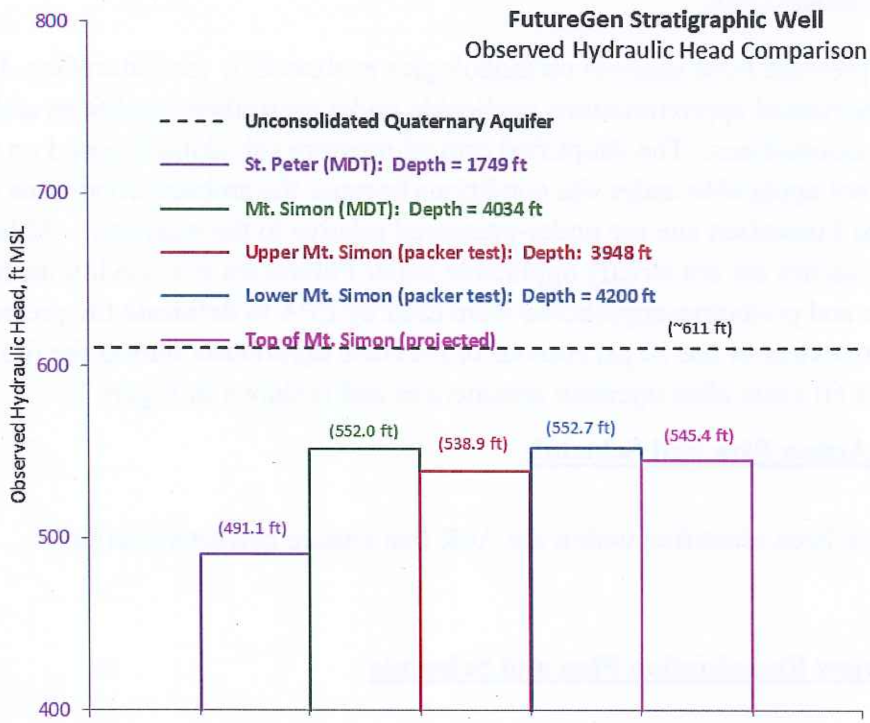

Figure 16. Observed Hydraulic Head Comparison between the Unconsolidated Quaternary Aquifer, St. Peter Sandstone, and Mount Simon Sandstone within the FutureGen Stratigraphic Well

Alternative approaches considered for delineation of an AoR inclusive of an area of elevated pressure

The FutureGen Alliance considered the applicability of and evaluated the project using an analytical solution (Cihan et al., 2011; 2013) and a range of other approaches (Table 13). The objective of these analyses was to assess, calculate, and account for critical pressure, which is the pressure great enough to mobilize fluids up an open conduit (i.e., an artificial penetration, fault, or fracture) from the injection zone into the overlying USDW. Methods evaluated are presented in Table 13.

Table 13. Methods Evaluated for Pressure Front Delineation

Approach	Results
AoR Guidance Equation 1	Not applicable
Nicot (2008)	13.76 psi
Birkholzer (2011)	9.65 psi
Cihan (2011): Assuming thief zones	Plume-sized AoR
Cihan (2011) Conservative: Assuming no thief zones	Large AoR

Pressure delineated AoR

Each of the pressure front analysis methodologies evaluated by the FutureGen Alliance (Table 13) are mathematical approximations applicable under prescribed conditions and subjected to simplifying assumptions. The simplified critical pressure calculations based on the open conduit concept are not applicable under site conditions because the ambient conditions in the lowermost USDW at the FutureGen site are under-pressured relative to the reservoir. Although the open conduit approaches are not strictly applicable under FutureGen site conditions, results from these conservative and protective approaches were used by EPA to delineate the pressure front AoR as the maximum extent of the 10 psi contour *of pressure differential* during the life of the project, which occurs 60 years after injection commences and is shown in Figure 15.

Corrective Action Plan and Schedule

No wells have been identified within the AoR that require corrective action.

Area of Review Reevaluation Plan and Schedule

Reevaluation Cycle

The FutureGen Alliance will reevaluate the AoR on an annual basis for the first 5 years following the initiation of injection operations (Figure 17). After the fifth year of injection, the AoR will be updated at a minimum of every 5 years as required by 40 CFR 146.84(b)(2)(i). An annual reevaluation in the first 5 years is intended to account for any operational variation during the startup period.

Some conditions will warrant reevaluation prior to the next scheduled cycle. To meet the intent of the regulations and protect USDWs, the following six conditions will warrant reevaluation of the AoR:

1. **Exceeding Fracture Pressure Conditions:** Pressure in any of the injection or monitoring wells exceeding 90 percent of the geologic formation fracture pressure at the point of measurement. This would be a violation of the permit conditions. The Testing and Monitoring Plan provides discussion of pressure monitoring.

   Action: The computational model will be calibrated to match measured pressures. Model outputs that calculate the change in AoR will be provided to EPA.

2. **Exceeding Established Baseline Hydrochemical/Physical Parameter Patterns:** A statistically significant difference between observed and baseline hydrochemical/physical parameter patterns (e.g., fluid conductivity, pressure, temperature) within the Ironton Formation immediately above the confining zone (ACZ1 and ACZ2 wells). The Student's t-test statistical procedure will be used to compare background (baseline) with observed

results. The Testing and Monitoring Plan provides extended information regarding how pressure, temperature, and fluid conductivity will be monitored within the Ironton Formation.

Action: In the event that hydrochemical/physical parameter trends suggest that leakage may be occurring, either the computational model or other models will be used to understand the observational parameter behavior.

3. **Compromise in Injection Well Mechanical Integrity:** A significant change in pressure within the protective annular pressurization system surrounding each injection well that indicates a loss of mechanical integrity at an injection well.

   Action: Injection wells suspected of mechanical integrity issues will be shut down and the cause of the pressure deviation determined. Mechanical integrity testing will be conducted and the computational model will be updated with mechanical integrity results to determine the severity and extent of the loss of containment. The Testing and Monitoring Plan provides extended information about the mechanical integrity tests that will be conducted in the injection wells.

4. **Departure in Anticipated Surface Deformation Conditions:** Surface deformation measurements that indicate an asymmetric or otherwise heterogeneous evolution of the injection zone pressure front, resulting in larger than predicted surface deformation outside the CO_2 plume. Areal surface deformation will be monitored using several technologies including differential synthetic aperture radar interferometry (DInSAR), which is a radar-based method that can measure very small changes in ground-surface elevation linked to pressure variations at depth. The area surveyed will extend beyond the predicted maximum extent of the CO_2 plume. If a measurable rise in the ground surface occurs outside the predicted extent, the AoR will be re-evaluated. The Testing and Monitoring Plan provides extended information about surface deformation monitoring.

   Action: The computational model will be calibrated to match observed pressures if they vary from the predicted deformation/pressure calculations.

5. **Seismic Monitoring Identification of Subsurface Structural Features:** Seismic monitoring data indicate the possible presence of a fault or fracture near the CO_2 injection zone in the sedimentary cover or in the basement (concentration of microearthquakes of $M \ll 1$ in elongated clusters). The Testing and Monitoring Plan provides extended information about the microseismic monitoring network.

   Action: The cause of the indicated microseismicity patterns will be evaluated. In conjunction, various operational parameters will be tested using the computational model to determine if the microseismic activity can be controlled to acceptable levels

6. **Seismic Monitoring Identification of Unexpected Plume Pattern:** Seismic monitoring data indicate a CO_2 plume migration outside the predicted extent. The observation of microearthquakes ($M \ll 1$) may also help define the actual shape of the maximum pressure field associated with the plume extensions.

Action: The computational model will be calibrated to match the location of observed microseismicity patterns indicative of plume extensions.

7. **Other triggers for reevaluation may include:** facility operating changes; new injection activities or other deep wells added in the AoR; new owner/operators; new site characterization data; a seismic event or other emergency; and unexpected changes in rate, direction, and extent of plume/pressure front movement.

Reevaluation Strategy

If any of these conditions occurs, the FutureGen Alliance will reevaluate the AoR to comply with requirements at 40 CFR 146.84 as described below. Ongoing direct and indirect monitoring data, which provide relevant information for understanding the development and evolution of the CO_2 plume, will be used to support reevaluation of the AoR. These data include: 1) the chemical and physical characteristics of the CO_2 injection stream based on sampling and analysis; 2) continuous monitoring of injection mass flow rate, pressure, temperature, and fluid volume; 3) measurements of pressure response at all site monitoring wells; and 4) CO_2 arrival and transport response at all site monitoring wells based on direct aqueous measurements and selected indirect monitoring method(s). The FutureGen Alliance will compare these observational data with predicted responses from the computational model and if significant discrepancies between the observed and predicted responses exist, the monitoring data will be used to recalibrate the model (Figure 17). In cases where the observed monitoring data agree with model predictions, an AoR reevaluation will consist of a demonstration that monitoring data are consistent with modeled predictions. As additional characterization data are collected, the site conceptual model will be revised and the modeling steps described above will be repeated to incorporate new knowledge about the site.

The FutureGen Alliance will submit a report notifying the UIC Program Director of the results of this reevaluation within 90 days of detection. At that time, the FutureGen Alliance will either: 1) submit the monitoring data and modeling results to demonstrate that no adjustment to the AoR is required; or 2) modify its Corrective Action, Emergency and Remedial Response, and other plans to account for the revised AoR. All modeling inputs and data used to support AoR reevaluations will be retained by the FutureGen Alliance for the period of the project.

To the extent that the reevaluated AoR is different from the one identified in this supporting documentation, the FutureGen Alliance will identify all active and abandoned wells and underground mines that penetrate the confining zone (the Eau Claire Formation) in the reevaluated AoR and will perform corrective actions on those wells. As needed, the FutureGen Alliance will revise all other plans, such as the Emergency and Remedial Response Plan, to take into account the reevaluated AoR and will submit those plans to the UIC Program Director for review and approval.

Note that seismic events are covered under the Emergency and Remedial Response Plan. A tiered approach to responding to seismic events will be based on magnitude and location. A notification procedure is provided in that plan.

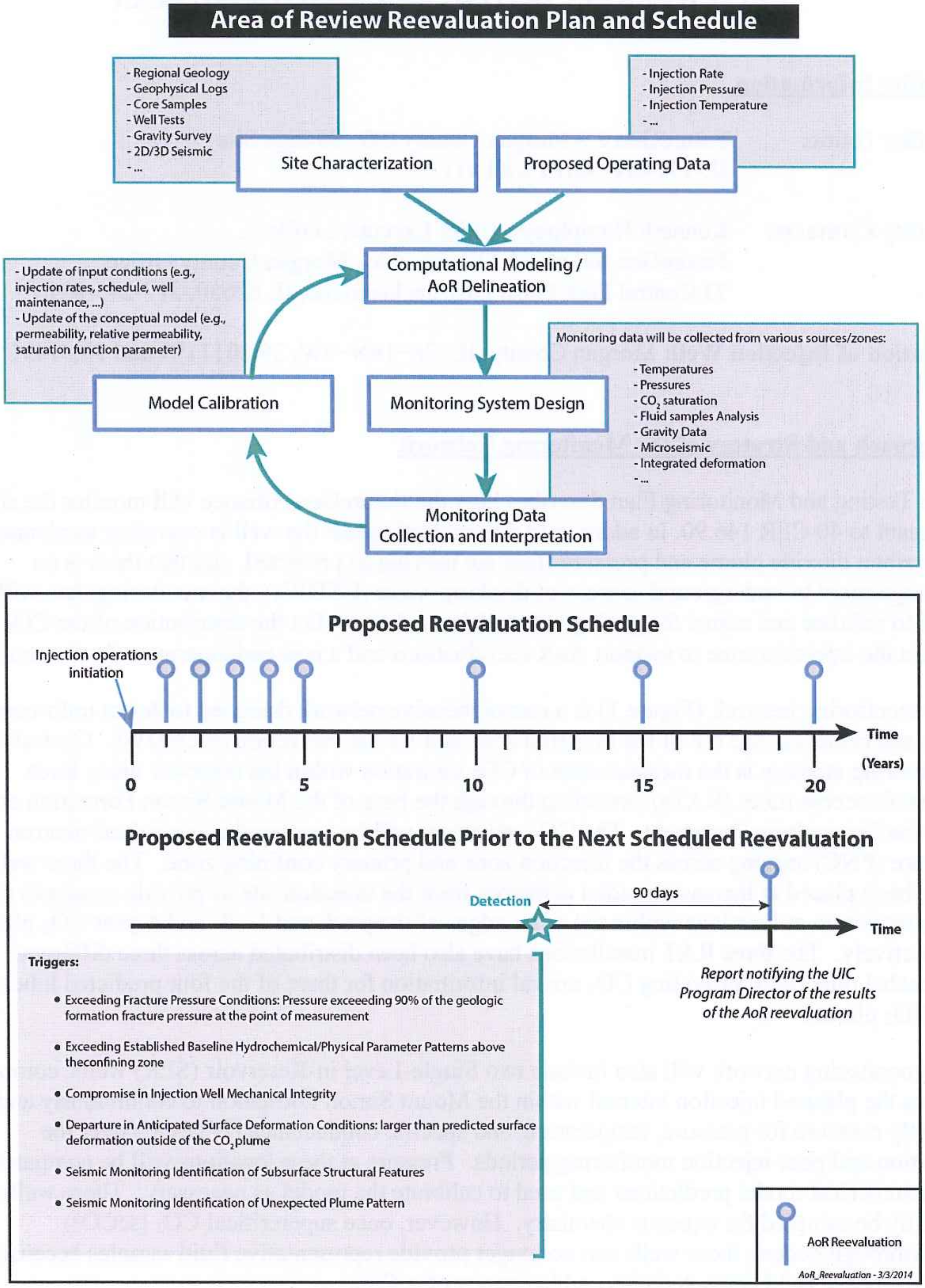

Figure 17. AoR Correction Action Plan Flowchart

ATTACHMENT C: TESTING AND MONITORING PLAN

Facility Information

Facility Name: FutureGen 2.0 Morgan County CO_2 Storage Site
IL-137-6A-0001 (Well #1)

Facility Contacts: Kenneth Humphreys, Chief Executive Officer,
FutureGen Industrial Alliance, Inc., Morgan County Office,
73 Central Park Plaza East, Jacksonville, IL 62650, 217-243-8215

Location of Injection Well: Morgan County, IL; 26–16N–9W; 39.80111°N and 90.07491°W

Approach and Strategy of the Monitoring Network

This Testing and Monitoring Plan describes how the FutureGen Alliance will monitor the site pursuant to 40 CFR 146.90. In addition to demonstrating that the well is operating as planned, the carbon dioxide plume and pressure front are moving as predicted, and that there is no endangerment to underground sources of drinking water (USDWs), the monitoring data will be used to validate and adjust the geological models used to predict the distribution of the CO_2 within the injection zone to support AoR reevaluations and a non-endangerment demonstration.

The monitoring network (Figure 1) is a comprehensive network designed to detect unforeseen CO_2 and brine leakage out of the injection zone and for the protection of USDWs. Central to this monitoring strategy is the measurement of CO_2 saturation within the reservoir using three reservoir access tubes (RATs) extending through the base of the Mount Simon Formation and into the Precambrian basement. The CO_2 saturation will be measured using pulsed-neutron capture (PNC) logging across the injection zone and primary confining zone. The three wells have been placed at increasing radial distances from the injection site to provide measures of CO_2 saturation at locations within the outer edges of the predicted 1-, 2- and 4-year CO_2 plumes, respectively. The three RAT installations have also been distributed across three different azimuthal directions, providing CO_2 arrival information for three of the four predicted lobes of the CO_2 plume.

The monitoring network will also include two Single-Level in-Reservoir (SLR) wells, completed across the planned injection interval within the Mount Simon Formation to continuously and directly measure for pressure, temperature, and specific conductance (P/T/SpC) over the injection and post-injection monitoring periods. Pressure at these locations will be compared with numerical model predictions and used to calibrate the model as necessary. These wells will initially be sampled for aqueous chemistry. However, once supercritical CO_2 ($scCO_2$) breakthrough occurs, these wells can no longer provide representative fluid samples because of the two-phase fluid characteristics and buoyancy of $scCO_2$.

Another central component of the monitoring strategy is to monitor for any unforeseen leakage from the reservoir as early as possible. This will be accomplished by monitoring for CO_2 and brine intrusion immediately above the confining zone. These two "early-detection" wells will be completed in the first permeable unit above the Eau Claire caprock, within the Ironton Sandstone. These wells will be continuously monitored for P/T/SpC, and periodically sampled to characterize aqueous chemistry. Leakage detected at the Above Confining Zone (ACZ) wells would most likely be identified based on pressure response, but it may also result in changes in aqueous chemistry.

The monitoring network will also include one well located in the lowermost USDW, the St. Peter Sandstone. This well will be instrumented to monitor continuously for P/T/SpC, and periodically samples will be collected for characterizing aqueous chemistry. This USDW well is co-located with the ACZ well located closest to the injection well site.

Comparison of observed and simulated arrival responses at the early-detection wells and shallower monitoring locations will be continued throughout the life of the project and will be used to calibrate and verify the model, and improve its predictive capability for confirming CO_2 containment and/or assessing the long-term environmental impacts of any CO_2 leakage. If deep early-detection monitoring locations indicate that primary confining zone leakage has occurred, a comprehensive near-surface-monitoring program will be activated to fully assess environmental impacts relative to baseline conditions.

Beyond the direct measures of the monitoring well network, two indirect monitoring techniques—deformation monitoring and microseismic monitoring—will be used to detect the development of the pressure front, which results from the injection of CO_2. The objective of the deformation monitoring is to provide a means to detect the development of an asymmetric plume that would be different from the predicted plume shape. The objective of the microseismic monitoring network is to accurately determine the locations, magnitudes, and focal mechanisms of injection-induced seismic events with the primary goals of 1) addressing public and stakeholder concerns related to induced seismicity, 2) estimating the spatial extent of the pressure front from the distribution of seismic events, and 3) identifying features that may indicate areas of caprock failure and possible containment loss.

The monitoring network will address transport uncertainties by adopting an "adaptive" or "observational" monitoring approach (i.e., the monitoring approach will be adjusted as needed based on observed monitoring and updated modeling results). This monitoring approach will involve continually evaluating monitoring results and making adjustments to the monitoring program as needed, including the option to install additional wells in outyears to verify CO_2 plume and pressure front evolution and/or evaluate leakage potential (any such changes to this testing and monitoring approach will be made in consultation with the UIC Program Director).

Specifically, as part of this adaptive monitoring approach, a pressure-monitoring well will be constructed within 5 years of the start of injection. The final placement/location of this well will be informed by any observed asymmetry in pressure front development during the early years of injection and will be located outside the CO_2 plume extent. The distance from the plume boundary will be based on the monitoring objective of providing information that will be useful for both leakage detection and model calibration within the early years of project operation. It is estimated that the well will be located less than 5 miles from the predicted plume extent in order to provide an intermediate-field pressure monitoring capability that would benefit leak detection capabilities and meet the requirement for direct pressure monitoring of the pressure front (i.e., outside the CO_2 plume area).

A second but less desirable approach would be to locate the well at a more distal location (e.g., 15-20 miles) so that there is time to install the well prior to pressure front arrival (at Waverley it is predicted to take 4 to 5 years). This location would have very limited benefit from a leak detection perspective, but it would be useful for calibrating the reservoir model.

<u>Quality assurance and surveillance measures:</u>

Data quality assurance and surveillance protocols adopted by the project have been designed to facilitate compliance with the requirements specified in 40 CFR 146.90(k). Quality Assurance (QA) requirements for direct measurements within the injection zone, above the confining zone, and within the shallow USDW aquifer that are critical to the Testing and Monitoring program (e.g., pressure and aqueous concentration measurements) are described in the Quality Assurance and Surveillance Plan (QASP) that is attached to this Testing and Monitoring Plan. These measurements will be performed based on best industry practices and the QA protocols recommended by the geophysical services contractors selected to perform the work. The QASP is presented in Appendix G of this Plan.

Collection and recording of continuous monitoring data will occur at the frequencies described in Table 1.

Table 1. Sampling and Recording Frequencies for Continuous Monitoring.

Well Condition	Minimum sampling frequency: once every	Minimum recording frequency: once every
For operating injection wells that are required to monitor continuously:	5 seconds	5 minutes [1]
For injection wells that are shut-in:	4 hours	4 hours
For monitoring wells (USDW, ACZ, SLR):	30 minutes	2 hours

[1] This can be an average of the sampled readings* over the previous 5-minute recording interval, or the maximum (or minimum, as appropriate) value identified over that recording interval

Notes:
Sampling frequency refers to how often the monitoring device obtains data from the well for a particular parameter. For example, a recording device might sample a pressure transducer monitoring injection pressure once every two seconds and save this value in memory.

Recording frequency refers to how often the sampled information gets recorded to digital format (such as a computer hard drive). Following the same example above, the data from the injection pressure transducer might be recorded to a hard drive once every minute.

