About this Document

This document compiles text from the FutureGen permit application for Morgan County Class VI UIC Wells 1, 2, 3, and 4 into the testing and monitoring plan template provided in the *Class VI Project Plan Development Guidance*. The intent is to identify whether sufficient information was provided in the permit application to complete the project plans; **this is not considered a complete or approvable project plan**.

Identified deficiencies and questions are presented in highlighted text.

To facilitate reference to applicant submittals, text is color-coded and sections of the original documents are noted (some text has been edited slightly):

- Red text is from the FutureGen permit application.
- Blue text is from the additional information provided in November 2013.
- Green text is from the additional information provided in December 2013.
- Purple text is from the additional information provided in January 2014 (including the Testing and Monitoring spreadsheet).
- Highlighted text identifies EPA's comments provided in February 2014

Text written by EPA is black.

Table and figure numbers reflect the labels in FutureGen's submissions.

Testing and Monitoring Plan

Facility Information

[from Section 1, Table 1.1]

Facility information is provided by FutureGen in Section 1 of the FutureGen 2.0 permit application for Morgan County Class VI UIC Wells 1, 2, 3, and 4. The contact person at the FutureGen Morgan County Office was provided in the requests for additional information.

Facility name: FutureGen 2.0 Project: Morgan County Class VI UIC Wells 1, 2, 3, and 4

Facility contacts (names, titles, phone numbers, email addresses): Kenneth Humphries, Chief Executive Officer, FutureGen Industrial Alliance, Inc., Morgan County Office, 73 Central Park Plaza East, Jacksonville, IL 62650, 217-243-8215

Location (town/county/etc.): Morgan County, IL; 26−16N−9W; 39.800266ºN and 90.07469ºW"

Carbon Dioxide Stream Analysis

FutureGen will conduct injection stream analysis to meet the requirements at 40 CFR 146.90(a), as described below and in Section 5.2.4.2 of their permit application.

[From Section 5.2.4.2: Injection Stream Analysis Parameters]

Based on the anticipated composition of the CO_2 stream, a list of parameters was identified for analysis (Chapter 4.0, Table 4.1). Samples of the CO_2 stream will be collected regularly (e.g., quarterly) for chemical analysis.

Table 1. Parameters and frequency for CO_2 stream analysis.

Parameter/Analyte	Frequency
pH	quarterly
Temperature	quarterly
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

How will FutureGen measure the pH of the gas stream?

Sampling methods:
[From Section 5.2.4.3: Sampling Method]

Grab samples of the CO_2 stream will be obtained for analysis of gases, including CO_2, O_2, H_2S, 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 small-diameter stainless steel tubing to accommodate sampling cylinders that will be used to collect the samples. A pressure regulator will be used to reduce the pressure of the CO_2 to approximately 250 psi so that the CO_2 is in the gas state when collected rather than a supercritical liquid. Cylinders will be purged with sample gas (i.e., CO_2) prior to sample collection to remove laboratory-added helium gas and ensure a representative sample.

Analytical techniques: *[Not specified.]*

Laboratory to be used/chain of custody procedures: *[Not specified.]*

Quality assurance and surveillance measures:
[from Section 5.6: Data Management]

A wide variety of monitoring data will be collected specifically for this project, under appropriate quality assurance protocols.

[from Section 5.8: Quality Assurance and Surveillance Plan]

Data quality assurance and surveillance protocols will be designed to facilitate compliance with requirements specified in 40 CFR 146.90(k).

A complete QASP will be needed.

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

FutureGen will conduct continuous monitoring of injection parameter to meet the requirements at 40 CFR 146.90(b), as described below and in Section 5.2.4 of their permit application.

[From Section 5.2.4.1: Continuous Monitoring of the CO_2 Injection Process]

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 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. Valving will be installed to select flow meters for measurement and for calibration. A single flow prover will be installed to calibrate the flow meters, and piping and valving will be configured to permit the calibration of each flow meter. The flow transmitters will each be connected to a remote terminal unit (RTU) on the flow meter skid.

The RTU will communicate with the Control Center through the well annular pressure maintenance and monitoring system (WAPMMS) programmable logic controller (PLC) located at the injection well site. The flow rate into each well will be controlled using a flow-control valve located in the CO_2 pipeline associated with each well. The control system will be programmed to provide the desired flow rate into three of the four injection wells, with the one remaining well receiving the balance of the total flow rate.

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 WAPMMS PLC at the injection well site.

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 WAPMMS PLC located at the injection well site.

[From 1/17/2014 response]

Mechanical strain gauges and thermocouples wires will be the primary monitoring devices for pressure and temperature and will be frequently re-calibrated (initially on a quarterly basis). In some wells a redundant fiber optic cable will also be installed as part of a comparison test with more standard gauges.

The injection wells will be completed with a string of 3.5 in.-OD tubing that extends from the wellhead at the surface to near the top of the perforated interval. A tubing string that is 4,000 ft long will extend approximately 11 ft below the top of the perforations. The tubing string will be held in place at the bottom by a packer that is positioned just above the uppermost perforations (approximate measured depth of 3,975 ft). An optical or electronic pressure-and-temperature (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. Because the bottom-hole P/T gauge will be attached to the tubing string, the gauge will be recalibrated or replaced only when the injection well tubing string is pulled, which would occur only if warranted by a downhole issue that can only be addressed by performing a well workover. In addition, 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, re-calibrated or replaced on a regular basis (e.g., semi-annually) to ensure they are providing accurate data. Because the surface instruments can be more readily accessed and maintained than the bottom-hole gauge, they will be used to control injection operations and trigger shutdowns.

The sampling and recording protocol of the pressure and temperature gauges is needed from FutureGen in order to determine if the sampling protocols meet Region 5s guidance on continuous monitoring. Specific information on the frequency at which temperature and pressure data will measured is also needed.

Corrosion Monitoring

FutureGen will conduct corrosion monitoring of well materials to meet the requirements at 40 CFR 146.90(c), as described below and in Section 5.3.2.2 of their permit application.

[From Section 5.3.2.2: Corrosion Monitoring]

Casing and Tubing

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 of casing and the injection tubing. The coupons will be removed quarterly and assessed for corrosion using the American Society for Testing and Materials (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. 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 casing inspection (wireline) logs. The frequency of running these tubing and casing inspection logs will be determined based on site-specific parameters and well performance. Wireline tools are lowered into the well to directly measure properties of the well tubulars that indicate corrosion. Four types of wireline tools are available for assessing corrosion of well materials—mechanical, electromagnetic, ultrasonic, and videographic. Mechanical, electromagnetic, and/or ultrasonic tools will be used primarily to monitor well corrosion (Table 2). These tools, or comparable tools from alternate vendors, will be used to monitor the condition of well tubing and casing.

Table 2. Examples of wireline tools for monitoring corrosion of casing and tubing (Table 5.6 of FutureGen's permit application).

Tool Name	**Mechanical**	**Ultrasonic**	**Electromagnetic**
	Multifinger Imaging Tool[(a)]	**Ultrasonic Imager Tool**[(a)]	**High-Resolution Vertilog**[(b)]
Type	Mechanical	Ultrasonic	Electromagnetic
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 O.D. (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

Tool Name	**Mechanical**	**Ultrasonic**	**Electromagnetic**
	Multifinger Imaging Tool[(a)]	**Ultrasonic Imager Tool**[(a)]	**High-Resolution Vertilog**[(b)]
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.

Mechanical casing evaluation tools, referred to as calipers, have multiple “fingers” that measure the inner diameter of the tubular as the tool is raised or lowered through the well. Modern-day calipers have several fingers and are capable of recording information measured by each finger so that the data can be used to produce highly detailed 3D images of the well. An example caliper tools is Schlumberger’s Multifinger Imaging Tool (Table 5.6). This tool is available in multiple sizes to accommodate various sizes of well tubing and casing.

Ultrasonic tools are capable of measuring wall thickness in addition to the inner diameter (radius) of the well tubular. Consequently, these tools can also provide information about the outer surface of the casing or tubing. Examples of ultrasonic tools include Schlumberger’s Ultrasonic Casing Imager (UCI) and Ultrasonic Imager (USI). The USI can also be used for cement evaluation, as discussed below. Specifications for the USI tool are listed in Table 5.6.

Electromagnetic tools 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. An example electromagnetic tool is Baker Hughes’ High-Resolution Vertilog (Table 5.6).

Mechanical caliper tools are excellent casing/tubing evaluation tools for internal macro-scale features of the casing/tubing string. Ultrasonic tools, such as the USI, are able to further refine the scale of feature detection and can evaluate cement condition. However, electromagnetic tools offer the most sensitive means for casing/tubing corrosion detection. When conducting casing inspection logging, both an ultrasonic and an electromagnetic tool will be run to assess casing corrosion conditions (the ultrasonic tool will also be run to provide information on cement corrosion).

