

# PRE-OPERATIONAL TESTING PROGRAM

## One Earth CCS

### Facility Information

Facility name: One Earth Sequestration LLC  
Injection Wells: OES #1, OES #2, OES #3

Facility contact: Mark Ditsworth, VP of Technology and Special Projects  
One Earth Sequestration LLC, 202 N Jordan Drive, Gibson City  
(217) 784-5321 ext. 215; mditsworth@oneearthenergy.com

Well location: McLean County, IL  
OES #1: 40.485183°N, -88.481202°W (NAD 1983)  
OES #2: 40.500444°N, -88.471786°W (NAD 1983)  
OES #3: 40.515989°N, -88.479214°W (NAD 1983)

### Introduction

The testing activities at the One Earth CCS 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 stratigraphic test well (OEE #1) was constructed for the purpose of site characterization. The well and the testing results are described in the permit application Narrative. OEE #1 will be converted to an in-zone monitoring well (IZM #1) for the project. The pre-operational formation testing program will be implemented, as applicable in OEE #1 and in each new injection well (OES #1, OES #2, and OES #3) to verify the chemical and physical characteristics of the injection zone and confining zone(s). The data gathered from OEE #1 is used to guide the scope of testing at each injection well and deep, in-zone monitoring well.

The pre-operational formation testing program will be implemented to obtain an analysis of the chemical and physical characteristics of the injection zone and confining zone(s) and that meets the testing requirements of 40 CFR 146.87 and well construction requirements of 40 CFR 146.86. The preoperational testing program will include a combination of logging, coring, formation geohydrologic testing (e.g., a pump test and/or injectivity tests), and other activities during the drilling and construction of the CO<sub>2</sub> injection wells.

The pre-operational testing program will determine or verify the depth, thickness, mineralogy, lithology, porosity, permeability, and geomechanical information of the Mt. Simon Sandstone (CO<sub>2</sub> injection zone), the overlying Eau Claire Formation (confining zone), and other key stratigraphic units intersected by the well that support Class VI siting and containment evaluations (e.g., Maquoketa Shale and New Albany Shale where logged), as applicable. In addition, formation-fluid characteristics will be obtained, where practicable, from the completed monitoring interval(s) in each well (i.e., Mt. Simon injection/IZM interval, Ironton–Galesville

ACZ interval, and/or St. Peter lowermost USDW interval, as applicable) to establish baseline conditions against which future measurements may be compared after the start of injection operations. 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<sub>2</sub> 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.

### **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. The pre-operational testing (including open borehole testing, analyzing core data, measuring brine salinity, etc.) will:

- Provide information on and evaluate estimations of in situ stress and the presence of potential weak planes for the confining zone and will confirm whether the Eau Claire has similar properties on which stress evaluations were based and validate predictions that there will be no fault slippage.
- Establish pore pressure and pore pressure gradient in the injection zone.
- Determine the fracture pressure of the injection and confining zones.
- Calculate the maximum allowable injection pressure based on the results of pre-operation fall-off testing and injectivity testing (described below).
- Establish baseline geochemistry for the injection zone and, where applicable, baseline groundwater chemistry in the lowermost USDW monitoring interval consistent with the indicator parameters and analytes identified in the Testing and Monitoring Plan
- . Baseline monitoring for the above-confining zone USDW is described in the Testing and Monitoring Plan.
- Establish baseline geochemistry of the Ironton–Galesville ACZ monitoring interval (as completed). Baseline monitoring for the above confining zone is described in the Testing and Monitoring Plan
- Establish a pre-operational 2D seismic baseline for comparison for later data collected after operation begins, as described in the Testing and Monitoring Plan. (See Narrative for discussion of 2D and 3D surveys conducted during site characterization.)

### ***Deviation Checks***

Two single-shot surveys will be acquired during the surface section installation, then at least every 500’ below the surface casing set depth to total depth. If wellbore deviation issues develop, additional surveys will be performed as necessary, and drilling methods will be adapted as needed.

