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Validating Geologic Storage Potential in the Midwestern USA through Multiple Field Demonstrations

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Abstract

The Midwestern Regional Carbon Sequestration Partnership (MRCSP) is implementing an integrated effort to validate the geologic storage potential in the Midwestern states within the USA through multiple field demonstrations. Validation of the geologic storage potential in this area requires regional geologic exploration along with site-specific demonstrations of CO_2 injection and monitoring. These demonstrations are being conducted in collaboration with energy companies in Appalachian Basin, Michigan Basin, and Cincinnati Arch geologic regions. Each field test incorporates extensive characterization, reservoir modeling, permitting, outreach, injection and monitoring in a deep saline reservoir setting. The progress that has been achieved during the past year, including the evaluation of injection at two test sites, is presented.

Keywords: Geologic Storage Tests, Regional Partnership, MRCSP, USA, Michigan Basin, Appalachian Basin, Cincinnati Arch

1. Introduction

The Department of Energy's (DOE's) Regional Carbon Sequestration Partnership (RCSP) Program in the USA is developing a national carbon sequestration framework through seven regional partnerships. The Midwest Regional Carbon Sequestration Partnership (MRCSP) covers eight Midwestern and eastern states. These states are a key energy producing region in the United States, and their large and fossil energy-intensive economies emit more than 750 million tonnes of CO_2 per year. These states are also a diverse geologic and carbon capture and storage (CCS) framework with two mature deep basins – Michigan Basin and Appalachian basin, separated by the uplifted arches region in Ohio, New York, Kentucky and Indiana; and Appalachian Valley and Ridge, crystalline Blue Ridge, Piedmont provinces, and the Coastal Plains sediments in the eastern part of the MRCSP. Integrated regional maps for a number of deep saline formations and caprock layers, as well as maps of regional oil and gas reservoirs, carbonaceous shales, and deep coal seams, have been prepared for the Regions [1]. Preliminary geologic storage capacity estimates based on these maps indicate that the MRCSP region has a diverse and immense geologic CO_2 storage potential (>500 Gt) dominated by the deep saline formations (~90% of storage capacity). The geologic features of the regions are being validated in three small-scale and one large-scale demonstrations being conducted in the Michigan Basin, Appalachian Basin, and Cincinnati Arch. Collectively, the MRCSP tests allow for validating the geologic storage options in key formations and testing applicable monitoring technologies for each setting.

The key formation characteristics and proposed demonstrations are summarized in Table 1. These tests are being conducted in collaboration with energy companies that are the potential future users of this technology. One small scale demonstration is located in the vicinity of several gas processing plants in Otsego County, which produce a relatively pure CO_2 stream. One of these plants operated by DTE has an associated compression and pipeline infrastructure for enhanced oil recovery (EOR) operations by Core Energy. A second small scale demonstrations is taking place at a relatively unexplored site at FirstEnergy's

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R.E. Burger Plant in the Appalachian Basin provides an opportunity to test multiple deep saline reservoir zones. The third small scale demonstration, which is located at Duke Energy's East Bend Plant in Kentucky, represents the uplifted arches geologic province between Illinois and Appalachian Basins with injection in the Mt. Simon Sandstone. Consistent with DOE's accelerated schedule for conducting large-scale demonstrations, MRCSP also has proposed using CO_2 from an ethanol plant in western Ohio for a large-scale injection of more than 250,000 metric tons per year for four years. In addition, site characterization is also being performed at an IGCC plant being built by Duke Energy in Edwardsport, Indiana.

The overall approach for each demonstration is to complete a preliminary analysis of the site geology based on available data, use these results to guide site characterization activities, and then perform field injection tests and monitoring. The site characterization phase includes activities such as seismic surveys; drilling, sampling, and testing of borehole(s); analysis of samples and field data; and reservoir simulations. A proactive stakeholder outreach program is implemented with the owners of the field test site to inform and obtain feedback from stakeholders. The CO_2 injection and monitoring phase begins after the underground injection control (UIC) permit has been obtained from the relevant regulatory authorities. Total amount injected will range from approximately 3,000 to 10,000 tons (small-scale) to up to 1,000,000 metric tons (large-scale). The injection and monitoring phase is followed by site closure. The data gained from these demonstrations will be used to conduct further modeling and evaluation in order to more meaningfully understand potential commercial scale CCS deployment options within the Region. A summary of the progress at each of the proposed field test sites are summarized in Table 2.