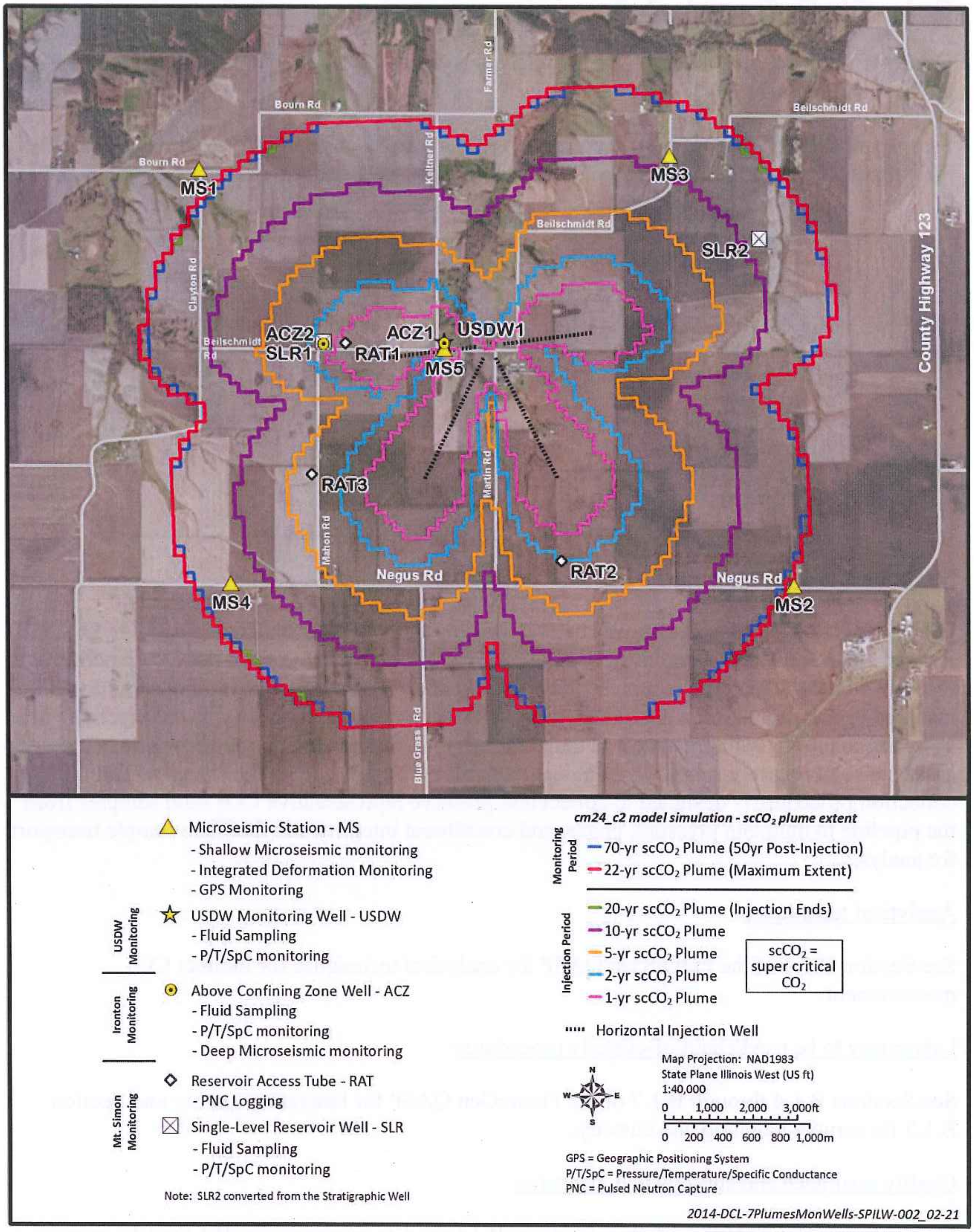

Figure 1. Monitoring Network Layout and Predicted Plume Extents at Multiple Time Intervals.

Carbon Dioxide Stream Analysis

FutureGen will conduct injection stream analysis to meet the requirements of 40 CFR 146.90(a), as described below.

Samples of the CO2 stream will be collected regularly (e.g., quarterly) for chemical analysis of the parameters listed in Table 2. Continuous monitoring is described in Table 1 of this plan.

Table 2. Parameters and Frequency for CO_2 Stream Analysis.

Parameter/Analyte	Frequency
Pressure	Continuous
Temperature	Continuous
CO_2 (%)	quarterly
Water (lb/mmscf)	quarterly
Oxygen (ppm)	quarterly
Sulfur (ppm)	quarterly
Arsenic (ppm)	quarterly
Selenium (ppm)	quarterly
Mercury (ppm)	quarterly
Argon (%)	quarterly
Hydrogen Sulfide (ppm)	quarterly

Sampling methods:

Grab samples of the CO_2 stream will be obtained for analysis of gases, including CO_2, O_2, H2S, Ar, and water moisture. Samples of the CO_2 stream will be collected from the CO_2 pipeline at a location where the material is representative of injection conditions. A sampling station will be installed in the ground or on a structure close to the pipeline and connected to the pipeline via a sampling manifold with pressure and temperature (P/T) instrumentation to accommodate double-sided constant pressure sampling cylinders that will be used to collect the samples. The collection procedure is designed to collect and preserve representative CO_2 fluid samples from the pipeline to maintain pressure, phase, and constituent integrity and facilitate sample transport for analysis.

Analytical techniques:

See Section B.1.4 of the FutureGen QASP for analytical techniques for indirect CO_2 measurement.

Laboratory to be used/chain-of-custody procedures:

See Sections B.1.4 through B.1.7 of the FutureGen QASP for laboratory quality and Section B.1.3 for sample handling and custody.

Quality assurance and surveillance measures:

See the FutureGen QASP, including Sections B.14 for data management, B.1 for CO_2 sampling and analysis, and B.1.3 and B.14 for analytical techniques and chain of custody procedures.

Continuous Recording of Injection Pressure, Rate, and Volume; Annulus Pressure

FutureGen will conduct continuous monitoring of injection parameters to meet the requirements of 40 CFR 146.90(b), as described below.

Continuous Recording of Injection Mass Flow Rate

The mass flow rate of CO_2 injected into the well field will be measured by a flow meter skid with a Coriolis mass flow transmitter for each well. Each meter will have an analog output (Micro Motion Coriolis Flow and Density Meter Elite Series or similar). A total of six flow meters will be supplied, providing for two spare flow meters to allow for flow meter servicing and calibration. The flow meters will be connected to the main CO_2 storage site SCADA system for continuous monitoring and control of the CO_2 injection rate into each well.

Continuous Recording of Injection Pressure

The pressure of the injected CO_2 will be continuously measured for each well at a regular frequency by an electronic pressure transmitter with analog output mounted on the CO_2 line associated with each injection well at a location near the wellhead. The transmitter will be connected to the annulus pressurization system (APS) programmable logic controller (PLC) located in the Control Building adjacent to the injection well pad.

Continuous Recording of Injection Temperature

The temperature of the injected CO_2 will be continuously measured for each well at a regular frequency by an electronic temperature transmitter. The temperature transmitter will be mounted in a temperature well in the CO_2 line at a location close to the pressure transmitter near the wellhead. The transmitter will be connected to the APS PLC located in the Control Building adjacent to the injection well pad.

Instruments for measuring surface injection pressure and temperature will be calibrated initially before commencing injection and recalibrated periodically as needed based on regular (e.g., quarterly) instrument checks. These instruments for measuring surface injection pressure and temperature will be recalibrated annually.

Bottomhole Pressure and Temperature

An optical or electronic P/T gauge will be installed on the outside of the tubing string, approximately 30 ft above the packer, and ported into the tubing to continuously measure CO_2 injection P/T inside the tubing at this depth. In addition, injection P/T will be continuously measured at the surface via real-time P/T instruments installed in the CO_2 pipeline near the pipeline interface with the wellhead.

The CO_2 injection stream will be continuously monitored at the surface for pressure, temperature, and flow, as part of the instrumentation and control systems for the FutureGen CO_2 Pipeline and Storage Project. The P/T will also be monitored within each injection well at a position located immediately above the injection zone at the end of the injection tubing. The downhole sensor will be the point of compliance for maintaining injection pressure below 90%

of formation fracture pressure. If the downhole probe goes out between scheduled maintenance events then the surface pressure limitation noted in Attachment A of this permit will be used as a backup until the downhole probe/gauge is repaired or replaced.

Corrosion Monitoring

FutureGen will conduct corrosion monitoring of well materials quarterly to meet the requirements of 40 CFR 146.90(c), as described below.

Corrosion of well materials will be monitored using the corrosion coupon method. Corrosion monitoring of well casing and tubing materials will be conducted using coupons placed in the CO_2 pipeline. The coupons will be made of the same material as the long string casing and the injection tubing. The coupons will be removed quarterly and assessed for corrosion using the ASTM International (ASTM) G1-03, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens (ASTM 2011). Upon removal, coupons will be inspected visually for evidence of corrosion (e.g., pitting). The weight and size (thickness, width, length) of the coupons will also be measured and recorded each time they are removed.

The corrosion rate will be calculated as the weight loss during the exposure period divided by the duration (i.e., weight loss method).

Casing and tubing will also be evaluated periodically for corrosion throughout the life of the injection well by running wireline casing inspection logs (CILs). The frequency of running these tubing and casing inspection logs will be determined based on site-specific parameters and well performance. Wireline tools will be lowered into the well to directly measure properties of the well tubulars that indicate corrosion. The tools (described in Table 3), which may be used to monitor the condition of well tubing and casing, include:

- Mechanical casing evaluation tools, referred to as calipers, which have multiple "fingers" that measure the inner diameter of the tubular as the tool is raised or lowered through the well.

- Ultrasonic tools, which are capable of measuring wall thickness in addition to the inner diameter (radius) of the well tubular and can also provide information about the outer surface of the casing or tubing.

- Electromagnetic tools, which are able to distinguish between internal and external corrosion effects using variances in the magnetic flux of the tubular being investigated. These tools are able to provide mapped (circumferential) images with high resolution such that pitting depths, due to corrosion, can often be accurately measured.

Table 3. Wireline Tools for Monitoring Corrosion of Casing and Tubing.

Tool Name	Mechanical	Ultrasonic	Electromagnetic
	Multifinger Imaging Tool[a]	**Ultrasonic Imager Tool[a]**	**High-Resolution Vertilog[b]**
Parameter(s) Measured	Internal radius; does not measure wall thickness	Inner diameter, wall thickness, acoustic impedance, cement bonding to casing Up to 180 measurements per revolution	Magnetic flux leakage (internal and external) Full 360-degree borehole coverage
Tool OD (in.)	1.6875, 2.75, 4 (multiple versions available)	3.41 to 8.625	2.2 to 8.25
Tubular Size That Can Be Measured Min/Max (in.)	2/4.5, 3/7, 5/10 (multiple versions available)	4.5/13.375	4.5/9.625
Comments, limitations, special requirements, etc.	Typically run on memory using slickline. Can also be run in surface real-time mode.	Can detect evidence of defects/corrosion on casing walls (internal/external), quality of cement bond to pipe, and channels in cement. Moderate logging speed (30 ft/min) is possible.	Can distinguish between general corrosion, pitting, and perforations. Can measure pipe thickness. High logging speed (200 ft/min) is possible. Cannot evaluate multiple strings of tubular simultaneously.

(a) Schlumberger Limited

(b) Baker Hughes, Inc.

Groundwater Quality Monitoring

FutureGen will conduct groundwater quality/geochemical monitoring above the confining zone to meet the requirements of 40 CFR 146.90(d).

FutureGen will conduct periodic fluid sampling throughout the injection phase in three wells constructed for the purpose of this project: two ACZ monitoring wells in the Ironton Sandstone (the first permeable unit above the confining zone) and a lowermost USDW well in the St. Peter Sandstone. Details about these wells are in Table 4, and Figure 1 is a map with the well locations. The coordinates (in decimal degrees) of the wells are in Appendix A of this plan. Well construction information and well schematics are in Appendix B of this plan.

Table 4. Monitoring Wells to Be Used for GroundWater/Geochemical Sampling Above the Confining Zone.

	Above Confining Zone (ACZ)	**USDW**
Number of Wells	2	1
Total Depth (ft)	3,470	2,000
Lat/Long (WGS84)	ACZ1: 39°48'01.24"N, 90°04'41.87"W ACZ2: 39°48'01.06"N, 90°05'16.84"W	USDW1: 39°48'01.73"N, 90°04'41.87"W
Monitored Zone	Ironton Sandstone	St. Peter Sandstone
Monitoring Instrumentation	Fiber-optic (microseismic) cable cemented in annulus; P/T/SpC probe in monitored interval*	P/T/SpC probe in monitored interval*

* The P/T/SpC (pressure, temperature, specific conductance) probe is an electronic downhole multi-parameter probe incorporating sensors for measuring fluid P/T/SpC within the monitored interval. The probe is installed inside the tubing string, which is perforated (slotted) over the monitoring interval. Sensor signals are multiplexed to a surface data logger through a single conductor wireline cable.

FutureGen will also conduct baseline sampling in the shallow, semi-consolidated glacial sediments that make up the surficial aquifer. This sampling will use nine private water wells and one shallow monitoring well that has been drilled for the project (Figure 2). The locations of the surficial aquifer monitoring wells are tabulated in Appendix C of this plan.

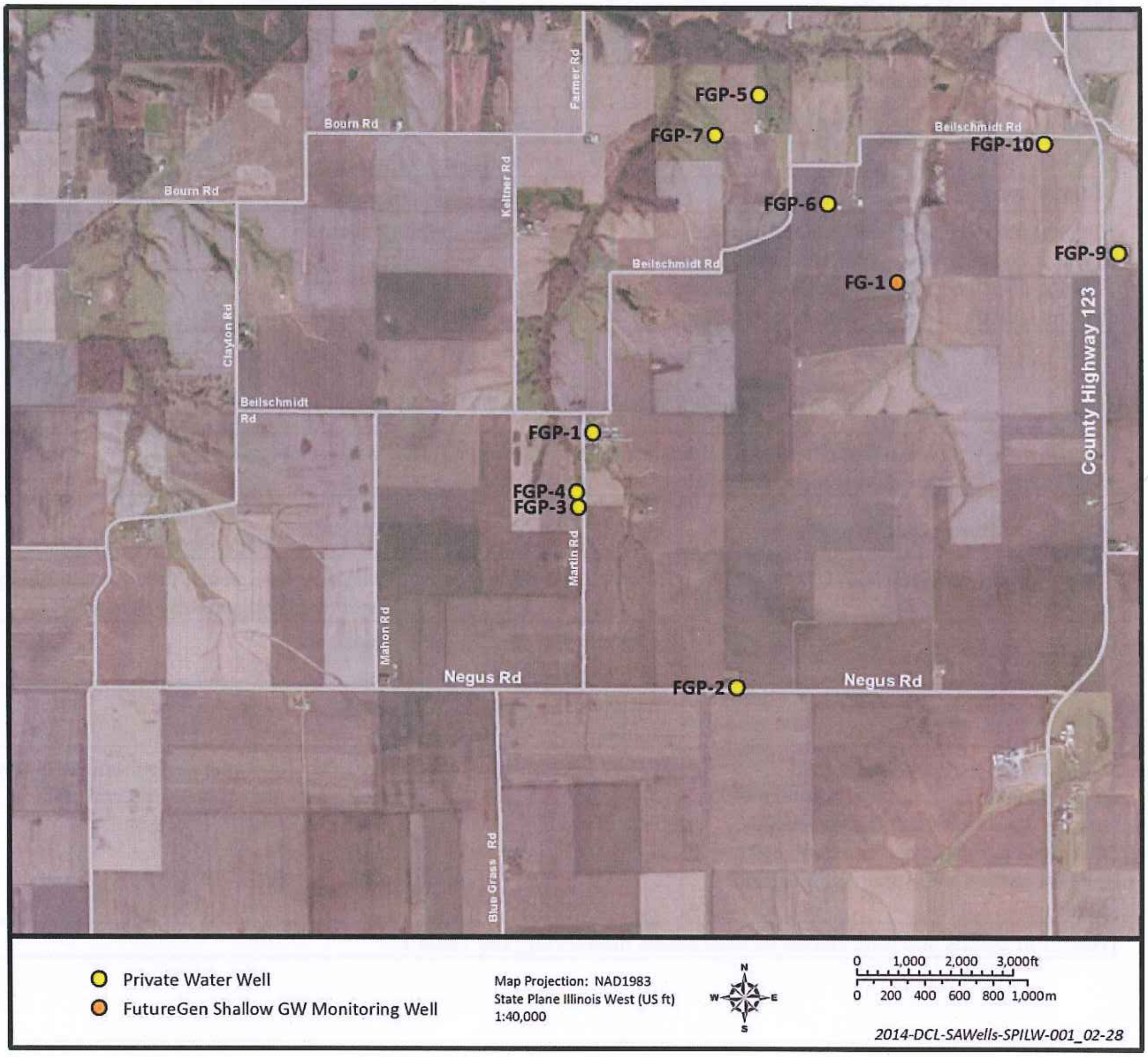

Figure 2. Surficial Aquifer Monitoring Well Locations. Well FG-1 is a dedicated well drilled for the purposes of the FutureGen 2.0 Project. FGP-1 through FGP-10 are local landowners' wells.

The tables below list the parameters that will be measured and the sampling frequencies. They include both dissolved gas compositional analysis (including CO_2) and measurements of dissolved inorganic carbon and pH. Continuous monitoring is described in Table 1 of this plan.

Table 5. Sampling Schedule for Surficial Aquifer Monitoring Wells.

Monitoring well name/location/map reference: Surficial aquifer monitoring wells (Figure 2) **Well depth/formation(s) sampled:** Shallow glacial sediments (approx. 17 ft – 49 ft)		
Parameter/Analyte	**Frequency (Baseline)**	**Frequency (Injection Phase)**
Dissolved or separate-phase CO_2	At least 3 sampling events	None planned
Water-level	At least 3 sampling events	None planned
Temperature	At least 3 sampling events	None planned
Other parameters, including total dissolved solids, pH, specific conductivity, major cations and anions, trace metals, dissolved inorganic carbon, total organic carbon, carbon and water isotopes, and radon	At least 3 sampling events	None planned

Table 6. Sampling Schedule for the USDW Monitoring Well.

Monitoring well name/location/map reference: One USDW monitoring well (see Figure 1) **Well depth/formation(s) sampled:** St. Peter Sandstone (2,000 ft)		
Parameter/Analyte	**Frequency (Baseline)**	**Frequency (Injection Phase)**
Dissolved or separate-phase CO_2	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
Pressure	Continuous, 1 year minimum	Continuous
Temperature	Continuous, 1 year minimum	Continuous
Other parameters, including total dissolved solids, pH, specific conductivity, major cations and anions, trace metals, dissolved inorganic carbon, total organic carbon, carbon and water isotopes, and radon	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
Note: For details and information on continuous monitoring, see Table 1.		

Table 7. Sampling Schedule for ACZ Monitoring Wells

Monitoring well name/location/map reference: Two ACZ monitoring wells (see Figure 1) **Well depth/formation(s) sampled:** Ironton Sandstone (3,470 ft)		
Parameter/Analyte	**Frequency (Baseline)**	**Frequency (Injection Phase)**
Dissolved or separate-phase CO_2	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
Pressure	Continuous, 1 year minimum	Continuous
Temperature	Continuous, 1 year minimum	Continuous
Other parameters, including total dissolved solids, pH, specific conductivity, major cations and anions, trace metals, dissolved inorganic carbon, total organic carbon, carbon and water isotopes, and radon	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
Note: For details and information on continuous monitoring, see Table 1.		

<u>Sampling methods</u>:

Sampling and analytical requirements for target parameters are given in Tables 8 and 9, respectively. A comprehensive suite of geochemical and isotopic analyses will be performed on collected fluid samples and analytical results will be used to characterize baseline geochemistry and provide a metric for comparison during operational phases. Selection of this initial analyte list was based on relevance for detecting the presence of fugitive brine and CO_2.

During all groundwater sampling, field parameters (pH, specific conductance, and temperature) will be monitored for stability and used as an indicator of adequate well purging (i.e., parameter stabilization provides indication that a representative sample has been obtained). Calibration of field probes will follow the manufacturer's instructions using standard calibration solutions. A comprehensive list of target analytes under consideration and groundwater sample collection requirements is provided in Table 8.

All sampling and analytical measurements will be performed in accordance with project quality assurance requirements, samples will be tracked using appropriately formatted chain-of-custody forms, and analytical results will be managed in accordance with a project-specific data management plan.

The relative benefit of each analytical measurement will be evaluated throughout the design and initial injection testing phase of the project to identify the analytes best suited to meeting project monitoring objectives under site-specific conditions. If some analytical measurements are shown to be of limited use, they will be removed from the analyte list and not carried forward through the operational phases of the project. This selection process will consider the uniqueness and signature strength of each potential analyte and whether their characteristics provide for a high-value leak-detection capability. Any modification to the parameter list in Table 8 will be made in consultation with the UIC Program Director. Modifications to the parameter list will also require modifications to the permits through the process described in 40 C.F.R. Part 144.

Table 8. Aqueous Sampling Requirements for Target Parameters.