Ground Water Quality Monitoring

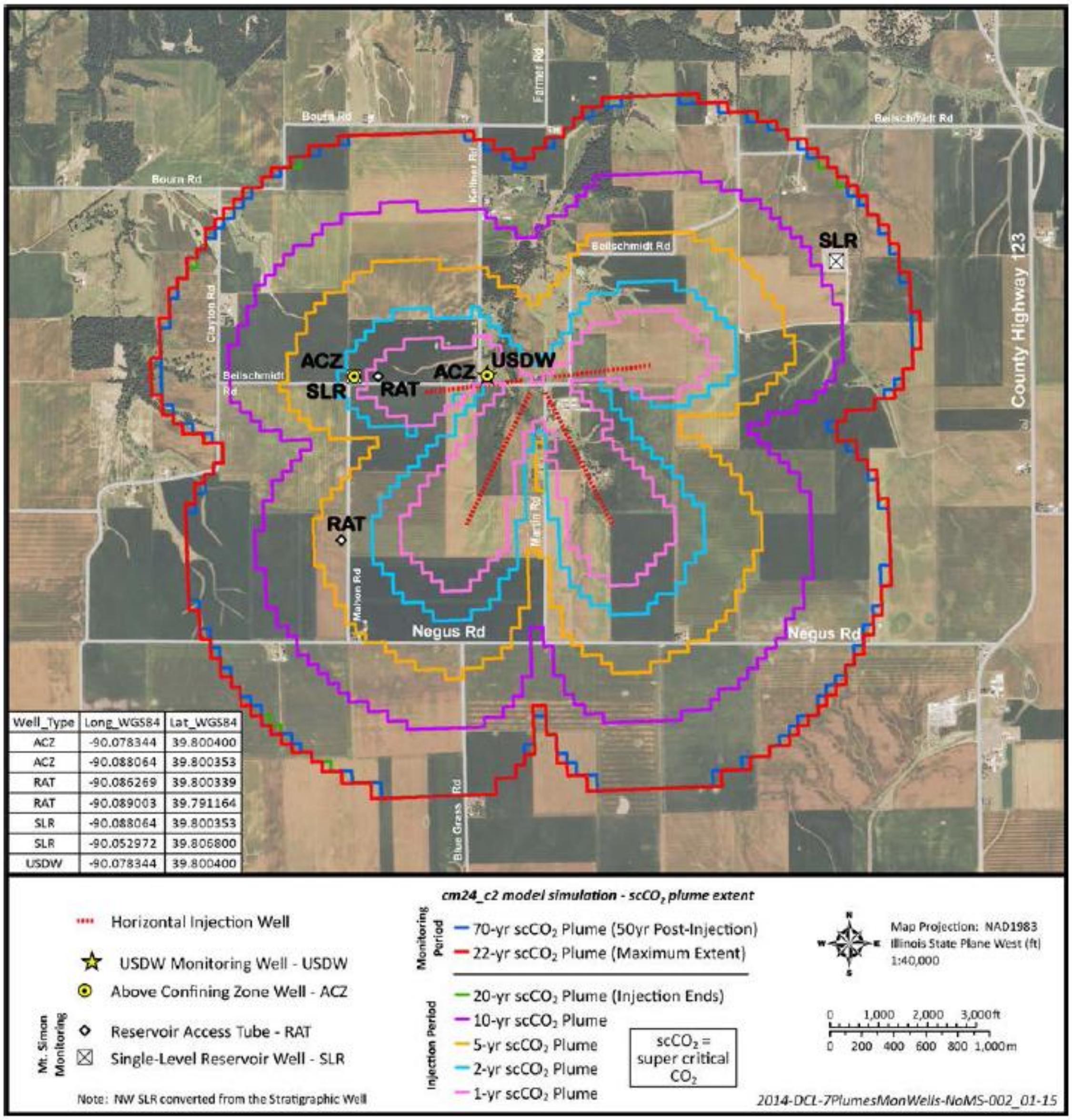
FutureGen will conduct ground water quality/geochemical monitoring above the confining zone to meet the requirements at 40 CFR 146.90(d). The following information is drawn from Sections 5.1.4 and 5.2.2 of FutureGen's permit application, as well as the supplemental information submitted in January 2014.

FutureGen will conduct periodic fluid sampling throughout the injection phase in three wells constructed for the purpose of this project: two above confining zone (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 on these wells are given in Table 3 and a map of the well locations is shown in Figure 1. Construction information has not yet been submitted.

Table 3. Monitoring wells to be used for ground water/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 (decimal degrees)	39.800400, -90.078344; 39.800353, -90.088064	39.800400, -90.078344
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 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.



Well_Type	Long_WGS84	Lat_WGS84
ACZ	-90.078344	39.800400
ACZ	-90.088064	39.800353
RAT	-90.086269	39.800339
RAT	-90.089003	39.791164
SLR	-90.088064	39.800353
SLR	-90.052972	39.806800
USDW	-90.078344	39.800400

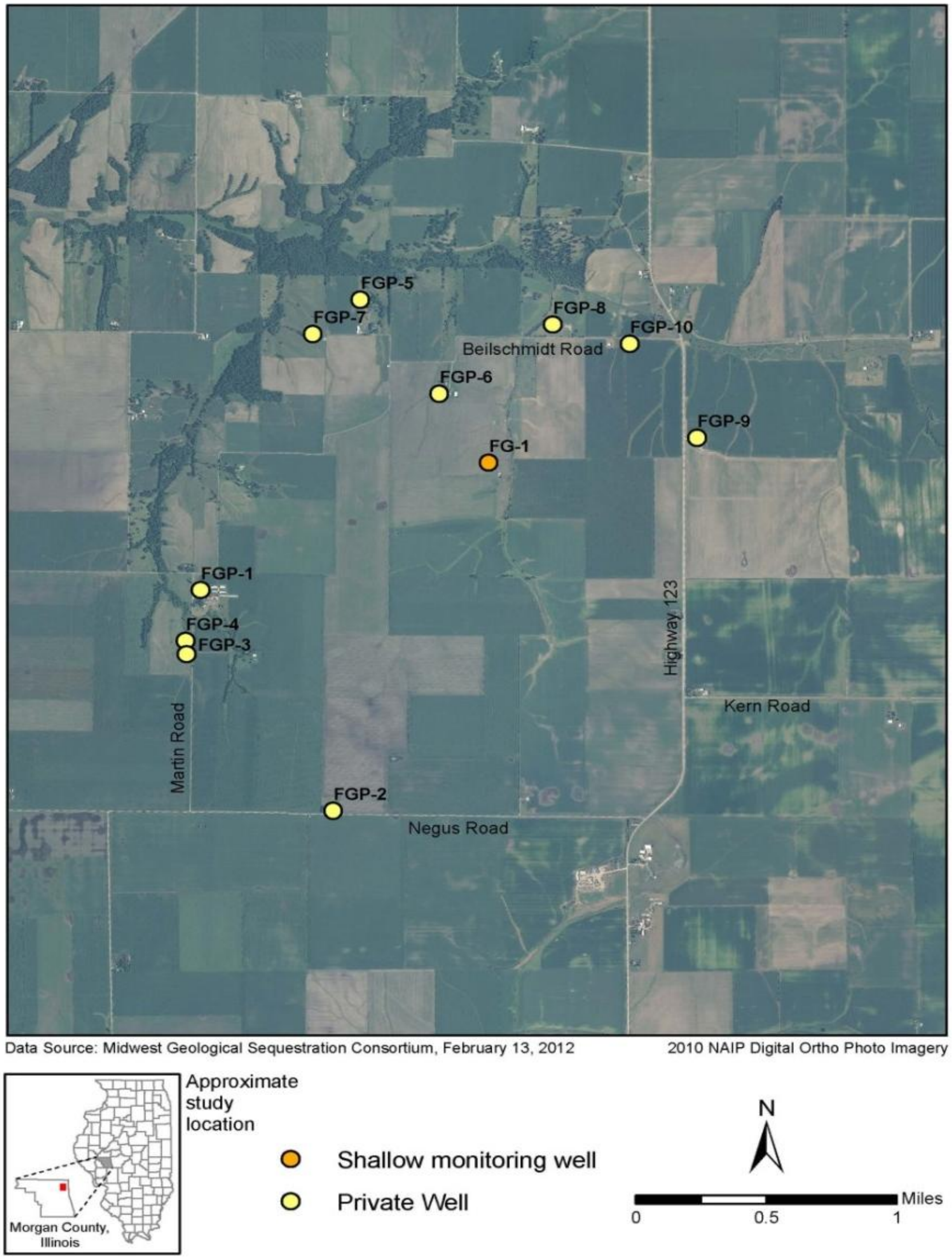
Note: NW SLR converted from the Stratigraphic Well

2014-DCL-7PlumesMonWells-NoMS-002_01-15

Figure 1. Locations of ACZ and USDW wells relative to FutureGen's injection zone monitoring wells, injection wells, and predicted plume extent.