Table 1. Key Formation Characteristics and Proposed Demonstrations

Demonstration Location	**EOR Field, Otsego County, MI**	**R.E. Burger Power Plant, Shadyside OH**	**East Bend Power Plant, Rabbit Hash, KY**	**TAME Ethanol Plant, Greenville, OH**	**Duke IGCC, Edwardsport, IN**
Geologic Setting	Michigan Basin	Appalachian Basin	Cincinnati Arch	Cincinnati Arch	Illinois Basin
Approximate Sediment Thickness (ft)	10,000	20,000	3,500	3,600	8,600
Primary Target Formation	Bass Islands Dolomite	Oriskany (O) Salina (S) Clinton (C)	Mt. Simon	Mt. Simon	Mt. Simon and others
Lithology	Dolostone	O: Sandstone S: Carbonates C: Sandstone	Quartz Sandstone	Quartz Sandstone	Sandstone
Target Depth Interval (ft)	3,190-3,515 ft	O: 5,923-5,954 S: 6,734-7,048 C: 8,207-8,274	3,200-3,500 (est.)	3,300-3,600 (est.)	7,500-8,600(est.)
Total Thickness (ft)	325	O: 31 S: 314 C: 67	300 (est.)	300 (est.)	1,100 (est.)
Avg. Porosity (%)	13	O: 3.2 S: 8.1 C: 3.2	12 (est.)	12 (est.)	10 (est.)
Avg. Perm. (mD)	22	O: 0.003 – 0.005 S: 0.008 – 0.08 C: 0.001 – 0.08	10-200 (est.)	50-400 (est.)	10-200 (est.)
Formation Pressure (psi)	1475	O: 2784 S: 3165 C: 3845	1410 (est.)	1450 (est.)	3,525(est.)
Formation Temperature (°F)	84	O: 140 S: 146 C: 160	87	88	130 (est.)
Total CO_2 Injection (metric tons)	10,241	3,000 (planned)	3,000 (planned)	1,000,000 (planned)	Not planned

Table 2. Status of Validation Progress Made at the MRCSP Field Test Sites

Site Name	**Michigan Basin, Otsego County**	**Appalachian Basin, R.E. Burger Plant**	**Cincinnati Arch, East Bend Plant**	**Cincinnati Arch, TAME Ethanol Plant**	**Illinois Basin, Duke IGCC**
Site Characterization	Complete	Complete	Ongoing	Planning stage	Ongoing (Piggyback on wastewater

					well)
Permitting	Complete	Complete	Permit application Submitted	National Environmental Policy Act (NEPA) review initiated	Not applicable
Outreach	Ongoing	Ongoing	Ongoing	Ongoing	Ongoing
Reservoir Modeling	Complete, validation underway	Pre-injection modeling complete	Preliminary modeling complete	Preliminary modeling underway	Not applicable
Injection Test	Complete	Ongoing	Planning stage	Planning stage	Not applicable
Monitoring	Complete	Ongoing	Planning stage	Planning stage	Not applicable
Site Closure	Not complete	Not complete	Not complete	Not complete	Not complete

2. Characterization and Reservoir Modeling

The site characterization phase has been completed at two of the field test sites and is ongoing at the remaining field test sites. Reservoir modeling is used for the injection system design and specifications, UIC Permitting (e.g., area of review determination and maximum injection pressure calculations); monitoring program development; and for Public outreach and communication materials. Figure 1 presents how the modeling process was integrated with the site characterization and field testing for the Michigan Basin demonstration. A similar approach will be followed at the other sites. Preliminary modeling was completed based on regional data to support field tests and proof-of-concept in each of the target CO_2 storage formation. A multiple phase model was used to simulate the various hydraulic, geochemical, and physical processes involved with CO_2 sequestration [2]. The general geologic framework is delineated with seismic surveys and regional data. CO_2 injection simulations were further refined based on the site characterization data collected from the deep well. Site specific hydraulic parameters are determined from deep test wells, with rock core tests, wireline logs, brine sampling, and other geotechnical tests. The actual injection rates and pressures measured in the field were used to calibrate the models following the injection test.