Parameter	Volume/Container	Preservation	Holding Time
Major Cations: Al, Ba, Ca, Fe, K, Mg, Mn, Na, Si,	20-mL plastic vial	Filtered (0.45 μm), HNO_3 to pH <2	60 days
Trace Metals: Sb, As, Cd, Cr, Cu, Pb, Se, Tl	20-mL plastic vial	Filtered (0.45 μm), HNO_3 to pH <2	60 days
Cyanide (CN-)	250-mL plastic vial	NaOH to pH > 12, 0.6 g ascorbic acid Cool 4°C,	14 days
Mercury	250-mL plastic vial	Filtered (0.45 μm), HNO_3 to pH <2	28 days
Anions: Cl^-, Br^-, F^-, SO_4^{2-}, NO_3^-	125-mL plastic vial	Filtered (0.45 μm), Cool 4°C	45 days
Total and Bicarbonate Alkalinity (as $CaCO_3^{2-}$)	100-mL HDPE	Filtered (0.45 μm), Cool 4°C	14 days
Gravimetric Total Dissolved Solids (TDS)	250-mL plastic vial	Filtered (0.45 μm), no preservation, Cool 4°C	7 days
Water Density	100-mL plastic vial	No preservation, Cool 4°C	
Total Inorganic Carbon (TIC)	250-mL plastic vial	H_2SO_4 to pH <2, Cool 4°C	28 days
Dissolved Inorganic Carbon (DIC)	250-mL plastic vial	Filtered (0.45 μm), H_2SO_4 to pH <2, Cool 4°C	28 days
Total Organic Carbon (TOC)	250-mL amber glass	Unfiltered, H_2SO_4 to pH <2, Cool 4°C	28 days
Dissolved Organic Carbon (DOC)	125-mL plastic vial	Filtered (0.45 μm), H_2SO_4 to pH <2, Cool 4°C	28 days
Volatile Organic Analysis (VOA)	Bottle set 1: 3-40-mL sterile clear glass vials Bottle set 2: 3-40-mL sterile amber glass vials	Zero headspace, Cool <6 °C, Clear glass vials will be UV-irradiated for additional sterilization	7 days
Methane	Bottle set 1: 3-40-mL sterile clear glass vials Bottle set 2: 3-40-mL sterile amber glass vials	Zero headspace, Cool <6 °C, Clear glass vials (bottle set 1) will be UV-irradiated for additional sterilization	7 days
Stable Carbon Isotopes $^{13/12}C$ ($\delta^{13}C$) of DIC in Water	60-mL plastic or glass	Filtered (0.45 μm), Cool 4°C	14 days
Radiocarbon ^{14}C of DIC in Water	60-mL plastic or glass	Filtered (0.45 μm), Cool 4°C	14 days
Hydrogen and Oxygen Isotopes $^{2/1}H$ (δD) and $^{18/16}O$ ($\delta^{18}O$) of Water	60-mL plastic or glass	Filtered (0.45 μm), Cool 4°C	45 days
Carbon and Hydrogen Isotopes (^{14}C, $^{13/12}C$, $^{2/1}H$) of Dissolved Methane in Water	1-L dissolved gas bottle or flask	Benzalkonium chloride capsule, Cool 4°C	90 days
Compositional Analysis of Dissolved Gas in Water (including N_2, CO_2, O_2, Ar, H_2, He, CH_4, C_2H_6, C_3H_8, iC_4H_{10}, nC_4H_{10}, iC_5H_{12}, nC_5H_{12}, and C_6+)	1-L dissolved gas bottle or flask	Benzalkonium chloride capsule, Cool 4°C	90 days
Radon (^{222}Rn)	1.25-L PETE	Pre-concentrate into 20-mL scintillation cocktail. Maintain groundwater temperature prior to pre-concentration	1 day
pH	Field parameter	None	<1 h
Specific Conductance	Field parameter	None	<1 h

HDPE = high-density polyethylene; PETE = polyethylene terephthalate.

Table 9. Analytical Requirements.

Parameter	Analysis Method	Detection Limit or Range	Typical Precision/ Accuracy	QC Requirements
Major Cations: Al, Ba, Ca, Fe, K, Mg, Mn, Na, Si,	ICP-AES, EPA Method 6010B or similar	1 to 80 μg/L (analyte dependent)	±10%	Daily calibration; blanks, LCS, and duplicates and matrix spikes at 10% level per batch of 20
Trace Metals: Sb, As, Cd, Cr, Cu, Pb, Se, Tl	ICP-MS, EPA Method 6020 or similar	0.1 to 2 μg/L (analyte dependent)	±10%	Daily calibration; blanks, LCS, and duplicates and matrix spikes at 10% level per batch of 20
Cyanide (CN-)	SW846 9012A/B	5 μg/L	±10%	Daily calibration; blanks, LCS, and duplicates at 10% level per batch of 20
Mercury	CVAA SW846 7470A	0.2 μg/L	±20%	Daily calibration; blanks, LCS, and duplicates and matrix spikes at 10% level per batch of 20
Anions: Cl^-, Br^-, F^-, SO_4^{2-}, NO_3^-	Ion Chromatography, EPA Method 300.0A or similar	33 to 133 μg/L (analyte dependent)	±10%	Daily calibration; blanks, LCS, and duplicates at 10% level per batch of 20
Total and Bicarbonate Alkalinity (as $CaCO_3^{2-}$)	Titration, Standard Methods 2320B	1 mg/L	±10%	Daily calibration; blanks, LCS, and duplicates at 10% level per batch of 20
Gravimetric Total Dissolved Solids (TDS	Gravimetric Method Standard Methods 2540C	10 mg/L	±10%	Balance calibration, duplicate samples
Water Density	ASTM D5057	0.01 g/mL	±10%	Balance calibration, duplicate samples
Total Inorganic Carbon (TIC)	SW846 9060A or equivalent Carbon analyzer, phosphoric acid digestion of TIC	0.2 mg/L	±20%	Quadruplicate analyses, daily calibration
Dissolved Inorganic Carbon (DIC)	SW846 9060A or equivalent Carbon analyzer, phosphoric acid digestion of DIC	0.2 mg/L	±20%	Quadruplicate analyses, daily calibration
Total Organic Carbon (TOC)	SW846 9060A or equivalent Total organic carbon is converted to carbon dioxide by chemical oxidation of the organic carbon in the sample. The carbon dioxide is measured using a non-dispersive infrared detector.	0.2 mg/L	±20%	Quadruplicate analyses, daily calibration
Dissolved Organic Carbon (DOC)	SW846 9060A or equivalent Total organic carbon is converted to carbon dioxide by chemical oxidation of the organic carbon in the sample. The carbon dioxide is measured using a non-dispersive infrared detector.	0.2 mg/L	±20%	Quadruplicate analyses, daily calibration
Volatile Organic Analysis (VOA)	SW846 8260B or equivalent Purge and Trap GC/MS	0.3 to 15 μg/L	±20%	Blanks, LCS, spike, spike duplicates per batch of 20
Methane	RSK 175 Mod Headspace GC/FID	10 μg/L	±20%	Blanks, LCS, spike, spike duplicates per batch of 20
Stable Carbon Isotopes $^{13/12}C$ ($\delta^{13}C$) of DIC in Water	Gas Bench for $^{13/12}C$	50 ppm of DIC	±0.2p	Duplicates and working standards at 10%

Parameter	Analysis Method	Detection Limit or Range	Typical Precision/ Accuracy	QC Requirements
Radiocarbon ^{14}C of DIC in Water	AMS for ^{14}C	Range: 0 i 200 pMC	±0.5 pMC	Duplicates and working standards at 10%
Hydrogen and Oxygen Isotopes $^{2/1}H$ (δ) and $^{18/16}O$ (^{18}O) of Water	CRDS H_2O Laser	Range: -500‰ to 200‰ vs. VSMOW	$^{2/1}H$: ±2.0‰ $^{18/16}O$: ±0.3‰	Duplicates and working standards at 10%
Carbon and Hydrogen Isotopes (^{14}C, $^{13/12}C$, $^{2/1}H$) of Dissolved Methane in Water	Offline Prep & Dual Inlet IRMS for ^{13}C; AMS for ^{14}C	^{14}C Range: 0 & DupMC	^{14}C: ±0.5pMC ^{13}C: ±0.2‰ $^{2/1}H$: ±4.0‰	Duplicates and working standards at 10%
Compositional Analysis of Dissolved Gas in Water (including N_2, CO_2, O_2, Ar, H_2, He, CH_4, C_2H_6, C_3H_8, iC_4H_{10}, nC_4H_{10}, iC_5H_{12}, nC_5H_{12}, and C_6+)	Modified ASTM 1945D	1 to 100 ppm (analyte dependent)	Varies by compon-ent	Duplicates and working standards at 10%
Radon (^{222}Rn)	Liquid scintillation after pre-concentration	5 mBq/L	±10%	Triplicate analyses
pH	pH electrode	2 to 12 pH units	±0.2 pH unit For indication only	User calibrate, follow manufacturer recommendations
Specific Conductance	Electrode	0 to 100 mS/cm	±1% of reading For indication only	User calibrate, follow manufacturer recommendations

ICP-AES = inductively coupled plasma atomic emission spectrometry; ICP-MS = inductively coupled plasma mass spectrometry; LCS = laboratory control sample; GC/MS = gas chromatography–mass spectrometry; GC/FID = gas chromatography with flame ionization detector; AMS = accelerator mass spectrometry; CRDS = cavity ring down spectrometry; IRMS = isotope ratio mass spectrometry; LC-MS = liquid chromatography-mass spectrometry; ECD = electron capture detector

Laboratory to be used/chain-of-custody procedures:

Samples will be tracked using appropriately formatted chain-of-custody forms. See Sections B.4.3 thru B.4.7 of the FutureGen QASP (Appendix G of this plan) for additional information.

Plan for guaranteeing access to all monitoring locations:

The land on which the ACZ and USDW wells are located will either be purchased or leased for the life of the project, so access will be secured.

Access to the surficial aquifer wells will not be required over the lifetime of the project. Access to wells for baseline sampling has been on a voluntary basis by the well owner. Nine local landowners agreed to have their surficial aquifer wells sampled. See Figure 2 for well locations.

Mechanical Integrity Testing

FutureGen will conduct external mechanical integrity testing (MIT) annually to meet the requirements of 40 CFR 146.90(e), as described below. The following MITs will be performed:

- **Pulsed-neutron capture (PNC) logging** to quantify the flow of water in or around the borehole. Following a baseline PNC log prior to the start of CO_2 injection, subsequent runs will be compared to the baseline to determine changing fluid flow conditions adjacent to the well bore (i.e., formation of channels or other fluid isolation concerns related to the well).

- **Temperature logging** to identify fluid movement along channels adjacent to the well bore. In addition to identifying injection-related flows behind casing, temperature logs can often locate small casing leaks.

To satisfy the annual MIT requirement, a PNC logging tool will be run in each injection well once per year to look for evidence of upward CO_2 migration out of the CO_2 storage zone. The PNC logging tool will be run twice during each event: once in the gas-view mode to detect CO_2 and once in the oxygen-activation mode to detect water.

A temperature log will also be collected in conjunction with each PNC logging run. Because the primary purpose of the external MIT is to demonstrate that there is no upward leakage of fluid out of the storage zone, the PNC logging tool will be run to a depth greater than the bottom of the caprock. Because the injection tubing will extend to a depth below the caprock, the PNC logs will be run inside the tubing; therefore, it will not be necessary to remove the injection tubing to conduct the PNC logging. A preliminary schedule for the annual well maintenance event is provided in Table 10.

Table 10. Schedule for Annual Injection Well Maintenance (per Well).

Activity	Work Days	Cum. Days
Shut down injection, isolate surface system	1	1
Allow well to sit undisturbed for 24 hours	1	2
Conduct PNC logging (external MIT)	2	4
Kill well	2	6
Slickline set plug in tubing above packer	0.5	6.5
Disconnect CO_2 pipeline, instruments, and other lines; remove Christmas tree valves for maintenance or replacement	0.5	7
Reinstall Christmas tree valves, re-connect CO_2 pipeline, instruments, and other lines	1	7
Slickline pull plug from packer	1	9
Perform annular pressure test, internal MIT	1	10
Return well to service	1	10

MIT = mechanical integrity test; PNC = pulsed-neutron capture.

MITs are also required to demonstrate that there are no significant leaks in the casing, tubing, or packer. This requirement will be met by continuously monitoring injection pressure on the annulus between tubing and long-string casing and annulus fluid volume. These functions will be provided by the Annular Pressurization System (APS), which is discussed in the Section of this document on "Continuous Recording of Injection Pressure, Rate, and Volume; Annulus Pressure."

All monitoring wells required under this permit will establish and maintain mechanical integrity. After construction, each monitoring well must establish Internal and External mechanical integrity. Wells that do not have a tubing and packer shall perform a pressure test on the casing. Each monitoring well that reaches the Eau Claire (the confining zone) shall establish mechanical integrity after construction, shall conduct an Internal mechanical integrity test at least every five years or continuously monitor the annulus, and shall conduct an External mechanical integrity test at least every five years. The testing of monitoring wells that reach the Eau Claire shall continue until they are plugged.It is also anticipated that it will be necessary to replace selected well components throughout the 20-year injection period, although the identity of the components and their frequency of replacement cannot be determined in advance. However, the components most likely to require replacement include the wellhead valves (selected portions), the tubing string, the packer, and the bottom-hole P/T gauge and associated cable. A preliminary schedule for the 5-year well maintenance event is provided in Table 11.

Table 11. Schedule for 5-Year Injection Well Maintenance Events (per Well).

Activity	Work Days	Cum. Days
Shut down injection, disassemble surface system	1	1
Arrive onsite with equipment rig-up/set-up	3	4
Conduct PNC logging (external MIT)	2	6
Kill well	2	8
Slickline set plug in tubing above packer	0.5	8.5
Disconnect CO_2 pipeline, instruments, and other lines; remove Christmas tree valves for maintenance or replacement	0.5	9
Pull tubing and P/T gauge and cable	1.5	10.5
Trip back in to pull packer	0.5	11
Pull packer	0.5	11.5
Reinstall new packer w/ plug, trip out to get P/T gauge and cable	1.5	13
Reinstall new P/T gauge and cable and injection tubing	1.5	14.5
Reinstall Christmas tree valves, re-connect CO_2 pipeline, instruments, and other lines.	1.5	16
Slickline pull plug from packer	1	17
Rig down and demobilize	3	20
Perform annular pressure test, internal MIT	1	21
Return well to service	1	22

Pressure Fall-Off Testing

FutureGen will conduct annual pressure fall-off testing to meet the requirements of 40 CFR 146.90(f), as described below. Pressure fall-off tests will provide the following information:

- Confirmation of hydrogeologic reservoir properties;
- Long-term pressure buildup in the injection reservoir(s) due to CO_2 injection over time;
- Average reservoir pressure, which can be compared to modeled predictions of reservoir pressure to verify that the operation is responding as modeled/predicted and identify the need for recalibration of the AoR model in the event that the monitoring results do not match expectations; and
- Formation damage (skin) near the well bore, which can be used to diagnose the need for well remediation/rehabilitation.

In the pressure fall-off test, flow is maintained at a steady rate for a period of time, then injection is stopped, the well is shut-in, and bottom-hole pressure is monitored and recorded for a period of time sufficient to make a valid observation of the pressure fall-off curve. Downhole or surface pressure gauges will be used to record bottom-hole pressures during the injection period and the fall-off period. Pressure gauges that are used for the purpose of the fall-off test shall have been calibrated no more than one year prior to the date of the fall-off test with current calibration certificates provided with the test results to EPA. In lieu of removing the injection tubing, the calibration of downhole pressure gauges will demonstrate accuracy by using a second pressure gauge, with current certified calibration, that will be lowered into the well to the same depth as the permanent downhole gauge. Calibration curves, based on annual calibration checks (using the second calibrated pressure gauge) developed for the downhole gauge, can be used for the purpose of the fall-off test. If used, these calibration curves (showing all historic pressure deviations) will accompany the fall-off test data submitted to EPA. Pressures will be measured at a frequency that is sufficient to measure the changes in bottom-hole pressure throughout the test period, including rapidly changing pressures immediately following cessation of injection. The fall-off period will continue until radial flow conditions are observed, as indicated by stabilization of pressure and leveling off of the pressure derivative curve. The fall-off test may also be truncated if boundary effects are encountered, which would be indicated as a change in the slope of the derivative curve, or if radial flow conditions are not observed. In addition to the radial flow regime, other flow regimes may be observed from the fall-off test, including spherical flow, linear flow, and fracture flow. Analysis of pressure fall-off test data will be done using transient-pressure analysis techniques that are consistent with EPA guidance for conducting pressure fall-off tests (EPA 1998, 2002).

See Section B.6 of the FutureGen QASP for details on pressure fall-off testing.

Carbon Dioxide Plume and Pressure-Front Tracking

FutureGen will conduct direct and indirect CO_2 plume and pressure-front monitoring to meet the requirements of 40 CFR 146.90(g).

The following describes FutureGen's planned monitoring well network for plume and pressure-front monitoring (monitoring wells used for monitoring above the confining zone are described above in the Groundwater Quality Monitoring section).

The design to be used for plume and pressure-front monitoring in the injection zone is as follows:

- **Two SLR wells** (one of which is a reconfiguration of the previously drilled stratigraphic well). These wells will be used to monitor within the injection zone beyond the east and west ends of the horizontal CO_2-injection laterals.

  Monitored parameters: pressure, temperature, and hydrogeochemical indicators of CO_2. To meet permit requirements for pressure front monitoring, at least one additional SLR well will be installed outside the lateral extent of the CO_2 plume but within the lateral extent of the defined pressure front AoR. This well will be installed within 5 years of the start of injection.

- **Three RAT wells.** These are fully cased wells, which support PNC logging. The wells will not be perforated to preclude CO_2 flooding of the borehole, which can distort the CO_2 saturation measurements.

  Monitored parameters: quantification of CO2 saturation across the reservoir and caprock.

Details about these wells are provided in Table 12 (the well locations are presented in Figure 1). The coordinates (in decimal degrees) of the wells are provided in Appendix A of this plan. Well construction information and well schematics are provided in Appendix B of this plan.

Table 12. Monitoring Wells to Be Used for Plume and Pressure-Front Monitoring.

	Single-Level In-Reservoir (SLR)	Reservoir Access Tube (RAT)
Number of Wells	2	3
Total Depth (ft)	4,150	4,465
Lat/Long (WGS84)	SLR1: 39°48'01.56"N, 90°05'16.84"W SLR2: 39°48'24.51"N, 90°03'10.73"W	RAT1: 39°48'01.28"N, 90°05'10.59"W RAT2: 39°47'13.09"N, 90°04'08.50"W RAT3: 39°47'32.25"N, 90°05'20.46"W
Monitored Zone	Mount Simon Sandstone	Mount Simon Sandstone
Monitoring Instrumentation	Fiber-optic P/T (tubing conveyed)* P/T/SpC probe in monitored interval**	Pulsed-neutron capture logging equipment

* Fiber-optic cable attached to the outside of the tubing string, in the annular space between the tubing and casing.

** The P/T/SpC (pressure, temperature, specific conductance) probe is an electronic downhole multi-parameter probe incorporating sensors for measuring fluid P/T/SpC within the monitored interval. The probe is installed inside the tubing string, which is perforated (slotted) over the monitoring interval. Sensor signals are multiplexed to a surface data logger through a single conductor wireline cable.

Direct Pressure Monitoring

FutureGen will conduct direct pressure-front monitoring to meet the requirements of 40 CFR 146.90(g)(1).

Continuous monitoring of injection zone P/T will be performed with sensors installed in wells that are completed in the injection zone. P/T monitoring in the injection well and all monitoring wells will be performed using a real-time monitoring system with surface readout capabilities so that pressure gauges do not have to be removed from the well to retrieve data.

The following measures will be taken to ensure that the pressure gauges are providing accurate information on an ongoing basis:

- High-quality (high-accuracy, high-resolution) gauges with low drift characteristics will be used.
- Gauge components (gauge, cable head, cable) will be manufactured of materials designed to provide a long life expectancy for the anticipated downhole conditions.
- Upon acquisition, a calibration certificate will be obtained for every pressure gauge. The calibration certificate will provide the manufacturer's specifications for range, accuracy (% full scale), resolution (% full scale), drift (< psi per year), and calibration results for each parameter. The calibration certificate will also provide the date that the gauge was calibrated and the methods and standards used.
- P/T gauges will be installed in the injection wells above any packers so they can be removed if necessary by removing the tubing string without pulling the packer. P/T gauges will be installed either above or below the packer in the SLR monitoring wells that will have tubing and packer. Redundant gauges may be run on the same cable to provide confirmation of downhole P/T.
- Upon installation, all gauges will be tested to verify they are functioning (reading/transmitting) correctly.

- Pressure gauges that are used for the purpose of direct pressure monitoring will be calibrated on an annual basis with current annual calibration certificates kept on file with the monitoring data. In lieu of removing the injection tubing, the calibration of downhole pressure gauges will demonstrate accuracy by using a pressure gauge, with current certified calibration, that will be lowered into the well to the same depth as the permanent downhole gauge. Calibration curves, based on all annual calibration checks (using the second calibrated gauge method described above) developed for the downhole gauge, may be used for the purpose of direct pressure monitoring. If used, these calibration curves, showing all historic pressure deviations, will be kept on file with the monitoring data.
- Gauges will be pulled and recalibrated whenever a workover occurs that involves removal of tubing. A new calibration certificate will be obtained whenever a gauge is recalibrated.

