

## Exploring Carbon Storage Frontiers: Insights from Legacy Exploration Data on the Scotian Shelf

Natasha M. MacAdam<sup>1</sup>, F.W.(Bill) Richards,<sup>1,2</sup> and Helen Cen<sup>1</sup>

<sup>1</sup>Nova Scotia Department of Natural Resources and Renewables

<sup>2</sup>Dalhousie University

### Summary

Nova Scotia boasts a rich history of offshore hydrocarbon exploration dating back to the 1960s, with the Sable Delta sands and Abenaki Bank carbonates hosting numerous reservoirs and saline aquifers. In response to the evolving energy landscape, carbon storage within these formations is now considered, aligning with a strategic shift toward a diversified and carbon-neutral portfolio. Leveraging expertise from offshore oil and gas, particularly in subsea geology and geophysical assessments, this knowledge directly informs the planning and execution of Carbon Capture and Storage (CCS) projects. The Nova Scotia Department of Natural Resources and Renewables (NRR) has conducted a comprehensive study on CCS potential across the Scotian Shelf, utilizing over 50 years of legacy seismic and geotechnical data from exploration efforts.

The Scotian Shelf has been identified as highly prospective for Geological Carbon Storage (GCS) since the early 2000s (Bachu, 2003; Bradshaw and Dance, 2005; IPCC Special Report, 2005) and this is one of multiple transitional energy opportunities in the so-called “energy corridor” (Dusseault and Wach, 2020) that extends into Maritime Canada from the NE USA.

The post-rift section of the Scotian Shelf forms a seaward-dipping and thickening monoclinical wedge, comprising a high net-to-gross Mesozoic wedge with an overlying Cenozoic layer rich in mud and marl, up to 1500m thick and thinning northwestward toward the coast. This regional Cenozoic section provides the ultimate top seal for GCS in Mesozoic deep saline aquifers in the Sable area, specifically the underlying Cretaceous and Jurassic section which feature extensive hydrostatic deep saline aquifers, particularly in the Kimmeridgian-Cenomanian Sable Island Delta, which interfingered with and dominated the underlying Bajocian-Berriasian Abenaki Carbonate Bank (e.g., Wade and Maclean, 1990). Within the Mesozoic aquifers, numerous inter-formational and intra-formational seals, specifically the O Marker limestones, Naskapi Shale, Sable Shale and Dawson Canyon Shale, are of varying extent and continuity. Together with the topseal, they force the modeled plume laterally, promoting residual CO<sub>2</sub> trapping at its trailing edge.

Our priority lies in the inboard, updip area, covering approximately 190 x 130 km. This region showcases optimal conditions for GCS within the deep saline aquifers/reservoirs of the Sable Island Delta, as detailed in studies by Wade and MacLean (1990) and Cant (1991). The selection criteria encompass depth, thickness, quality, hydrostatic pressures, and proximity to the shore. Notably, this region is positioned updip of the shelf-margin-delta rollover-anticline play, which historically has been the focal point for proven hydrocarbon resources along the margin. However, exploration activity in this area has been sparse, particularly northwards, with only three wells in the updip half and limited legacy 2D seismic data, in stark contrast to the extensive 3D seismic coverage and drilling in the more productive downdip area (e.g. Smith et al., 2014).

