wells prior to initiating regular CO_2 injection.
Internal mechanical integrity refers to the absence of leaks in the tubing, packer, and casing above the packer. External mechanical integrity refers to the absence of fluid movement/leaks through channels adjacent to the injection well bore that could result in fluid migration into an USDW.
External Mechanical integrity tests are required to demonstrate no significant fluid movement into an underground source of drinking water through vertical channels adjacent to the injection well bore. This is typically demonstrated through an oxygen activation log, a temperature log, a noise log, or an alternative test approved by the UIC Program Director. The procedure and type of MIT will depend on the conditions of the site and the well. At present, temperature logs as well as cement bond logs as noted in Table 3 are planned.

Table 3: External mechanical integrity tests for injection wells

Logging Program

[redacted]

A baseline temperature log and oxygen-activation log will be run on the well after well construction but prior to commencing CO_2 injection to provide a baseline reference for comparing future temperature logs and oxygen-activation logs as they relate to the well's external mechanical integrity. In addition, each injection and in-zone monitoring well will be equipped with a fiber optic cable to measure temperature. Baseline DTS temperature measurements will be mapped and recorded as a reference for future MIT's as referenced in the Testing and Monitoring Plan.

A more detailed discussion of internal and external mechanical integrity testing during the service life of the injection wells is provided in the Testing and Monitoring Plan.

3.4.1 Oxygen activation log

A wireline tool is deployed to activate oxygen by emitting high-energy neutrons from a neutron source. The activated isotopes emit gamma radiation which is measured by the wireline tool. Gamma ray measurements are used to calculate water flow direction and velocity. If water flow outside of the casing is detected it could indicate the potential loss of external mechanical integrity. To minimize false positives, a calibration will be performed, and measurements will be confirmed at several nearby depths and/or under a minimum of three varying injection rates. Additional details are included provided in the Testing and Monitoring Plan.

3.4.2 Temperature log

Temperature logging detects leaks by measuring temperature anomalies due to fluid movement adjacent to the well bore. Fluid leaks from the wellbore are typically a different temperature compared to native fluids. Temperature logs are run after the well has been shut-in long enough for temperature effects to dissipate, leaving a relatively simple temperature profile (typically ~36 hours). While the absolute gradients may differ due to injection history, the relative profiles should be consistent. If there has been a leak of fluid out of the well, there may be anomalous heating or cooling effect as compared to the baseline or another log. Gradient variation due to lithologic changes are expected. Note that to be effective, temperature logging tools must have good thermal coupling to the borehole environment. Depending on phase of CO_2 in the well, this may require that the wellbore be displaced with water or brine and thermally stabilized prior to running the logging tools. Distributed fiber sensing or electric wireline deployed temperature measurement devices can be used and should be of sufficient resolution and sufficiently calibrated to detect changes. Additional details are included provided in the Testing and Monitoring Plan.

3.5 Pulsed neutron monitoring

Pulsed neutron logging detects leaks by measuring changes in the capture cross section of the fluids and gasses in the pore space of the rock using a wireline tool that emits neutrons which are slowed to a thermal velocity through elastic and inelastic collisions with the nuclei of the environment's elements and ultimately captured. These interactions are sensitive to fluid type and saturation changes in the formation and in the casing-formation annulus. Therefore, pulsed neutron measurements can be used to monitor the formation fluids as well as identify mechanical integrity problems. The pulsed neutron Sigma (Σ) is the thermal neutron capture cross section or the rate at which thermal neutrons are captured by the formation matrix and fluids. The capture cross section can be used to detect fluid changes behind casing over time to verify the well external mechanical integrity. Open hole wireline logs for lithologic definition and baseline pulsed neutron logs are key inputs to this type of monitoring. A more detailed discussion is provided in the Testing and Monitoring Plan.

Below is a summary of the MITs and pressure fall-off tests to be performed prior to injection:

Table 2. Pre-Operational Testing Schedule

[redacted]

[redacted] will notify EPA at least 30 days prior to conducting the tests and provide a detailed description of the testing procedure. Notice and the opportunity to witness these tests/logs shall be provided to EPA at least 48 hours in advance of a given test/log.

3.6 Geomechanical Testing

Geomechanical characterization of the injection and confining zones for the project will be assessed by analyzing one or more of the following datasets: well log data, core analysis, and in-situ injection tests. Data from stratigraphic test well as well as injectors may be used for this purpose. These analysis may include, but are not limited to, triaxial compressive tests of core samples, dipole sonic and image logs, and step rate tests (SRT). Additionally, drill stem tests (DST's) may be performed to validate injectivity, pressures and permeability of the injection zone. Results will be used to constrain the direction and magnitude of the principal components of the in-situ stress field as well as fracture gradient. Depending on the results of the initial set of analyses, additional modeling may be performed to support fault and fracture understanding.

An SRT will be performed in the Starkey Sandstone interval to determine the following:

1. Fracture opening pressure (fracture gradient)
2. Fracture propagation pressure
3. Fracture closure pressure

SRT involves analyzing pressure response to increasing injection rates over similar periods of time. The high-level procedure is as follows:

1. Record static pressure and temperature for a minimum of one hour.
2. Rig-up pump truck, ensure sufficient volume of fluid is present at location to initiate testing.
3. Pressure test lines above maximum anticipated operating pressure, but below equipment rating.
4. Begin SRT:
    a. Pump first step of test at first desired rate for a defined period.
    b. After first step is completed, increase rate to next step for same defined step time.
    c. Repeat step a, b unit end of test.