Injection P/T will also be continuously measured at the surface via real-time P/T instruments installed in the CO_2 pipeline near the pipeline interface with the wellhead. The surface instruments will be checked, and if necessary, recalibrated or replaced on a regular basis (e.g., semi-annually) to ensure they are providing accurate data.

Direct pressure monitoring in the injection zone will take place as indicated in Table 13. Continuous monitoring is described in Table 1 of this plan.

Table 13. Monitoring Schedule for Direct Pressure-Front Tracking.

Well Location/Map Reference	Depth(s)/Formation(s)	Frequency (Baseline)	Frequency (Injection Phase)
Injection Well 1	Mount Simon/4,030 ft.	Continuous	Continuous
Injection Well 2	Mount Simon/4,030 ft.	Continuous	Continuous
Injection Well 3	Mount Simon/4,030 ft.	Continuous	Continuous
Injection Well 4	Mount Simon/4,030 ft.	Continuous	Continuous
Two single-level monitoring wells (SLR Wells 1 and 2)	Mount Simon/4,150 ft.	Continuous	Continuous
Note: For details and information on continuous monitoring, see Table 1.			

See Section B.7 of the FutureGen QASP for further discussion of pressure monitoring.

<u>Plan for guaranteeing access to all monitoring locations:</u>

The land on which these wells are located will either be purchased or leased for the life of the project, so access will be secured.

Direct Geochemical Plume Monitoring

FutureGen will conduct direct CO_2 plume monitoring to meet the requirements of 40 CFR 146.90(g)(1).

Fluid samples will be collected from monitoring wells completed in the injection zone before, during, and after CO_2 injection. The samples will be analyzed for chemical parameter changes that are indicators of the presence of CO_2 and/or reactions caused by the presence of CO_2. Direct fluid sampling in the injection zone will take place as indicated in Table 14. Continuous monitoring is described in Table 1 of this plan.

Table 14. Monitoring Schedule for Direct Geochemical Plume Monitoring.

Monitoring well name/location/map reference: Two SLR monitoring wells (see Figure 1) **Well depth/formation(s) sampled:** Mount Simon Sandstone (4,150 ft)		
Parameter/Analyte	**Frequency (Baseline)**	**Frequency (Injection Phase)**
Dissolved or separate-phase CO_2	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
Pressure	Continuous, 1 year minimum	Continuous
Temperature	Continuous, 1 year minimum	Continuous
Other parameters, including major cations and anions, selected metals, general water-quality parameters (pH, alkalinity, total dissolved solids, specific gravity), and any tracers added to the CO_2 stream	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
Note: For details and information on continuous monitoring, see Table 1.		

<u>Sampling methods:</u>

Periodically, fluid samples will be collected from the monitoring wells completed in the injection zone. Fluid samples will be collected using an appropriate method to preserve the fluid sample at injection zone temperature and pressure conditions. Examples of appropriate methods include using a bomb-type sampler (e.g., Kuster sampler) after pumped or swabbed purging of the sampling interval, using a Westbay sampler, or using a pressurized U-tube sampler (Freifeld et al. 2005).

Fluid samples will be analyzed for parameters that are indicators of CO_2 dissolution (Table 15), including major cations and anions, selected metals, and general water-quality parameters (pH, alkalinity, total dissolved solids [TDS], specific gravity). Changes in major ion and trace element geochemistry are expected in the injection zone. Analysis of carbon and oxygen isotopes in injection zone fluids and the injection stream ($^{13/12}C$, $^{18/16}O$) provides another potential supplemental measure of CO_2 migration. Where stable isotopes are included as an analyte, data quality and detectability will be reviewed throughout the active injection phase and discontinued if these analyses provide limited benefit. Sampling and analytical requirements for target parameters are given in Tables 15 and 16 respectively.

The relative benefit of each analytical measurement will be evaluated throughout the design and initial injection testing phase of the project to identify the analytes best suited to meeting project monitoring objectives under site-specific conditions. If some analytical measurements are shown to be of limited use, they will be removed from the analyte list and not carried forward through the operational phases of the project. This selection process will consider the uniqueness and signature strength of each potential analyte and whether their characteristics provide for a high-value leak-detection capability. Any modification to the parameter list in Table 8 will be made in consultation with the UIC Program Director. Modifications to the parameter list will also require modifications to the permits through the process described in 40 C.F.R. Part 144.

Table 15. Aqueous Sampling Requirements for Target Injection Zone Parameters.

Parameter	Volume/Container	Preservation	Holding Time
Major Cations: Al, Ba, Ca, Fe, K, Mg, Mn, Na, Si,	20-mL plastic vial	Filtered (0.45 μm), HNO_3 to pH <2	60 days
Trace Metals: Sb, As, Cd, Cr, Cu, Pb, Se, Tl	20-mL plastic vial	Filtered (0.45 μm), HNO_3 to pH <2	60 days
Cyanide (CN-)	250-mL plastic vial	NaOH to pH > 12, 0.6 g ascorbic acid Cool 4°C,	14 days
Mercury	250-mL plastic vial	Filtered (0.45 μm), HNO_3 to pH <2	28 days
Anions: Cl^-, Br^-, F^-, SO_4^{2-}, NO_3^-	125-mL plastic vial	Filtered (0.45 μm), Cool 4°C	45 days
Total and Bicarbonate Alkalinity (as $CaCO_3^{2-}$)	100-mL HDPE	Filtered (0.45 μm), Cool 4°C	14 days
Gravimetric Total Dissolved Solids (TDS)	250-mL plastic vial	Filtered (0.45 μm), no preservation, Cool 4°C	7 days
Water Density	100 mL plastic vial	No preservation, Cool 4°C	
Total Inorganic Carbon (TIC)	250-mL plastic vial	H_2SO_4 to pH <2, Cool 4°C	28 days
Dissolved Inorganic Carbon (DIC)	250-mL plastic vial	Filtered (0.45 μm), H_2SO_4 to pH <2, Cool 4°C	28 days
Total Organic Carbon (TOC)	250-mL amber glass	Unfiltered, H_2SO_4 to pH <2, Cool 4°C	28 days
Dissolved Organic Carbon (DOC)	125-mL plastic vial	Filtered (0.45 μm), H_2SO_4 to pH <2, Cool 4°C	28 days
Volatile Organic Analysis (VOA)	Bottle set 1: 3-40-mL sterile clear glass vials Bottle set 2: 3-40-mL sterile amber glass vials	Zero headspace, Cool <6 °C, Clear glass vials will be UV-irradiated for additional sterilization	7 days
Methane	Bottle set 1: 3-40-mL sterile clear glass vials Bottle set 2: 3-40 mL sterile amber glass vials	Zero headspace, Cool <6 °C, Clear glass vials (bottle set 1) will be UV-irradiated for additional sterilization	7 days
Stable Carbon Isotopes $^{13/12}C$ ($\delta^{13}C$) of DIC in Water	60-mL plastic or glass	Filtered (0.45 μm), Cool 4°C	14 days
Radiocarbon ^{14}C of DIC in Water	60-mL plastic or glass	Filtered (0.45μm), Cool 4°C	14 days
Hydrogen and Oxygen Isotopes $^{2/1}H$ (δD) and $^{18/16}O$ ($\delta^{18}O$) of Water	60-mL plastic or glass	Filtered (0.45μm), Cool 4°C	45 days
Carbon and Hydrogen Isotopes (^{14}C, $^{13/12}C$, $^{2/1}H$) of Dissolved Methane in Water	1-L dissolved gas bottle or flask	Benzalkonium chloride capsule, Cool 4°C	90 days
Compositional Analysis of Dissolved Gas in Water (including N_2, CO_2, O_2, Ar, H_2, He, CH_4, C_2H_6, C_3H_8, iC_4H_{10}, nC_4H_{10}, iC_5H_{12}, nC_5H_{12}, and C_6+)	1-L dissolved gas bottle or flask	Benzalkonium chloride capsule, Cool 4°C	90 days
Radon (^{222}Rn)	1.25-L PETE	Pre-concentrate into 20-mL scintillation cocktail. Maintain groundwater temperature prior to pre-concentration	1 day
pH	Field parameter	None	<1 h

Parameter	Volume/Container	Preservation	Holding Time
Specific Conductance	Field parameter	None	<1 h

HDPE = high-density polyethylene; PETE = polyethylene terephthalate.

Table 16. Analytical Requirements.

Parameter	Analysis Method	Detection Limit or Range	Typical Precision/ Accuracy	QC Requirements
Major Cations: Al, Ba, Ca, Fe, K, Mg, Mn, Na, Si,	ICP-AES, EPA Method 6010B or similar	1 to 80 µg/L (analyte dependent)	±10%	Daily calibration; blanks, LCS, and duplicates and matrix spikes at 10% level per batch of 20
Trace Metals: Sb, As, Cd, Cr, Cu, Pb, Se, Tl	ICP-MS, EPA Method 6020 or similar	0.1 to 2 µg/L (analyte dependent)	±10%	Daily calibration; blanks, LCS, and duplicates and matrix spikes at 10% level per batch of 20
Cyanide (CN^-)	SW846 9012A/B	5 µg/L	±10%	Daily calibration; blanks, LCS, and duplicates at 10% level per batch of 20
Mercury	CVAA SW846 7470A	0.2 µg/L	±20%	Daily calibration; blanks, LCS, and duplicates and matrix spikes at 10% level per batch of 20
Anions: Cl^-, Br^-, F^-, SO_4^{2-}, NO_3^-	Ion Chromatography, EPA Method 300.0A or similar	33 to 133 µg/L (analyte dependent)	±10%	Daily calibration; blanks, LCS, and duplicates at 10% level per batch of 20
Total and Bicarbonate Alkalinity (as $CaCO_3^{2-}$)	Titration, Standard Methods 2320B	1 mg/L	±10%	Daily calibration; blanks, LCS, and duplicates at 10% level per batch of 20
Gravimetric Total Dissolved Solids (TDS	Gravimetric Method Standard Methods 2540C	10 mg/L	±10%	Balance calibration, duplicate samples
Water Density	ASTM D5057	0.01 g/mL	±10%	Balance calibration, duplicate samples
Total Inorganic Carbon (TIC)	SW846 9060A or equivalent Carbon analyzer, phosphoric acid digestion of TIC	0.2 mg/L	±20%	Quadruplicate analyses, daily calibration
Dissolved Inorganic Carbon (DIC)	SW846 9060A or equivalent Carbon analyzer, phosphoric acid digestion of DIC	0.2 mg/L	±20%	Quadruplicate analyses, daily calibration
Total Organic Carbon (TOC)	SW846 9060A or equivalent Total organic carbon is converted to carbon dioxide by chemical oxidation of the organic carbon in the sample. The carbon dioxide is measured using a non-dispersive infrared detector.	0.2 mg/L	±20%	Quadruplicate analyses, daily calibration
Dissolved Organic Carbon (DOC)	SW846 9060A or equivalent Total organic carbon is converted to carbon dioxide by chemical oxidation of the organic carbon in the sample. The carbon dioxide is measured using a non-dispersive infrared detector.	0.2 mg/L	±20%	Quadruplicate analyses, daily calibration
Volatile Organic Analysis (VOA)	SW846 8260B or equivalent Purge and Trap GC/MS	0.3 to 15 µg/L	±20%	Blanks, LCS, spike, spike duplicates per batch of 20
Methane	RSK 175 Mod Headspace GC/FID	10 µg/L	±20%	Blanks, LCS, spike, spike duplicates per batch of 20
Stable Carbon Isotopes $^{13/12}C$ ($1^{13}C$) of DIC in Water	Gas Bench for $^{13/12}C$	50 ppm of DIC	±0.2p	Duplicates and working standards at 10%

Parameter	Analysis Method	Detection Limit or Range	Typical Precision/ Accuracy	QC Requirements
Radiocarbon ^{14}C of DIC in Water	AMS for ^{14}C	Range: 0 i 200 pMC	±0.5 pMC	Duplicates and working standards at 10%
Hydrogen and Oxygen Isotopes $^{2/1}H$ (δ) and $^{18/16}O$ ($1^{18}O$) of Water	CRDS H_2O Laser	Range: -500‰ to 200‰ vs. VSMOW	$^{2/1}H$: ±2.0‰ $^{18/16}O$: ±0.3‰	Duplicates and working standards at 10%
Carbon and Hydrogen Isotopes (^{14}C, $^{13/12}C$, $^{2/1}H$) of Dissolved Methane in Water	Offline Prep & Dual Inlet IRMS for ^{13}C; AMS for ^{14}C	^{14}C Range: 0 & DupMC	^{14}C: ±0.5pMC ^{13}C: ±0.2‰ $^{2/1}H$: ±4.0‰	Duplicates and working standards at 10%
Compositional Analysis of Dissolved Gas in Water (including N_2, CO_2, O_2, Ar, H_2, He, CH_4, C_2H_6, C_3H_8, iC_4H_{10}, nC_4H_{10}, iC_5H_{12}, nC_5H_{12}, and C_6+)	Modified ASTM 1945D	1 to 100 ppm (analyte dependent)	Varies by compon-ent	Duplicates and working standards at 10%
Radon (^{222}Rn)	Liquid scintillation after pre-concentration	5 mBq/L	±10%	Triplicate analyses
pH	pH electrode	2 to 12 pH units	±0.2 pH unit For indication only	User calibrate, follow manufacturer recommendations
Specific Conductance	Electrode	0 to 100 mS/cm	±1% of reading For indication only	User calibrate, follow manufacturer recommendations

ICP-AES = inductively coupled plasma atomic emission spectrometry; ICP-MS = inductively coupled plasma mass spectrometry; LCS = laboratory control sample; GC/MS = gas chromatography–mass spectrometry; GC/FID = gas chromatography with flame ionization detector; AMS = accelerator mass spectrometry; CRDS = cavity ring down spectrometry; IRMS = isotope ratio mass spectrometry; LC-MS = liquid chromatography-mass spectrometry; ECD = electron capture detector

Laboratory to be used/chain-of-custody procedures:

See Section B.4 of the FutureGen QASP for groundwater and brine sampling, analysis, chain-of-custody procedures. Additionally, see Section B.7 of the FutureGen QASP for protocols for plume and pressure-front tracking.

Plan for guaranteeing access to all monitoring locations:

The land on which these wells are located will either be purchased or leased for the life of the project, so access will be secured.

Indirect Carbon Dioxide Plume and Pressure-Front Tracking

FutureGen will conduct indirect plume and pressure-front monitoring to meet the requirements of 40 CFR 146.90(g)(2).

The screening of the indirect monitoring approaches was conducted as part of the Front End Engineering Design process. The selected indirect technologies will include the following:

- PNC logging for determination of reservoir CO_2 saturation;
- Integrated deformation monitoring;
- Time-lapse gravity; and
- Microseismic monitoring.

The monitoring schedule for these techniques is provided in Table 17. Continuous monitoring is described in Table 1 of this plan. The sections below describe these indirect methods.

Table 17. Monitoring Schedule for Indirect Plume and Pressure-Front Monitoring.

Monitoring Technique	Location	Frequency (Baseline)	Frequency (Injection Phase)
Pulsed-neutron capture logging	RAT Wells 1, 2, and 3	3 events	Quarterly for 5 years and annually thereafter
Integrated deformation monitoring	5 locations (see Figure 1)	1 year minimum	Continuous
Time-lapse gravity monitoring	46 locations (see Figure 3)	3 events	Annually
Passive seismic monitoring (microseismicity)	Surface measurements (see Figure 1) plus downhole sensor arrays at ACZ Wells 1 and 2	1 year minimum	Continuous (1 scene per month)
Note: For details and information on continuous monitoring, see Table 1.			

Pulsed-neutron capture logging

Once the reservoir model has been refined based on site-specific information from the injection site, predictive simulations of CO_2 arrival response will be generated for each RAT installation. These predicted responses will be compared with monitoring results throughout the operational phase of the project and significant deviation in observed response would result in further action, including a detailed evaluation of the observed response, calibration/refinement of the numerical model, and possible modification to the monitoring approach and/or storage site operations.

The coordinates (in decimal degrees) of the RAT wells are in Appendix A of this plan. Well construction information and well schematics are in Appendix B of this plan.

Integrated deformation monitoring

Integrated deformation monitoring (see Figure 1 for locations) integrates ground data from permanent Global Positioning System (GPS) stations, tiltmeters, supplemented with annual Differential GPS (DGPS) surveys, and larger-scale Differential Interferometric Synthetic

Aperture Radar (DInSAR) surveys to detect and map temporal ground-surface deformation. These data reflect the dynamic geomechanical behavior of the subsurface in response to CO_2 injection. These measurements will provide useful information about the evolution and symmetry of the pressure front. These results will be compared with model predictions throughout the operational phase of the project and significant deviation in observed response would result in further action, including a detailed evaluation of the observed response, calibration/refinement of the numerical model, and possible modification to the monitoring approach and/or storage site operations.

Orbital SAR data will be systematically acquired and processed over the storage site with at least 1 scene per month to obtain advanced InSAR time series. These data will come from X-band TerraSAR-X, C-band Radarsat-2, X-Band Cosmo-Skymed or any other satellite instrument that will be available at the time of data collection.

Widespread overall temporal decorrelation is anticipated except in developed areas (e.g., roads, infrastructure at the site, and the neighboring towns) and for the six corner cubes reflectors that will be deployed on site. These isolated coherent pixels will be exploited to measure deformation over time and different algorithms (e.g., persistent scatters, small baseline subsets, etc.) will be used to determine the best approach for the site.

Data from 5 permanent tiltmeters and GPS stations will be collected continuously (MS1-MS5 locations in Figure 1). In addition, annual geodetic surveys will be conducted using the Real-Time Kinematic (RTK) technique where a single reference station gives the real-time corrections, providing centimeter-level or better accuracy. Deformations will be measured at permanent locations chosen to measure the extent of the predicted deformation in the AoR and also used by the gravity surveys (see time-lapse gravity monitoring).

To establish a comprehensive geophysical and geomechanical understanding of the FutureGen site, InSAR and field deformation measurements will be integrated and processed with other monitoring data collected at the site: microseismicity, gravity, pressure and temperature. This unique and complete geophysical data set will then be inverted to constrain the CO_2 plume shape, extension and migration in the subsurface.

Time-lapse gravity monitoring

The objective of gravity monitoring is to observe changes in density distribution in the subsurface caused by the migration of fluids, which could potentially help define the areal extent of the CO_2 plume or detect leakage.

FutureGen will use a network of forty six permanent stations that were established in 2011 during a gravity survey for the purpose of future reoccupation surveys. Approximately 35 complementary stations will be established for a total of 81 stations. A map of the gravity stations is provided in

Figure 3. The coordinates (in decimal degrees) of the stations are provided in Appendix D.

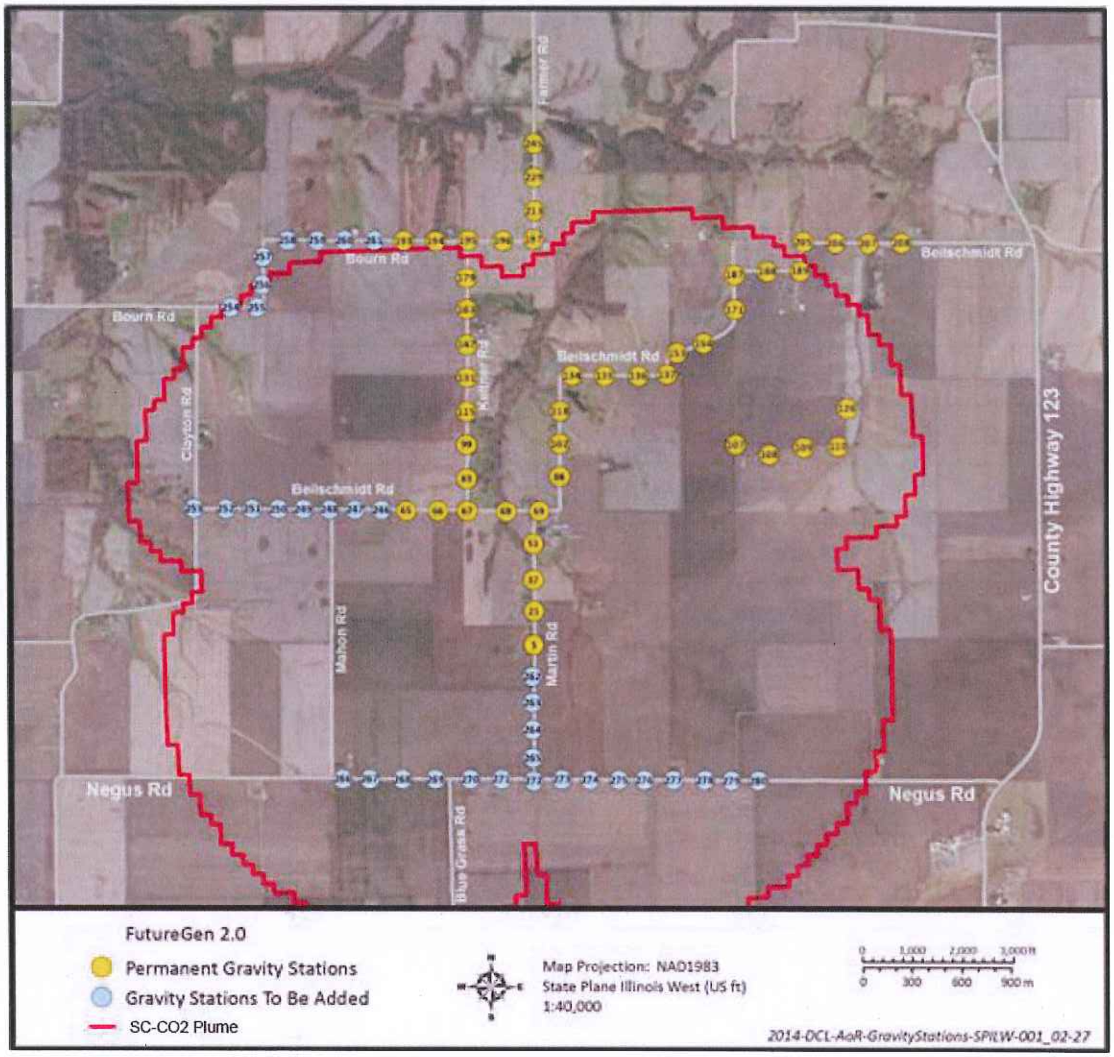

Figure 3. Permanent Gravity Station Locations (with supplemental DGPS).

