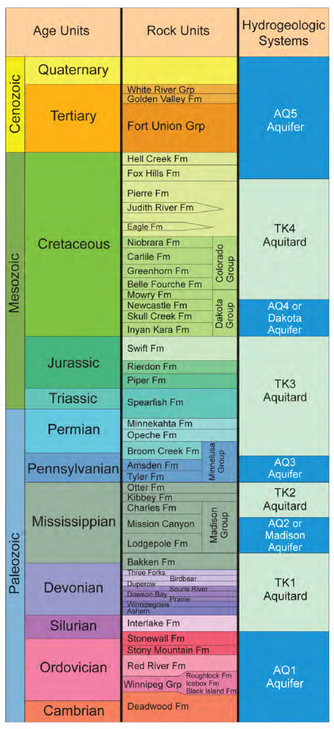
CO_2 Storage Capacity Estimates for Stacked Brine-Saturated Formations in the North Dakota Portion of the Williston Basin

James A. Sorensen,[a] Terry P. Bailey,[a] Steven A. Smith,[a] Charles D. Gorecki,[a] David W. Fischer,[b] Wesley D. Peck,[a] Edward N. Steadman,[a] and John A. Harju[a]

[a]*Energy & Environmental Research Center (EERC), University of North Dakota, Grand Forks, ND 58202 USA*
[b]*Fischer Oil and Gas, 5749 83rd Street South, Grand Forks, ND 58201, USA*

Abstract

As part of its ongoing regional characterization efforts, the Plains CO_2 Reduction (PCOR) Partnership has conducted a detailed evaluation of the potential CO_2 storage capacity of several stacked brine-saturated formations. The study area in central North Dakota, referred to as the Washburn area, encompasses 7500 square miles and is home to seven coal-fired stationary industrial sources which combine for annual emissions of over 36 million tons of CO_2. The stratigraphy of the Washburn area includes several thick and laterally continuous formations of brine-saturated clastics and carbonates of moderate to high porosity and permeability, many of which are separated by extensive shales and evaporites. The potential injection target formations include carbonates of the Ordovician Red River Formation and the Mississippian Mission Canyon Formation and sandstones of the Pennsylvanian–Permian Broom Creek Formation and the Cretaceous Dakota Group. Formations that could act as seals were also evaluated for thickness and extent. Characterization of the sink and seal formations in the Washburn area was accomplished using an approach that integrated publicly available well log data from over 50 wells, core analyses, drill stem test data, water analyses, and other published data to construct detailed petrophysical models. Results indicate that brine-saturated formations in the Washburn area of North Dakota have a CO_2 storage capacity greater than 13 billion tons.



Washburn Area Sink and Seal System

Four distinct regional aquifer systems are potential CO_2 sinks in the Washburn Study Area:

AQ4 Hydrogeologic System

- Lower Cretaceous Dakota Group contains two discrete sandstone aquifers, the Newcastle and Inyan Kara.
- AQ4 Aquifer is capped over 1000 meters of shales from the Cretaceous Mowry, Greenhorn, and Pierre Formations.

AQ3 Hydrogeologic System

- Pennsylvanian–Permian Broom Creek contains the thickest beds of high-porosity sandstones in the Washburn Study Area.
- AQ3 Aquifer is capped by the shales and evaporites of the Permian Opeche and Triassic Spearfish Formations.

AQ2 Hydrogeologic System

- The Mississippian Mission Canyon Formation is dominated by carbonates and several good porosity zones were evaluated, including the Midale, State "A," Frobisher, and Tilston members.
- AQ2 Aquifer is capped by the tight carbonates and evaporites of the Mississippian Charles Formation.

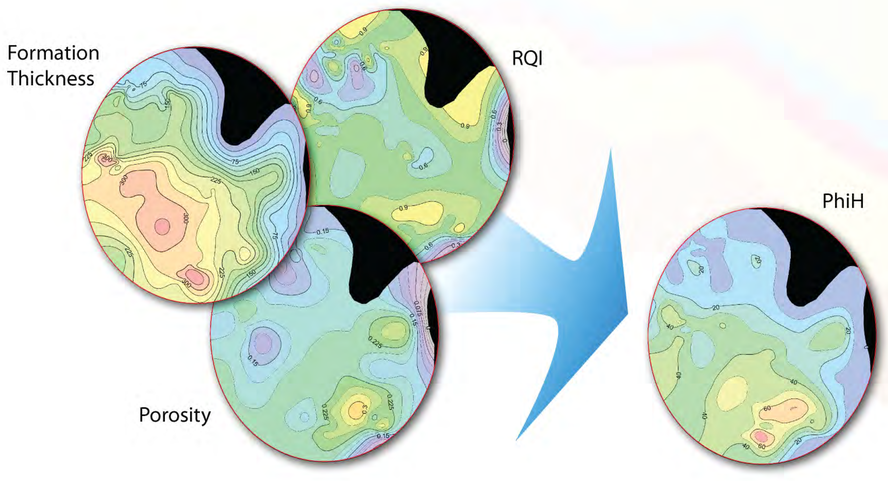
AQ1 Hydrogeologic System

- The three separate formations that make up the AQ1 aquifer are the Ordovician Red River carbonates, Ordovician Black Island sandstones, and the Cambrian-Ordovician Deadwood Formation.
- Two members were evaluated in the Red River Formation, the Red River "B" and "C" intervals.
- AQ1 Aquifer is capped by the tight carbonates, evaporites, and shales of Ordovician, Silurian, and Devonian age.

