

Quarterly Report

Grant No. DE-SC-0001761

Report period: From October 1, 2009 to December 31, 2009

1) Project activity during this quarter

(a) Planned activities

1. Establish MICHCARB Center by:

- Creating statewide digital databases for samples and well records for Michigan's geological formations relevant to CO₂ storage, containment and potential for enhanced oil recovery
- Beginning to accumulate data with which to construct maps and tables of physical properties
- Implementing internal data share (intranet) to facilitate compilation of information into a digital atlas

2. Begin to conduct geologic and fluid flow modeling to address specific predictive uses of CO₂ storage and enhanced oil recovery, including:

- Compiling data for geological and fluid flow models
- Formulation of models, integrating data, and running the models
- Applying models to specific predictive uses of CO₂ storage and enhanced oil recovery

3. Initiate technical research on CO₂ sequestration and enhanced oil recovery by:

- Conducting initial basic and applied research of characterizing Michigan oil and gas and saline reservoirs for CO₂ storage potential volume, injectivity and containment

4. Lay the groundwork for technology transfer to members of industry and governmental agencies by:

- Establishing an Internet Website at which all data, reports and results will be accessible (site usage statistics will be maintained)
- Introducing MICHCARB programs at industry and governmental workshops and meetings

5. Bring into existence a CO₂ geological sequestration outreach and education center for Michigan at MGRRE by:

- Creating education materials including physical demonstration models and displays that can be used in outreach and for education events
- Working with partners in Michigan geo-resource industries, energy utility companies, State and local governments, K-12 classrooms and teachers and public groups

(b) Actual activities: All planned activities were conducted and good progress was made as described in detail in attachments.

2) Results achieved on the project during this QPR time period

(a) Results planned consisted mainly of:

- See *Planned Activities* 1) (a) 1-5, above.

(b) Results consisted of:

- See Attachments 1-6, *Reports on Planned Activities and Press Release*

3) Activities which went better or worse than expected:

(a) Because additional work-study students helped sort and inventory well samples and data, we made much greater progress this quarter than we anticipated.

(b) A very large collection of cores and cuttings became available unexpectedly, as did an enormous collection of wireline logs—all excellent data for the project.

(c) Substantial progress was made implementing software (STOMP - WCS; Subsurface Transport Over Multiple Phases- Water, Carbon Dioxide, Salt; Pacific Northwest National Lab open source code) for supercritical CO₂ injection simulation modeling by graduate students and faculty advisors during the first quarter. Coupled with good progress on geological characterization of important CO₂ injection zone

reservoirs, we have generated reasonable injectivity models to simulate CO₂ injection rates in an existing borehole with good geological characterization data. This progress indicates that we may not need to hire a post-doctoral associate to augment our research personnel in this area.

- (d) We had to overcome several technical issues in implementing our intranet server. Implementing this resource was far more time-consuming than expected.
- (e) Positive response from the Michigan Dept of Environmental Quality for permitting a new clean coal power plant proposed by the Consumers Energy Company in Bay Co., Michigan (see attached press release at Attachment 6) will result in continued forward progress on a proposed stratigraphic test well in support of the company's Carbon Capture and Geological Sequestration (CC&GS) assessment. Western Michigan University researchers in the MICHCARB program are working closely with Consumers and will actively participate in assessment of results from the new test well. This synergy and progress on the acceleration of CC&GS in Michigan is a central goal of the MICHCARB program and an important milestone for our research goals.

4) Project problems, solutions and changes during the quarter

- (a) Because of significant progress in subsurface CO₂ injection simulation modeling, we are evaluating the redirection of funding originally intended for a post doctoral associate to a graduate student assistantship for an experienced (non-traditional), Civil Engineering graduate student with professional fluid flow modeling experience who will begin to conduct research in the second quarter.
- (b) Because of the importance of developing intranet and internet data resources for internal data analysis and compilation and for external technology transfer, resources are being re-directed for hiring a data management professional with web authoring experience. The intent is to effectively and efficiently integrate the development of internal (intranet) and external (internet) data sharing/data access resources.