Passive seismic monitoring (microseismicity)

The microseismic monitoring network (see Figure 1; downhole arrays will also be installed at the two ACZ wells) will be used to accurately determine the locations, magnitudes, and focal mechanisms of injection-induced seismic events with the primary goals of 1) addressing public and stakeholder concerns related to induced seismicity, 2) estimating the spatial extent of the pressure front from the distribution of seismic events, and 3) identifying features that may indicate areas of caprock failure and possible containment loss. Seismic monitoring considerations are also addressed in the Emergency and Remedial Response Plan (Attachment F of this permit).

Testing & Monitoring Techniques and Procedures

The techniques and procedures in the Testing & Monitoring Plan may be revised to incorporate best practices that develop over time. Such revisions will be governed under Section B of this permit "PERMIT ACTIONS."

APPENDIX A: Deep Monitoring Wells Coordinates

Well ID	Well Type	Latitude (WGS84)	Longitude (WGS84)
ACZ1	Above Confining Zone 1	39.80034315	-90.07829648
ACZ2	Above Confining Zone 2	39.80029543	-90.08801028
USDW1	Underground Source of Drinking Water	39.80048042	-90.0782963
SLR1	Single-Level in-Reservoir 1	39.8004327	-90.08801013
SLR2	Single-Level in-Reservoir 2	39.80680878	-90.05298062
RAT1	Reservoir Access Tube 1	39.80035565	-90.08627478
RAT2	Reservoir Access Tube 2	39.78696855	-90.06902677
RAT3	Reservoir Access Tube 3	39.79229199	-90.08901656

APPENDIX B: Monitoring Well Construction and Schematics

- **ACZ Well Construction and Drilling Information**
- **USDW Well Construction and Drilling Information**
- **SLR1 Well Construction and Drilling Information**
- **SLR2 Well Construction and Drilling Information**
- **RAT Well Construction and Drilling Information**

ACZ Well Construction and Drilling Information

Construction detail for the Above Confining Zone (ACZ) wells is provided in Figure B-1. One of the ACZ wells will be located approximately 1,000 ft west of the injection well site, within the region of highest pressure buildup. The other ACZ well will be located approximately 0.75 mi west of the injection site on the same drill pad as single-level in-reservoir well 1 (SLR1). These selected ACZ locations focus early-detection monitoring within the region of elevated pressure and are proximal to six of nine project-related caprock penetrations (four injection wells, two reservoir wells, and three reservoir access tubes [RATs]). The ACZ wells will be used to collect fluid samples and for continuous pressure, temperature, specific conductance (P/T/SpC) and microseismic monitoring. A fiber-optic cable with integral geophones for microseismic monitoring will be secured to the outside of the casing and cemented in place. This design will permit unobstructed access to the inside of the casing and screen for planned sampling and monitoring activities.

To begin, a 30-in. borehole will be drilled and 24-in.-OD conductor casing will be installed to near the contact with Pennsylvanian bedrock (150 ft) (Figure B-1). Next, the boring will step down to a 20-in. borehole and 16-in. casing to approximately 600 ft. Below 600 ft, the hole will step down to a 14-3/4-in. hole lined with 10-3/4-in. casing to below the base of the Potosi Dolomite. Casing to the base of the Potosi Dolomite (~3,100 ft) is needed to case off the karstic lost-circulation zone encountered while drilling the stratigraphic well. After cementing the 10-3/4-in. casing in place a 9-1/2-in. borehole will be drilled into the top of the underlying confining zone. The base of the Ironton Sandstone in the stratigraphic well was 3,425 ft bgs. The bottom of the ACZ wells should be drilled a bit further (to ~3,470-ft depth) into the top of the Eau Claire Formation to positively identify the Ironton/Eau Claire contact and to create sufficient borehole to accommodate a 50-ft-long section of blank 5-1/2-in. casing below the well screen. If the ongoing modeling effort focused on evaluating early-detection capabilities in the ACZ wells indicates that detection is improved by moving the screen to near the top of the Ironton Formation, then the borehole will be plugged back prior to well completion.

After the 9-1/2-in. borehole has been drilled to total depth, the borehole will be developed to remove mud cake, cuttings, and drill fluids via circulation. Development will continue until all drilling mud has been effectively removed from the borehole wall. After the borehole has been circulated clean, a final casing string will be installed. The final casing string will be 5-1/2-in. OD and will include a ~20-ft-long stainless-steel well screen installed across the selected monitoring interval. A 50-ft-long section of blank casing will be attached below the screen to provide a sump for collecting any debris that may enter the well over time. A swellable packer may be placed immediately above and below the screened interval to help ensure zonal isolation (see Figure B-2). The annulus casing packer (ACP) and a stage-cement tool will be placed above the well screen to isolate and keep cement away from the screen. In addition to the stainless-steel well screen, the lowermost 200 ft of the 5-1/2-in. casing string (including the section that spans the Ironton Sandstone [3,286–3,425 ft bgs]) will be a corrosion-resistant alloy material (e.g., S13Cr110). The remainder of the 5-1/2-in. casing string will be carbon steel. Corrosion-resistant cement will be used to cement the final casing string up to ~3,100-ft depth. Regular cement will be used to seal the remainder of the 5-1/2-in. casing to ground surface. All other casing strings will be cemented with standard well cement. A summary of the borehole and casing program for the ACZ wells is in figure B.1.

Table B.1. Casing and Borehole Program for the ACZ Monitoring Wells.

Section	Borehole Depth (ft)	Borehole Diam. (in.)	Casing OD (in.)	Casing Grade	Casing weight (lb/ft)	Casing Connection
Conductor Casing	150	30 (min.)	24	B	140	PEB
Surface Casing	600	20	16	K-55	84	BTC
Intermediate Casing	3,100	14-3/4	10-3/4	K-55	51	BTC
Long Casing (with a 20-ft-long screened section)	3,470	9-1/2	5-1/2	J-55 (0-3,100 ft); S13Cr110 (3,100–3,470 ft)	17	LTC (J-55); Vam Top or similar (S13Cr110)

Grade B is equivalent to line pipe; BTC = buttress thread connection; Cr = chromium; LTC = long thread connection; PEB = plain end beveled.

Notes:

Actual casing grades and weights may differ based on material available at the time of construction.

All depths are approximate and may be adjusted based on information obtained when the well is drilled.

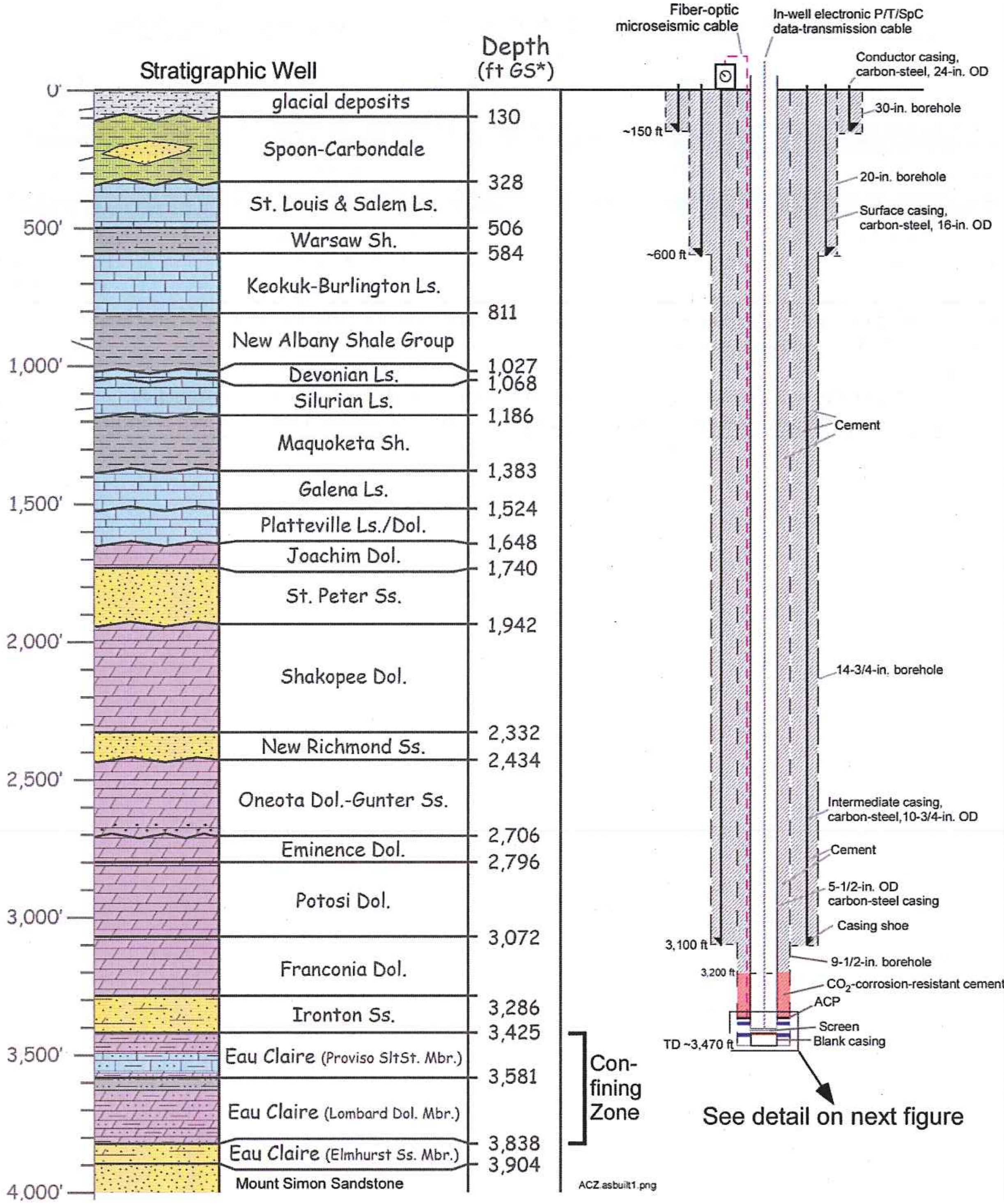

Figure B-1. Well Construction Diagram for the ACZ Monitoring Wells.

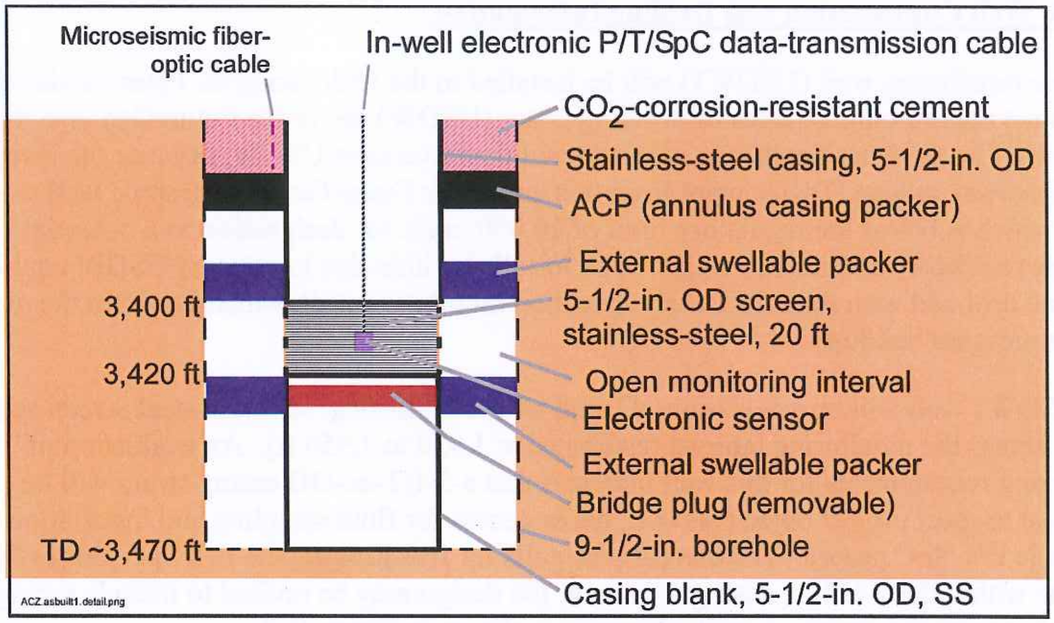

Figure B-2. Construction Detail for ACZ Monitoring Wells.

USDW Well Construction and Drilling Information

A single monitoring well (USDW1) will be installed in the Ordovician St. Peter Sandstone, the lowermost underground sources of drinking water (USDW) above the FutureGen injection reservoir. The St. Peter Sandstone is considered the lowermost USDW, because the measured total dissolved solids (TDS) content from this unit at the FutureGen stratigraphic well was 3,700 mg/L, which is below the regulatory limit of 10,000 mg/L for designation as a potential USDW. A single regulatory compliance well will be installed within this lowermost USDW aquifer, on the same drill pad with the ACZ1 early-detection monitoring well, which is within the region of highest pressure buildup.

The USDW1 well will be a 5-1/2-in.-OD well with a 20-ft-long, stainless-steel screen section placed across the monitoring interval (estimated at 1,930 to 1,950 ft). An evaluation of monitoring requirements for this well indicates that a 5-1/2-in.-OD casing string will be sufficient to meet project objectives (i.e., allow access for fluid sampling and installation of downhole P/T/SpC probes. The current plan calls for free hanging the P/T/SpC probes by wireline within the 5-1/2-in. casing; however, the design may be revised to include tubing and packer to secure the probe. A well schematic is shown in Figure B-3.

To begin, a 20-in. borehole will be drilled and 16-in. conductor casing will be installed to near the contact with Pennsylvanian bedrock (Figure B-3). Next, the boring will step down to a 14-3/4-in. borehole and 10-3/4-in. casing to approximately 600 ft. After cementing the 10-3/4-in. casing in place, a 9-1/2-in. borehole will be drilled to a short distance below the base of the USDW (St. Peter Sandstone) (to ~2,000-ft depth) to positively identify the St. Peter Sandstone/Shakopee Dolomite contact. After the 9-1/2-in. borehole has been drilled to total depth, the borehole will be developed to remove mud cake, cuttings, and drill fluids via circulation. Development will continue until all drilling mud has been effectively removed from the borehole wall. After the borehole has been circulated clean, a final casing string will be installed. The final casing string will be 5-1/2-in. OD and will include a ~20-ft-long stainless-steel well screen near the bottom (see screened interval construction detail for USDW1 in Figure B-4).

Stainless-steel casing (e.g., 13Cr), 5-1/2-in. OD, will be used in the lower 300 ft of the well including the entire St. Peter Sandstone. Standard carbon-steel casing will be used above depths of ~1,700 ft. A 20-ft-long, 5-1/2-in.-OD stainless-steel well screen will be incorporated into the final casing string and positioned to span the desired monitoring interval. Approximately 50 ft of blank casing will extend from immediately below the screen to the bottom of the well (Figure B-3). External swellable packers may be placed above and below the screened interval to help ensure zonal isolation (see Figure B-4). A removable bridge plug may be installed just below the screen to isolate it from the rat hole below. Standard well cement will be used to cement all casing strings.

A summary of the borehole and casing program for the USDW1 well is provided in Table B-2.

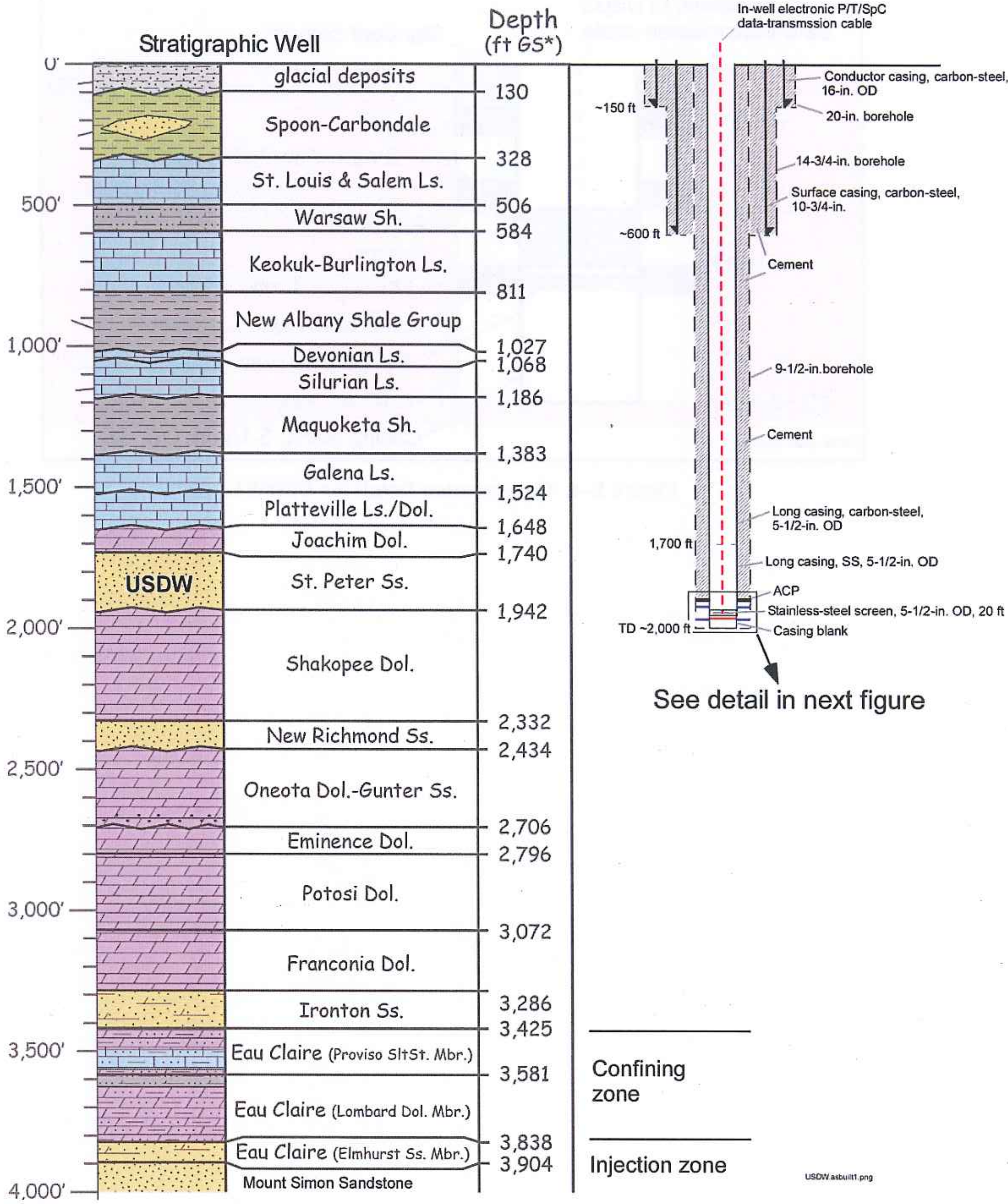

Figure B-3. Well Construction Diagram for the USDW1 Monitoring Well.

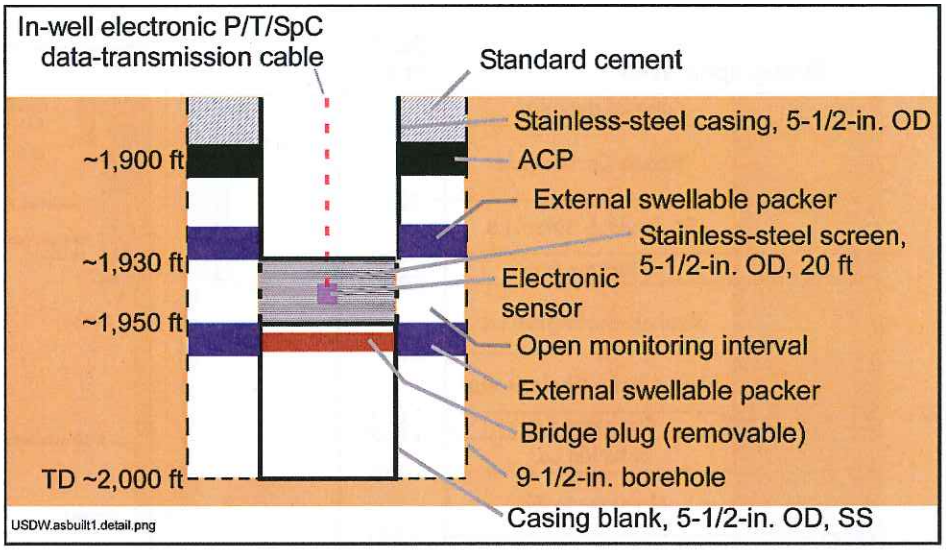

Figure B-4. Construction Detail for USDW1.