### ***Tests and Logs***

Open-borehole logs will be run to obtain densely spaced, in situ, structural, stratigraphic, physical, chemical, and geomechanical information for Mt. Simon Sandstone, the Eau Claire confining zone, and other key 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. 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 the stratigraphic test well, as well as OES #2 and OES#3, may be used for this purpose. These analyses may include, but are not limited to, triaxial compressive tests of core samples, dipole sonic and image logs, and step rate tests (SRT) in the injection zone. Additionally, drill stem tests (DSTs) may be performed to validate injection zone injectivity, pressures, and permeability. Results will be used to constrain the direction and magnitude of the principal components of the in-situ stress field as well as the fracture gradient. Depending on the results of the initial analyses, additional modeling may be performed to support understanding of faults and fractures.

Pore pressure was measured in the test well in both the St. Peter sandstone and the Mt. Simon sandstone formations using drill-stem testing (DST). The DST consisted of two flowing periods followed by two shut-in periods, which are used to determine the static pore pressure. Similar methods will be used to determine pore pressure in the injection interval of the OEE injection wells.

The fracture pressure of the injection and confining zones will be determined in accordance with 40 CFR 146.87(d)(1). This information, in conjunction with predictions of pore pressures within the injection zone, is used to support the determination of an appropriate injection pressure to ensure that injection will not initiate or propagate fractures in the confining zone [40 CFR 146.83(a)(2)].

An SRT, following recommended guidance from the US EPA (US EPA, 1999), will be performed in the Mt. Simon interval of the injection wells to determine the following:

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

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.

A modular dynamic testing wireline tool may also be used to simulate a formation test or step rate test to estimate fracture pressure in the injection and confining zone. Several pressure measurements vs. depth, similar to OEE #1, will be run. These test results will be supplemented by wireline well log analyses (sonic and density) and core analyses.

Fluid temperature, pH, conductivity, reservoir pressure, and static fluid level of the injection zone will be measured before injection.

Salinity of formation fluids will be characterized in the completed injection-zone and monitoring intervals (Mt. Simon injection/IZM interval; Ironton–Galesville ACZ interval; and St. Peter lowermost USDW interval, as applicable).. Where practicable, formation-fluid samples will be collected during drilling or well-testing operations to allow direct laboratory determination of total dissolved solids (TDS). In intervals where sampling is not feasible, formation-water salinity

will be estimated using standard geophysical logs (e.g., resistivity and spontaneous potential), consistent with the requirements of 40 C.F.R. § 146.87(a).

***Coring***

Sidewall core samples will be collected from the Mount Simon CO<sub>2</sub> injection zone and the overlying Eau Claire Formation confining zone. The collection of any whole core is to be determined. Core intervals will be selected based on real-time -openhole log interpretation, image logs, and lithologic indicators, and will remain within the approximate depth ranges identified below. The coring program will augment the whole- core and sidewall core dataset obtained from stratigraphic test well OEE #1, which provided the primary formation characterization required under 40 C.F.R. § 146.87(b). The injection well coring program is therefore focused on confirming formation properties, calibrating wireline logs, and verifying confining zone- integrity.

Approximate formation depth intervals based on OEE #1 are:

- Mount Simon Sandstone (Injection Zone): approximately 6,250–6,470 ft
- Eau Claire Formation (Primary Confining Zone): approximately 3,900–4,450 ft

Across the three injection wells, OES anticipates collecting 10–12 RSWC samples from the Mount Simon and 8–10 RSWC samples from the Eau Claire in each well. These slightly expanded ranges provide additional lithologic and geomechanical coverage in the absence of planned whole core recovery in the injection wells. Additional limited RSWC samples may be collected from monitoring wells where technically feasible- to support lithologic and geomechanical characterization, where technically feasible and consistent with well design and completion objectives, of the St. Peter Sandstone, Ironton–Galesville, Maquoketa, or New Albany formations.

The coring and testing program for injection wells OES #1, OES #2, and OES #3 is provided in Table 1.

**Table 1.** *Coring and testing program for injection wells OES#1, OES #2 and OES #3.*

<b><i>Core Analysis Type</i></b>	<b><i>Parameters</i></b>	<b><i>Formations</i></b>	<b><i>Approximate Depth Interval (ft)</i></b>
<i>Routine Core Analysis</i>	<i>Porosity, Permeability, Grain Density, Fluid Saturations</i>	<i>Mt. Simon and Eau Claire</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>Tight Rock Analysis</i>	<i>Porosity, permeability, capillary behavior</i>	<i>Eau Claire</i>	<i>4,050–4,350</i>

