POTENTIAL CAPACITY FOR GEOLOGIC CARBON SEQUESTRATION IN THE MIDCONTINENT RIFT SYSTEM IN MINNESOTA

POTENTIAL CAPACITY FOR GEOLOGIC CARBON SEQUESTRATION IN THE MIDCONTINENT RIFT SYSTEM IN MINNESOTA: EXECUTIVE SUMMARY

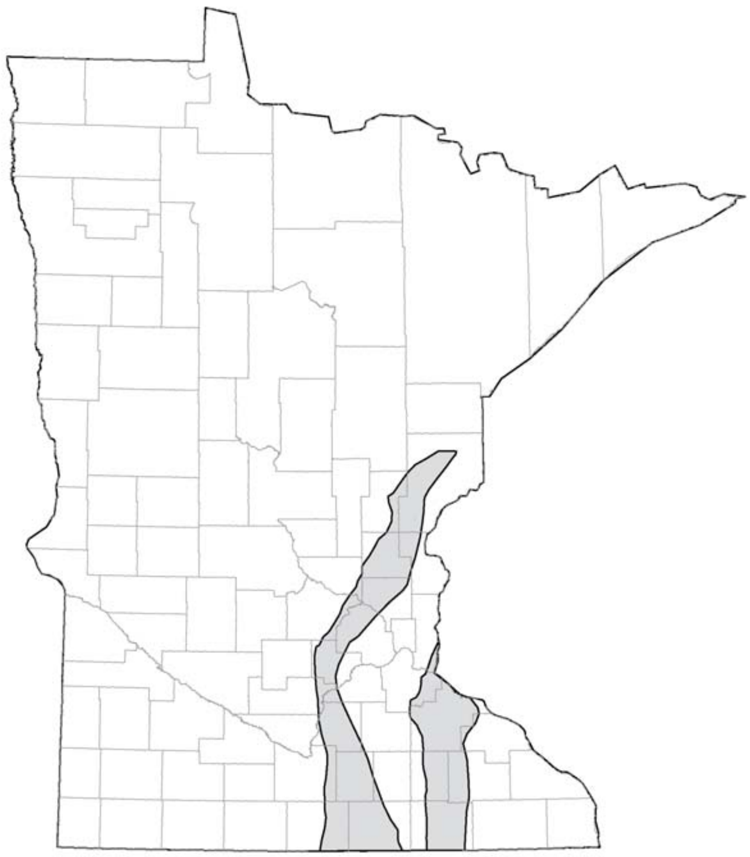
Increasing concern about climate change has necessitated the assessment of ways to reduce greenhouse gas emissions, while concurrently increasing our preparedness for climate change and variability. For example, in 2007, the Minnesota Legislature set goals to reduce our emissions 15% by 2015, 30% by 2025, and 80% by 2050. These reductions can be achieved by reducing combustion of fossil fuels, and by reducing other activity that generates greenhouse gases. Changes in land use can induce increased storage of carbon in soil and vegetation, thus facilitating terrestrial sequestration of emissions from the full range of sources, including vehicle emissions. In the case of stationary sources of carbon dioxide (CO_2) emissions, however, such as the coal-fired electrical generating stations, ethanol plants, and other stationary sources that make up over one-third of Minnesota CO_2 emissions, the technology to capture CO_2 is available, pending developments in methods and costs. The likely fate of CO_2 captured from stationary sources would be storage by geologic sequestration, also known as carbon capture and storage, by injection into underground geologic formations where it can be stored for long periods of time to prevent its escape to the atmosphere. This method is in the early deployment phase worldwide, but estimates indicate it may permit 15 to 55% of the emissions reductions needed to avoid dangerous levels of climate change. In addition, analyses indicate that achieving these reductions will be less costly if geologic carbon sequestration is an option. Another geologic technique is mineral carbonation, in which CO_2 is reacted with material from mining, producing mineral products for disposal or use in construction. While Minnesota has favorable geology for this option, the method is not fully developed and the costs remain high.