5) Other topics of interest: Please see attachments

6) Status of project at end of period: Project is on time and on budget to date.

Authors: David A. Barnes and William B. Harrison

Date: December 31, 2009

Please see following Attachments 1-6.

Attachment 1 Report on Establishing the Resource Center at MGRRE

- **Developing statewide and site-specific digital research databases—Data added this quarter:**
 - Core analysis data (largely porosity and permeability data)—hand entered from paper records 503 wells
 - Mudlogs—113 scanned and added to database
 - Wireline logs—sorted 560 donated logs to be added to database
 - Cuttings—cuttings sorted and inventoried from 1300 wells, some historic core tests
 - Cores—10 pallets of donated cores sorted, added existing core inventory
- **Compiling all information into a digital atlas**
 - Compile and merge data from on-site collections and from several Access databases maintained by the Michigan Department of Environmental Quality (MDEQ). When complete, these data will form the basis of a master data resource. These data resources can then be readily formatted for use in subsurface data analysis software (HIS Petra) to enable mapping and cross-sectional analyses of prospective intervals.

Attachment 2 Report on Conducting Geologic and Fluid Flow Modeling

- **Compiling data for geological and fluid flow models**
 - Investigated methodology used by the Illinois EPA for injection test analysis. Hydrogeological data generated from deep waste injection wells may be used to determine the potential for a saline aquifer to accept injected CO₂. Pressure fall-off test (PFT) data is used to make inferences about the size of an aquifer/reservoir or to quantitatively describe the hydraulic conductivity of an aquifer/reservoir.
 - The PFT data has been cataloged according to its utility, which is dependent on the rigor in which the data was collected. The data that is of lower quality can be used to make inferences about reservoir compartmentalization and the best data can be used to calculate the hydraulic conductivity of aquifers.
 - With PFT analysis we should be able to make scale and injectivity inferences about important CO₂ injection targets. Analysis is being conducted for two saline aquifer injection targets in Michigan: the Mount Simon Sandstone and Sylvania Sandstone formations, from 25 wells with approximately 60 discrete test data sets (the number of useful test data sets is not yet established)
 - We have obtained academic licensing for Fekete FASTWELLTEST reservoir engineering software for injection-PFT test /Pressure Transient Analysis.
- **Formulation of models, integrating data, and running the models**
 - Established existing subsurface saline reservoir data sources and collected data for injection simulation model parameter values as input for STOMP-WCS injection simulations. Most subsurface geological data for injection simulation modeling has been compiled for the Devonian Sylvania Sandstone formation in central Lower Michigan (Figure 2-1).
 - Geostatistical models have been developed for several areas of interest to pattern and interpolate important subsurface fluid flow variables such as permeability and porosity. We have acquired academic licensing for and student researchers are exploring the relative merits of SGeMS (Stanford Geostatistical Modeling Software) and Schlumberger- Petrel geological modeling software. Utilized STOMP-WCS to model injection of supercritical CO₂ into the Sylvania Sandstone deep saline aquifer in central Lower Michigan.
 - Recent simulations are far more realistic and successful than initial efforts as a result of better/more realistic input parameters. We now have a better understanding of the relative importance/need for accuracy of simulation input parameters (Figures 2-2a and b).
 - Substantial work was done to augment incomplete documentation of the STOMP-WCS software. The Pacific Northwest National Laboratory scientists/software developers have been extensively consulted to fill in significant gaps in software documentation. A work product will probably include updates/enhancements to the existing software documentation for other neophyte users of STOMP-WCS.

