FACT SHEET FOR PARTNERSHIP FIELD VALIDATION TEST

Midwest Regional Carbon Sequestration Partnership (MRCSP)

NETL Cooperative Agreement DE-FC26-05NT42589

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Submitted by Battelle

September 2008

Michigan Basin Geologic Test, Otsego County Michigan	
Principal Investigator	Dave Ball, Battelle (614-424-4901; balld@battelle.org)
Test Location	Charlton 30/31 Field, Otsego County, Michigan
Amount and Source of CO_2	10,241 metric tons Source = DTE Turtle Lake Gas Processing Plant, Otsego Co., Michigan
Field Test Partners (Primary Sponsors)	DTE Energy (Detroit Edison)
	Core Energy LLC
	Western Michigan University/Michigan Basin Core Research Laboratory

Summary of Field Test Site and Operations:

The site is located at State-Charlton 30/31 field, Southern Dover Township/Northern Chester Township, Otsego County, Michigan (Figure 1). This location is an enhanced oil recovery (EOR) field operated by Core Energy and is in the vicinity of a DTE gas processing plant outside of Gaylord, Michigan. The area is composed of state forest in rolling to hilly topography with little development beyond some farms and scattered homes.

The objective at this site is to test carbon dioxide (CO_2) sequestration in deep saline reservoirs (Figure 2). This portion of the basin is in an area of active EOR projects. High purity CO_2 is available from natural gas processing plants in the area (CO_2 is a byproduct of the gas produced). Periodically, this CO_2 is used for EOR in the Niagaran Reefs. The CO_2 is captured, compressed, and injected in the reefs to flush out residual oil in the rocks. This makes a significant amount of infrastructure available for testing CO_2 sequestration in saline formations located adjacent to Niagaran Reefs.

The site is situated in the Michigan Basin, a regional geologic structure in which sedimentary rocks form a basin in the lower peninsula of Michigan. Like most of the MRCSP region, thick sequences of sedimentary rock overlie Precambrian age basement rock at the site (Figure 2). The target sequestration interval is the Bass Islands Dolomite. The Bass Islands Group in the Michigan Basin consists mostly of light brown to buff dolostone with argillaceous dolostone and anhydrite present lower in the section. The entire Bass Islands interval reaches a thickness of 300-600 ft in the central basin but thins substantially due to erosional unconformity in the southwest corner of the basin. Near the well site, the Bass Islands formation can be correlated in well logs. In addition, higher quality logs in Otsego County show very good lithologic correlation for the unit across the county. In core from the test well, the Bass Islands Group was present at a depth interval of 3,442-3,700 ft. A high-density anhydrite interval was present in the lower section at 3,515-3,700 ft.