With respect to the deep injection method, an option for Minnesota is export of CO_2 from stationary sources by pipeline to one or more potentially willing jurisdictions such as North Dakota or Illinois, where apparently suitable geologic repositories have been confirmed. It is possible, however, that saline formations in Minnesota could be confirmed as geologic CO_2 repositories, possibly enabling carbon storage without the requirement for negotiations with neighboring jurisdictions and export by pipeline. The only rocks in Minnesota that potentially have the required reservoir properties below about a kilometer depth, the depth required for efficient CO_2 storage, are sequences of sedimentary rocks associated with the Midcontinent Rift, a southwestward extension of the Lake Superior basin that extends to Kansas. Criteria for confirmation of potential include depth, porosity, permeability, presence of a seal, integrity relative to previous drilling or fractures, appropriate chemistry relative to lack of drinking water potential and chemical trapping mechanisms, and adequate data availability.

As part of efforts by Minnesota to take steps toward dealing with the climate change issue, therefore, this report summarizes current knowledge and knowledge gaps regarding the potential capacity for geologic carbon sequestration in the Midcontinent Rift System (MRS) in Minnesota, as required by 2007 state legislation, while also discussing the mineral carbonation option. By reviewing published, unpublished, and new data, the report reviews available information pertinent to the potential long-term storage of carbon in Minnesota geologic formations. To do so, the study assesses the potential for porous and permeable sandstone layers deeper than one kilometer below the surface that are capped by less permeable shale, with emphasis on formation properties that determine injectivity, storage capacity, and seal effectiveness. Included is discussion on characteristics of key sedimentary units within the Midcontinent Rift System in Minnesota, including (1) likely depth, temperature, and pressure; (2) physical properties, including the ability to contain and transmit fluids; (3) the type of rocks present; (4) structure and geometry, including folds and faults; and (5) hydrogeology, including water chemistry and water flow. In addition, computer modelling methods are discussed and applied to the Minnesota context to the extent that could readily be achieved. The study thus identifies the most promising formations and geographic areas in Minnesota for physical analysis of carbon sequestration potential.

The prospective rocks primarily are known with respect to their depth and thickness on the basis of geophysical surveys. These seismic, gravity and magnetic interpretations indicate that sedimentary basins associated with the Midcontinent Rift in Minnesota are to a large degree associated with depths and volumes that are compatible

with sequestration of CO_2. The area where sedimentary rocks are more than 1 km thick, including both the most promising rocks, Bayfield Group sandstones, and overlying rocks that contribute to making up required depth, are presently thought to encompass two north-south belts on either side of the Twin Cities, running from Pine County and Washington County, south to Iowa (box). Available geophysical information thus indicates that there is sufficient sedimentary rock depth and thickness in the Midcontinent Rift System sedimentary basins in the region for further consideration of sequestration capacity to be warranted.



Estimated extent of sedimentary rocks thicker than 1 km in Minnesota, the depth required for potential carbon sequestration, based on 3D gravity modelling by Allen (1994), and scattered shallow drillhole intersections. Additional 3D gravity modelling, taking advantage of currently available methods and computing power, is needed to clarify and refine these estimated extents, prior to further geophysical surveys, drilling, and modelling meant to clarify the extent, thickness, and character of the rocks, to determine if potential is present

There is little in available geophysical information, however, that addresses porosity or permeability of these rocks. Although factors other than porosity can affect seismic velocity, the available velocity data from seismic refraction surveys do not look promising, as most values exceed 12,000 ft/sec, which are values higher than those typical of highly porous rock. Nonetheless, further work using new methods, such as velocity or waveform analysis of either existing or, if necessary, new seismic reflection data could be implemented to potentially better address porosity. Another approach might be to use magnetotelluric methods to look for conductive brines in the sedimentary section, which would indirectly indicate porosity, while additional 3D gravity modelling is needed to clarify extent and thickness, using currently available methods and computing power.