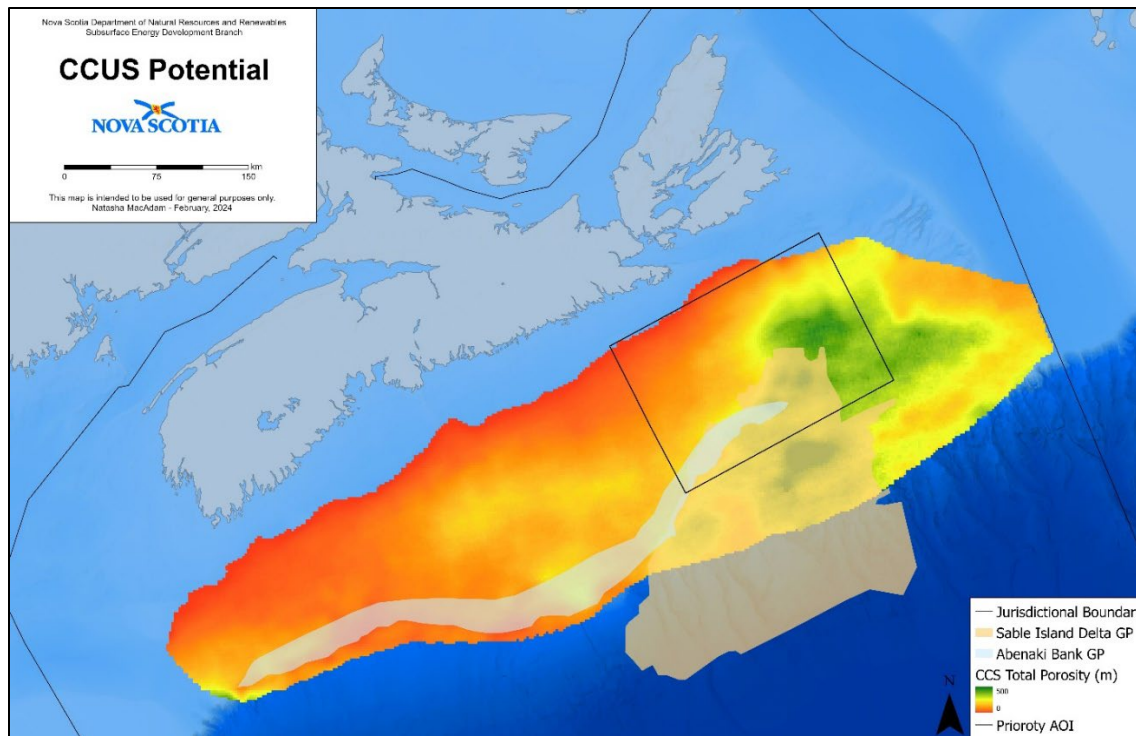


Figure 1: Modeled storage potential (porosity meters) and area of interest. Sable Island Delta modified from Kendall and Deptuck (2012), Abenaki Bank from Kidston et al. (2007) and Erosional edge of Jurassic from Cant (1991).

## Method and Results

The NRR completed its first Scotian Shelf Geological Carbon Storage study in 2022, with the investigations based on shelf-wide geocellular pore volume models. These models used storage efficiency factors ranging from 1% to 5% and varying depth and area constraints to facilitate the calculation of storage capacities. The resulting numbers are consistent with independent studies conducted at Dalhousie University and the EAGE's MINUS CO<sub>2</sub> Challenge in 2021/2022 (Chakraborty et al., 2022). Since then, the widely quoted storage efficiencies of 1-8% (in CCS atlases) have been challenged on the basis of pressure maintenance below topseal fracture pressures. More recently, efficiencies of 0.3 to 1% are thought to be more realistic at the substantial injection rates and pressures required to meet 2DS 2050 targets in the 5-10 Gtpa range (Thibeau and Mucha, 2011).

In 2010, Pothier, Wach, and Zentilli provided qualitative one-line descriptions of suitable seal-reservoir pairs of the basins and sub-basins within the Maritimes and Scotian Basins (Magdalen, Cumberland, Fundy, Sydney, Sable, Orpheus, Abenaki). Subsequently, in 2019, O'Connor et al. conducted sub-regional dynamic modeling of Geological Carbon Storage (GCS) on the Scotian Shelf. This was further augmented by static shelf-wide geocellular modeling studies in 2021/22, utilizing methodologies inspired by published CO<sub>2</sub> atlases in Norway, the USA, and the UK (NPD, 2019; Vidas et al., 2012; Bentham et al., 2014).

