Ontario has Limited Potential for CO_2 Sequestration

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Our Argument

We wish to make a single, explicit argument. We believe that the revisions to legislation and regulations being considered by MNDNRF ('the Ministry'), should assume that the sedimentary rocks beneath South Western (SW) Ontario have limited accessible pore volumes to store CO_2 emissions from the industries in SW Ontario (steel, cement & lime, Lambton County chemical industries and all oil refineries).

Despite the estimates of Shafeen *et al.*[1] that the estimated storage capacity of the Cambrian-age formations beneath Lake Erie is 442 Mt CO_2, it appears that this is based on several relatively favourable parameter choices that have not been confirmed in the field. The storage capacity is likely much less than 442 Mt CO_2. This means that the annual industrial emissions of about 20 Mt CO_2 in SW Ontario will cause competition for storage volume and that the province will have to manage storage rights as is now occurring in Alberta. It should be remembered that the provincial working group[2] on carbon sequestration adopted the Shafeen estimate and the concept of CO_2 injection in the middle of Lake Erie.

Furthermore, we believe that projects that enhance oil, gas or formation water recovery <u>should be permitted</u> with appropriate regulations. These regulations could tax any additional oil and gas produced as a result of carbon sequestration without inhibiting the use the pore space of depleted oil and gas fields; i.e., "*we should not throw the baby out with the bathwater*". Taking these potential assets off the table seems counter-productive, given the limited pore volumes that might be exploited for sequestration.

In addition, in depleted oil and gas fields beneath SW Ontario that may be re-purposed for CO_2 sequestration, new regulations could prevent release of previously injected CO_2. At any production well, should there be breakthrough of CO_2 which had been injected nearby as part of a CCS (carbon capture & storage) project, the production well would be plugged and abandoned once some stipulated threshold CO_2 emission rate was measured. This would keep the captured CO_2 in storage.

In this way, enhanced oil and gas production would not be prohibited but discouraged through taxation and thereby regulated to allow industry to access the pore space it needs for CO_2 sequestration beneath

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[1] Shafeen, A., Croiset, E., Douglas, P.L., Chatzis, I. 2004. CO_2 sequestration in Ontario, Canada. Part I: storage evaluation of potential reservoirs. *Energy Conversion and Management* **45**: 2645–2659 | https://doi.org/10.1016/j.enconman.2003.12.003

[2] Carter, T., Gunter, W., Lazorek, M. and Craig, R., 2007. *Geological sequestration of carbon dioxide: a technology review and analysis of opportunities in Ontario.* Climate Change Research Report-Ontario Forest Research Institute, (CCRR-07). Ontario Ministry of Natural Resources, Sault Ste. Marie, Ontario.

SW Ontario. We submit that these two provisions – taxation of enhanced production and wellhead regulation of CO_2 emissions – be included in the revision of the OGSR Act.

What likelihood is there of 442 Mt CO_2 storage beneath SW Ontario?

There are several factors and physical processes that take place during CO_2 injection that may limit the ultimate amount of pore volume that can be accessed:

1. Small pores in shales, limestones and sandstones cannot be invaded by CO_2 to displace the formation water because of capillary effects that impede the process (capillary "entry pressure", or "capillary blockage").
2. Barriers to CO_2 injection exist; for example, CO_2 cannot invade a porous and permeable stratum if the stratum is isolated by low-permeability shales and carbonates.
3. Heterogeneity, that is, large differences in permeability among different strata, tends to reduce displacement efficiency; the injected fluids under pressure tend to "channel" into the high permeability zones, and bypass the lower permeability zones.
4. Viscous fingering takes place when a low-viscosity fluid (super-critical CO_2) is "pushed" under pressure into a porous medium that is saturated with a higher viscosity pore fluid (water or brine). The low-viscosity fluid "fingers" into the porous medium instead of forming a uniform and stable displacement front. This reduces overall access to the available pore volume.
5. Gravity segregation can take place, so that supercritical CO_2 injected at the base of a porous stratum migrates quickly to the top of the stratum because its density (0.80 g/cm^3) is far lower than the density of the pore fluid (NaCl brine with a density of 1.15 – 1.20 g/cm^3). This restricts access to the pore volumes in the lower part of the stratum.
6. If the rock mass at depth is naturally fractured and these fractures are sufficiently open to serve as pathways for the injected CO_2, instead of lateral flow and displacement, the injected CO_2 may move upward because of buoyancy, degrading the positive aspects of lateral displacement.
7. Salt precipitation can be triggered in saturated brines when the pH changes or the solute chemistry changes (some CO_2 becomes dissolved in the pore water); precipitated solids can block pore throats and restrict access to the invading CO_2, reducing displacement efficiency[3].
8. Finally, the pores are saturated with brine (except in depleted oil and gas fields); if the brine is displaced by injection of CO_2, it must go somewhere. If its broad areal dissipation is inhibited, regional pressurization[4] will occur, and this will reduce the injectivity of the formation to CO_2.

Each of these can restrict access to the available pore volume, and understanding their aggregate impact is vital to project planning. Some might be "managed", such as deliberate CO_2 injection high in the zone

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[3] According to Don White, GSC Ottawa, salt plugging has been observed at the base of the injection well at the Aquistore pilot project in southern Saskatchewan. This has caused 90% of injected CO_2 to enter an upper zone of the Cambrian Fm. that comprises only 10% of the injection interval.

[4] The concept of sequestration of millions of tonnes of CO_2 beneath Lake Erie would eventually cause regional pressurization beneath adjacent US states with a possibility of causing brine discharge from legacy wells in New York state, Pennsylvania and Ohio. Consequently, initial sequestration will likely occur on-shore beneath SW Ontario. Therefore, the available pore space under Crown land beneath Lake Erie may not be usable because of regional pressurization and the liability issues arising in the adjacent American states.

so that there is stabilized downward displacement. However, these processes tend to restrict the efficacy of pore fluid displacement, reducing the pore volumes available for sequestration.

Therefore, it should be appreciated by the Ministry that only a small fraction of the pore volume in the subsurface has proven accessible in CO_2 sequestration projects. While it is possible to occupy 10% of the pore volume with CO_2 during lab experiments, the percentage of the pore space being occupied during initial injection, the storage efficiency coefficient, is likely to be of the order of 2-3% at the aquifer scale. The means that – at least initially before reservoir engineering operations might improve storage – only 2-3% of the pore volume (not 10%) will be accessible[5].

While these processes are amenable to mathematical modeling and prediction, it is essential that the subsurface is adequately characterized. There is no alternative to the drilling of evaluation wells, obtaining core samples, running a suite of suitable geophysical logs, performing in situ injectivity tests, executing a series of laboratory tests, and combining all of these into a process called "stochastic modeling", whereby their impacts can be estimated.

The Ministry must recognize the potential impacts of these physical processes, even if they are difficult to quantify at present. They will reduce the pore volume available for CO_2 sequestration. For the above reasons, it is necessary that any changes to the regulations do not inhibit using the depleted oil and gas reservoirs of SW Ontario for CO_2 sequestration.

[5] Bachu, S., 2015. Review of CO_2 storage efficiency in deep saline aquifers. *International Journal of Greenhouse Gas Control*, *40*, pp.188-202.