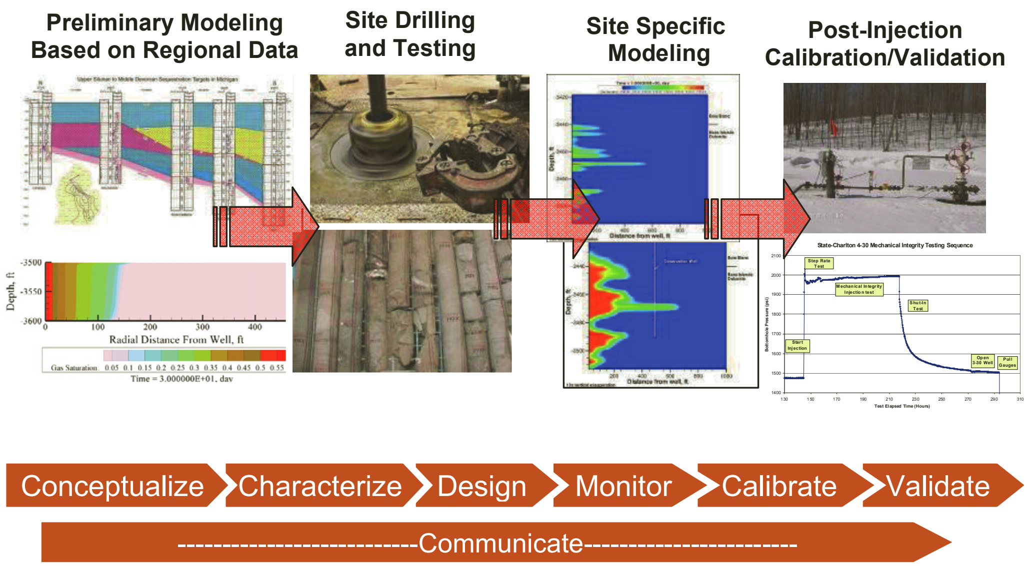

Figure 1. Modeling and field testing process followed for the Michigan Basin, Otsego County demonstration

3. Regulatory and Outreach Issues

The geologic tests continues to provide opportunities to interact with a spectrum of stakeholders, including permitting and regulatory bodies, and grow awareness of CCS technologies and their potential for deployment in the Region. Table 3 summarizes the regulatory framework for the geologic tests. The three MRCSP Phase II small-scale tests are being conducted under the Environmental Protection Agency (EPA) Class V UIC process and permits have been obtained to conduct the demonstrations at the Michigan Basin and Appalachian Basin test sties. The process was generally similar to either Class II or Class I-Non Hazardous UIC permits, with some flexibility due to small injection size and experimental nature. The regulatory framework for the large-scale demonstration is under development. The Ohio EPA has indicated that the Class I – Non Hazardous UIC permit will be more applicable to the Phase III test in Ohio. The permitting process has required a team effort, sustained attention, and communication with regulatory agencies.

Public acceptability is recognized as an important aspect of the DOE RCSP program; outreach activities and research into public perceptions of the technology are a funded component. Each demonstration involves stakeholder research, formation of an outreach team, message and materials development, proactive/targeted engagement, and a response/feedback process. The MRCSP maintains a public record of activities, via written reports and its website (www.mrcsp.org), where stakeholders can obtain information about the program. In collaborative research among the West Coast Regional Carbon Sequestration Partnership, Southwest Regional Carbon Sequestration Partnership, and the MRCSP, factors such as past experience with government, desire for compensation, and/or perceived benefit to the community were found to be of greater concern than the concern about the risks of the technology itself [3]. In the Midwest, issues of trust were central to perceptions of CCS in that focus group participants doubted the ability of the government or the project developers to ensure their safety. This underlying distrust of government and the private sector was an even greater concern than the risks of CCS technology [3]. These themes were often encountered during outreach events for the demonstrations. Collaboration with host sites is critical for an effective outreach program; the efforts of proactive outreach are paying off in the form of cautious support for CCS on the part of many and constructive discussion with those who are less supportive.