    Note: The actual rates and periods will be finalized based on well conditions.
5. Shut-in well. Record the time of shut-in, the rate prior to shut-in and the shut-in pressure.
6. Rig-down pump truck. Monitor pressure falloff for minimum of 12-hour period.

The data from this test will be analyzed using appropriate analysis software, and the results will be included in the post installation reporting. Gauge calibration records will be provided at this time as well.

3.7 Annulus pressure test procedures for injection well

After the injection wells are completed, including the installation of tubing, packer, and annular fluid, a test of the well's internal mechanical integrity will be performed by conducting an annular pressure test (Standard Annulus Pressure Test (SAPT)). This is a short-term test wherein the fluid in the annular space between the tubing and casing is pressurized once the well is in thermal equilibrium. The well is then shut-in, and the pressure of the annular fluid is monitored for leak-off. A calibrated digital gauge will be installed on the annulus and pressure will be monitored for a period of no less than 60 minutes. Test will be performed consistent with approved and accepted guidance and regulations [40 CFR 146.89 (a)]. If the well does not meet pressure change threshold requirement, the tubing and packer may need to be removed from the well to determine the cause of the leak.

The general procedure for the test includes:

1. Before initiating the test, thermal equilibrium will be ensured. Thermal equilibrium will be assumed under the following circumstances:
    a. Injection has not occurred for approximately 24 hours, or sufficient data indicates the wellbore temperature is static. The scenario constitutes a static SAPT.
    b. Injection is occurring at a constant rate (±5%), often referred to as a dynamic APT.
2. Calibrated digital gauge will be installed on the casing-tubing annulus. Initial pressures will be noted for deviation calculations.
3. The annulus pressure will be increased to no less than [redacted]. The fluid level in the system will be noted prior to increasing the annulus pressure.
4. The annulus system will be disconnected to ensure that it is properly isolated for the test. The annulus and tubing pressure will be monitored for a period of one-hour, taking readings every 10-minutes.
5. The annulus system will be reconnected once the test has concluded. Annulus pressure will be brought back to normal pre-test operating pressure (or an acceptable lower pressure) by blowing down pressure from the annulus head tank. The final fluid level in the system will be noted and analyzed for deviation.

4.0 Pre-Injection Testing Plan – Deep Monitoring

The testing and logging procedure for the deep monitoring wells will be similar to the injection well program summarized in Table 2 Testing and Monitoring Plan. The exact tests and procedures will depend on new information available from the planned stratigraphic test well and information provided represents an example of the program that will be developed when additional information is available.

4.1 Tests and Logs

Open-borehole logs will be run to obtain densely spaced, in situ, structural, stratigraphic, physical, chemical, and geomechanical information for Winters Shale, the Starkey Clean Sand, the Capay Shale, and other relevant geologic formations. Open-borehole characterization logs will be obtained at the surface casing point, the intermediate casing point, and at the long-string casing point (i.e., total borehole depth). No open-borehole wireline logs are planned to be run in the conductor casing borehole. Open-borehole logs may include caliper, gamma, spontaneous potential (or brine formation equivalent), resistivity, neutron, density, photoelectric cross-section, sonic (full waveform), nuclear magnetic resonance, resistivity-based, and/or acoustic-based micro-image, and gamma spectroscopy logs.
Fluid temperature, pH, conductivity, reservoir pressure, and static fluid level of the injection zone will be measured prior to injection.

Below is a summary of the MITs to be performed on the monitoring well(s), SLR1 and SLR2, after installation and prior to commencing CO_2 injection operations:

Table 3. Mechanical Integrity Tests

[redacted]

Notice and the opportunity to witness the test/log shall be provided to EPA at least 48 hours in advance of a given test/log.

4.2 Annulus pressure test procedures for monitoring well

The Standard Annulus Pressure Test (SAPT) as described above will also be used to determine internal mechanical integrity of the in zone and above zone monitoring wells. See additional detail for Injection well annulus pressure test.

5.0 Pressure Fall-Off Test Procedures:

Baseline pressure fall-off tests (PFO) will be conducted as described in the Testing and Monitoring Plan and in the Pre-Operational Testing Plan. The objective of the testing is to periodically monitor for changes in the near well bore environment that would impact injectivity or cause injection pressures to increase (US EPA, 2013). Testing location and frequency
Baseline pressure fall-off testing will be performed in each injection well: [redacted].
A pressure falloff test has a period of injection followed by a period of no-injection or shut-in. Normal injection will be used during the injection period preceding the shut-in portion of the falloff tests. However, if the rate causes relatively large changes in bottomhole pressure, the rate may be decreased. A minimum, one week of relatively continuous injection will precede the shut-in portion of the falloff test. The pressure Fall-Off data will be measured using a downhole gauge sampling at 5-second intervals. The gauges may be those used for day-to-day data acquisition, or a pressure gauge conveyed via wireline. Surface or downhole gauges will be used to inform test duration. The shut-in period of the falloff test will be adequate to assure that enough pressure transient data are collected to calculate the average pressure. Quantitative analysis of the measured data is used to estimate formation characteristics, including transmissivity, permeability, and a skin factor. The measured parameters will be compared to those used in site computational modeling and Area of Review delineation.

6.0 References

U.S. Environmental Protection Agency, 2013. *Geologic Sequestration of Carbon Dioxide – Underground Injection Control (UIC) Program Class VI Well Testing and Monitoring Guidance.*