<i>Petrography / Thin Section</i>	<i>Mineralogy, lithology, porosity type, grain size</i>	<i>Mt. Simon and Eau Claire</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>X-Ray Diffraction</i>	<i>Mineralogy</i>	<i>Mt. Simon and Eau Claire</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>Gamma Ray Log</i>	<i>Lithology, Porosity, Grain Size Distribution, Geologic Contacts</i>	<i>All Cored Intervals</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>Scratch Tests</i>	<i>Hardness</i>	<i>Mt. Simon and Eau Claire</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>Relative Permeability</i>	<i>Relative Permeability, Wettability</i>	<i>Mt. Simon</i>	<i>6,300–6,450</i>
<i>Mercury Injection Capillary Pressure or similar</i>	<i>Capillary Pressure</i>	<i>Mt. Simon and Eau Claire (Intervals TBD)</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>Triaxial Tests or similar</i>	<i>Rock Strength, Ductility, Poisson's Ratio, Young's Modulus</i>	<i>Mt. Simon and Eau Claire</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>Rock Compressibility</i>	<i>Compressibility</i>	<i>Mt. Simon and Eau Claire (Intervals TBD)</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>Scanning Electron Microscopy (QEM/FIB)</i>	<i>Mineralogy, Petrography, Pore Geometry</i>	<i>Mt. Simon and Eau Claire</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>CT Scanning</i>	<i>Fracture Analysis, Porosity, Grain Size Distribution, Volumetrics</i>	<i>All Cored Intervals</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>Laser Particle Size Distribution</i>	<i>Grain Size Distribution</i>	<i>Mt. Simon and Eau Claire</i>	<i>Mount Simon: 6,250–6,470 Eau Claire: 3,900–4,450</i>
<i>Pressure Decay Permeability</i>	<i>Permeability</i>	<i>Eau Claire</i>	<i>4,050–4,350</i>

### ***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<sub>2</sub> 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 Director of the EPA. 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 2 are planned.

***Table 2. External mechanical integrity tests for injection wells***

<b>Name</b>	<b>Depth Interval (feet)</b>	<b>Open Hole Logs</b>	<b>Cased Hole Logs</b>
<i>Pre-Operational Testing Program</i>			
<i>Permit Number: IL-113- 6A-0001 (OES #1), IL-113-6A-0002 (OES #2), and IL-113-6A-0003 (OES #3)</i>			

<b>Surface</b>	0 – 374	Resistivity SP Caliper	Radial CBL and VDL (Ultrasonic optional) Temperature Oxygen Activation
<b>Intermediate</b>	374 – 4,046	Resistivity SP Caliper	Radial CBL and VDL (Ultrasonic optional) Temperature
<b>Long</b>	4,046 – 7,100	Resistivity SP Caliper Porosity Gamma Ray Fracture Finder	Radial CBL and VDL (Ultrasonic optional) Temperature Oxygen Activation

A baseline temperature log and oxygen-activation log will be run on the well after well construction but prior to commencing CO<sub>2</sub> 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.

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.

### **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.

### **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. 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.

### **Pulsed Neutron Monitoring**

Pulsed neutron logging detects leaks by measuring changes in the capture cross section of the fluids and gases 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 changes in

fluid type and saturation in the formation and the casing-formation annulus. Therefore, pulsed neutron measurements can be used to monitor formation fluids and identify mechanical integrity problems. The pulsed neutron Sigma ( $\Sigma$ ) 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's external mechanical integrity. Open-hole wireline logs for lithologic definition and baseline pulsed-neutron logs are key inputs to this type of monitoring.

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

**Table 3. Pre-Operational Testing Schedule**

Class VI Rule Citation	Rule Description	Test Description	Program Period
40 CFR 146.89(a)(1)	MIT - Internal	Annulus pressure test	After well completion
40 CFR 146.87(a)(4)	MIT - External	Cement bond log	After cementing shallow, intermediate, and long strings
40 CFR 146.87(a)(4)	MIT - External	Temperature log	After cementing shallow, intermediate, and long string
40 CFR 146.87(a)(4)	MIT - External	Pulsed Neutron	After cementing long string
40 CFR 146.87(e)(1)	Testing prior to operating	Injection and Pressure fall-off test	After well completion

One Earth Sequestration, LLC 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.

### **Pre-Injection Testing Plan – Deep Monitoring**

The testing and logging procedure for the deep monitoring wells will be similar to the injection well program.