4. Injection

As indicated in Table 2, an injection test has been completed for the Bass Islands Dolomite in the Michigan Basin. The injection test has yielded valuable data on the potential for geologic sequestration. Injection of more than 10,000 metric tons of CO_2 was conducted between February and March 2008 in the saline formation at about 1,100 meters, making this the largest deep saline reservoir injection in the US. Existing infrastructure for EOR operations (taking place beneath the target injection zone at a depth of about 1,500 meters) allowed for a relatively large amount of CO_2 to be injected and an extensive monitoring program. An initial step-rate test and shut-in test was completed with CO_2 prior to sustained injection as part of UIC mechanical integrity testing. The step-rate test provided data on hydraulic behavior of the reservoir system and the general trend suggests injection rates of over 1,500 metric tons per day may be possible; however, the pressure increase is difficult to interpret. For example, the overall pressure increased only 30 psi from 250-500 metric ton per day injection rate.

A total of 10,241 metric tons CO_2 was injected from February 18-March 8, 2008 (including initial mechanical integrity test volume). Figure 2 presents the injection rate and pressure measured during the test. The injection rate increased from 400 to 600 metric tons per day after one week. Some fluctuations in the injection rate were caused by supply variations at compression station. The injection well was shut-in for one month after injection to track reservoir pressures decline and allow stabilization. As shown in Figure 2, bottomhole pressures were 2,000 to 2,020 psi during injection and generally stable throughout the 18 days of injection. Overall, testing indicates rates of 600 metric tons/day (tpd) or higher may be sustained in the Bass Islands Dolomite.

Table 3. Regulatory Framework for the Geologic Tests

Test Site	Michigan Basin, Otsego County	Appalachian Basin, R.E. Burger Plant	Cincinnati Arch, East Bend Plant	Cincinnati Arch, TAME Ethanol Plant
State	Michigan	Ohio	Kentucky	Ohio
Drill Test Well	MI DEQ Office of Geological Survey	Ohio Department of Natural Resources	Requires US EPA Region 4 UIC Class V Permit	To Be Determined
Injection Test	US EPA Region 5 UIC Class V Permit	Ohio EPA UIC Class V Permit	US EPA Region 4 UIC Class V Permit	Ohio EPA To Be Determined

5. Monitoring

The objective of monitoring is to assess the status of CO_2 from the delivery system to the storage reservoir, including injection and storage of the injected CO_2 in the deep geologic reservoir. Monitoring technologies for CO_2 sequestration were reviewed and a subset of options was selected based on the proposed injection system specifications and geologic setting. Figure 3 presents an illustration of the methods used for the Michigan Basin Test site. A fundamental portion of monitoring focused on the injection system to ensure that the injection process and equipment were operating properly during the test. This effort also tracked basic parameters such as injection pressures, flow rates, and physical properties of the injection fluid. Tracking the movement and alteration of the injected CO_2 in the subsurface and monitoring leakage were also critical components of the monitoring program to ensure long-term storage and demonstrate the extent of the CO_2. A brief description of the monitoring techniques and preliminary results are summarized in Table 4.

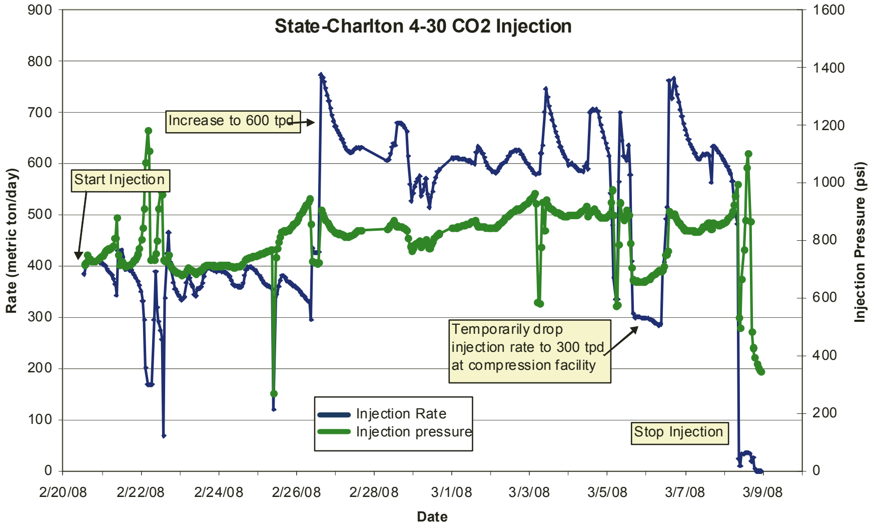

Figure 2. CO_2 Injection rates and pressure for the Michigan Basin, Otsego County DemonstrationReservoir Model Validation