Lat/Longs for the wells identified in Figure 1 should be tabulated on a separate page and placed as an attachment to the testing and monitoring plan template.

FutureGen will also conduct baseline sampling in the shallow, semi-consolidated glacial sediments that make up the surficial aquifer, using approximately 10 local landowner wells and one well drilled for the project (Figure 2).



Data Source: Midwest Geological Sequestration Consortium, February 13, 2012 2010 NAIP Digital Ortho Photo Imagery

Figure 2. Surficial aquifer monitoring locations. Well FG-1 is a dedicated well drilled for the purposes of the FutureGen project, while wells FGP-1 through FGP-10 are local landowner wells.

Locations for the surficial wells must be identified with lat/long coordinates. These coordinates can be tabulated and attached to the end of the testing and monitoring plan template.

[Adapted from the spreadsheet submitted on 1/29/14:]

Sampling will take place at the frequencies specified in Table 4 (for the surficial aquifers), Table 5 (for the St. Peter), and Table 6 (for the Ironton). Because near-surface environmental impacts are not expected, surficial aquifer (<100 ft bgs) monitoring will only be conducted for a sufficient duration to establish baseline conditions (minimum of 3 sampling events); surficial aquifer monitoring is not planned during the injection phase, however, the need for additional surficial aquifer monitoring will be continually evaluated throughout the operational phases of the project, and may be reinstituted if conditions warrant. Given our current conceptual understanding of the subsurface environment, early and appreciable impacts on near-surface environments are not expected, so extensive networks of surficial aquifer monitoring wells are not warranted.

Target parameters for the ACZ wells include pressure, temperature, and hydrogeochemical indicators of CO_2 and brine composition. 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. 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 their characteristics provide for a high value leak detection capability. Once baseline conditions have been established, observed differences in the geochemical and isotopic signature between the reservoir and overlying monitoring intervals, along with predictions of leakage-related pressure response, will be used to specify triggers values that would prompt further action, including a detailed evaluation of the observed response and possible modification to the monitoring approach and/or storage site operations. This evaluation will be supported by numerical modeling of theoretical leakage scenarios that will be used to evaluate leak detection capability and interpret any observed pressure and/or geochemical/isotopic change in the ACZ wells.

Target parameters for the USDW and surficial aquifer wells include pressure, temperature, and hydrogeochemical indicators of CO_2 and brine composition. A comprehensive suite of geochemical and isotopic analyses will be performed on collected fluid samples during the baseline monitoring period. Selection of this initial analyte list was based on relevance for detecting the presence of fugitive brine and CO_2. Results for this comprehensive set of analytes will then 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 their characteristics provide for a high value leak detection capability. Trigger values for the lowermost USDW monitoring well and the surficial aquifer monitoring wells have not been defined. If a leakage response is observed in the ACZ early-detection monitoring wells (Ironton) then the decision not to institute USDW aquifer triggers will be reevaluated based on the magnitude of the observed leakage response and predictive simulations of CO_2 transport between the Ironton and the St. Peter aquifers.

Note: The information in the following tables is drawn from Tables 5.3, 5.4, and 5.5 of FutureGen's permit application, updated to reflect the most recent submissions. Tables 5.4 and 5.5 of the permit application give a fairly comprehensive list of target parameters that are under consideration, including a brief description of sampling and analysis requirements. However, FutureGen has not yet submitted a final list of the planned parameters; see the text above. In particular, dissolved and/or separate-phase CO_2 is not listed as a target parameter under consideration in Tables 5.4 and 5.5, and this should be discussed further. Depending on the final suite of parameters chosen, it may be appropriate to monitor for CO_2 indirectly, e.g. by monitoring dissolved inorganic carbon concentrations in combination with pH as recommended by researchers such as Wilkin and Digiulio (2010). However, this determination will need to be made after the final list of parameters is received. (Reference: Wilkin, R.T. and D.C. Digiulio. 2010. Geochemical Impacts to Groundwater from Geologic Carbon Sequestration: Controls on pH and Inorganic Carbon Concentrations from Reaction Path and Kinetic Modeling. Environ. Sci. Technol. 44(12): 4821-4827.)

Table 4. 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	Not listed in Tables 5.4, 5.5	None planned
Pressure	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 5. Sampling schedule for 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	Not listed in Tables 5.4, 5.5	Not listed in Tables 5.4, 5.5
Pressure	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
Temperature	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
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

Table 6. 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	Not listed in Tables 5.4, 5.5	Not listed in Tables 5.4, 5.5
Pressure	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
Temperature	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
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

Sampling methods:
[From Section 5.2.2.3: Sampling and Analysis]

A sampling plan is referenced below, but not provided; also FutureGen cites cost as a factor in selecting methods – costs should not be a factor.

Specific field sampling protocols will be described in a project-specific sampling plan to be developed prior to initiation of field test operations, once the test design has been finalized. The work will comply with applicable EPA regulatory procedures and relevant American Society for Testing and Material, ISGS, and other procedural standards applicable for groundwater sampling and analysis. All sampling and analytical measurements will be performed in accordance with project quality assurance requirements (see Section 5.8), 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 (see Section 5.6). Investigation-derived waste will be handled in accordance with site requirements.

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 5.4. The relative benefit (and cost) 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 and/or cost prohibitive, they will be removed from the analyte list. All analyses will be performed in accordance with the analytical requirements listed in Table 5.5. Additional analytes may be included for the shallow USDW based on landowner requests (e.g., coliform bacteria). If implemented, monitoring for tracers will follow standard aqueous sampling protocols for the naphthalene sulfonate tracer, but a pressurized sample for the PFT tracer will be required because the PFT will be partitioned into the gas phase.

Sampling and analytical techniques for target parameters are given in Table 7 and Table 8, respectively.

Note: We assume that FutureGen intends to test for all these parameters during the baseline sampling described above. However, clarification is needed. We will update these tables based on any further information submitted.

Table 7. Aqueous sampling requirements for target parameters (adapted from Table 5.4 of FutureGen's permit application).

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, Ba, Cd, Cr, Cu, Pb, Hg, Se, Tl	20-mL plastic vial	Filtered (0.45 µm), HNO_3 to pH <2	60 days
Anions: Cl^-, Br^-, F^-, SO_4^{2-}, NO_3^-,	20-mL plastic vial	Cool 4°C	45 days
Gravimetric Total Dissolved Solids (TDS), compare to TDS by calculation from major ions	250-mL plastic vial	Filtered (0.45 µm), no preservation Cool 4°C	
Water Density	100 mL plastic vial	Filtered (0.45 µm), no preservation Cool 4°C	60 days
Alkalinity	100 mL HDPE	Filtered (0.45 µm) Cool 4°C	5 days
Dissolved Inorganic Carbon (DIC)	20-mL plastic vial	Cool 4°C	45 days
Total Organic Carbon (TOC)	40 mL glass	unfiltered	14 days
Carbon Isotopes (^{14}C, $^{13/12}C$)	5-L HDPE	pH >6	14 days
Water Isotopes ($^{2/1}H$, $^{18/16}O$)	20-mL glass vial	Cool 4°C	45 days
Radon (^{222}Rn)	1.25-L PETE	Pre-concentrate into 20-mL scintillation cocktail. Maintain groundwater temperature prior to pre-concentration	1 day
Naphthalene Sulfonate or Fluorinated Benzoic Acid Tracers (aqueous phase)	500 mL HDPE	Filtered (0.45 µm), no preservation	60 days
Perfluorocarbon Tracer (PFT) ($scCO_2$ or gas phase)	500 mL glass	unfiltered, Cool 4°C	60 days
pH	Field parameter	None	<1 h
Specific Conductance	Field parameter	None	<1 h
Temperature	Field parameter	None	<1 h

HDPE = high-density polyethylene; PETE = polyethylene terephthalate

Table 8. Analytical requirements (adapted from Table 5.5 of FutureGen's permit application).