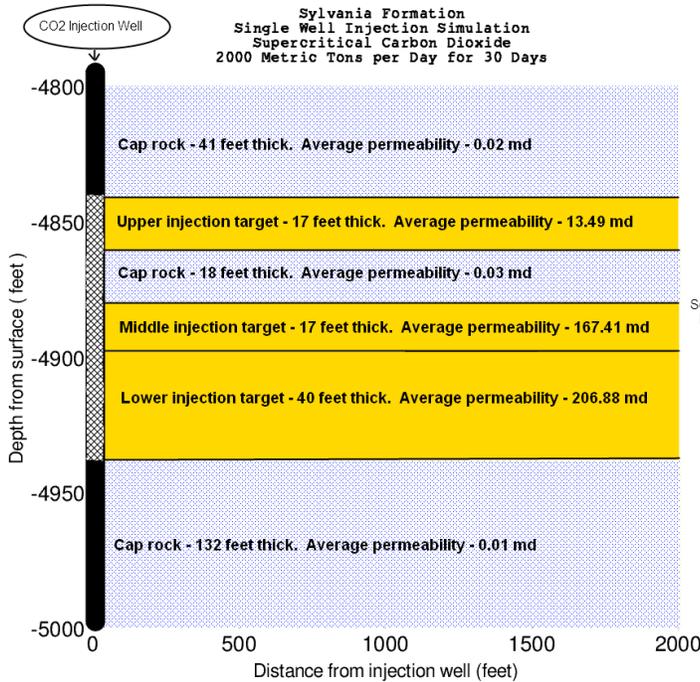


Figure 2-1

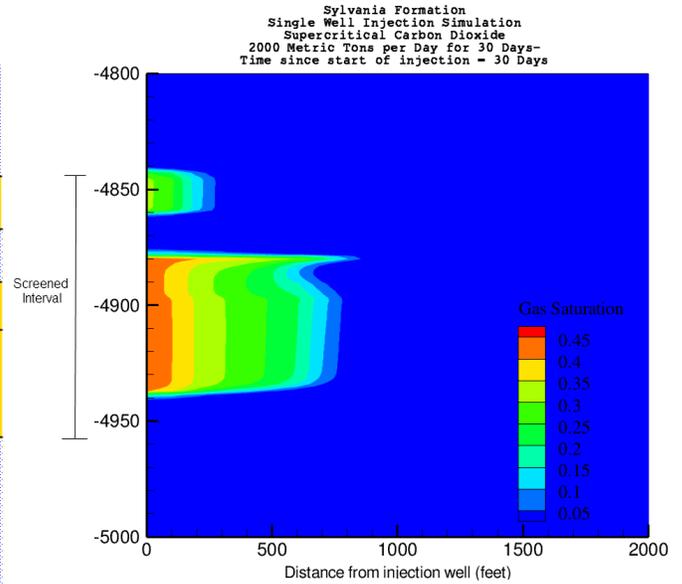


Figure 2-2a

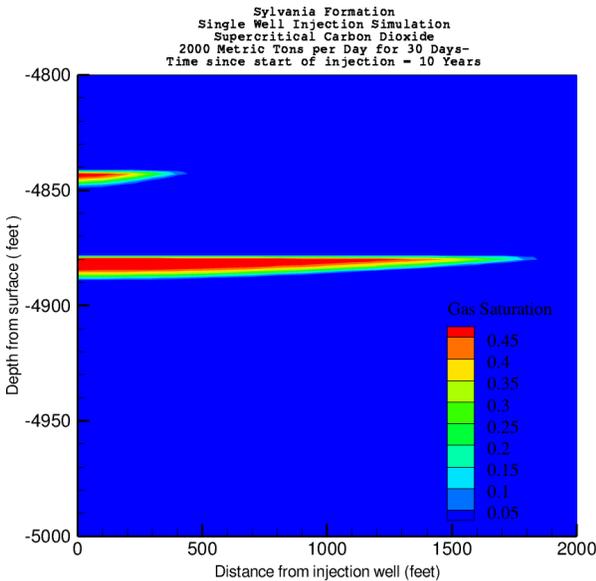


Figure 2-2b

- **Application of models to specific predictive uses of CO₂ storage and Enhanced Oil Recovery**