Simulations indicated injection rates of 500 metric tons CO_2 per day are feasible in the Bass Islands Dolomite. In practice, injection rate was more variable during testing. After calibrating the model to actual injection rates, the results were compared to field observations. Elevated CO_2 saturations were not predicted for the observation well in the simulations, which showed CO_2 moving about 152 m (500 ft) from the injection well (Figure 4). This prediction agreed with the no-field observed change in CO_2 saturations at the observation well located about 152 m (500 ft) from the injections well. As shown in Table 5, the modeled pressure responses at the injection and observation well are reasonably close to observed valued during the injection test. Model calibration to field continues using actual injection rates; however, this effort looks to be a minor refinement [2].

6. Conclusions

Each field test incorporates extensive site characterization, reservoir modeling, permitting, outreach, injection and monitoring in a deep saline reservoir setting. Significant progress was achieved at the Michigan Basin, Otsego County demonstration site, which included site characterization, outreach, permitting, and injection and monitoring. Injection of 10,241 metric tons of CO_2 was conducted during February and March 2008, making this the largest deep saline reservoir injection completed in the US. Monitoring techniques at this site include cross well seismic, acoustic emissions, PFT tests, wireline logging, brine/chemistry fluid sampling, and continuous pressure-temperature monitoring. The Bass Islands Dolomite in northern Michigan Basin has suitable injectivity for CO_2 sequestration at an industrial scale, on the order of several hundred thousand metric tons per year in one well. The well tests proved useful in analyzing injection potential. Injection test analysis was used to define the hydraulic behavior of the reservoir system in terms of flow behavior and leakage. The reservoir simulations provided fairly accurate predictions of hydraulic response to injection.

The overall approach followed for the Michigan Basin test site will continue to be implemented at other MRCSP Phase II test sites. The 2-D seismic survey of the area around the R.E. Burger Plant has been completed, along with drilling a 2,500 meters deep test well in early 2007. An injection well permit was issued by the Ohio EPA in September 2008 and the injection test is underway. A background geologic assessment, 2-D seismic survey, initial outreach, and permit preparation for the site have been completed at the East Bend Plant test site. An injection well and potentially an observation well will be drilled after permitting is completed, followed by injection and monitoring of about 3,000 metric tons of commercial CO_2.