Table B-2. Casing and Borehole Program for the USDW Monitoring Well.

Section	Borehole Depth (ft)	Borehole Diam. (in.)	Casing OD (in.)	Casing Grade	Casing weight (lb/ft)	Casing Connection
Conductor Casing	150	20	16	B	55	PEB
Surface Casing	600	14-3/4	10-3/4	J-55	40.5	BTC
Intermediate Casing	NA	NA	NA	NA	NA	NA
Long Casing (with 20-ft-long screened section)	2,000	9-1/2	5-1/2	J-55 (0-1,700 ft); S13Cr110 (1,700–2,000 ft)	17	LTC (J-55); Vam Top or similar (S13Cr110)

Grade B is equivalent to line pipe; BTC = buttress thread connection; Cr = chromium; LTC = long thread connection; PEB = plain end beveled.
Notes:
Actual casing grades and weights may differ based on material available at the time of construction.
All depths are approximate and may be adjusted based on information obtained when the well is drilled.

As discussed above, the well will be developed by air lift prior to installing the downhole P/T/SpC probe. If necessary, further development via air lift or pumping may be conducted after the well has been completed. During development activities, groundwater samples will be collected and tested for turbidity and other field parameters to ensure adequate development.

SLR1 Well Construction and Drilling Information

As illustrated in Figure B-5, a 20-in.-diameter conductor casing within a 26- to 30-in. hole will be installed into the Pennsylvanian bedrock to 150 ft bgs. This will be followed by a 17-1/2-in. hole lined with 13-3/8-in. casing to ~600 ft before drilling a 12-1/4-in. hole lined with 9-5/8-in. intermediate casing into the top of the confining zone (Proviso member) to a depth of approximately 3,450 ft bgs. Next, cement grout will be emplaced, under pressure, in the annular space behind the 9-5/8-in. casing and around the casing shoe until it rises to the surface. This will be followed by a downhole cement bond log and pressure testing to ensure there are no leakage pathways behind the 9-5/8-in. casing or shoe. After testing the seal integrity of the 9-5/8-in. casing, an uncased 7-7/8-in. to 8-1/2-in. open borehole will be drilled to ~4,150 ft bgs. Once at total depth, the open portion of the borehole will be developed to remove all cuttings and drill fluids via circulation and pumping of formation water. Development will continue until all drilling mud has been effectively removed from the borehole wall and pumped water is clear of particulates. Following development, a final 5-1/2-in.-OD casing string will be installed and cemented in place. Once the casing installation is complete, the 5-1/2-in. casing and surrounding cement will be perforated over the interval between 4,000 and 4,100 ft bgs, creating a 100-ft monitoring interval within the injection zone.

The portion of the 5-1/2-in. casing that penetrates the reservoir and the Eau Claire caprock (from total depth to ~3,450 ft bgs) will be composed of corrosion-resistant alloy material (e.g., S13Cr110) (Figure B-6). Corrosion-resistant cement will be used to cement the final casing string across this same interval. This specially formulated type of cement is more finely ground than regular cement and thus resists CO_2 infiltration into the more-reactive cement pores. Above the caprock and overlying the CO_2 reservoir, regular cement will be used to seal the remainder of the 5-1/2-in. casing (i.e., above 3,450 ft). All other casing strings will be cemented with standard well cement. A summary of the borehole and casing program for the SLR1 well is provided in Table B-3.

Table B-3. Casing and Borehole Program for the SLR1 Monitoring Well.

Section	Borehole Depth (ft)	Borehole Diam. (in.)	Casing OD (in.)	Casing Grade	Casing weight (lb/ft)	Casing Connection
Conductor casing	150	26 to 30	20	B	94	PEB
Surface casing	600	17-1/2	13-3/8	J-55	61	BTC
Intermediate casing	3,450	12-1/4	9-5/8	J-55	36	STC
Long casing (with 100-ft perforated section)	4,150	7-7/8 or 8-1/2	5 -1/2	J-55 (0-3,450 ft); S13Cr110 (3,450-4,150 ft)	17	LTC (J-55); Vam Top or similar (S13Cr110)
Tubing	4,100	NA	2-7/8	13Cr80	6.5	EUE

Grade B is equivalent to line pipe; BTC = buttress thread connection; Cr = chromium; EUE = externally upset end; LTC = long thread connection; PEB = plain end beveled; STC = short thread connection.
Notes:
Actual casing grades and weights may differ based on material available at the time of construction.
All depths are approximate and may be adjusted based on information obtained when the well is drilled.

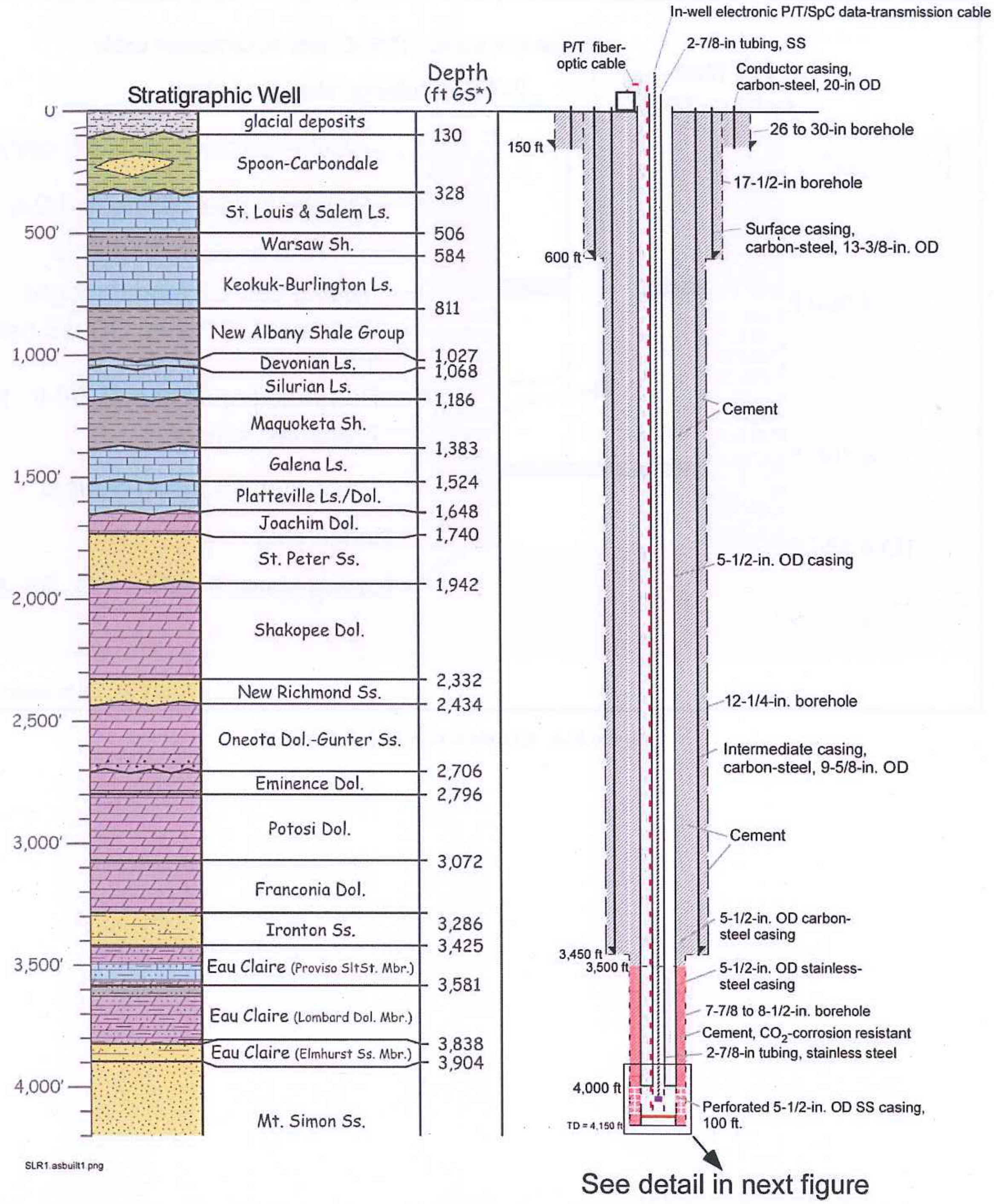

Figure B-5 Construction Diagram for the New Single-Level in-Reservoir Monitoring Well (SLR1).

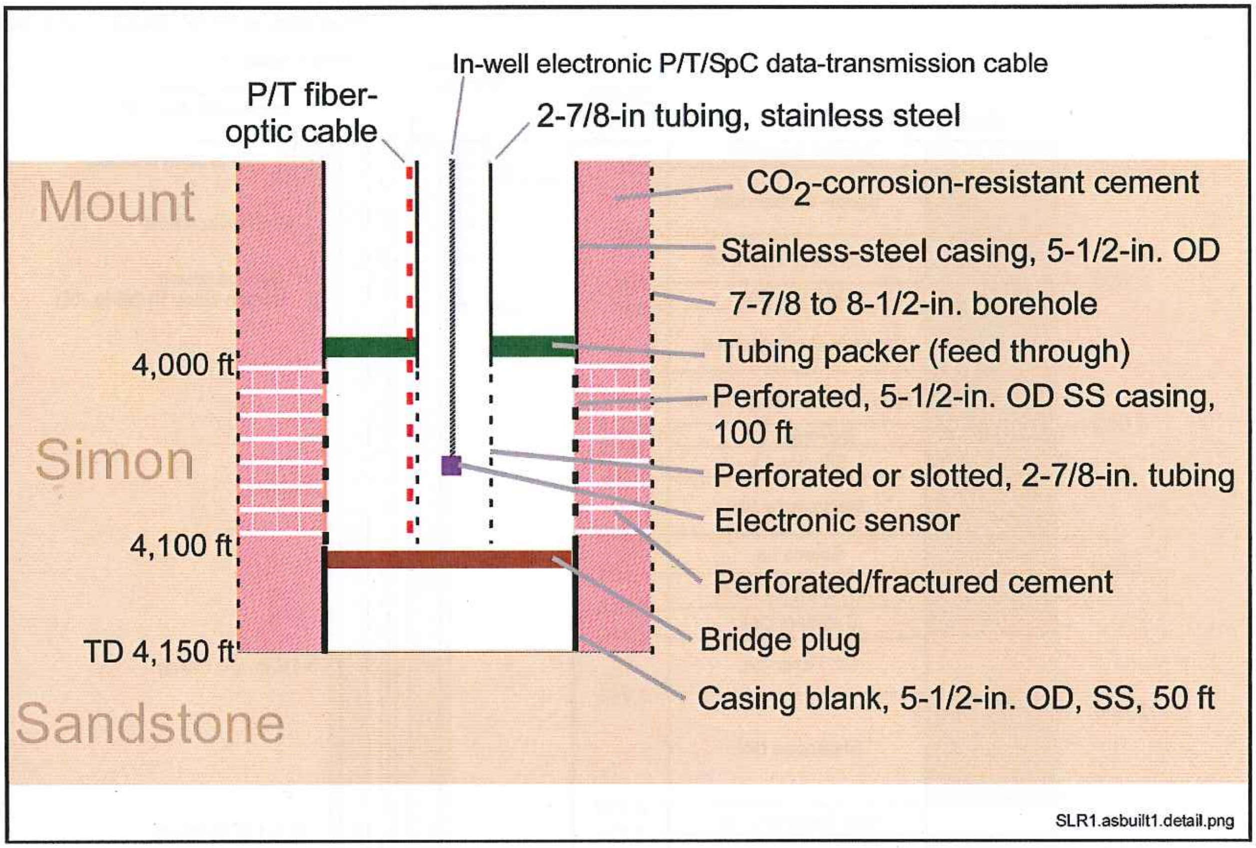

Figure B-6. Construction Detail for SLR1

SLR2 Well Construction and Drilling Information

Currently, the stratigraphic well is cased to 3,948 ft with 10-3/4-in. casing to below the top of the Mount Simon Sandstone (Figure). Below this is a 14-3/4-in. open borehole to a depth of 4,018 ft, then a 9-1/2-in. borehole to a total depth of 4,812 ft, which extends approximately 400 ft into Precambrian basement rock. The borehole below the intermediate casing is currently uncased. The planned design for the reconfigured stratigraphic well (SLR2) includes backfilling the bottom 660 ft of the borehole with CO_2-resistant cement to ~4,150 ft (Figure B-8) before installing a 7-in.-OD casing string to 4,150 ft bgs. The 7-in casing will then be cemented in place using CO_2-resistant cement to near the top of the caprock (3,450 ft) followed by regular cement to the surface. The 7-in. well will be constructed using 7-in stainless steel (S13Cr110) casing to a depth of approximately 4,000 ft. Above this depth, carbon-steel casing will be used. After the cement job has been completed, the 7-in. casing and cement will be perforated to construct a 100-ft-long Mount Simon Sandstone monitoring interval between the depths of 4,000 and 4,100 ft. Following perforation and well development activities, a removable bridge plug may be installed just below the perforated interval to isolate it from the rathole below. A 2-7/8-in.-OD tubing string will then be run inside the 7-in. casing to near the bottom of the perforated interval. The installed tubing will be perforated (slotted) across the 4,000- to 4,100-ft-depth interval and isolated to this zone via a tubing packer above (Figure B-8). A summary of the borehole and casing program for the SLR2 well is provided in Table B-4.

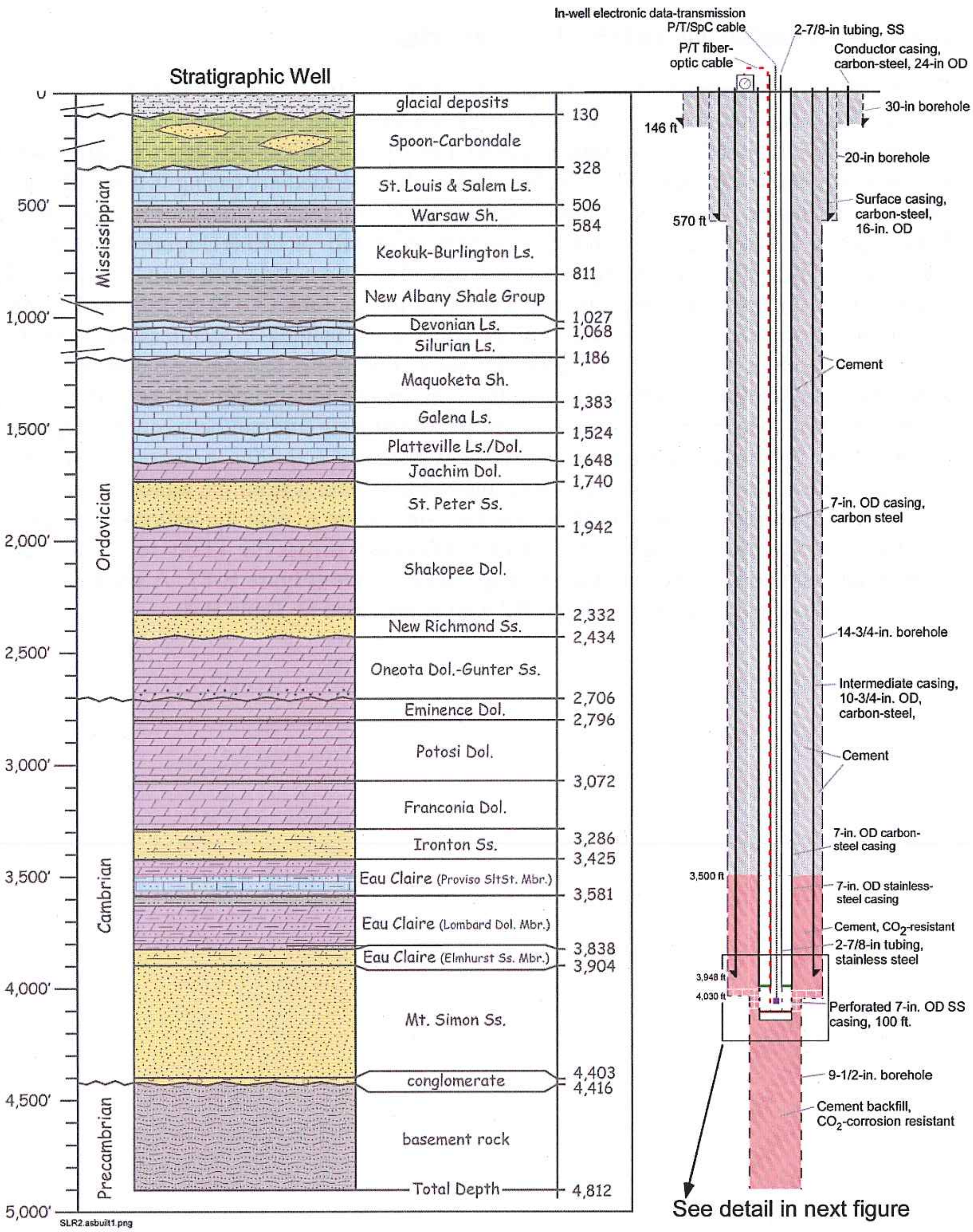

Figure B-7. Construction Diagram for the Stratigraphic Well Reconfigured as a Single-Level in-Reservoir Monitoring Well (SLR2).

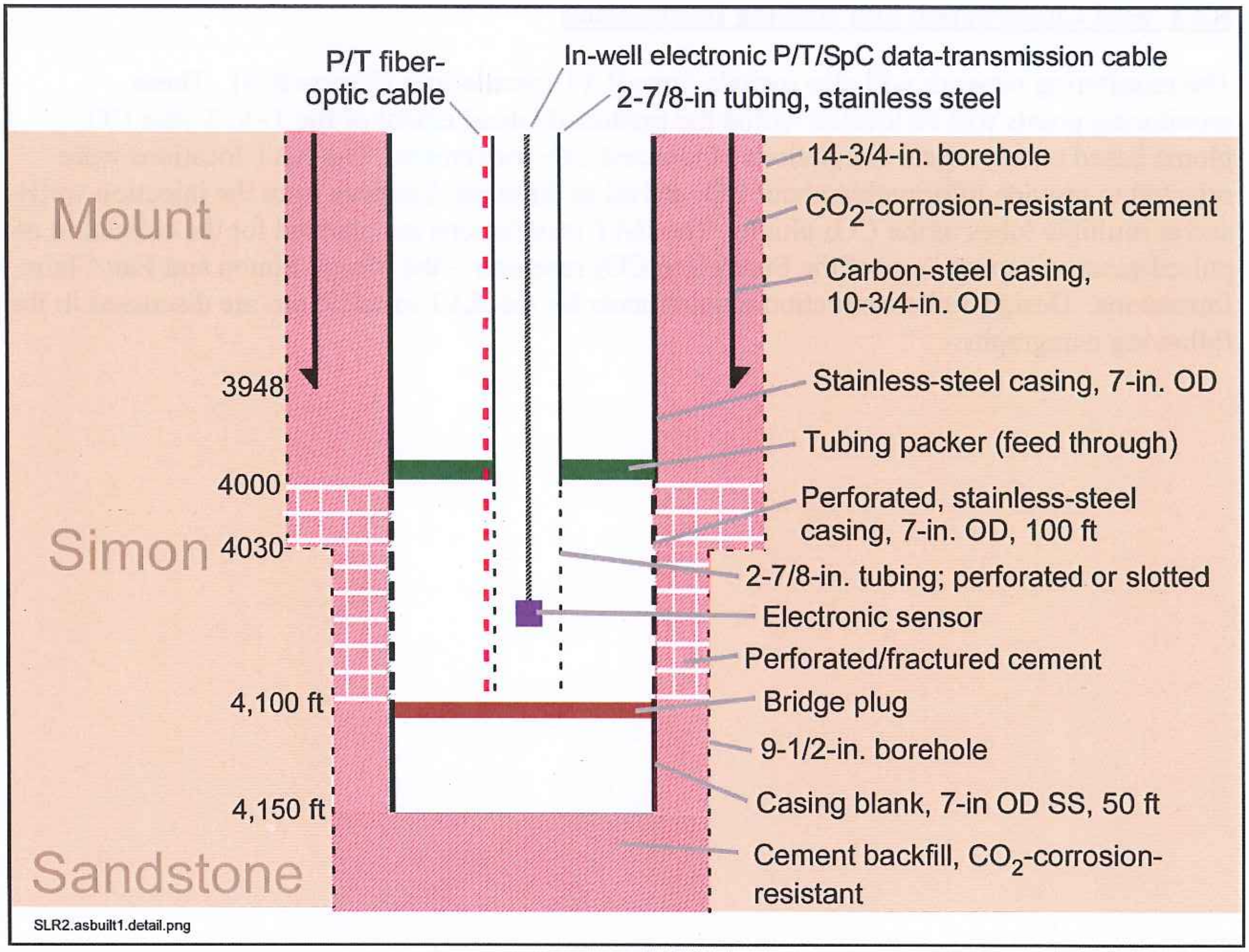

Figure B-8. Construction Detail for SLR2

Table B-4. Casing and Borehole Program for the SLR2 Monitoring Well

Section	Borehole Depth (ft)	Borehole Diam (in.)	Casing OD (in.)	Casing Grade	Casing weight (lb/ft)	Casing Connection
Conductor casing	132	30	24	PEB	140	Welded
Surface casing	556	20	16	J-55	84	BTC
Intermediate casing	3,948	14-3/4	10-3/4	N-80	51	BTC
Long casing (with 100-ft perforated section)	4,150	9-1/2 to 14-3/4	7	N-80 (0-3,500): S13Cr110 (3,500-TD)	29	LTC (N-80); VAM TOP (S13Cr110)
Tubing	4,100	NA	2-7/8	13Cr80	6.5	EUE

BTC = buttress thread connection; Cr = chromium; EUE = externally upset end; LTC = long thread connection; PEB = plain end beveled.
Note: Actual casing grades and weights may differ based on material available at the time of construction.