- Work on modeling this quarter has focused on the Sylvania Sandstone in central Lower Michigan, an important, but as yet poorly understood regional geological sequestration target. We have worked closely with a Michigan electric power utility company, Consumers Energy, in the formulation of plans for a stratigraphic test well in Saginaw County, Michigan. The well is intended to acquire important new data to validate regional geological characterization studies and provide

a comprehensive subsurface data set for the critical evaluation of the Sylvania Sandstone for site-specific, commercial-scale geological sequestration. Permitting of this stratigraphic test well and other regulatory decisions will be dependent, in part, on our preliminary assessment of the significance of the Sylvania Sandstone saline aquifer geological sequestration target through geological characterization and injection simulation modeling (press release at Attachment 6).

Attachment 3 Report on Technical Research on CO₂ Sequestration and Enhanced Oil Recovery

- **Conducting basic and applied research of characterizing Michigan oil and gas and saline reservoirs for CO₂ storage potential volume, injectivity and containment**
 - The majority of work in this area has focused on the geological characterization of two highly prospective, regional saline reservoir, geological sequestration targets in Michigan, the Mount Simon Sandstone and the Sylvania Sandstone formations. Both of these formations have been exploited as subsurface waste water disposal zones and/or brine mining targets. We are focusing our investigations on better understanding the geological controls on spatial distribution and fluid flow properties in these important geological sequestration targets.
 - Geological studies of sequestration targets fall into three general categories
 - Stratigraphic and sedimentology analysis of subsurface well log and core sample material to interpret geological controls on gross rock properties and the spatial distribution of basic rock types.
 - Petrologic analysis of rock sample materials to interpret mineralogical and textural controls on fluid flow properties and relate these properties to regional stratigraphic relationships.
 - Petrophysical analysis of rock and fluid flow properties in injection and confining zone formations from rock sample and wireline log data.
 - Mount Simon Sandstone Geological Characterization research results:
 - Emphasis this quarter was on documenting the variation in Mount Simon Sandstone geological characteristics and resultant fluid flow properties from wells in Southeastern Lower Michigan. Detailed sedimentologic analysis of cores from three wells in the Mt. Simon (Figure 3-1) was completed.

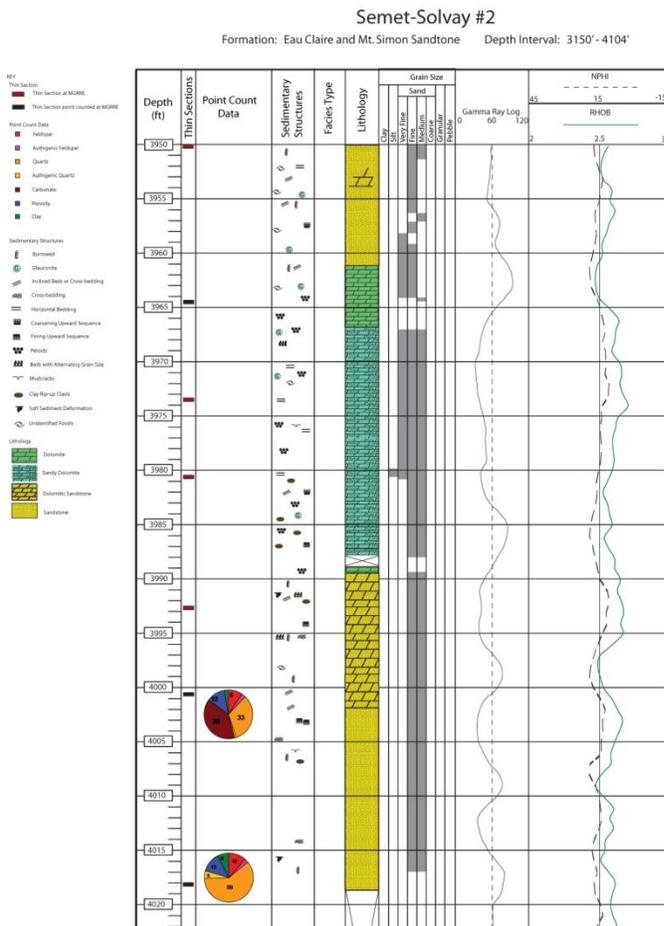


Figure 3-1

- Petrographic analysis was conducted on existing and new thins sections (23) to evaluate mineralogical and textural properties and relate these properties to wireline log response.
- Geostatistical models were developed to infer the spatial distribution of fluid flow properties (porosity and permeability) for individual wells and the regional well data in the Mount Simon Sandstone.