Thus while depth and thickness of the rocks are amply demonstrated, required information on porosity and permeability is inadequately established from geophysical surveys, and the same conclusion applies to a review, synthesis, and limited new analyses of their lithostratigraphy, depositional history, physical properties, and hydrogeology. Therefore, these rocks may not be sufficiently well characterized to permit a fully informed judgment on their suitability as a site for the sequestration of CO_2, but the limited available information indicates that the MRS has attributes that make it far less suitable for sequestration than other sites currently being considered across the country. On the positive side, the MRS contains the only sedimentary rocks in Minnesota that extend to depths required for sequestration, including sandstone bodies that at relatively shallow depths of 2500 ft (762m) or less are known to locally have moderate porosity and permeability. Shale and mudstone intervals are present, which appear to be of sufficiently low matrix permeability to serve as seals. An additional positive attribute is the lack of previous exploration, as reservoirs that have a history of exploration and production tend to have been penetrated by large numbers of often-undocumented drill holes that may not have been properly abandoned, presenting a significant and unquantifiable risk of leakage. These attributes thus suggest that the MRS can not yet be ruled out as a potential site for deep geologic sequestration of CO_2.

On the negative side, however, the known and inferred properties of the MRS in Minnesota and neighboring areas indicate that there is only a very small probability that it contains the geologic attributes necessary to serve as a site for deep geologic sequestration of CO_2. Geophysical logs of deep exploratory boreholes in Iowa and Wisconsin, petrographic analyses of sandstone in those states as well as Michigan and Minnesota, and the limited number of tests on samples from Minnesota cores as part of this project indicate that sandstone at the depth required for sequestration is relatively low in porosity and permeability. Permeability has been measured to be orders of magnitude too low for sequestration to be viable everywhere it has been tested in the MRS. Furthermore, the MRS is associated with a more complex tectonic history compared to other sites being investigated, and therefore features such as faults and fractures may play a larger role in site evaluation. For example, low permeability beds in the MRS that are necessary to serve as seals on top of potential CO_2 reservoirs are known to contain fractures with evidence of fluid flow. Fractures associated with faults are believed to serve as conduits for deep MRS groundwater to travel upward across such seals to overlying freshwater aquifers today. Identification and mapping of such features will be a more difficult task compared to the relatively simple structural settings being assessed elsewhere. Thus while much information is available for regions elsewhere in the US, such a body of geologic knowledge does not exist for the Midcontinent Rift. If it is determined that further research is warranted, a comprehensive investigation encompassing geophysical surveys, multiple deep and thoroughly analyzed exploratory boreholes, followed by stratigraphic, structural, tectonic and hydrogeologic interpretation will be necessary to bring the understanding of these rocks up to a level analogous to that presently available for where sequestration is being implemented. Early-phase characterization of the rift thus would require significantly more time and expense than was expended for initial assessments elsewhere.