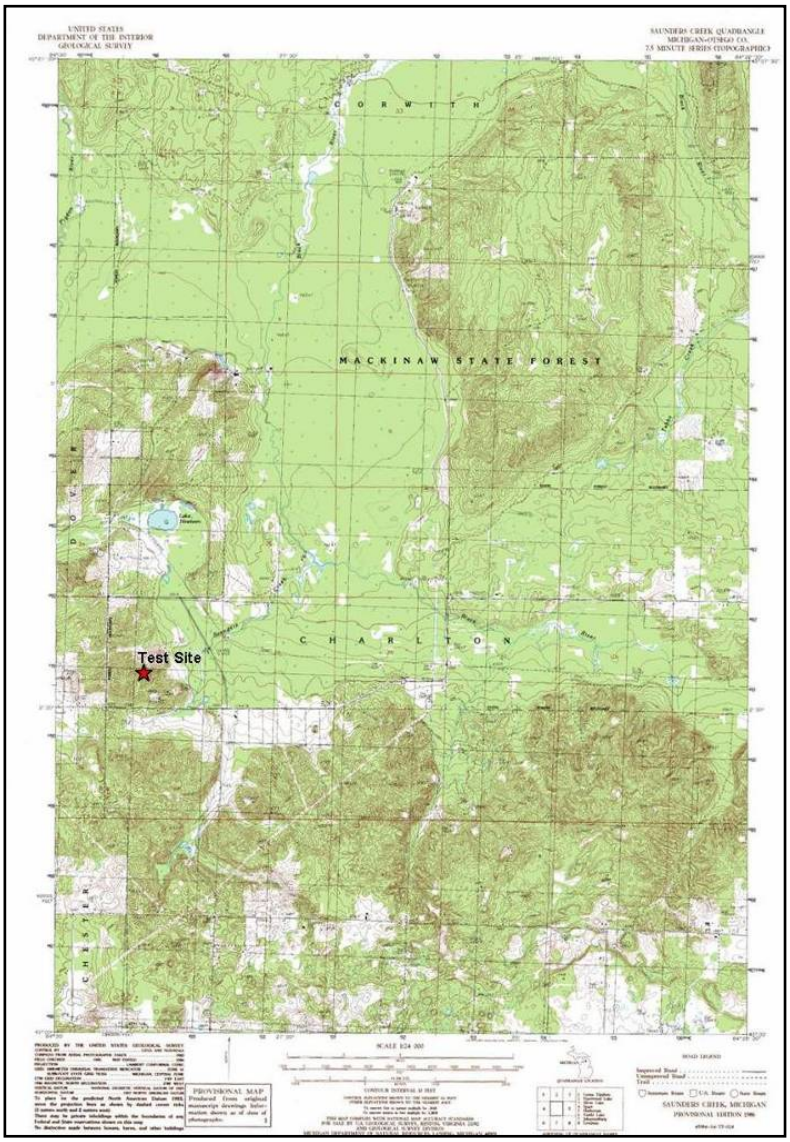

Figure 1. Site location map

Transitional upsection in core and logs is a porous and permeable dolostone unit at 3,442-3,515 ft, informally referred to here as the Bass Islands dolomite. This interval is the main injection target and is characterized by interbedded, laminated algal dolomudstone, minor cross-bedded and sandy dolograinstone, intraclast beds, and disrupted karstic breccia zones.

The Bass Islands Dolomite is overlain by the Lower Devonian Bois Blanc Formation, a wide spread lithostratigraphic unit in the Michigan Basin subsurface characterized by cherty carbonates ranging from calcareous chert, to cherty limestone and dolostone, to limestone and dolomitic limestone. This unit is considered an intermediate containment zone. Rock layers dip toward the south at about 50 ft/mile in the study area, and no faulting or fracturing exists in the area beyond subtle changes in thickness.

Shale and dense limestone units in the Bois-Blanc-Amherstberg group provide containment immediately above the Bass Islands Dolomite. In most parts of the basin, the Amherstburg is dense, tight limestone. The Amherstburg ranges in thickness from a zero edge in the southwest to more than 300 ft thick in the central basin. In the test well, the Amherstburg was 248 ft thick at a depth interval of 2,942 - 3,190 ft. The rock is