- Sylvania Sandstone Geological Characterization research results
 - Compilation of subsurface data resources for the Devonian Sylvania Sandstone was accomplished during this quarter (Figure 3-2) and extensive regional wireline log analysis (150 wells), construction of interpreted cross sections, and core to log correlation (partial core samples from 6 wells and core analysis data from 50 wells) was completed (Figure 3-3). Important petrophysical relationships were established to discriminate effective versus ineffective porosity and reservoir properties in the Sylvania.

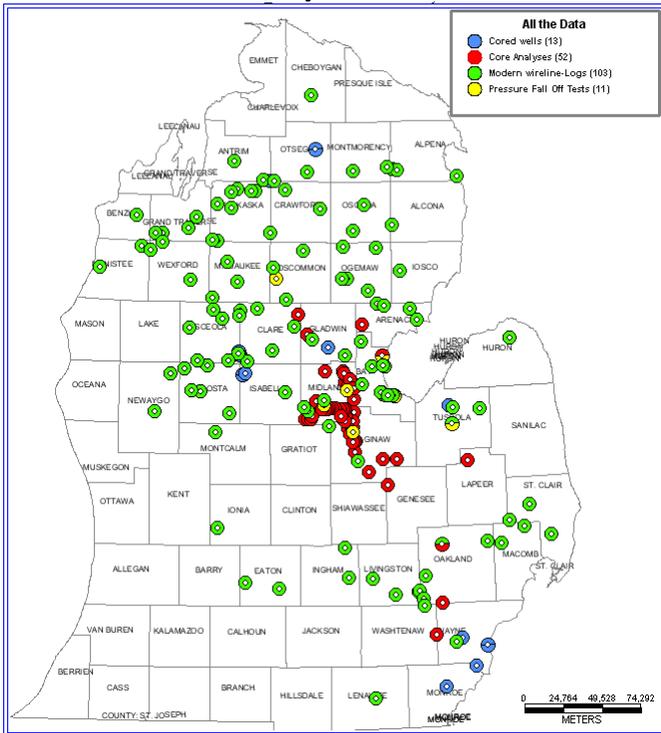


Figure 3-2. Subsurface data distribution for the Sylvania Sandstone.

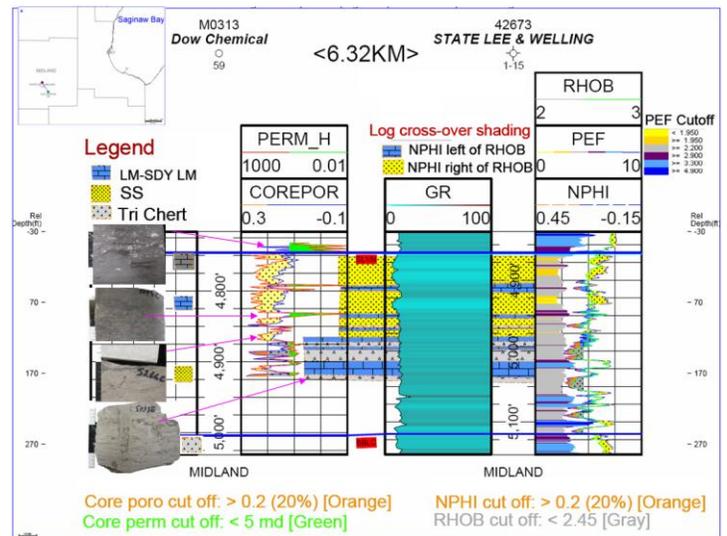


Figure 3-3a. “Pseudo”-core to log correlation to establish the wireline log properties of effective reservoir facies in the Sylvania Sandstone.