Utilizing a representative well dataset, including sonic porosities and Vshale cutoffs, within Schlumberger Petrel software, effective pore volume models were constructed. Storage efficiency

factors ranging from 1% to 3-5% are applied over varying depth intervals and areas to compute storage capacity. Results consistently demonstrate world-class GCS potential on the Scotian Shelf, with estimated capacities ranging from tens to hundreds of gigatons (Gt) of supercritical CO<sub>2</sub> (scCO<sub>2</sub>), and potential commercial projects could span hundreds or thousands of injection wells, each capable of accepting 0.5 to 1.0 million tons (Mt) of scCO<sub>2</sub> per year for up to three decades.

Comparatively, these findings align with similar studies in the UK and Norwegian North Sea and Gulf of Mexico regions but contrast results of a study of the northeastern USA shelf, which extends into the Georges Bank Basin, Long Island Platform, and Baltimore Canyon Trough. Though the geologic models were similar, the modeling utilized higher storage efficiencies and less stringent depth limits and V<sub>shale</sub> and porosity cutoffs, yielding roughly double the storage capacity. Methodological uncertainties in GCS assessments are acknowledged, particularly concerning high-side estimations. Additionally, pertinent analyses of carbon capture and transport costs in the northeastern and midwestern USA offer insights relevant to both the northeastern USA and the Scotian Margin (Schmelz et al., 2020).

The potential for GCS in the shelf's deep saline aquifers far surpasses that of the depleted oil and gas fields or fields using scCO<sub>2</sub> for miscible floods. This is primarily because conventional large-scale structural or stratigraphic trapping isn't necessary. This is evident on the Scotian Shelf, where GCS potential in depleted fields is minimal compared to more productive basins (Rizk et al., 2022). The efficacy of GCS in "open" unstructured deep saline aquifers is intricate and not immediately apparent beyond small-scale trapping mechanisms. Residual trapping, facilitated by scCO<sub>2</sub> displacing water and subsequently forming globules, along with dissolution trapping, contributes to significant scCO<sub>2</sub> saturation levels over time. Ultimately, mineralogical trapping solidifies scCO<sub>2</sub>, ensuring long-term storage efficacy (Gershenson et al., 2014; Bennion and Bachu, 2008).

## Results, Observations, Conclusions

Collectively, these studies underscore the world-class CCS potential of the Scotian Shelf, with estimates ranging from tens of gigatons (Gt) of supercritical CO<sub>2</sub> (scCO<sub>2</sub>) to a maximum of 1 teraton (Tt) scCO<sub>2</sub>, with a most likely range of 100-200 Gt scCO<sub>2</sub>. The deep saline aquifers found on the Scotian Shelf bear resemblance to the Utsira Formation above the Sleipner Field in Norway, where the technical feasibility of offshore CCS has been demonstrated, alongside seismic monitoring efforts dating back to 1996 (e.g., NPD, 2019).

Further technical work on GCS in the Sable Subbasin should focus on dynamic modeling, investigating pressure build-up relative to seal capacity at injection wells, potential for salt precipitation, and modeling the potential for preferential updip migration in fluvio-deltaic and estuarine channels that are observed on existing downdip 3D surveys. From a commercial perspective, regulatory adjustments are necessary for licensing acreage and international transport of scCO<sub>2</sub>.

## References

Chakraborty, A., Barbosa, M.R.S, Rizk, A.M.R., Watts, K., Richards, F.W. and Wach, G. 2022. Minus CO<sub>2</sub> Challenge 2021/2022 – Student teams evaluate potential world-class carbon storage capacity offshore Nova Scotia, Eastern Canada. First Break, Vol 30.