Methodology

Use well logs to identify zones of porosity
Use available well data to construct formation structure maps
Create a low, mid, and high case for each of the target formations using:
- Reservoir Quality Index (RQI) = the percentage of the thickness that meets a specific cutoff criteria
- Porosity
- Interval thickness varying with distance away from the well control

Create a low-, mid-, and high case effective porosity-thickness (PhiH) by multiplying the low-, mid-, and high-case RQI, porosity, and thickness maps together



Storage Capacity Calculation

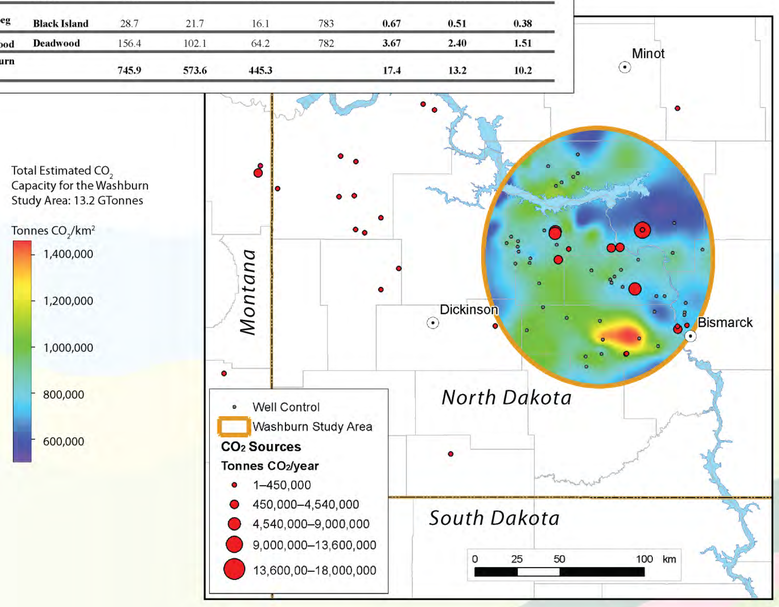
CO_2 storage capacity was calculated using the U.S. Department of Energy (DOE) methodology: $G_{CO2} = \frac{([\text{Pore Volume}] * \rho_{CO2} * E)}{1000 \text{ kg/tonne}}$

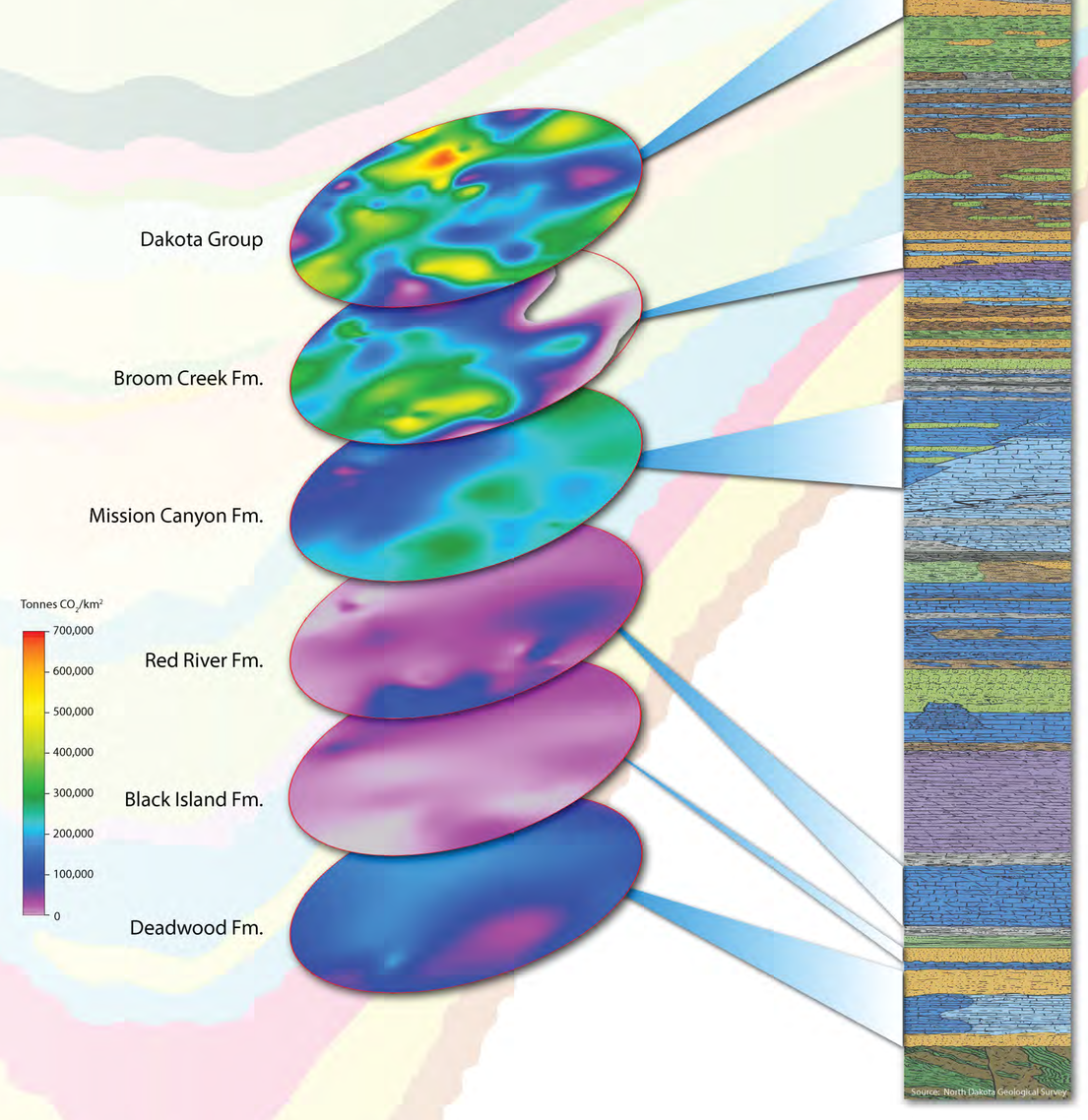
Where: G_{CO2} = Total mass of the CO_2 that could potentially be stored (tonnes)
Pore Volume = Total effective pore space in each horizon (m^3)
ρ_{CO2} = Density of CO_2 under reservoir temperature and pressure (kg/m^3)
E = Efficiency factor representing the fractional amount of pore space contacted by injected CO_2 (range 0.04–0.01)