Parameter	Analysis Method	Detection Limit or Range	Typical Precision/ Accuracy	QC Requirements
Major Cations: Al, Ba, Ca, Fe, K, Mg, Mn, Na, Si,	ICP-OES, PNNL-AGG-ICP-AES (similar to EPA Method 6010B)	0.1 to 1 mg/L (analyte dependent)	±10%	Daily calibration; blanks and duplicates and matrix spikes at 10% level per batch of 20
Trace Metals: Sb, As, Ba, Cd, Cr, Cu, Pb, Hg, Se, Tl	ICP-MS, PNNL-AGG-415 (similar to EPA Method 6020)	1 µg/L for trace elements	±10%	Daily calibration; blanks and duplicates and matrix spikes at 10% level per batch of 20
Anions: Cl^-, Br^-, F^-, $SO4^{2-}$, NO_3^-, CO_3^{2-}	Ion Chromatography, AGG-IC-001 (based on EPA Method 300.0A)		±15%	Daily calibration; blanks and duplicates at 10% level per batch of 20
TDS	Gravimetric Method Standard Methods 2540C	12 mg/L	± 5%	Balance calibration, triplicate samples
Water Density	Standard Methods 227	0.0001 g/mL	±0.0%	Triplicate measurements
Alkalinity	Titration, standard methods 102	4 mg/L	±3 mg/L	Triplicate titrations
Dissolved Inorganic Carbon (DIC)	Carbon analyzer, phosphoric acid digestion of DIC	0.002%	±10%	Triplicate analyses, daily calibration
Total Organic Carbon (TOC)	Carbon analyzer; total carbon by 900°C pyrolysis minus DIC = TOC	0.002%	±10%	Triplicate analyses, daily calibration
Carbon Isotopes ($^{14/12}C$, $^{13/12}C$)	Accelerator MS	10^{-15}	±4‰ for ^{14}C; ±0.2‰ for ^{13}C	Triplicate analyses
Water Isotopes ($^{2}H/^{1}H$, $^{18/16}O$)	Water equilibration coupled with IRMS ; Alternatively, consider WS-CRDS	10^{-9}	IRMS: ±1.0‰ for ^{2}H; ±0.15‰ for ^{18}O; WS-CRDS: ±0.10‰ for ^{2}H; ±0.025‰ for ^{18}O	Triplicate analyses
Radon (^{222}Rn)	Liquid scintillation after pre-concentration	5 mBq/L	±10%	Triplicate analyses
Naphthalene Sulfonate **<u>or</u>** Benzoic Acid Tracer (aqueous phase)	Liquid chromatography-mass spectrometry (LC-MS) **<u>or</u>** gas chromatography with electron capture detector (ECD)	5 parts per trillion (5 x 10^{12}) **<u>or</u>** 10 parts per quadrillion (10 x 10^{15})	Varies with conc.,±30% at detection limit	Duplicates 10% of samples, significant number of blanks for cross-contamination
Perfluorocarbon Tracer (PFT) (scCO2 or gas phase)	Gas chromatography with electron capture detector (ECD)	10 parts per quadrillion (10 x 10^{15})	Varies with conc., ±30% at detection limit	Duplicates 10% of samples, significant number of blanks for cross-contamination

Parameter	**Analysis Method**	**Detection Limit or Range**	**Typical Precision/ Accuracy**	**QC Requirements**
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
Temperature	Thermocouple	5 to 50°C	±0.2°C For indication only	Factory calibration

ICP = inductively coupled plasma; IRMS = isotope ratio mass spectrometry; MS = mass spectrometry; OES = optical emission spectrometry; WS-CRDS = wavelength scanned cavity ring-down spectroscopy

Laboratory to be used/chain of custody procedures:
[from Section 5.2.2.3 Sampling and Analysis]

[S]amples will be tracked using appropriately formatted chain-of-custody forms.

FutureGen lacks detail in its description of laboratory and chain of custody procedures. FutureGen should provide a more detailed Testing and Monitoring Plan containing this information. [Request from FutureGen.]

Quality assurance and surveillance measures:

[from Section 5.8: Quality Assurance and Surveillance Plan]

Data quality assurance and surveillance protocols adopted by the project will be 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 MVA program (e.g., pressure and aqueous concentration measurements) are covered in Sections 5.2.2 and 5.2.3 above. QA requirements for selected geophysical methods, which provide indirect measurements of CO_2 nature and extent and are being tested for their applicability under site conditions, are not addressed in this 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.

FutureGen lacks detail in its description of quality assurance and surveillance protocols. FutureGen should provide a more detailed Testing and Monitoring Plan containing this information. [Request from FutureGen.]

Plan for guaranteeing access to all monitoring locations:

[Adapted from the spreadsheet submitted on 1/29/14:]

The locations of the ACZ and USDW wells has been finalized, pending final signing of landowner agreements. For these wells, the land 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. Ten local landowners originally agreed to have their surficial aquifer wells sampled, one opted out during a recent sampling event.

External Mechanical Integrity Testing

FutureGen will conduct external mechanical integrity testing to meet the requirements at 40 CFR 146.90(e), as described below and in Section 5.3.2 of their permit application.

Note: the discussion of MITs in the permit application appears to describe the purpose of MITs and background, but does not describe the actual tests FutureGen will perform (we retain it for now). Additional information is needed for the Testing and Monitoring Plan; a table outlining the MITs and a schedule for performing them is recommended.

Temperature Logging

Temperature logs can be used 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.

Injection of CO_2 will have a cooling or heating effect on the natural temperature in the storage reservoirs, depending on the temperature of the injected CO_2 and other factors. Once injection starts, the flowing temperature will stabilize quickly (assuming conditions remain steady). When an injection well is shut-in for temperature logging, the well bore fluid begins to revert toward ambient conditions. Zones that have taken injectate, either by design or not, will exhibit a “storage” signature on shut-in temperature surveys (storage signatures are normally cold anomalies in deeper wells, but may be cool or hot depending on the temperature contrast between the injectate and the reservoir). Losses behind pipe from the injection zone can be detected on both flowing and shut-in temperature surveys and exhibit a “loss” signature.

For temperature logging to be effective for detecting fluid leaks, there should be a contrast in the temperature of the injected CO_2 and the reservoir temperature. The greater the contrast in the CO_2 when it reaches the injection zone and the ambient reservoir temperature, the easier it will be to detect temperature anomalies due to leakage behind casing. Based on data from the stratigraphic well, ambient bottom-hole temperatures in the Mount Simon Sandstone are expected to be approximately 100°F; the temperature of the injected CO_2 is anticipated to be on the order of 72°F to 90°at the surface (depending on time of year) but will undergo some additional heating as it travels down the well. After the baseline (i.e., prior to injection) temperature log has been run to determine ambient reservoir temperature in each well, it will be possible to determine whether there will be sufficient temperature contrast to make the temperature log an effective method for evaluating external mechanical integrity. Temperature logging would be conducted through the tubing and therefore would not require removal of the tubing and packer from the well.

The Alliance will consult the EPA Region 5 guidance for conducting temperature logging (EPA2008) when performing this test.

Oxygen-Activation Logging

Oxygen activation is a geophysical logging technique that uses a pulsed-neutron capture tool to quantify the flow of water in or around a borehole. For purposes of demonstrating external mechanical integrity, a baseline oxygen activation will be run prior to the start of CO_2 injection and compared to later runs 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).
The pulsed-neutron tool emits high-energy neutrons that interact with water molecules present in the casing-formation annular space, among others. This temporarily activates oxygen (16O) to produce an isotope of nitrogen (16N) that decays back to oxygen with a half-life of 7.1 seconds and emits an easily detected gamma ray. Typical pulsed-neutron capture tools have two or three gamma-ray detectors (above and below the neutron source) to detect the movement of the activated molecules, from which water velocity can then be calculated. The depth of investigation for oxygen-activation logging is typically less than 1 ft; therefore, this log type provides information immediately adjacent to the well bore.

Repeat runs will be made under conditions that mimic baseline conditions (e.g., similar logging speeds and tool coefficients) as closely as possible to ensure comparability between baseline and repeat data.

The Alliance will consult the EPA Region 5 guidance for conducting the oxygen-activation logging (EPA 2008) when performing this test.

Suggested language: Proposed external mechanical integrity test procedures will be submitted to the EPA Region 5 office for review, at least 30 days before any anticipated test. The permittee will work with the EPA Region 5 office to accommodate any comments they may have on the proposed test procedures.

[from Section 5.3.2: Mechanical Integrity Testing During Service Life of Well]

As discussed in the Construction and Operations Plan (Section 4.3), an initial (baseline) temperature log and/or oxygen-activation log will be run on the well after well construction but prior to commencing CO_2 injection. These baseline log(s) will serve as a reference for comparing future temperature and/or oxygen-activation logs for evaluating external mechanical integrity. The following sections describe temperature logging and oxygen-activation logging during the service life of the well. A third type of mechanical integrity test—a RTS—is also described. This method may be used in addition to temperature logging or oxygen-activation logging, if needed, to help explain results, but in itself, is not an approved external mechanical integrity method for the conditions present at the injection wells.

[from Section 5.3.2.2: *Corrosion Monitoring]*

Note that cement evaluation beyond the preliminary cement-bond log is not required for Class VI wells under MIT or corrosion monitoring (40 CFR 146.89 and 146.90). However, it is recognized that cement integrity over time can influence the mechanical integrity of an injection well. Therefore, cement- evaluation logs will be run when tubing is removed from the well (i.e., during well workovers).