RAT Well Construction and Drilling Information

The monitoring network will also include three RAT installations (Figure B-9). These monitoring points will be located within the predicted lateral extent of the 1- to 3-year CO_2 plume based on numerical simulations of injected CO_2 movement. The RAT locations were selected to provide information about CO_2 arrival at different distances from the injection wells and at multiple lobes of the CO_2 plume. The RAT installations are planned for the collection of pulsed-neutron capture logs of the FutureGen CO_2 reservoir—the Mount Simon and Eau Claire formations. Design and construction requirements for the RAT installations are discussed in the following paragraphs.

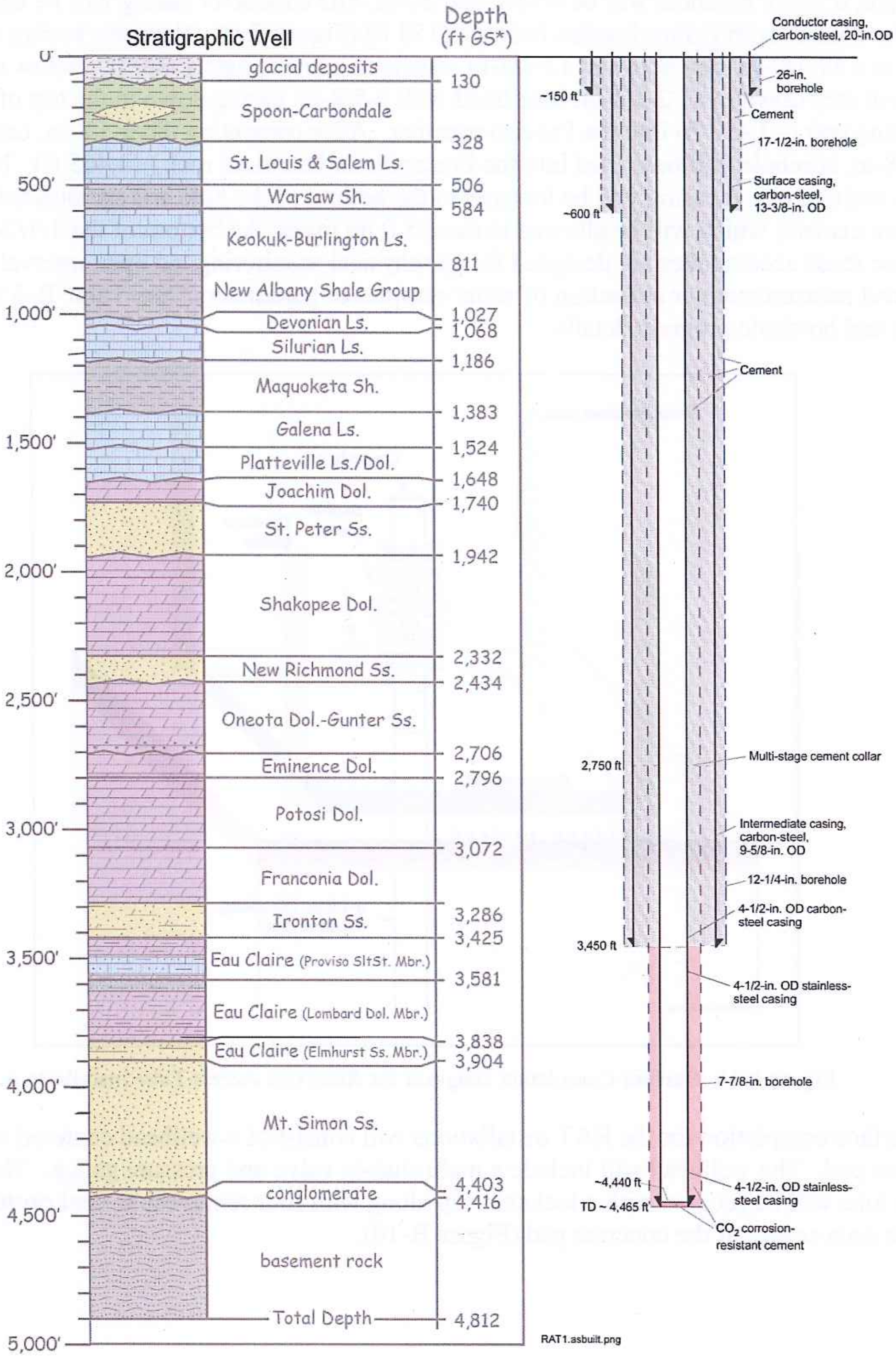

Figure B-9. Construction Diagram for the Three Reservoir Access Tube Installations.

To begin, a 26-in. borehole will be drilled and 20-in.-OD conductor casing will be installed to near the contact with Pennsylvanian bedrock (150 ft) (Figure B-9). Next, the boring will step down to a 17-1/2-in. borehole and 13-3/8-in. casing to approximately 600 ft. Below 600 ft, the hole will step down to a 12-1/4-in. hole lined with 9-5/8-in. casing down to the top of the confining unit (~3,450 ft) into the Proviso member. After cementing the 9-5/8-in. casing in place a 7-7/8-in. borehole will be drilled into the Precambrian basement rock (~4,465 ft). Next, a 4-1/2-in. stainless-steel casing will be lowered to the bottom of the hole and surrounded by CO_2-resistant cement, which will be allowed to rise 25 ft up inside the bottom of the 4-1/2-in. casing. Because these access tubes are designed for geophysical monitoring, no open interval will exist for direct measurement or collection of water samples or parameters. See Table B-5 for the RAT casing and borehole program details.

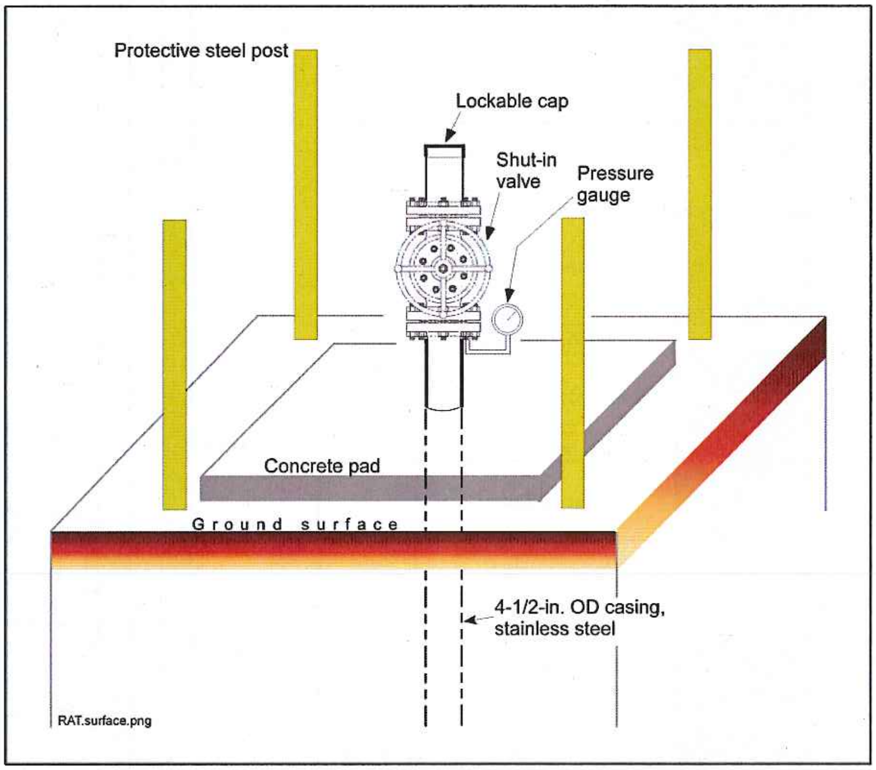

Figure B-10. Surface Completion Diagram for Reservoir Access Tube Installations.

The surface completion for the RAT installations will consist of a wellhead centered over a concrete pad. The wellhead will include a main shut-in valve and pressure gauge. The top of the access tube will be secured with a lockable cap along with four removeable steel protective posts outside each corner of the concrete pad (Figure B-10).

Table B-5. Casing and Borehole Program for the Reservoir Access Tubes.

Section	Borehole Depth (ft)	Borehole Diameter (in.)	Casing OD (in.)	Casing Grade	Casing weight (lb/ft)	Casing Connection
Conductor Casing	150	26 to 30	20	B	94	PEB
Surface Casing	600	17 1/2	13 3/8	J-55	61	BTC
Intermediate Casing	~3,450	12 1/4	9 5/8	J-55	36	STC
Long Casing	~4,465	7 7/88 to 8 1/2	4 1/2	J-55 (0-3,500 ft); S13Cr110 (3,500-4,465 ft.)	10.5	STC

Grade B is equivalent to line pipe; BTC = buttress thread connection; Cr = chromium; LTC = long thread connection; PEB = plain end beveled.

Notes:

Actual casing grades and weights may differ based on material available at the time of construction.

All depths are approximate and may be adjusted based on information obtained when the well is drilled.

APPENDIX C: Surficial Aquifer Monitoring Well Locations

Well ID	Well Type	Latitude	Longitude
FG-1	FutureGen Shallow Monitoring Well	39.80675	-90.05283
FGP-1	Private Well	39.79888	-90.0736
FGP-2	Private Well	39.78554	-90.0639
FGP-3	Private Well	39.79497	-90.0746
FGP-4	Private Well	39.79579	-90.0747
FGP-5	Private Well	39.81655	-90.0622
FGP-6	Private Well	39.81086	-90.057560
FGP-7	Private Well	39.81444	-90.065241
FGP-9	Private Well	39.80829	-90.0377
FGP-10	Private Well	39.81398	-90.0427

APPENDIX D: Permanent Gravity Station Locations

Station#	Latitude	Longitude	
0	39.73424	-90.22926	= NGS PID#KC0540, monument at Central Plaza Park, Jacksonville - point tied to 137 on 11/10/11 - this will be the reference used in future surveys.
5	39.79266	-90.07426	Nailed Permanent Stations
21	39.79449	-90.07424	
37	39.79617	-90.07425	
53	39.79814	-90.07427	
65	39.79991	-90.08316	
66	39.79990	-90.08090	
67	39.79989	-90.07886	
68	39.79988	-90.07616	
69	39.79989	-90.07384	
83	39.80164	-90.07889	
86	39.80176	-90.07240	
99	39.80349	-90.07888	
102	39.80352	-90.07239	
107	39.80348	-90.05998	
108	39.80295	-90.05766	
109	39.80332	-90.05519	
110	39.80339	-90.05277	
115	39.80526	-90.07887	
118	39.80529	-90.07237	
126	39.80544	-90.05216	
131	39.80710	-90.07886	
134	39.80721	-90.07154	
135	39.80720	-90.06922	
136	39.80720	-90.06687	
137	39.80727	-90.06485	
147	39.80888	-90.07885	
153	39.80842	-90.06413	
154	39.80894	-90.06224	
163	39.81078	-90.07885	
171	39.81077	-90.06002	
179	39.81248	-90.07884	
187	39.81265	-90.05999	
188	39.81283	-90.05770	
189	39.81286	-90.05538	
193	39.81447	-90.08326	
194	39.81447	-90.08103	
195	39.81451	-90.07870	
196	39.81449	-90.07629	
197	39.81457	-90.07419	
205	39.81443	-90.05513	
206	39.81436	-90.05287	
207	39.81435	-90.05064	
208	39.81437	-90.04825	
213	39.81609	-90.07408	
229	39.81790	-90.07408	

Station#	Latitude	Longitude	
245	39.81971	-90.07407	
246	39.79996722210	-90.08494295	Permanent Stations to be added prior to commencing injection.
247	39.79997642140	-90.08680687	
248	39.79998533330	-90.08861842	
249	39.79999393550	-90.09043265	
250	39.80000198450	-90.09213566	
251	39.80001079270	-90.09400542	
252	39.80001951540	-90.09586339	
253	39.80003000000	-90.09810508	
254	39.81088084490	-90.09544073	
255	39.81088937800	-90.09358759	
256	39.81211009600	-90.0932439	
257	39.81361707930	-90.0931657	
258	39.81450582940	-90.09142522	
259	39.81450590850	-90.08939647	
260	39.81450595100	-90.08745444	
261	39.81450596010	-90.0853458	
262	39.79094794920	-90.07434558	
263	39.78955807990	-90.07434813	
264	39.78808280800	-90.07435083	
265	39.78655838880	-90.07435362	
266	39.78543344990	-90.08777897	
267	39.78542392910	-90.08587085	
268	39.78541218410	-90.0835256	
269	39.78540044900	-90.08119175	
270	39.78540873070	-90.07875712	
271	39.78542609070	-90.07656216	
272	39.78533023230	-90.07434254	
273	39.78541496330	-90.07234073	
274	39.78538771320	-90.07041894	
275	39.78537326690	-90.06835921	
276	39.78537180190	-90.06658679	
277	39.78537006050	-90.06452139	
278	39.78536811720	-90.06226638	
279	39.78533703980	-90.06040206	
280	39.78532614220	-90.05850696	

APPENDIX E: Microseismic Monitoring and Integrated Deformation Station Locations

Well ID/Station ID	Well / Station Type	Latitude (WGS84)	Longitude (WGS84)
MS1	• Microseismic monitoring Station 1(shallow borehole) • Integrated deformation monitoring station	39.8110768	-90.09797015
MS2	• Microseismic monitoring Station 2 (shallow borehole) • Integrated deformation monitoring station	39.78547402	-90.05028403
MS3	• Microseismic monitoring Station 3 (shallow borehole) • Integrated deformation monitoring station	39.81193502	-90.06016279
MS4	• Microseismic monitoring Station 4 (shallow borehole) • Integrated deformation monitoring station	39.78558513	-90.09557015
MS5	• Microseismic monitoring Station 5 (shallow borehole) • Integrated deformation monitoring station	39.80000524	-90.07830287
ACZ1	• Deep microseismic station (deep borehole)	39.80034315	-90.07829648
ACZ2	• Deep microseismic station (deep borehole)	39.80029543	-90.08801028

APPENDIX F: Injection Well Continuous Monitoring Device Locations

Sampling Locations for Continuous Monitoring	
Test Description	**Location**
Annular Pressure Monitoring	Surface
Injection Pressure Monitoring	Surface
Injection Pressure Monitoring - primary	Reservoir - 3,850 feet below ground surface
Injection Rate Monitoring	Surface
Injection Volume Monitoring	Surface
Temperature Monitoring - primary	Surface
Temperature Monitoring	Reservoir - 3,850 feet below ground surface

APPENDIX G: Quality Assurance and Surveillance Plan

FutureGen 2.0 –
CO_2 Pipeline and Storage Project

Quality Assurance and Surveillance Plan

Revision 1

FutureGen Industrial Alliance, Inc.
1101 Pennsylvania Ave., Sixth Floor
Washington, DC 20004

August 2014

A. Project Management

A.1 Title and Approval Sheet

FutureGen 2.0 – CO_2 Pipeline and Storage Project

Quality Assurance and Surveillance Plan

Revision 1

FutureGen Industrial Alliance, Inc.
1101 Pennsylvania Ave., Sixth Floor
Washington, DC 20004

<u>**Approvals**</u>:

Project Manager Battelle	Tyler J Gilmore	Date
Monitoring, Verification, and Accounting Task Lead Battelle	Vince R. Vermeul	Date
Project Quality Engineer Battelle	William C. Dey	Date

A.2 Table of Contents

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Acronyms and Abbreviations

3D	three-dimensional
4D	four-dimensional
ACP	annulus casing packer
ACZ	above confining zone
AMS	accelerator mass spectrometry
AoR	Area of Review
API	American Petroleum Institute
APS	Annulus Pressurization System
ASTM	ASTM International (formerly the American Society for Testing and Materials)
bgs	below ground surface
CCS	carbon capture and storage
CEO	Chief Executive Officer
CFR	Code of Federal Regulations
CMP	Configuration Management Plan
CO_2	carbon dioxide
CVAA	cold vapor atomic absorption
DGPS	Differential Global Positioning System
DIC	dissolved inorganic carbon
DInSAR	Differential Interferometric Synthetic Aperture Radar
DOC	dissolved organic carbon
ECD	electron capture detector
EPA	U.S. Environmental Protection Agency
GC	gas chromatography
GC/FID	gas chromatography with flame ionization detector
GC/HID	gas chromatography with helium ionization detector
GC/MS	gas chromatography-mass spectrometry
GC/SCD	gas chromatograph with sulfur chemiluminescence detector
GPS	Global Positioning System
GS	Geologic Sequestration
HDI	How Do I…? (Pacific Northwest National Laboratory's web-based system for deploying requirements and procedures to staff)
IARF	infinite-acting radial flow
ICP	inductively coupled plasma
ICP-AES	inductively coupled plasma atomic emission mass spectrometry
ICP-MS	inductively coupled plasma mass spectrometry
IRMS	isotope ratio mass spectrometry
ISBT	International Society of Beverage Technologists
LC-MS	liquid chromatography-mass spectrometry
LCS	laboratory control sample

MIT	mechanical integrity testing
MMT	million metric tons
MS	mass spectrometry
MVA	Monitoring, Verification, and Accounting
NA	not applicable
OD	outside diameter
OES	optical emission spectrometry
P	pressure
P/T	pressure-and-temperature
P/T/SpC	pressure, temperature, and specific conductance
PDMP	Project Data Management Plan
PFT	perfluorocarbon tracer
PLC	programmable logic controller
PM	Project Manager
PNC	pulsed-neutron capture
PNWD	Battelle Pacific Northwest Division
QA	quality assurance
QASP	Quality Assurance and Surveillance Plan
QC	quality control
QE	Quality Engineer
RAT	reservoir access tube
RTD	resistance temperature detector
RTK	Real-Time Kinematic
RTU	remote terminal unit
SAR	Synthetic Aperture Radar
SCADA	Supervisory Control and Data Acquisition
$scCO_2$	supercritical carbon dioxide
SLR	single-level in-reservoir
SME	subject matter expert
SNR	signal-to-noise ratio
SpC	specific conductance
T	temperature
TC	thermocouple
TCD	thermal conductivity detector
TDMP	Technical Data Management Plan
TIC	total inorganic carbon
TOC	total organic carbon
UIC	Underground Injection Control
USDW	underground source of drinking water
VOA	Volatile Organic Analysis
WS-CRDS	wavelength scanned cavity ring-down spectroscopy

Definitions

Injection interval: The open (e.g., perforated) section of the injection well, through which the carbon dioxide (CO_2) is injected.

Injection zone: A geologic formation, group of formations, or part of a formation that is of sufficient areal extent, thickness, porosity, and permeability to receive CO_2 through a well or wells associated with a geologic sequestration project.

Prover: A device that verifies the accuracy of a gas meter.

Reservoir: A subsurface body of rock having sufficient porosity and permeability to store and transmit fluids (Schlumberger Oilfield Glossary). Used interchangeably with injection zone.

Sigma: A measure of the decay rate of thermal neutrons as they are captured.

A.3 Distribution List

Table A.1 lists the individuals that should receive a copy of the approved Quality Assurance and Surveillance Plan (QASP) and any subsequent revisions.

Table A.1. Distribution List

Name	Organization	Project Role(s)	Contact Information (telephone / email)
K. Humphreys	FutureGen Industrial Alliance, Inc.	Chief Executive Officer	202-756-2492 Khumphreys@futgen.org
T. J. Gilmore	Battelle PNWD	Project Manager	509-371-7171 Tyler.Gilmore@pnnl.gov
W. C. Dey	Battelle PNWD	Quality Engineer	509-371-7515 William.Dey@pnnl.gov
V. R. Vermeul	Battelle PNWD	Task Lead – Monitoring, Verification, and Accounting; Groundwater Quality Monitoring; CO_2 Plume and Pressure-Front Tracking	509-371-7170 Vince.Vermeul@pnnl.gov
M. E. Kelley	Battelle Columbus	Task Lead – CO_2 Injection Stream Monitoring; Corrosion Monitoring; External Well Integrity Testing	614-424-3704 kelleym@battelle.org
A. Bonneville	Battelle PNWD	Task Lead – Indirect Geophysical Monitoring	509-371-7263 Alain.Bonneville@pnnl.gov
R. D. Mackley	Battelle PNWD	Task Lead – USDW Groundwater Geochemical Monitoring, and Indicator Parameter Monitoring	509-371-7178 rdm@pnnl.gov
F. A. Spane	Battelle PNWD	Task Lead – Hydrologic Testing; Pressure Fall-Off Testing	509-371-7087 Frank.Spane@pnnl.gov

A.4 Project/Task Organization

The high-level project organizational structure for the FutureGen 2.0 CO_2 Pipeline and Storage Project is shown in Figure A.1 (Alliance 2013a).