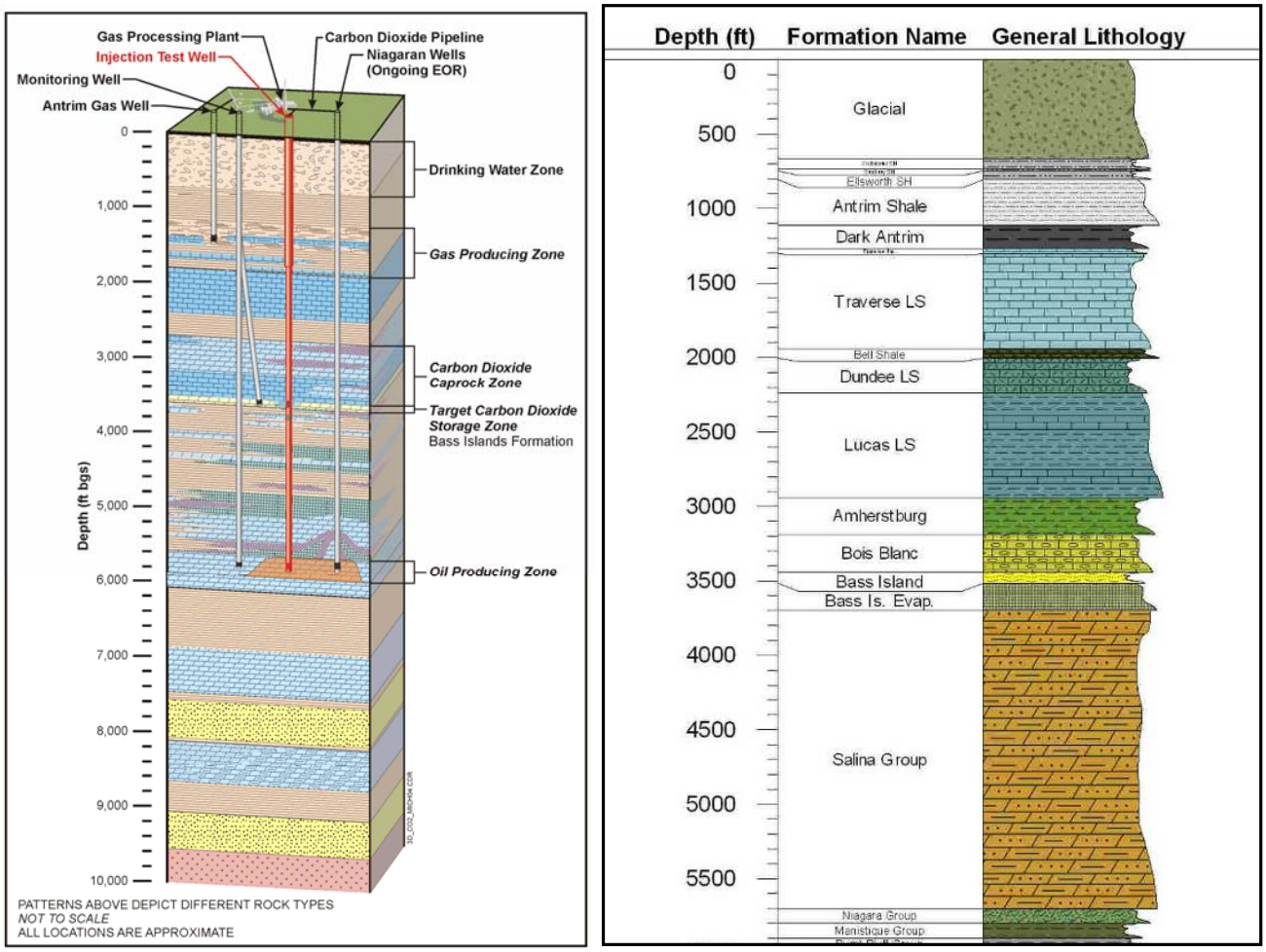

Figure 2. Conceptual diagram of CO_2 sequestration tests for Otsego County Michigan site (left). Geologic stratigraphic column (Bass Islands Dolomite is at 3,400-3,500 ft) (right).

generally very dense with little visible porosity in most intervals. Additional salt and anhydrite layers, which are considered excellent sealing units, are present in the overlying Lucas Formation. Possibly due to these salt layers, the rocks are saturated with brine in excess of 100,000 mg/L. The deepest underground source of drinking water in the area is from shallow glacial drift less than 50 ft deep. Total thickness of glacial drift is over 500 ft thick.

Many oil and gas wells penetrate the target storage reservoir in the area. Over 135 wells in the area were identified; however, most are cased through the target injection interval or completed in the shallower Antrim shale. Therefore, borehole leakage is not considered a significant pathway. No other leakage routes were identified.

Geology at the site is very well-characterized due to oil and gas exploration in the area. Many wells have been drilled in the area. As such, many well logs are available. In addition, a 3D seismic survey was completed through the area as part of another DOE program and was made available to MRCSP. However, most wells did not log the target zone (Bass Islands Dolomite). Consequently, there are only basic logs through the interval. Some additional logging and sidewall cores through the zone were necessary to confirm good porosity and permeability.

The overall site plan for the Michigan Basin Site is to utilize existing infrastructure to facilitate a CO_2 injection test and monitoring. General steps of the site plan are listed as follows:

1) Preliminary Geologic Assessment of Potential Storage Reservoirs and Caprocks − This work involved compiling available well logs, developing geologic cross-sections, delineating target storage reservoirs, and identifying any issues related to geologic storage that may affect the project. Michigan Core Research Laboratory has completed this task.

2) Site Characterization Field Work − Drilling of an injection test well at State-Charlton #4-30 was completed in late November 2006. Approximately 180 ft of full rock core were collected from the Bois Blanc-Bass Islands interval in four core runs (this represents the first full rock core obtained from this formation in the Michigan Basin). A nearby plugged Niagaran Oil well (#C3-30A) was recompleted for monitoring. It was drilled directionally at a kickoff depth of approximately 1,700 ft and drilled toward the State-Charlton #4-30 test well about 500 ft laterally away from the injection well.