Also part of the current study was numerical simulation initiated at the University of Minnesota Department of Geology and Geophysics, to obtain insights into current methods, to clarify needed information, and to take steps toward building the capacity that would be required for iterative simulation should subsequent steps proceed. Concurrently, this research contributes to broader knowledge relevant to topics such as groundwater as well as mineral and energy resources, and positions Minnesota to contribute to carbon sequestration research more broadly. Current numerical modelling is, however, in the initial stages required in a comprehensive CO_2 project since a wide range of geologic conditions as well as injection and storage scenarios have yet to be fully explored. Significantly more detailed studies, both in the field and via numerical modeling, will be needed for the analysis to play needed roles in eventually determining whether the MRS has characteristics favorable to CO_2 storage. A limited range of injection scenarios have been tested, however, varying solute injection rate as well as aquifer and caprock permeability and porosity between scenarios. Within the ranges of geologic parameters currently expected in the rift, the current model suggests that the following reservoir properties would be feasible for CO_2 storage if they were to be confirmed: aquifer permeability, 10^{-15} m^2 to 10^{-13} m^2; aquifer porosity, 4% to 20%; caprock permeability, 10^{-21} m^2 to10^{-18} m^2; and caprock porosity, 6% to 16%. Currently under way is an expansion of modeling capabilities to include multiphase behavior, as well as varying reservoir geometries and conditions. A subsequent phase of modeling could proceed as a three-year effort to improve the numerical multiphase fluid flow modeling environment. Initial work would be possible without the aid of field studies, as model geology could be improved by analysis of existing or new rock cores, while shallow wells that intersect saline brines could be sampled in order to support reactive transport modeling. Results from these improved models would then contribute to selection of sites for geophysical surveys, which in turn would support improved model iterations. Similarly, model iterations and scenarios would contribute to drillhole site selection, if called for, and again, direct data on rock composition and geometry together with brine composition from deep borehole sampling would again improve model iterations, continuing the cycle. Iterative field investigations and modeling would continue until required confidence levels concerning the feasibility of CO_2 storage are reached, at which time field tests of CO_2 injection and storage could be considered.

In summary, a spring 2007 bill passed by the 85th Minnesota Legislative Session as S.F. No. 2096, the omnibus environment, natural resources, energy and commerce appropriations, signed by Governor Pawlenty on May 8, 2007, provided for carbon sequestration studies, including funding to the Minnesota Geological Survey (MGS) for the purposes of geologic carbon sequestration assessment. A draft report therefore was prepared by staff of Minnesota Geological Survey and University of Minnesota Department of Geology and Geophysics, and a technical review meeting attended by local, state, and national authorities was held January 17, 2008. Appreciation is expressed to all participants in the technical review. On the basis of the contents of this report, along with broader considerations, the report authors present the following conclusions and recommendations.

Conclusions:

1. At the outset, it is stressed that currently available data indicate that there is a very low probability of success in confirming suitable geologic conditions for deep geologic sequestration of CO2 in Minnesota. At the same time, it is acknowledged that these same data are inadequate to rule out the most prospective rocks
2. Sedimentary rocks of adequate thickness are present in two north-south belts on either side of the Twin Cities, but limited data to date have indicated that their properties are not favorable for CO_2 storage
3. Minnesota may require, however, knowledge at a higher level of certainty than presently possible to indicate whether geologic carbon sequestration is a potential option for implementation within the State - for this, more geophysical surveys, drilling, and numerical modeling of CO2 storage will be required to permit a reasonably informed judgment.

Recommendations:

1. Concurrent with any further geologic analysis and assessment of other emission reduction options, effort presumably is required in CO_2 source characterization, analysis of pipeline systems, drinking water protection, arrangements for the activity, and community consultations, along with further analysis of the mineral carbonation option
2. Should it be established that a more a conclusive determination of in-state sequestration potential is needed, taking into consideration costs, a 3-year program including deep (~2 km) drilling will be required
3. A one-year pre-drilling phase costing about one million dollars would include geophysical surveys, further analysis of cores and water chemistry, including analysis of regional diagenesis, and numerical modeling of CO2 storage
4. Drilling in the second year should be conducted at the minimum expense required to satisfactorily answer the questions at hand, possibly as much as ten million dollars. Inexpensive coring methods should be explored, while it is recognized that oilfield methods, including comprehensive downhole logging, may well be needed. A third year would then be required for analysis of field data, including integration of the data by further numerical CO2 storage modeling, leading to reporting.

The key conclusion of the report is, therefore, that, unlike better known rocks in oil or coal producing regions, we have little information on the Rift. A major effort costing tens to hundreds of millions of dollars would therefore be required to test the Rift sedimentary rocks in Minnesota for required reservoir capacity and properties, and the probability that these requirements would not be confirmed, despite this effort, is high.