Pressure Fall-Off Testing

FutureGen will conduct pressure fall-off testing to meet the requirements at 40 CFR 146.90(f), as described below and in Section 5.3.1 of their permit application.

Note: the discussion of fall-off testing in the permit application appears to describe the purpose of the tests and background, but does not describe the actual tests FutureGen will perform (we retain it for now) or the frequency. Additional information is needed for the Testing and Monitoring Plan.

[from Section 5.3.1: *Pressure Fall-Off Testing]*

Pressure fall-off tests conducted after the start of CO_2 injection operations 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
- formation damage (skin) near the well bore, which can be used to diagnose the need for well remediation/rehabilitation.

The EPA has not issued guidance for conducting pressure fall-off testing at GS sites; however, guidance is available for conducting these tests for Class I UIC wells (see for example EPA 2002, 1998). These guidelines will be followed when conducting pressure fall-off tests for the FutureGen 2.0 Project.

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 will be calibrated on an annual basis with current annual calibration certificates provided with test results to EPA. In lieu of removing the injection tubing, the calibration of downhole pressure gauges will demonstrate accuracy by utilizing 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).

[from Section 5.8: Quality Assurance and Surveillance Plan]

Data quality assurance and surveillance protocols adopted by the project will be 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 MVA program (e.g., pressure and aqueous concentration measurements) are covered in Sections 5.2.2 and 5.2.3 above. QA requirements for selected geophysical methods, which provide indirect measurements of CO_2 nature and extent and are being tested for their applicability under site conditions, are not addressed in this 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. Additional information is needed.

Carbon Dioxide Plume and Pressure Front Tracking

FutureGen will conduct direct and indirect carbon dioxide plume and pressure-front monitoring to meet the requirements of 40 CFR 146.90(g). The following information is drawn from Sections 5.1.4 and 5.2.3 of FutureGen's permit application and the additional information submitted in January 2014.

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 Ground Water Quality Monitoring section).

[Adapted from 1/17/2014 submission]

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

- **Two single-level in-reservoir (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.

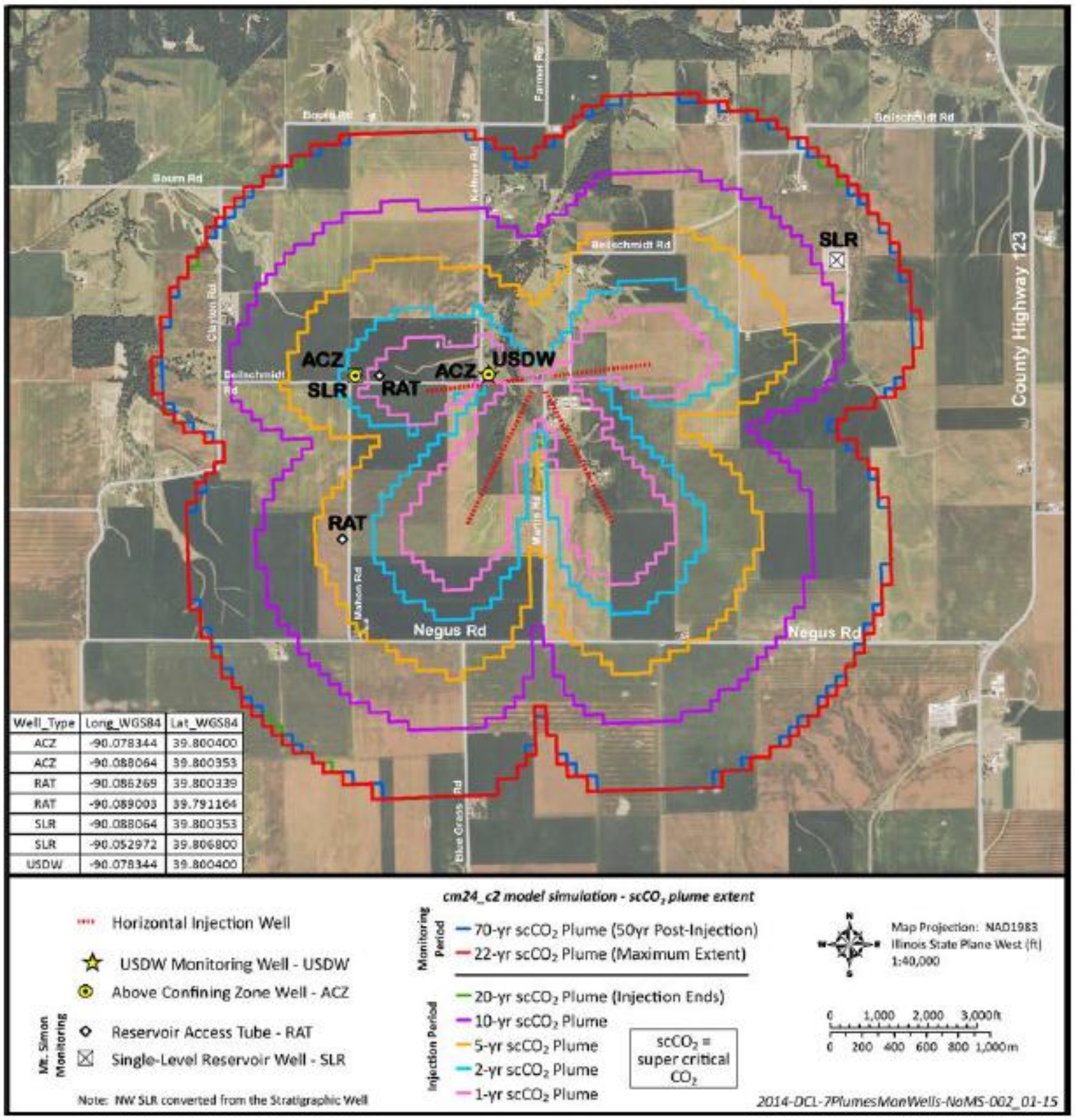
- **Two reservoir access tube (RAT) wells.** These are fully cased wells, which allow access for monitoring instrumentation in the reservoir via pulsed-neutron logging equipment. The wells will not be perforated so as to avoid two-phase flow near the borehole, which can distort the CO2 saturation measurements. Monitored parameters: quantification of CO_2 saturation across the reservoir and caprock.

Details on these wells are given in Table 9 and a map of the well locations is shown in Figure 3. Construction information has not yet been submitted.

Table 9. Monitoring wells to be used for plume and pressure-front monitoring.

	Single-Level In-Reservoir (SLR)	Reservoir Access Tube (RAT)
Number of Wells	2	2
Total Depth (ft)	4,150	4,465
Lat/Long (decimal degrees)	39.800353, -90.088064; 39.806800, -90.052972	39.800339, -90.086269; 39.791164, -90.089003
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 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 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.



Well_Type	Long_WGS84	Lat_WGS84
ACZ	-90.078344	39.800400
ACZ	-90.088064	39.800353
RAT	-90.086269	39.800339
RAT	-90.089003	39.791164
SLR	-90.088064	39.800353
SLR	-90.052972	39.806800
USDW	-90.078344	39.800400

Figure 3. Locations of SLR and RAT wells relative to FutureGen's above-confining-zone monitoring wells, injection wells, and predicted plume extent.

Lat/Longs for the wells identified in Figure 3 should be tabulated on a separate page and placed as an attachment to the testing and monitoring plan template.

Direct Pressure Monitoring

FutureGen will conduct direct pressure-front monitoring to meet the requirements at 40 CFR 146.90(g)(1). The following information is drawn from Section 5.2.3 of FutureGen's permit application and the additional information submitted in January 2014.

[From Section 5.2.3.3: Pressure Monitoring]

Continuous monitoring of injection zone pressure and temperature will be performed with sensors installed in wells that are completed in the injection zone. Pressure and temperature 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. Power for the injection well will be provided by a dedicated line power supply. Power for all monitoring wells will be provided by a stand-alone solar array with battery backup so that a dedicated power supply to these more distal locations is not required.

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), and 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.

- Gauges will be installed above any packers so they can be removed if necessary for recalibration by removing the tubing string. Redundant gauges may be run on the same cable to provide confirmation of downhole pressure and temperature.

- 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 utilizing 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.

[From 1/17/2014 submission]

The injection wells will be completed with a string of 3.5 in.-OD tubing that extends from the wellhead at the surface to near the top of the perforated interval. A tubing string that is 4,000 ft long will extend approximately 11 ft below the top of the perforations. The tubing string will be held in place at the bottom by a packer that is positioned just above the uppermost perforations (approximate measured depth of 3,975 ft). An optical or electronic pressure-and-temperature (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 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, re-calibrated or replaced on a regular basis (e.g., semi-annually) to ensure they are providing accurate data. Because the surface instruments can be more readily accessed and maintained than the bottom-hole gauge, they will be used to control injection operations and trigger shutdowns.