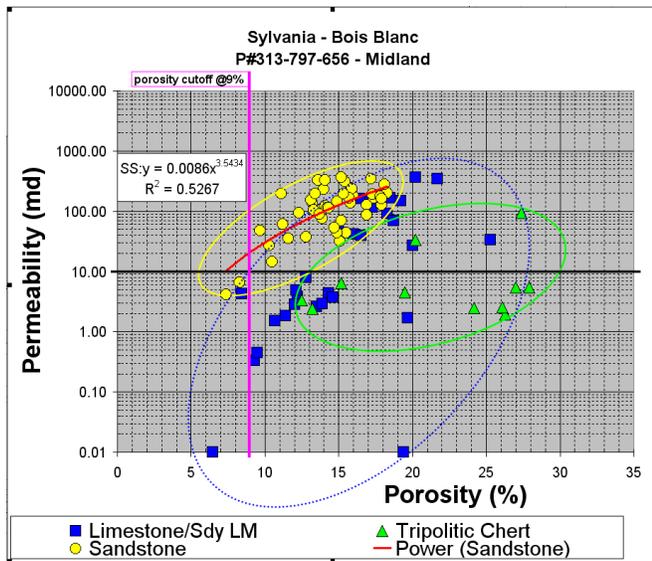


Figure 3-3b. Plot of core analysis data, porosity and permeability, for interpreted lithofacies of the Sylvania Sandstone.

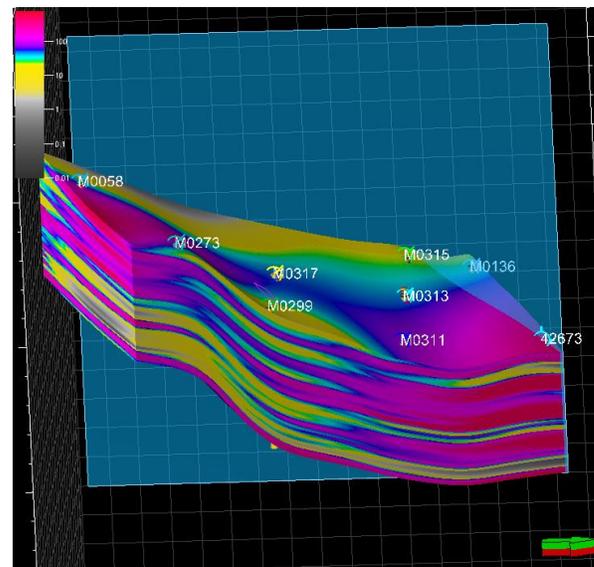


Figure 3-4. 3-D model of permeability distribution in the Sylvania Sandstone

- **Gathering new data, geologic samples, fluid analyses and other test information pertinent to geological carbon storage (GCS) from deep wells that are drilled into Michigan geological formations for reasons other than GCS, primarily by the oil and gas industry (“piggyback” drilling and testing)**

Attachment 4 Report on Technology Transfer to Members of Industry and Governmental Agencies

- **Establishing an Internet Website at which all data, reports and results will be easily accessible** (site usage statistics will be maintained).
 - From the MICHCARB website, all the databases for MGRRE are available at: http://wst023.west.wmich.edu/ind/Data_on-line.htm
- **Disseminating information about MICHCARB/accelerating the deployment of CC&GS in Michigan**
 - Dr. Barnes was an invited attendee at the annual EPA Midwest Carbon Sequestration Conference, Angola, IN, July 28 - 29, 2009
 - Barnes was a presenter at a Joint conference with AAPG/SEG/SPE Hedburg Research Conference on *Geological Carbon Sequestration: Prediction and Verification* in Vancouver, BC, Canada on August 16-19, 2009. Poster presentation: *Geological Sequestration of Carbon Dioxide in the Cambrian Mount Simon Sandstone: Regional Storage Capacity, Site Characterization, and Large Scale Injection Feasibility; Michigan Basin, USA*
 - Barnes was a participant in a briefing presented to Stanley (Skip) Pruss (Michigan Director of Energy, Labor, Economic Development) and Brandon Hofmeister (Gov Granholm’s deputy Legal Counsel) along with a Wolverine Power Cooperative Inc.-led group concerning the Wolverine Clean Energy Venture initiative and a Phase I DOE funding application for the “Beneficial uses of Industrial Emissions” funding. The meeting was held in Lansing, Michigan, on Monday, Sept 21, 2009.