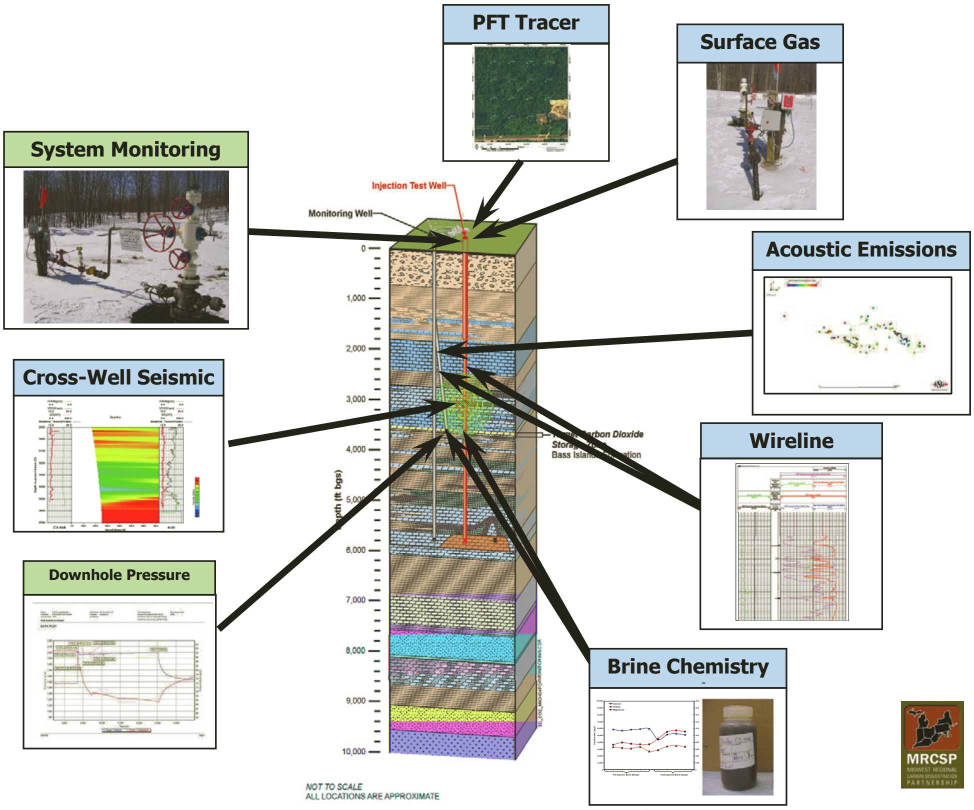

Figure 3. Monitoring Techniques Implemented for the Michigan Basin Demonstration

Table 4. Monitoring Techniques and Preliminary Results, Michigan Basin.

Monitoring Technique	Description and Preliminary Results
Surface CO_2 Detector	Alerts bystanders to any release of carbon dioxide higher than atmospheric levels. No release occurred.
Acoustic Emissions	Two, eight level geophone arrays installed in two nearby wells to monitor for any small seismic events. These events are indicative of the movement of the pressure wave associated with injection. In addition, these arrays help to verify seal integrity. Injection did not cause any type of significant microseismic events
Downhole Pressure/ Temperature Gauges	Pressures in the target reservoir returned to normal levels about two weeks after injection stopped. During injection, downhole pressures were fairly constant at about 2,000-2,020 psi and temperature declined to 61 ºF. Downhole loggers in the monitoring well (completed about 500 ft from the injection well) showed a pressure increase of about 60 psi during injection; no change was observed in temperature.
Crosswell Seismic	Technique to compare the velocity and amplitude changes to the injection interval from the introduction of carbon dioxide. Excellent signal to noise ratio and high energy source yield resolution of only a few meters. A post injection survey is compared to one run prior to injection and any observed changes can be attributed to the CO_2. Results of the post-injection cross-well seismic survey indicated a presence of CO_2 in the Bass Islands Dolomite and some indication of gas saturation (possibly methane) in overlying storage zone but no movement through the caprocks.

Tracer Study	Working with NETL, PFT were introduced into the injection stream. Atmospheric and soil gas samples are periodically taken and tested for the tracer. A final sampling event was completed June 2008. Results showed no indication of leakage to the vadose zone or atmosphere.
System Monitoring	System monitoring provided fundamental information necessary for UIC permitting on injection rates, wellhead pressure, and the properties of the injected CO_2.
Wireline Logging	A post-injection Reservoir Saturation Tool (RST) log was run in the monitoring well; results confirmed that CO_2 did not reach the monitoring well, as expected.
Brine Chemistry/ Fluid Sampling	Samples were taken from the monitoring well both pre and post injection and compared. The repeat sampling indicated a drop in calcium and an increase in magnesium that may be related to the CO_2 injection, suggesting complex sulfate system.

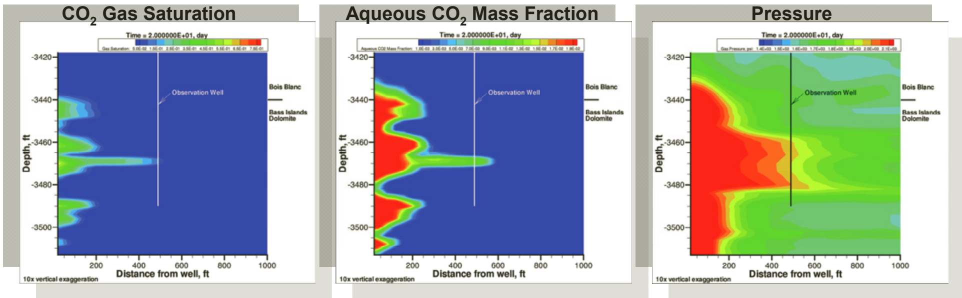

Figure 4. STOMPCO2 Simulation Results at the End of Injection (500 tpd for 20 days)

Table 6. Reservoir Modeling Validation – Preliminary Results

	Maximum Bottom hole Pressure	
Monitoring Point	**STOMPCO2 Simulated (psi)**	**Observed (psi)**
Michigan Basin Injection Well	2,100	2,020
Downgradient Monitoring Well	1,555*	1,535

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