#### ***Well Deviation Checks***

Two single shot surveys will be acquired during the surface section, then at least every 500' below the surface casing set depth to total depth. If wellbore deviation issues develop, additional surveys will be performed as necessary, and drilling methods will be adapted as needed.

#### ***Tests and Logs***

Open-borehole logs will be run to obtain densely spaced, in situ, structural, stratigraphic, physical, chemical, and geomechanical information for Mount Simon Sandstone, the Eau Claire confining zone, and other key 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, pressure, and static fluid level will be measured in the completed monitoring interval(s) prior to injection, as applicable.

Below is a summary of the MITs to be performed on the deep monitoring well(s), IZM#1 and IZM#2, after installation and prior to commencing CO<sub>2</sub> injection operations:

**Table 4. Mechanical Integrity Tests**

Test Name	Test Description	Program Period
MIT – Internal	Annulus Pressure Test	After well completion
MIT – External	Cement Bond Log	During installation

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.

**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, the well is shut-in, and the pressure of the annular fluid is monitored for leak-off. EPA Region 5 (EPA 2008) \* requires comparison of the pressure change throughout the test period to 3 percent of the test pressure (0.03 x test pressure). If the annulus test pressure decreases by this amount or more, the well has failed to demonstrate internal mechanical integrity. If the annulus pressure changes by less than 3 percent during the test period, the well has demonstrated internal mechanical integrity. If the well does not meet this requirement, the tubing and packer may need to be removed from the well to determine the cause of the leak. EPA Region 5 guidance (EPA 2008) \* for conducting the test will be consulted when performing this test.

The general procedure for the test is summarized from EPA 2008 and includes:

1. The tubing/casing annulus (annulus) will be filled with liquid. Temperature stabilization of the well and annulus liquid is necessary prior to conducting the test. This will be achieved by filling the annulus with liquid and either ceasing injection or maintaining stabilized injection (i.e., continuous injection at a constant rate and constant injection fluid temperature) before and through the test.
2. No unapproved substances will be added to the annulus liquid.
3. After stabilization, the annulus will be pressurized to a surface pressure of no less than 300 psig. A positive pressure differential of at least 100 psi between the annular space and the injection tubing pressure will be maintained throughout the entire annulus (from the top of the packer to the surface). Specific gravity differences between liquids in the annulus and the tubing should be accounted for when determining the appropriate test pressure.
4. Following pressurization, the annular system will be isolated from the source of pressure. The annulus system will remain isolated for a period of no less than 60 minutes.

5. During the active CO<sub>2</sub> injection phase, internal mechanical integrity will be continuously monitored by the well annular pressure maintenance and monitoring system, as discussed in more detail in the Testing and Monitoring Plan. After the SAPT test period has been completed, the valve to the annulus will be opened and liquid returns from the annulus observed and measured.

### **Annulus Pressure Test Procedures for Monitoring Well:**

The Standard Annulus Pressure Test (SAPT) as described above and in EPA 2008 will also be used to determine internal mechanical integrity of the in-zone and above-zone monitoring wells. See additional details for the injection well annulus pressure test.

### **Injection and Pressure Fall-Off Test Procedures:**

Baseline pressure fall-off testing is required upon completion of the injection wells prior to their operation (i.e., injection) to characterize reservoir (injection zone) hydrogeologic properties (40 CFR 146.87(e)(1)) and at least once every 5 years once injection operations begin (40 CFR 146.90(f)) to confirm site-characterization information, assess reservoir and well conditions, and inform AoR reevaluations. Baseline pressure fall-off tests (PFO) will be conducted prior to authorization of injection using the procedures described herein; recurring PFO testing during operations is described in the Testing and Monitoring Plan. The objective of the testing is to gather data needed to calculate maximum allowable injection pressure and 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 (OES#1, OES#2, OES#3):

A pressure falloff test has a period of injection followed by a period of no-injection or shut-in. Injection pressures, up to the critical pressure will be used during falloff tests. If the rate causes relatively large changes in bottomhole pressure, the rate may be decreased. 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 ensure 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.

## References

U.S. Environmental Protection Agency, 1999. Step Rate Test Procedure, *Region 8, Underground Injection Control (UIC) Office*.

U.S. Environmental Protection Agency, 2008. *Determination of the Mechanical Integrity of Injection Wells, Region 5, Underground Injection Control (UIC) Branch Regional Guidance #5*.

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