Key points in the presentation were:

 1. Significance of the CC&GS project in light of objectives laid out by the MGA [Carbon Capture and Storage Policy Principles](#)
 2. Strength of the team involved in the proposed CC&GS project
 - a. WPC, Core Energy, Hitachi, Dow Chemical, Burns and Rowe Engineering, and Western Michigan Un. for a post combustion-based advanced amine carbon capture and geological sequestration with CO₂ /EOR program
 3. Potential economic impact of CO₂/EOR to Michigan’s economy
 - Written program description and brief introduction to program was presented to 61 industry and government representatives at November 5, 2009, PTTC workshop in Mt. Pleasant, Michigan.
 - Barnes was invited to participate in a briefing to State Representative Douglas A. Geiss (Majority Vice Chair of the Michigan House of Representatives Energy and Technology Committee) and staff regarding a legislative initiative to establish indemnification for components of Carbon Capture and Geological Sequestration in Michigan. This initiative was championed by the Holland Board of Public Works and CC&GS research collaborators, Praxair, Inc. The meeting was held in Lansing, Michigan, on Tuesday, Nov. 10, 2009.
 - Several papers addressing Geological Carbon Sequestration in Michigan were published during the quarter:
 - Barnes DA, Bacon, DH, and. Kelley, SR, (2009), *Geological Sequestration of Carbon Dioxide in the Cambrian Mount Simon Sandstone: Regional Storage Capacity, Site Characterization, and Large Scale Injection Feasibility; Michigan Basin, USA*. Environmental Geosciences, v. 16, no. 3 (September 2009), pp. 163–183.
 - Kirschner, J.P. and Barnes, D.A., (2009); *Geological Sequestration Capacity of the Dundee Limestone, Michigan Basin, USA*. Environmental Geosciences, v. 16, no. 3 (September 2009), pp. 127–138.
 - Harrison, WB, III, Grammer, GM, and Barnes, DA, (2009) *Reservoir Characteristics of the Bass Islands Dolomite in Otsego Co., Michigan – Results for a Saline Reservoir*

Attachment 5 Report on Outreach to Industry, the General Public and K-12 Community

- **Outreach to industry and the general public**
 - Barnes was an invited presenter at the 2009 Annual Meeting in Kalamazoo of the Michigan Economic Development Association. His presentation title was *Realities of Alternative Energy*, Friday, August 2, 2009.
 - Linda Harrison attended Chamber of Commerce Legislative meetings to discuss related issues
 - August 2009 exhibited at WMU Day on the Capitol lawn in Lansing, Michigan. Outreach staff spoke at length with legislators and members of public. Core and data from test well displayed on table and posters.
 - Brochures created and distributed beginning October 2009.
 - Have begun preparing presentations for different audiences.
 - Staff exhibited at Southwest Michigan Science Educators Conference November 2009, also attended by some non-teachers.
 - Will present new posters and PowerPoints along with displays to Rep. Fred Upton in Jan. 2010.