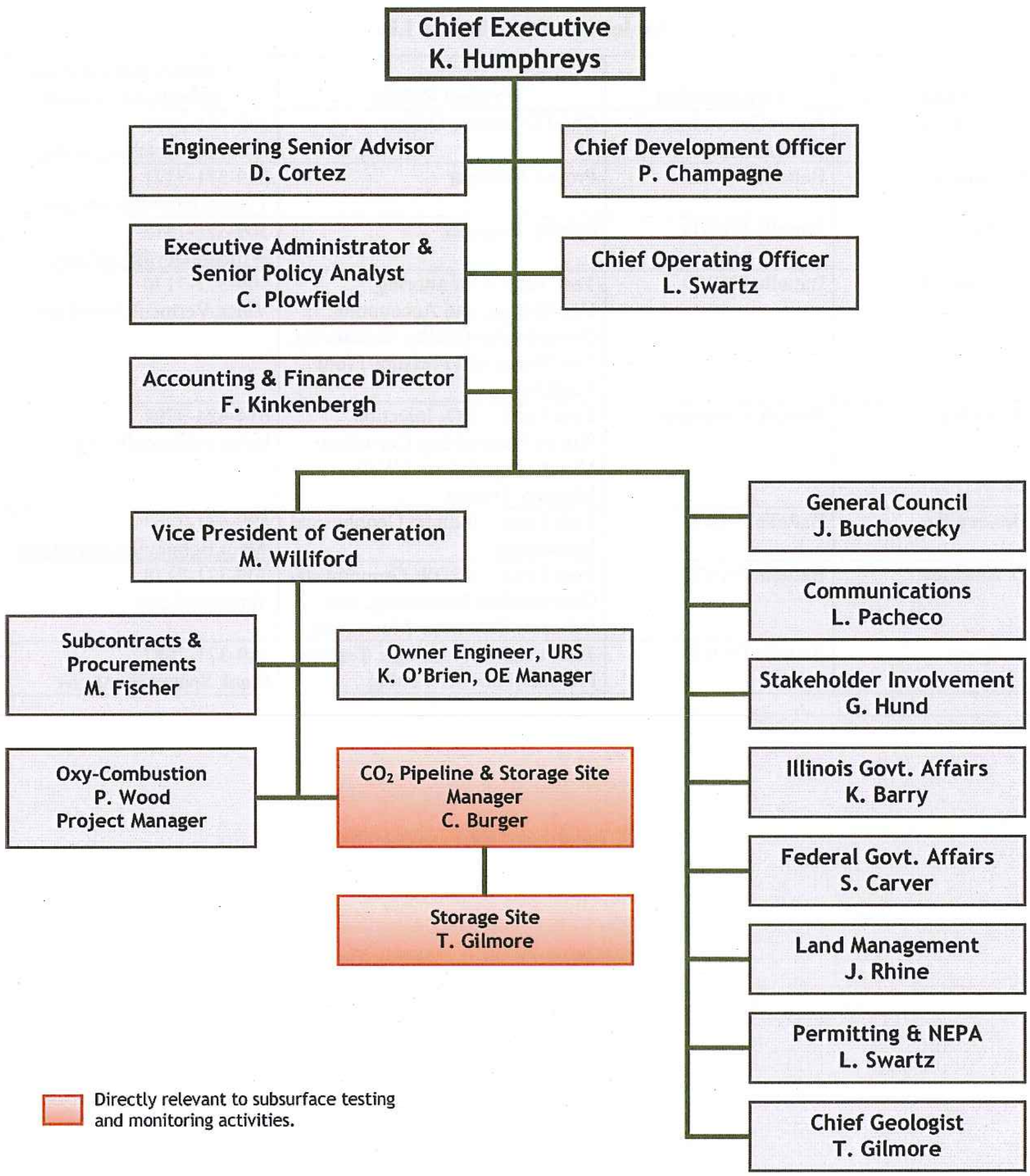
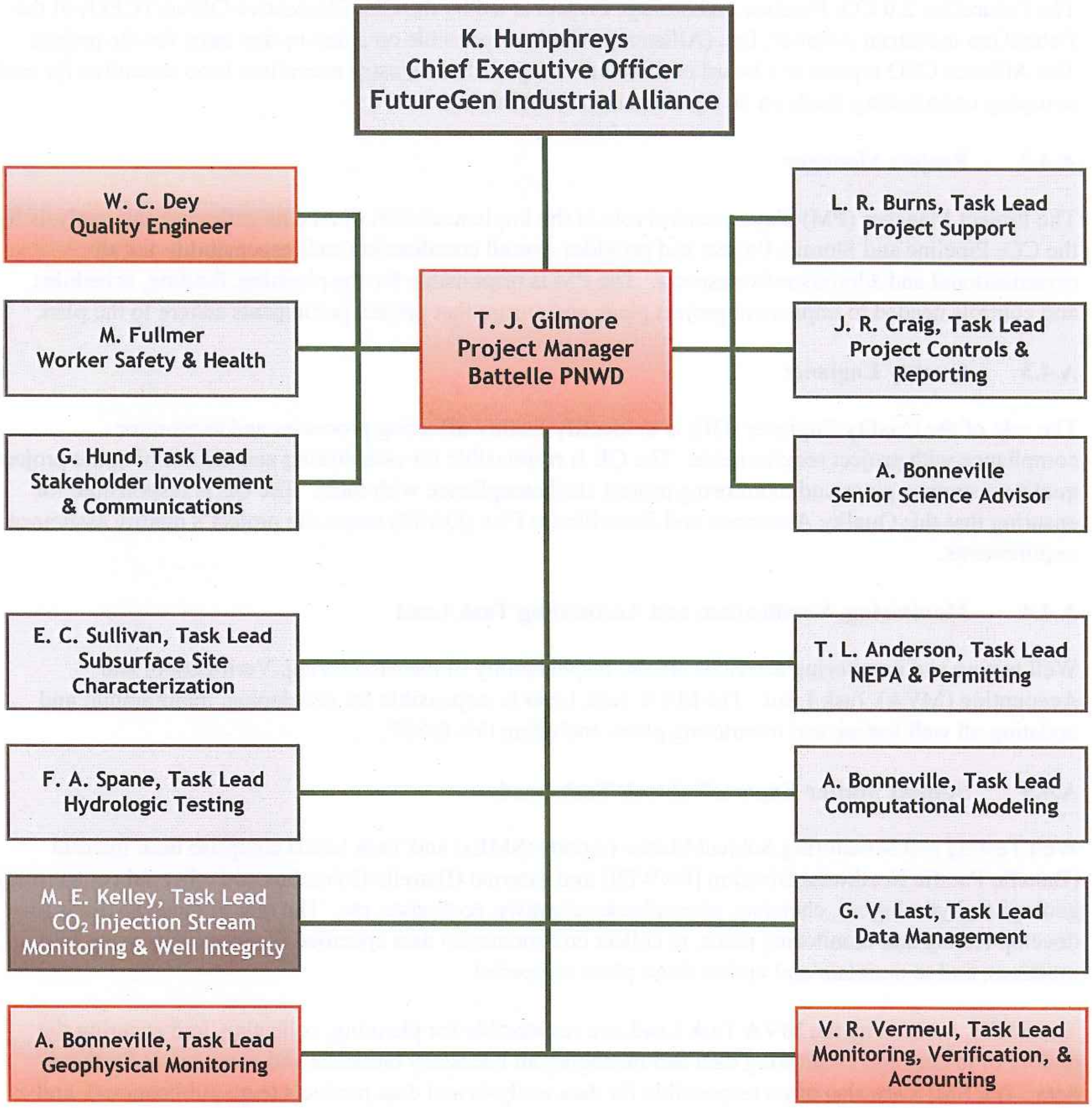


Figure A.1. CO_2 Pipeline and Storage Project Structure (after Alliance 2013a)

The organizational structure specific to well testing and monitoring is shown in Figure A.2.



Shaded boxes are directly relevant to subsurface testing and monitoring activities.
Boxes with white text are non-Battelle PNWD staff.

Figure A.2. Task Level Project Organization Relevant to Well Testing and Monitoring

A.4.1 Alliance Chief Executive Officer

The FutureGen 2.0 CO_2 Pipeline and Storage Project is led by the Chief Executive Officer (CEO) of the FutureGen Industrial Alliance, Inc. (Alliance), who is responsible on a day-to-day basis for the project. The Alliance CEO reports to a board of directors composed of industry executives (one executive for each company contributing funds on an equal basis to the Alliance).

A.4.2 Project Manager

The Project Manager (PM) plays a central role in the implementation of all data gathering and analysis for the CO_2 Pipeline and Storage Project and provides overall coordination and responsibility for all organizational and administrative aspects. The PM is responsible for the planning, funding, schedules, and controls needed to implement project plans and ensure that project participants adhere to the plan.

A.4.3 Quality Engineer

The role of the Quality Engineer (QE) is to identify quality-affecting processes and to monitor compliance with project requirements. The QE is responsible for establishing and maintaining the project quality assurance plans and monitoring project staff compliance with them. The QE is responsible for ensuring that this Quality Assurance and Surveillance Plan (QASP) meets the project's quality assurance requirements.

A.4.4 Monitoring, Verification, and Accounting Task Lead

Well testing and monitoring activities are the responsibility of the Monitoring, Verification, and Accounting (MVA) Task Lead. The MVA Task Lead is responsible for developing, maintaining, and updating all well testing and monitoring plans, including this QASP.

A.4.5 Subject Matter Experts/Subtask Task Leads

Well Testing and Monitoring Subject Matter Experts (SMEs) and Task Leads comprise both internal (Battelle Pacific Northwest Division [PNWD]) and external (Battelle Columbus and other subcontractors) geologists, hydrologists, chemists, atmospheric scientists, ecologists, etc. The role of these SMEs is to develop testing and monitoring plans, to collect environmental data specified in those plans using best practices, and to maintain and update those plans as needed.

The SMEs, assisted by the MVA Task Lead, are responsible for planning, collecting, and ensuring the quality of testing and monitoring data and managing all necessary metadata and provenance for these data. The SMEs are also often responsible for data analysis and data products (e.g., publications), and acquisition of independent data quality/peer reviews.

A.5 Problem Definition/Background

A.5.1 Purpose and Objectives

The FutureGen CO_2 Pipeline and Storage Project is part of the larger FutureGen 2.0 Project aimed at demonstrating the technical feasibility of oxy-combustion technology as an approach to implementing carbon capture and storage (CCS) from new and existing coal-fueled energy facilities. The advancement of CCS technology is critically important to addressing CO_2 emissions and global climate change concerns associated with coal-fueled energy. The objective of this project is to design, build, and operate a commercial-scale CCS system capable of capturing, treating, and storing the CO_2 off-gas from a oxy-combustion coal-fueled power plant located in Meredosia, Morgan County, Illinois. Using safe and proven pipeline technology, the CO_2 will be transported to a nearby storage site, located near Jacksonville, Illinois, where it will be injected into the Mount Simon and Eau Claire formations at a rate of 1.1 million metric tons (MMT) of CO_2 each year, for a planned duration of at least 20 years.

The objective of the CO_2 Pipeline and Storage project is to demonstrate utility-scale integration of transport and permanent storage of captured CO_2 in a deep geologic formation (a.k.a. geologic sequestration) and to demonstrate that this can be done safely and ensure that the injected CO_2 is retained within the intended storage reservoir.

A.5.2 Background

The U.S. Environmental Protection Agency (EPA) established requirements for CO_2 geologic sequestration under the Underground Injection Control (UIC) Program for Geologic Sequestration (GS) Class VI Wells. These federal requirements (codified in the U.S. Code of Federal Regulations [40 CFR 146.81 et seq.], known as the Class VI Rule) set minimum technical criteria for CO_2 injection wells for the purposes of protecting underground sources of drinking water (USDWs). Testing and Monitoring Requirements (40 CFR 146.90) under the Class VI Rule require owners or operators of Class VI wells to develop and implement a comprehensive testing and monitoring plan that includes injectate monitoring; corrosion monitoring of the well's tubular, mechanical, and cement components; pressure fall-off testing; groundwater quality monitoring; and CO_2 plume and pressure-front tracking. These requirements (40 CFR 146.90[k]) also require owners and operators to submit a QASP for all testing and monitoring requirements.

This QASP details all aspects of the testing and monitoring activities that will be conducted, and ensures that they are verifiable, including the technologies, methodologies, frequencies, and procedures involved. As the project evolves, this QASP will be updated in concert with the Testing and Monitoring Plan.

A.6 Project/Task Description

The FutureGen CO_2 Pipeline and Storage Project will undertake testing and monitoring as part of its MVA program to verify that the Morgan County CO_2 storage site is operating as permitted and is not endangering any USDWs. The MVA program includes operational CO_2 injection stream monitoring, well corrosion and mechanical integrity testing, geochemical and indicator parameter monitoring of both the reservoir and shallow USDWs, and indirect geophysical monitoring, for characterizing the complex fate and transport processes associated with CO_2 injection. Table A.2 summarizes the general Testing and Monitoring tasks, methods, and frequencies.

Table A.2. Monitoring Tasks, Methods, and Frequencies by Project Phase

Monitoring Category	Monitoring Method	Baseline 3 yr	Injection (startup) ~3 yr	Injection ~2 yr	Injection ~15 yr	Post-Injection 50 yr
CO_2 Stream Analysis	Grab sampling and analysis	3 events, during commissioning	Quarterly	Quarterly	Quarterly	NA
Continuous Recording of Injection Pressure, Rate, and Annulus Pressure	Continuous monitoring of injection process (injection rate, pressure, and temperature; annulus pressure and volume)	NA	Continuous	Continuous	Continuous	NA
Corrosion Monitoring	Corrosion coupon monitoring of Injection Well Materials	NA	Quarterly	Quarterly	Quarterly	NA
Groundwater Quality Monitoring	Fluid sample collection and analysis in all ACZ and USDW monitoring wells	3 events	Quarterly	Semi-Annual	Annual	Every 5 yr
	Electronic P/T/SpC probes installed in ACZ and USDW wells	1 yr min	Continuous	Continuous	Continuous	Continuous
External Well Mechanical Integrity Testing	PNC and Temperature logging	Once after well completion	Annual	Annual	Annual	Annual until wells plugged
	Cement-evaluation and casing inspection logging	Once after well completion	During well workovers	During well workovers	During well workovers	NA
Pressure Fall-Off Testing	Injection well pressure fall-off testing	NA	Every 5 yr	Every 5 yr	Every 5 yr	NA
Direct CO_2 Plume and Pressure-Front Monitoring	Fluid sample collection and analysis in SLR monitoring wells	3 events	Quarterly	Semi-Annual	Annual	Every 5 yr
	Electronic P/T/SpC probes installed in SLR wells	1 yr min	Continuous	Continuous	Continuous	Continuous
Indirect CO_2 Plume and Pressure-Front Monitoring	Passive seismic monitoring (microseismicity)	1 yr min	Continuous	Continuous	Continuous	Continuous
	Integrated deformation monitoring	1 yr min	Continuous	Continuous	Continuous	Continuous
	Time-lapse gravity	3 events	Annual	Annual	Annual	NA
	PNC logging of RAT wells	3 events	Quarterly	Quarterly	Annual	Annual

ACZ = above confining zone; NA = not applicable; PNC = pulsed-neutron capture; P/T/SpC = pressure, temperature, and specific conductance; RAT = reservoir access tube; SLR = single-level in-reservoir; USDW = underground source of drinking water.

A.6.1 CO_2 Injection Stream and Corrosion/Well Integrity Monitoring

The CO_2 injection stream will be continuously monitored at the surface for pressure, temperature, and flow, as part of the instrumentation and control systems for the FutureGen 2.0 CO_2 Pipeline and Storage Project. Periodic grab samples will also be collected and analyzed to track CO_2 composition and purity.

The pressure and temperature will be monitoring within each injection well at a position located immediately above the injection zone at the end of the injection tubing. The downhole sensor will be the point of compliance for maintaining injection pressure below 90 percent of formation fracture pressure.

CO_2 Stream Analysis

The composition and purity of the CO_2 injection stream will be monitored through the periodic collection and analysis of grab samples.

Continuous Recording of Injection Pressure, Rate, and Volume; Annulus Pressure

Pressure monitoring of the CO_2 stream at elevated pressure will be done using local analog gauges, pressure transmitters, or pressure transmitters with local digital readouts. Flow monitoring will be conducted using Coriolis mass type meters. Normal temperature measurements will be made using thermocouples (TCs) or resistance temperature detectors (RTDs). A Supervisory Control and Data Acquisition (SCADA) system will be used to transmit operational power plant, pipeline, and injection well data long distances (~30 mi) for the pipeline and storage project.

Corrosion Monitoring

Samples of injection well materials (coupons) will be periodically monitored for signs of corrosion to verify that the well components meet the minimum standards for material strength and performance and to identify well maintenance needs.

External Well Mechanical Integrity Testing

Wireline logging, including pulsed-neutron capture (PNC) logs (both in the gas-view and oxygen-activation modes) and temperature logs, and cement-evaluation and casing inspection logging, will be conducted to verify the absence of significant fluid movement through potential channels adjacent to the injection well bore and/or to determine the need for well repairs.

A.6.2 Storage Site Monitoring

The objective of the storage site monitoring program is to select and implement a suite of monitoring technologies that are both technically robust and cost-effective and provide an effective means of 1) evaluating CO_2 mass balance (i.e., verify that the site is operating as permitted) and 2) detecting any unforeseen containment loss (i.e., verify that the site is not endangering any USDWs). Both direct and indirect measurements will be used collaboratively with numerical models of the injection process to verify that the storage site is operating as predicted and that CO_2 is effectively sequestered within the targeted deep geologic formation and is fully accounted for. The approach is based in part on reservoir-monitoring wells, pressure fall-off testing, and indirect (e.g., geophysical) methods. Early-detection monitoring wells will target regions of increased leakage potential (e.g., proximal to wells that penetrate the caprock). During baseline monitoring, a comprehensive suite of geochemical and isotopic analyses will be performed on fluid samples collected from the reservoir and overlying monitoring intervals.

These analytical results will be used to characterize baseline geochemistry and provide a metric for comparison during operational phases. Selection of this initial analyte list was based on relevance for detecting the presence of fugitive brine and CO_2. The results for this comprehensive set of analytes will be evaluated and a determination made regarding which analytes to carry forward through the operational phases of the project. This selection process will consider the uniqueness and signature strength of each potential analyte and whether its characteristics provide for a high-value leak-detection capability. Indicator parameters will be used to inform the monitoring program. Once baseline conditions and early CO_2 arrival responses have been established, observed relationships between analytical measurements and indicator parameters will be used to guide less-frequent aqueous sample collection and reduced analytical parameters in later years.

Monitoring Well Network (Geochemical and Indicator Parameter Monitoring)

The monitoring well network will address transport uncertainties by using an "adaptive" or "observational" approach to monitoring (i.e., the monitoring approach will be adjusted as needed based on observed monitoring results).

Two aquifers above the primary confining zone will be monitored for any unforeseen leakage of CO_2 and/or brine out of the injection zone. These include the aquifer immediately above the confining zone (Ironton Sandstone, monitored with above confining zone [ACZ] wells) and the St. Peter Sandstone, which is separated from the Ironton by several carbonate and sandstone formations and is considered to be the lowermost USDW. In addition to directly monitoring for CO_2, wells will initially be monitored for changes in geochemical and isotopic signatures that may provide indication of CO_2 leakage. Wells will also be instrumented to detect changes in the stress regime (via pressure in all wells and microseismicity in selected wells) to avoid over-pressurization within the injection or confining zones that could compromise sequestration performance (e.g., caprock fracturing). Table A.3 describes the planned monitoring well network for geochemical and indicator parameter monitoring. Figure A.3 illustrates the nominal monitoring well layout.

Table A.3. Planned Monitoring Wells in the Network

	Single-Level In-Reservoir (SLR)	Above Confining Zone (ACZ)	USDW
Number of Wells	2	2	1
Total Depth (ft)	4,150	3,470	2,000
Monitored Zone	Mount Simon SS	Ironton SS	St. Peter SS
Monitoring Instrumentation	P/T/SpC probe in monitored interval[(a)]	Fiber-optic (microseismic) cable cemented in annulus; P/T/SpC probe in monitored interval[(a)]	P/T/SpC probe in monitored interval[(a)]

(a) The P/T/SpC probe is an electronic downhole multi-parameter probe incorporating sensors for measuring fluid pressure (P), temperature (T), and specific conductance (SpC) within the monitored interval. The probe will be installed inside a tubing string, which is perforated (slotted) over the monitoring interval. Measurements will be recorded with a data logger at each well location and also transmitted to the MVA data center in the control building.

SS = sandstone.