[From the spreadsheet submitted 1/29/14]

Once the reservoir model has been updated with detailed site specific information from the injection site, predictive simulations of pressure response will be generated for each single-level reservoir monitoring well. These predicted responses will be compared to 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.

Direct pressure monitoring in the injection zone will take place as shown in Table 10.

Table 10. Monitoring schedule for direct pressure-front tracking.

Well Location/Map Reference	Depth(s)/Formation(s)	Frequency (Baseline)	Frequency (Injection Phase)
Injection Well 1	Mt. Simon/4,030 ft.	Continuous	Continuous
Injection Well 2	Mt. Simon/4,030 ft.	Continuous	Continuous
Injection Well 3	Mt. Simon/4,030 ft.	Continuous	Continuous
Injection Well 4	Mt. Simon/4,030 ft.	Continuous	Continuous
Two single-level monitoring wells (SLR Wells 1 and 2)	Mt. Simon/4,150 ft.	Continuous	Continuous

Quality assurance and surveillance measures:

[from Section 5.8: Quality Assurance and Surveillance Plan]

Data quality assurance and surveillance protocols adopted by the project will be 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 MVA program (e.g., pressure and aqueous concentration measurements) are covered in Sections 5.2.2 and 5.2.3 above. QA requirements for selected geophysical methods, which provide indirect measurements of CO_2 nature and extent and are being tested for their applicability under site conditions, are not addressed in this 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.

FutureGen lacks detail in its description of quality assurance and surveillance protocols. FutureGen should provide a more detailed Testing and Monitoring Plan containing this information. [Request from FutureGen.]

Plan for guaranteeing access to all monitoring locations:
[From the spreadsheet submitted 1/29/14]

The location of these wells has been finalized, pending final signing of landowner agreements. The land 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 at 40 CFR 146.90(g)(1). The following information is drawn from Section 5.2.3 of FutureGen's permit application and the additional information submitted in January 2014.

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 shown in Table 11.

Table 11. Monitoring schedule for direct geochemical plume monitoring.

Monitoring well name/location/map reference: Two SLR monitoring wells (see Figure 3)
Well depth/formation(s) sampled: Mt. 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	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
Temperature	At least 3 sampling events	Quarterly for 3 years, then semi-annually for 2 years and annually thereafter
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

Sampling methods:
[Adapted from Section 5.2.3.4: Aqueous Monitoring]

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). These types of pressurized sampling methods are needed to collect the two-phase fluids (i.e., aqueous and $scCO_2$ solutions) for measurement of the percent water and CO_2 present at the monitoring location. Fluid samples will be analyzed for parameters that are indicators of CO_2 dissolution (Table 12), including major cations and anions, selected metals, general water-quality parameters (pH, alkalinity, TDS, specific gravity), and any tracers added to the CO_2 stream. Changes in major ion and trace element geochemistry are expected in the injection zone, but the arrival of proposed fluorocarbon or sulfonate tracers (co-injected with the CO_2) should provide an improved early-detection capability, because these compounds can be detected at 3 to 5 orders of magnitude lower relative concentration. 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 techniques for target parameters are given in Table 12 and Table 13, respectively.

Note: Section 5.2.3.4 indicates that all parameters in Table 5.4 will be selected. However, clarification is needed, especially because CO_2 is not specifically listed in Table 5.4. We will update this table based on any further information submitted.

Table 12. Sampling Techniques for Target parameters for the injection zone (adapted from Table 5.4 of FutureGen's permit application).

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, Ba, Cd, Cr, Cu, Pb, Hg, Se, Tl	20-mL plastic vial	Filtered (0.45 µm), HNO_3 to pH <2	60 days
Anions: Cl^-, Br^-, F^-, SO_4^{2-}, NO_3^-,	20-mL plastic vial	Cool 4°C	45 days
Gravimetric Total Dissolved Solids (TDS), compare to TDS by calculation from major ions	250-mL plastic vial	Filtered (0.45 µm), no preservation Cool 4°C	
Water Density	100 mL plastic vial	Filtered (0.45 µm), no preservation Cool 4°C	60 days
Alkalinity	100 mL HDPE	Filtered (0.45 µm) Cool 4°C	5 days

Parameter	Volume/Container	Preservation	Holding Time
Dissolved Inorganic Carbon (DIC)	20-mL plastic vial	Cool 4°C	45 days
Total Organic Carbon (TOC)	40 mL glass	unfiltered	14 days
Carbon Isotopes (^{14}C, $^{13/12}C$)	5-L HDPE	pH >6	14 days
Water Isotopes ($^{2/1}H$, $^{18/16}O$)	20-mL glass vial	Cool 4°C	45 days
Radon (^{222}Rn)	1.25-L PETE	Pre-concentrate into 20-mL scintillation cocktail. Maintain groundwater temperature prior to pre-concentration	1 day
Naphthalene Sulfonate or Fluorinated Benzoic Acid Tracers (aqueous phase)	500 mL HDPE	Filtered (0.45 µm), no preservation	60 days
Perfluorocarbon Tracer (PFT) ($scCO_2$ or gas phase)	500 mL glass	unfiltered, Cool 4°C	60 days
pH	Field parameter	None	<1 h
Specific Conductance	Field parameter	None	<1 h
Temperature	Field parameter	None	<1 h

HDPE = high-density polyethylene; PETE = polyethylene terephthalate

Table 13. Analytical requirements (adapted from Table 5.5 of FutureGen's permit application).

Parameter	Analysis Method	Detection Limit or Range	Typical Precision/ Accuracy	QC Requirements
Major Cations: Al, Ba, Ca, Fe, K, Mg, Mn, Na, Si,	ICP-OES, PNNL-AGG-ICP-AES (similar to EPA Method 6010B)	0.1 to 1 mg/L (analyte dependent)	±10%	Daily calibration; blanks and duplicates and matrix spikes at 10% level per batch of 20
Trace Metals: Sb, As, Ba, Cd, Cr, Cu, Pb, Hg, Se, Tl	ICP-MS, PNNL-AGG-415 (similar to EPA Method 6020)	1 µg/L for trace elements	±10%	Daily calibration; blanks and duplicates and matrix spikes at 10% level per batch of 20
Anions: Cl^-, Br^-, F^-, $SO4^{2-}$, NO_3^-, CO_3^{2-}	Ion Chromatography, AGG-IC-001 (based on EPA Method 300.0A)		±15%	Daily calibration; blanks and duplicates at 10% level per batch of 20
TDS	Gravimetric Method Standard Methods 2540C	12 mg/L	± 5%	Balance calibration, triplicate samples
Water Density	Standard Methods 227	0.0001 g/mL	±0.0%	Triplicate measurements
Alkalinity	Titration, standard methods 102	4 mg/L	±3 mg/L	Triplicate titrations

Parameter	**Analysis Method**	**Detection Limit or Range**	**Typical Precision/ Accuracy**	**QC Requirements**
Dissolved Inorganic Carbon (DIC)	Carbon analyzer, phosphoric acid digestion of DIC	0.002%	±10%	Triplicate analyses, daily calibration
Total Organic Carbon (TOC)	Carbon analyzer; total carbon by 900°C pyrolysis minus DIC = TOC	0.002%	±10%	Triplicate analyses, daily calibration
Carbon Isotopes ($^{14/12}$C, $^{13/12}$C)	Accelerator MS	10^{-15}	±4‰ for ^{14}C; ±0.2‰ for ^{13}C	Triplicate analyses
Water Isotopes (^{2}H/^{1}H, $^{18/16}$O)	Water equilibration coupled with IRMS ; Alternatively, consider WS-CRDS	10^{-9}	IRMS: ±1.0‰ for ^{2}H; ±0.15‰ for ^{18}O; WS-CRDS: ±0.10‰ for ^{2}H; ±0.025‰ for ^{18}O	Triplicate analyses
Radon (^{222}Rn)	Liquid scintillation after pre-concentration	5 mBq/L	±10%	Triplicate analyses
Naphthalene Sulfonate **or** Benzoic Acid Tracer (aqueous phase)	Liquid chromatography-mass spectrometry (LC-MS) **or** gas chromatography with electron capture detector (ECD)	5 parts per trillion (5 x 10^{12}) **or** 10 parts per quadrillion (10 x 10^{15})	Varies with conc.,±30% at detection limit	Duplicates 10% of samples, significant number of blanks for cross-contamination
Perfluorocarbon Tracer (PFT) (scCO2 or gas phase)	Gas chromatography with electron capture detector (ECD)	10 parts per quadrillion (10 x 10^{15})	Varies with conc., ±30% at detection limit	Duplicates 10% of samples, significant number of blanks for cross-contamination
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
Temperature	Thermocouple	5 to 50°C	±0.2°C For indication only	Factory calibration

ICP = inductively coupled plasma; IRMS = isotope ratio mass spectrometry; MS = mass spectrometry; OES = optical emission spectrometry; WS-CRDS = wavelength scanned cavity ring-down spectroscopy

Laboratory to be used/ chain of custody procedures:

[Not specified.]