3) Injection System Design and Construction − An injection system was designed and constructed at the Michigan Basin Site in early 2007. This system is integrated with the existing EOR infrastructure at the area and does not involve any extensive new or innovative design elements. A short branch of pipe was run to the injection well from the existing 6 inch diameter supercritical EOR line nearby the injection site.

4) Permitting − An Underground Injection Control (UIC) permit was applied for and obtained from the US EPA Region V, the regulatory body governing the UIC process for Michigan. After the permit was issued on August 23, 2007, an appeal was subsequently filed and activities were put on hold pending an outcome of the appeal. The US EPA Environmental Appeals Board (EAB) denied the Petition for Review on the UIC permit on December 20, 2007, allowing the test to proceed.

5) CO_2 Injection Testing and Monitoring (Completed) − A total of 10,241 metric tons CO2 was injected into the Bass Islands dolomite from February 8 through March 8, 2008, beginning with mechanical integrity tests. Injection rates were stepped up until reaching ~600 metric tons per day (the maximum capacity of the compression facility), and sustained until the injection was stopped. Surface system monitoring included a flowmeter at the compressor station, a flowmeter at the wellhead, interannulus wellhead monitor, and periodic sampling of the gas stream. Surface leakage/health and safety monitoring included NETL tracer testing and CO_2 gas sensor array at the surface. Bottomhole pressure/temperature gauges with data loggers were installed in the 4-30 injection well and the C3-30A monitoring well. Microseismic arrays were logged during the test in the 3-30 monitoring well and another deep well near the site during injection.

6) Post Injection Monitoring and Site Closure (On going) − Post injection monitoring was completed and data were analyzed for system performance and storage security. The injection and monitoring well were shut-in after injection for approximately one month to allow the pressures to recover to pre-injection levels. Data from wellhead and bottomhole gauges showed that pressures in the target reservoir had 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. Brine samples collected from the monitoring well showed some subtle changes in calcium and magnesium concentrations that may be related to the CO_2 injection, suggesting complex sulfate system. Microseismic monitoring data suggested that injection did not cause any type of significant microseismic events. 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. 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 in overlying storage zone but no movement through the caprocks. A final PFT soil gas tracer sampling event was completed June 27, 2008. Results from this method have shown no indication of leakage to the vadose zone or atmosphere. A final report is being prepared.

Research Objectives:

The primary research objective is to test CO_2 sequestration in the Bass Islands Dolomite, a significant CO_2 sequestration target for the area. The test results also should be applicable to other parts of the Michigan Basin, which is a very attractive sequestration target in the MRCSP region. In addition, these tests support sequestration of CO_2 from gas processing operations along the northern reef trend in Michigan.

At this site, a fairly significant volume of CO_2 (10,000 tons) was injected because the source is available from the nearby DTE Energy gas processing plant. In addition, an abandoned EOR well was retrofitted at the site for

monitoring. This allowed for more extensive monitoring of the injected CO_2, including cross-well seismic. Closure monitoring was performed to assess the fate of the injected CO_2. There is currently periodic CO_2 flooding for EOR in Niagaran Reefs at the proposed Michigan Basin Site and there has not been any sign of leakage or other problems. Consequently, closure monitoring is focused on ensuring the CO_2 has been safely sequestered and monitoring any geochemical changes over time in the reservoirs.

Summary of Modeling and MMV Efforts:

Numerical simulations of CO2 injection were completed with the STOMPCO2 simulator, which was designed to model complex, coupled hydrologic, chemical, and thermal processes, including multifluid flow and transport, partitioning of CO2 into the aqueous phase, and chemical interactions with aqueous fluids and rock minerals along with the accurate representation of fluid properties. Initial reservoir simulations with the reservoir model STOMPCO2 of the proposed injection tests indicated that the injected CO2 would extend less than 500 ft from the well and the pressure increase would extend less than 1,000 ft from the well. The reservoir model is being calibrated to monitoring data; initial analysis suggests the model was fairly accurate and will need minor refinement.

In addition to injection system monitoring, a monitoring, mitigation and verification (MMV) program was designated for the site consisting of brine chemistry analysis, downhole pressure gauging, temporal wireline RST monitoring in a monitoring well, cross-well seismic imaging of CO_2 field, microseismic monitoring of the CO_2 injection, and soil gas monitoring of PFT tracers in the injectate (Table 1).