An efficiency factor (E) of 0.03 was used for the following reasons:
- In the DOE methodology for calculating storage capacity, there are seven variables used to calculate E, and the first three deal with the "effective pore volume" of the entire basin or region.
- By only selecting the intervals that are amenable to CO_2 storage and determining the aerial extent, injectable thickness, and effective porosity of these formations, the potential range of E was changed to 0.03 to 0.34.
- By using an E = 0.03, the most conservative estimate for regional CO_2 storage was calculated for the Washburn Study Area. It is worth noting that a more optimistic estimate of the storage capacity could be as much as an order of magnitude higher.

Group or Formation	Formation or Member	Pore Volume (billion m^3) High	Mid	Low	CO_2 Density kg/m^3	CO_2 Capacity (Gtonnes) High	Mid	Low
Dakota	Newcastle	5.9	4.3	2.9	754	0.13	0.10	0.07
	Inyan Kara	222.5	177.0	152.9	756	5.04	4.01	3.46
	Total Dakota	228.4	181.2	155.8		**5.18**	**4.11**	**3.53**
Minnelusa	**Broom Creek**	124.8	102.2	82.4	766	**2.86**	**2.34**	**1.89**
Mission Canyon	Midale	27.3	23.2	19.6	769	0.63	0.54	0.45
	State A	5.3	4.4	3.4	769	0.12	0.10	0.08
	Frobisher	72.4	59.3	48.0	769	1.67	1.37	1.12
	Tilston	60.0	54.8	42.9	770	1.60	1.27	0.99
	Total M C	165.0	141.7	113.9		**4.02**	**3.28**	**2.64**
Red River	Red River B	10.1	5.5	2.6	778	0.24	0.13	0.06
	Red River C	32.5	19.3	10.3	778	0.76	0.45	0.24
	Total Red River	42.6	24.7	12.9		**1.00**	**0.59**	**0.30**
Winnipeg	**Black Island**	28.7	21.7	16.1	783	**0.67**	**0.51**	**0.38**
Deadwood	**Deadwood**	156.4	102.1	64.2	782	**3.67**	**2.40**	**1.51**
Washburn Total		**745.9**	**573.6**	**445.3**		**17.4**	**13.2**	**10.2**

High-, mid-, and low-case storage capacity estimates based on high-, mid-, and low-case pore volumes for target formations in the Washburn study area. An efficiency factor of 0.03 was used in each case.





Conclusions

By using publicly available well file information, the PCOR Partnership was able to use a map-based approach to develop petrophysical models of several stacked saline aquifer systems in the Washburn area of North Dakota. The petrophysical models provided the basis for estimating CO_2 storage capacity of 11 potential target injection intervals in seven different formations within four distinct regional aquifer systems as classified by the U.S. Geological Survey Groundwater Atlas. The total CO_2 storage capacity in the evaluated formations in the Washburn area has been estimated to range from approximately 10 billion tonnes to nearly 20 billions tonnes.