- Bachu, S. 2003. Screening and ranking of sedimentary basins for sequestration of CO<sub>2</sub> in geological media in response to climate change. *Environmental Geology*, 44, 277-289.
- Bennion, D. B. and Bachu, S. 2008. Drainage and Imbibition Relative Permeability Relationships for Supercritical CO<sub>2</sub>/Brine and H<sub>2</sub>S/Brine Systems in Intergranular Sandstone, Carbonate, Shale, and Anhydrite Rocks. SPE 99326.
- Bentham, M., Mallows, T., Lowndes, J. and Green, A. 2014. CO<sub>2</sub>STORage evaluation database (CO<sub>2</sub>Stored). The UK's online storage atlas. *Energy Procedia*, 63, 5103–5113.
- Bradshaw, J. and Dance, T. 2005. Mapping geological storage prospectively of CO<sub>2</sub> for the world's sedimentary basins and regional source to sink matching. In *Greenhouse Gas Control Technologies*, 7, 583-591.
- Cant, D. 1991. East Coast Basin Atlas Series: Scotian Shelf; Atlantic Geoscience Centre, Geological Survey of Canada.
- Dusseault, M.B. and Wach, G.D. 2020. Saltwire. Greening the Maritime grid — let's lead world in energy transition. Available online from: <https://www.saltwire.com/nova-scotia/opinion/maurice-b-dusseault-grant-wach-greening-the-maritime-grid-lets-lead-world-in-energy-transition-489931/>
- Gershenzon, N. I., Soltanian, M., Ritzi R.W. Dominic, D.F., 2014. Influence of small-scale heterogeneity on CO<sub>2</sub> trapping processes in deep saline aquifers. *Energy Procedia* 59 (2014) 166 – 173
- IPCC. 2005. Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp.
- NPD. Norwegian Petroleum Directorate. CO<sub>2</sub> storage Atlas. Norwegian North Sea. Available from: <https://www.npd.no/en/facts/publications/co2-atlases/co2-storage-atlas-norwegian-north-sea/>
- O'Connor, D., Richards, B., Angel, M. and Wach, G. 2019. Dynamic Modeling of Buoyant Fluid Flow in Rollover Anticlines, Offshore Nova Scotia, Canada: Implications for Hydrocarbon Distribution, Potential Carbon Capture and Storage (CCS) and Future Activity in the Sable Subbasin. Energy3 Canada's Energy Conference, Halifax, Nova Scotia. October 16-18, 2019.
- Pothier, H.D., Wach, G.D. and Zentilli, M. 2010. Reservoir and Seal Pairs: Carbon sequestration in Atlantic Canada, GeoCanada 2010, Program with Abstracts, May 10-14, 2010, Calgary, Canada.
- Schmelz, W.J., Hochman, G., Miller K.G. 2020. Total cost of carbon capture and storage implemented at a regional scale: northeastern and midwestern United States. Available online from: <https://royalsocietypublishing.org/doi/10.1098/rsfs.2019.0065>
- Smith, B.M, et al. 2014. Resource Assessment of Undeveloped Significant Discoveries on the Scotian Shelf. Nova Scotia. Available online from: <https://www.cnsopb.ns.ca/resource-library/geoscience-reports>.
- Thibeau, S. and Mucha, V. 2011. Have We Overstimulated Saline Aquifer CO<sub>2</sub> Storage Capacities? *Oil & Gas Science and Technology – Rev. IFP Energies nouvelles*, Vol. 66 (2011), No. 1, pp. 81-92
- Vidas, H. et al. 2012. Analysis of the Costs and Benefits of CO<sub>2</sub> Sequestration on the U.S. Outer Continental Shelf. Prepared Under BOEM Contract M10PC00117 by ICF International. Available from: [https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Oil\\_and\\_Gas\\_Energy\\_Program/Energy\\_Economics/External\\_Studies/OCS%20Sequestration%20Report.pdf](https://www.boem.gov/sites/default/files/uploadedFiles/BOEM/Oil_and_Gas_Energy_Program/Energy_Economics/External_Studies/OCS%20Sequestration%20Report.pdf)
- Wade, J.A., and MacLean, B.C. 1990. *Geology of the Continental Margin of Eastern Canada*. Edited by M.J.Keen and G.L.Williams. Geological Society of America *Geology of North America Series*. pp. 169-238.