Quality assurance and surveillance measures:
[from Section 5.8: Quality Assurance and Surveillance Plan]

Data quality assurance and surveillance protocols adopted by the project will be 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 MVA program (e.g., pressure and aqueous concentration measurements) are covered in Sections 5.2.2 and 5.2.3 above. QA requirements for selected geophysical methods, which provide indirect measurements of CO_2 nature and extent and are being tested for their applicability under site conditions, are not addressed in this 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.

FutureGen lacks detail in its description of quality assurance and surveillance protocols. FutureGen should provide a more detailed Testing and Monitoring Plan containing this information. [Request from FutureGen.]

Plan for guaranteeing access to all monitoring locations:
[From the spreadsheet submitted 1/29/14]

The location of these wells has been finalized, pending final signing of landowner agreements. The land 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 at 40 CFR 146.90(g)(2). The following information is drawn from Section 5.2.3 of FutureGen's permit application and the additional information submitted in January 2014.

Note: Full evaluation of FutureGen's plume and pressure-front monitoring program will need to take place in conjunction with evaluation of the final AoR modeling submissions. Based on the modeling efforts, FutureGen should provide predicted values over time at each well or monitoring site and describe how the monitoring data will be compared to these results. FutureGen should also provide details about the planned areal extent/resolution of the geophysical methods. [Request from FutureGen.]

[From November 2013 response]

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:

- pulsed neutron capture logging or determination of reservoir CO_2 saturation
- integrated deformation monitoring
- time-lapse gravity
- microseismic monitoring

The schedule for these monitoring techniques is given in Table 14.

Table 14. Monitoring schedule for indirect plume and pressure-front monitoring.

Monitoring Technique	Location	Frequency (Baseline)	Frequency (Injection Phase)
Pulsed neutron capture logging	RAT Wells 1 and 2	3 events	Quarterly for 5 years and annually thereafter
Integrated deformation monitoring	5 locations (see Figure 4 below)	1 year min.	Continuous
Time-lapse gravity monitoring	46 locations (see Figure 5 below)	3 events	Annually
Passive seismic monitoring (microseismicity)	Surface measurements (see Figure 4 below) plus downhole sensor arrays at ACZ Wells 1 and 2	1 year min.	Continuous

[Adapted from the spreadsheet submitted 1/29/14]

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 to 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.

Integrated deformation monitoring

Integrated deformation monitoring integrates ground data from permanent GPS stations, tiltmeters, supplemented with annual 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 on 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.

Integrated deformation monitoring will take place at the locations shown in Figure 4.

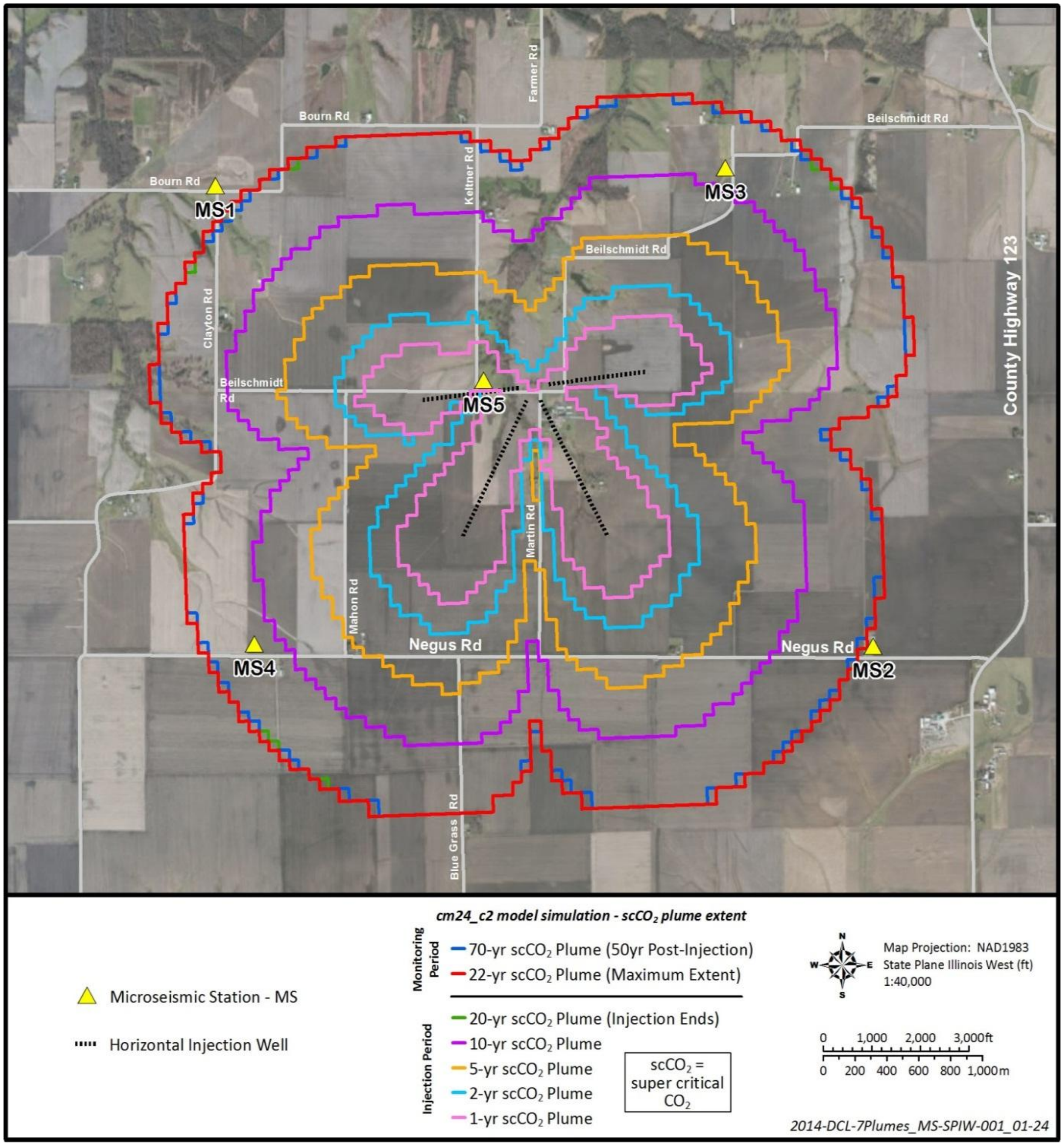


Figure 4. Collocated Microseismic and Integrated Surface Deformation Monitoring Stations.

Locations for the microseismic stations must be identified with Lat/Long coordinates. These coordinates can be tabulated and attached to the end of the testing and monitoring plan template.

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; estimate the areal extent of the CO_2 plume. This technology has been successfully applied to a variety of subsurface injection studies, including carbon sequestration at Sleipner (Arts et al. 2008); aquifer recharge studies in Utah and elsewhere (Chapman et al. 2008; Davis and Batzle 2008); and to hydrocarbon waterflood surveillance in Alaska (Ferguson et al. 2007).

Gravity changes at the surface are expected to be small but analysis of long-term trends may allow for tracking of the CO_2 plume. The cost of implementing this technology is the lowest of all methods considered and can be combined with Differential Global Positioning System (DGPS) surveys conducted as part of the integrated surface deformation monitoring to further reduce costs.

Gravity anomalies associated with CO_2 injection are expected to be quite small, but by averaging many measurements, meaningful signal may be observed. In addition, information obtained from annual time-lapse gravity surveys will be used to help guide the adaptive monitoring strategy. This method requires no permanent infrastructure to implement.

A map of the proposed gravity stations is provided in Figure 5. The gravity data are supplemental data for comparison with other monitoring methodologies. No trigger levels will be defined.