Table 1. Measurement Technologies Employed at Field Test Site

Measurement technique	Measurement parameters	Application
Water composition	CO_2, HCO_3, CO_3^{2-} Major ions Trace elements Salinity	Quantifying solubility and mineral trapping Quantifying CO_2-water-rock interactions Detecting leakage into shallow groundwater aquifers
Subsurface pressure	Formation pressure Annulus pressure Groundwater aquifer pressure	Control of formation pressure below fracture gradient Wellbore and injection tubing condition Leakage out of the storage formation
Well logs	Brine salinity Sonic velocity CO_2 saturation	Tracking CO_2 movement in and above storage formation Tracking migration of brine into shallow aquifers Calibrating seismic velocities for 3D seismic surveys
Crosswell seismic imaging	P and S wave velocity Reflection horizons Seismic amplitude attenuation	Detecting detailed distribution of CO_2 in the storage formation Detection leakage through faults and fractures
Passive seismic monitoring	Location, magnitude and source characteristics of seismic events	Development of microfractures in formation or caprock CO_2 migration pathways
Monitoring of Perfluorocarbon tracers (PFTs) in soil gas	Soil gas composition, PFTs	Detect leakage

Source: IPCC Special Report on Carbon Dioxide Capture and Storage

Accomplishments to Date:

All work at this site has been completed including injection of 10,241 metric tons CO2:

- Site preparation activities were completed in the Summer of 2006.
- A preliminary geologic assessment was completed by Western Michigan/Michigan Core Research Laboratory describing the regional geologic setting, target sequestration rock formations, and other

issues in the Fall of 2006

- A new test/injection well of about 5000 ft depth was drilled and an existing nearby EOR well was recompleted as a monitoring well about 500 ft laterally from the injection well. This all occurred in the November, December 2006 timeframe.
- Approximately 180 ft of full rock core were collected from the Bois Blanc-Bass Islands interval in four core runs (this represents the first full rock core obtained from this formation in the Michigan Basin).
- A Class V UIC permit was completed through US EPA Region 5 EPA. An individual owning land near the injection site appealed the permit, which caused the permit to be placed on hold pending review by the EPA EAB. The EAB denied the appeal, which focuses on property rights, as outside the scope of EPA's UIC process.
- A series of pre-injection mechanical integrity tests were performed from February 8 through 13 and provided to U.S. EPA Region 5 UIC program to receive permission to inject. Full injection testing started February 20 and finished March 9.
- A total of 10,241 metric tons CO2 were injected into the targeted Bass Islands Dolomite formation. The well was then shut-in to monitor post injection pressure recovery and allow the system to stabilize.
- A comprehensive MMV program was implemented along with injection including wellhead flow monitoring, downhole pressure logging, brine sampling, microseismic monitoring, wireline logging, crosswell seismic, surface gas metering, PFT soil gas tracer monitoring, and .

Summarize Target Sink Storage Opportunities and Benefits to the Region:

- This test demonstrated industrial-scale CO2 sequestration potential in the Bass Islands Dolomite. Injection rates of 600 metric tons per day were sustained, which is equivalent to an annual rate of 219,000 metric tons per year.
- The test promotes CO_2 sequestration at Antrim gas fields, currently the 10th most prolific gas play in the continental U.S. Currently, over 1 million metric tons CO2 per year is produced in the area from gas processing plants.
- Geologic characterization from the test well confirms permeability and porosity in the upper Bass Island Dolomite is suitable for injection. Average porosity was 21% with an average permeability of 22 mD. Consequently, this interval is being targeted for injection; although, the entire Bass-Island Dolomite-Bois Blanc interval from 3,190-3,515 ft is considered the storage interval.
- Added value in performing the test at an active oil and gas field in a real-world setting.
- Added value in utilizing the only existing CO_2 EOR pipeline in the eastern U.S. Much of the infrastructure for CO_2 capture, transport, and injection already exists at the Michigan Basin site. A gas processing plant that exists near the site provides a supply of high-purity CO_2.
- Added value in sequestering anthropogenic CO_2 as a byproduct from natural gas processing, resulting in actual net sequestration of CO_2.
- Added value in utilizing existing 3D seismic data through site.

Cost*:

Total Project Cost: $23,745,399

DOE Share: $17,458,272 (73.52%)

Non-Doe Share: $6,287,127 (26.48%)

(*) Costs are for overall MRCSP Phase II project

Field Project Key Dates:

Baseline Completed: Fall 2006

Drilling Operations Begin: Late Fall 2006

Injection Operations Begin: February 2008

MMV Events: TBD