- **Outreach to the K-12 community**
 - **Partnership development**
 - MGRRE's K-12 Outreach Program, CoreKids, has previously established partnerships with K-12 schools, scouting groups and other youth organizations which will become part of MICHCARB's network.
 - CoreKids partnerships in climate change curriculum development, Keystone Science School, and New England Science Center Collaborative will be sources of some educational content on GCS.
 - Brochures announcing MICHCARB have been created and will be sent to CoreKids mailing list and state educators' mailing list in early 2010.
 - **Creation of Educational Materials**
 - Posters about climate change and geological CO₂ sequestration and model of EOR is on display at MGRRE for all visitors to observe.
 - Incorporated additional CO₂ sequestration content into existing CoreKids presentations on Climate Change and on Natural Resources
 - Initiated temporary MICHCARB website:
<http://www.wmich.edu/corekids/CarbonDioxideSequestration.html>.
 - Visitors in first month from four states and two countries.
 - **Development of dissemination plans**
 - Outreach staff has discussed content and venues for presentations, teacher workshops, website, science fairs, and exhibits. Many of these events will be at schools and venues previously visited by CoreKids staff.
 - School, scout and summer camp visits scheduled for Jan – June 2010 (~1000 students)
 - Teacher Workshop: CO₂ sequestration will be major topic of Keystone Science School Climate Status Investigations teacher training to be held at WMU July 27-28, 2010. This will reach approximately 40 teachers from around the state of Michigan.
 - Will exhibit at the Michigan Science Teachers' Association Meeting in March 2010.
 - Will present workshop for Teachers including CO₂ content at MSTTA meeting March 2010.
 - Keystone Science School will hold 2nd Youth Policy Summit in partnership with CoreKids, MGRRE and MICHCARB July 24-29, 2010. Forty high school students and their teachers will spend a week discussing energy related issues, to include CO₂ sequestration, and come to consensus on recommendations to be made public.
 - **Dissemination of educational information on GCS**

- Exhibited at Southwest Michigan Science Educators Conference -
- Since Oct. 1, 2009, presented CO₂ sequestration educational content to:
 - 3rd grade GT students at Plainwell Starr Elementary School
 - 3rd grade students at New Buffalo Elementary School
 - 6th grade students at Benton Harbor Middle School
 - Teachers at Northglade Montessori (Elementary)
 - 6th grade students at Gull Lake Middle School

Attachment 6—Press Release

www.michigan.gov Release Date: December 29, 2009

Contact: Robert McCann (517) 373-7917

Agency: Environmental Quality

DEQ Approves Air Permit for Consumers Energy Company Coal-Fired Power Plant

December 29, 2009

The Department of Environmental Quality has approved the air permit for an 830 megawatt coal-fired power plant in Hampton Township proposed by Consumers Energy Company, with the condition that Consumers Energy Company will retire up to 958 megawatts of coal-fired generating capacity from seven of the company's oldest existing coal plants in Michigan. The decision follows a period of extensive review by the DEQ of Consumers Energy Company's application, supporting information, and public comment.

The conditions of the permit issued today will additionally ensure that the project uses state-of-the art technology including scrubber and hydrated lime injection control for sulfur dioxide, acid gasses, and hazardous air pollutants; baghouse control for particulate and hazardous air pollutants; carbon injection for mercury control; and selective catalytic reduction for nitrogen oxide control. The project will be ready to employ carbon capture and sequestration technology to reduce greenhouse gas emissions once that technology becomes commercially feasible.

Consumers Energy Company currently utilizes one of the nation's oldest coal-fired generation fleets, averaging 50 years of age. As a result, this project will create an overall reduction of a number of harmful emissions due to antiquated generating equipment being replaced with newer and cleaner technology. Those reductions include a decrease of particulate matter (PM10) emissions by at least 807 tons per year, SO₂ emissions by 18,900 tons, NO_x emissions by 5,350 tons, lead emissions by 240 pounds, and mercury emissions by 353 pounds.

The DEQ has prepared a Response to Comments Document, which provides the department's responses to comments received during the public comment period of the permitting process and at the public hearing. Copies of the Response to Comments Document and the revised Permit to Install are available online by referencing Permit to Install Number 341-07 at: <http://www.deq.state.mi.us/aps/cwerp.shtml>.

Editor's note: DEQ news releases are available on the department's Internet home page at www.michigan.gov/deq.

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