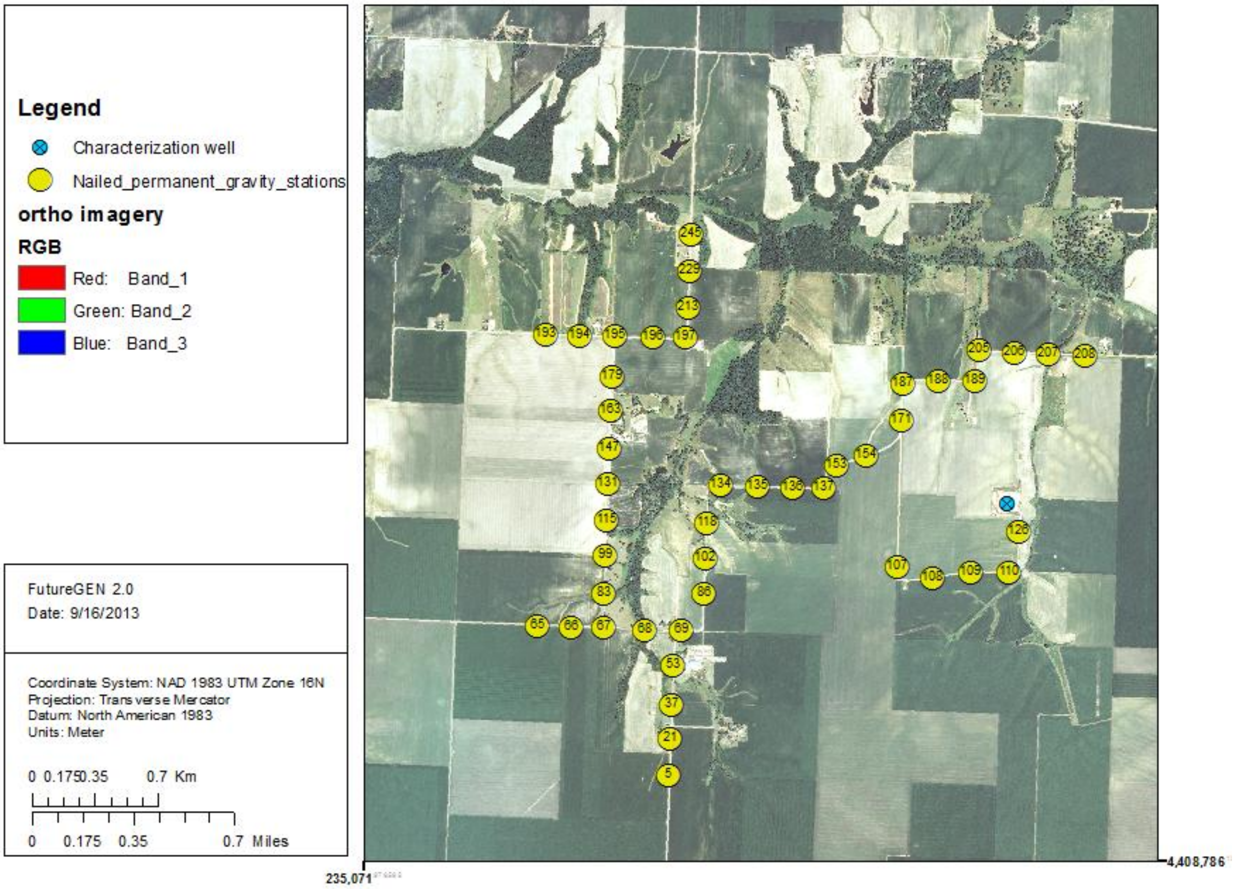


Figure 5. Location of Permanent Gravity and Supplemental DGPS Stations.

Locations for the permanent gravity stations must be identified with Lat/Long coordinates. These coordinates can be tabulated and attached to the end of the testing and monitoring plan template.

Passive seismic monitoring (microseismicity)

Note: Some of this information may need to be included in the Emergency and Remedial Response Plan instead of or in addition to this Testing and Monitoring Plan.

The objective of the microseismic monitoring network (Figure 4; downhole arrays will also be installed at the two ACZ wells) 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. Once a seismic event has been identified, a decision must be made regarding the level of impact a given event could have on storage site operations, whether a response is required, and if yes, what the response will be. This decision and response framework will consist of an automated event location and magnitude determination, followed by an alert for a technical review in order to reduce the likelihood of false positives. Identification of events with sufficient magnitude or that are located in a sensitive area (caprock) will be used as input for decisions that guide the adaptive strategy. Seismic events that affect the operations of CO_2 injection can be divided into two groups/tiers: 1) events that create felt seismicity at the surface and may lead to public concern or structural damage, and 2) events not included in group one, but that might indicate failure or impending failure of the caprock. The operational protocol for responding to events in group one (Tier I) will follow a "traffic light" approach (modified after Zoback 2012; National Research Council 2012) that uses three operational states:

1. Green: Continue normal operations unless injection-related seismicity is observed with magnitudes greater than M=2.

2. Yellow: Injection-related seismic events are observed with magnitude $2 < M < 4$. The injection rate will be slowed and the relationship between rate and seismicity will be studied to guide mitigation procedures, including reduced operational flow rates.

3. Red: Magnitude 4 or greater seismic events are observed. Injection operations will stop and an evaluation will be performed to determine the source and cause of the ground motion.

Tier II operational responses to an event or collection of events that indicate possible failure of the primary confining zone may include initiation of supplemental adaptive monitoring activities, injection rate reduction in one or more injection laterals, or pressure reduction using brine extraction wells.

The UIC Program Director will not require monitoring under 146.90(h). The paragraphs and Table 15, identified under "Surface Air and/or Soil Gas Monitoring", can be deleted.

Surface Air and/or Soil Gas Monitoring (if required by the UIC Program Director)

Future Gen is considering certain activities for surface air/and soil gas monitoring, as well as other types of monitoring, which are described in Section 5. It is not known at this time if EPA will require this type of monitoring.

This section may be deleted or revised, pending Region 5's decision to require surface air/and soil gas monitoring. (Note: They aren't planning on doing surface monitoring unless there is a leak or EPA requires it. If it's the former, this may belong in the Emergency and Remedial Response Plan, if not already there.)

[From Section 5.0: Testing and Monitoring Plan]

Additional surface or near-surface monitoring approaches that may be implemented include shallow groundwater monitoring, soil-gas monitoring, atmospheric monitoring, and ecological monitoring. If implemented, the associated networks of shallow monitoring locations will be designed to provide 1) a thorough assessment of baseline conditions at the site and 2) spatially distributed monitoring locations that can be routinely sampled throughout the life of the project. The need for surface-monitoring approaches will be continually evaluated throughout the design and operational phases of the project, and may be discontinued if deemed unnecessary for the MVA assessment. Given our current conceptual understanding of the subsurface environment, early and appreciable impacts on near-surface environments are not expected, and thus extensive networks of USDW aquifer, surface-water, soil-gas, and atmospheric monitoring stations are not warranted. Any implemented surface-monitoring networks would be optimized to provide good areal coverage while also focusing on areas of higher leak potential (e.g., near the injection wells or other abandoned well locations). If deep early-detection monitoring locations indicate that a primary confining zone containment loss has occurred, a comprehensive near-surface-monitoring program could be implemented to fully assess environmental impacts relative to baseline conditions.

Sampling methods: *[Not planned unless required.]*

Analytical techniques: *[Potential methods in table below.]*

Table 15. Potential techniques for near-surface monitoring (from Table 5.2 of FutureGen's permit application).

Monitoring Category	Monitoring Method	Description

Monitoring Category	**Monitoring Method**	**Description**
Soil-Gas Monitoring	Shallow soil-gas monitoring	Soil-gas collector chambers and/or standard soil-gas sampling points will be used to monitor the concentration of CO2 and other non-condensable gases (e.g., N, O) in shallow soils.
	Tracer and isotopic signature monitoring	Soil-gas sampling for carbon and oxygen isotopic signature and/or tracer compounds injected along with the CO2 to improve leak-detection capabilities.
Atmospheric Monitoring	Fixed-point CO2 and tracer monitoring	Continuous CO2 measurement at fixed location, with routine sampling for CO2 and tracer gas concentrations. Tracer gases will provide improved leak-detection capability.
	Mobile CO2 and tracer monitoring	Periodic measurements of CO2 and tracer gas using a mobile, real-time instrument, near injection/monitoring wells and along transects spanning the AoR.
	Weather Station (at two fixed-point locations	Measurements of air temperature, relative humidity, precipitation, barometric pressure, solar radiation, soil moisture, and soil temperature.
Ecological Monitoring	Baseline ecological survey	Pre-operational monitoring and characterization to establish baseline conditions for comparisons with operational monitoring results.
	Continuous surface-water monitoring	Continuous measurement of pH, temperature, electrical conductivity, and dissolved oxygen content of nearby surface waters.
	Remotely sensed data for vegetation condition assessment	Satellite imagery used to characterize vegetation conditions and detect subtle changes in normal plant growth processes and relative vegetation stress.

Laboratory to be used/ chain of custody procedures: *[Not planned unless required.]*

Quality assurance and surveillance measures: *[Not planned unless required.]*

Plan for guaranteeing access to all monitoring locations: *[Not planned unless required.]*

Additional Monitoring *(if required by the UIC Program Director)*

Future Gen is considering additional monitoring, which are described in Section 5 of the permit application and presented in the Surface Air and/or Soil Gas Monitoring section of this checklist above. It is not known at this time if EPA will require additional monitoring.

Attachments

Map showing monitoring well locations; boundary of geophysical survey areas

Monitoring well schematics