Nova Scotia's Carbon Sinks and 2050 Net-Zero Scenarios

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Executive summary

In 2019, the Nova Scotia legislature passed *An Act to Achieve Environmental Goals and Sustainable Prosperity*, and in 2021 the *Environmental Goals and Climate Change Reduction Act* was introduced, both of which set an emissions target for 2030 (at least 53% below the levels that were emitted in 2005) and stated that the province would reach net-zero emissions by 2050 (by balancing greenhouse gas emissions with greenhouse gas removals and other offsetting measures).

The 2030 target can be achieved if the Atlantic Loop is completed, giving the province access to power from Hydro Québec, as explained in An Analysis of the Greenhouse Gas Emissions Reduction Targets in Nova Scotia's Environmental Goals and Sustainable Prosperity Act of 2019.

Nova Scotia is not alone in its pledge to achieve net-zero by mid-century; an increasing number of other organizations and jurisdictions are doing the same thing. Net-zero requires an entity to balance its actual emissions from all emissions *sources* and any emissions *sinks* it may claim (typically a combination of changes in land use or forestry, or both, technologies for carbon capture and use or carbon capture and storage in geological structures, and emissions credits purchased in emissions trading systems):

$$Total\ Emissions = Emissions\ sources - Emissions\ sinks$$

If the $Total\ emissions$ are zero, the entity has reached net-zero, and if they are less than zero, the entity could sell the emissions as credits; however, if $Total\ emissions$ are greater than zero (i.e., the $Emissions\ sources$ exceed the $Emissions\ sinks$), the entity will need to reduce its emissions in another way, such as purchasing emissions credits.

This report examines Nova Scotia's existing emissions sinks and possible geological stores. It begins with an examination of the different types of emission sinks and the technologies for capturing and storing carbon. Natural sinks (forests, croplands, and wetlands) and carbon capture and storage technologies (direct air capture or DAC and geological structures) are reviewed, first in terms of how the process works, then the process's ability to capture carbon, and finally, the advantages and disadvantages of the process.

This is followed by a detailed analysis of Nova Scotia's natural sinks, the strength of their carbon flux, limitations on their long-term storage ability, the threats facing the sinks (such as drought, fire, or excess moisture), and the vulnerabilities of the sink to these threats. The report has found that in 2019, the province's forests and wetlands absorbed about 11.6 Mt CO_2e, while the croplands emitted about 0.15 Mt CO_2e. This is summarized in Table 1 of the report.

Table 1: Nova Scotia's 2019 carbon sinks baseline summary

Sink	Potential
Forests	9.7 Mt CO_2/y absorbed
Cropland	0.15 Mt CO_2e/y released
Wetlands	1.91 Mt CO_2e/y absorbed

The report also examines the potential for geological sequestration in the province. With the proper carbon capture and storage technology, the potential for carbon storage will be in gigatonnes (Gt) of carbon rather than megatonnes (Mt). This could be financially beneficial to the province and its development needs to be a priority

To get an understanding of the emissions reduction requirements from the province's 2019 levels, we considered three net-zero scenarios for the province in 2050 determined by the CO_2 flux strength: constant strength (the sink strength in 2050 is the same as in 2019), increasing strength (sink strength increases at different, evidence-based rates), and decreasing strength (the sink strengths decrease by 10% of the 2019 capacity per decade).

As Figure 3 from the report shows, in the increasing flux strength scenario, the total allowable emissions sources in 2050 would be about 13.9 Mt CO_2e from natural sinks (wetlands: -2.1 Mt, croplands: -0.2 Mt, and forests: -11.6 Mt). Since the province's total emissions in 2019 were about 16.2 Mt, the province would need to reduce its emissions by about -2.3 Mt. If the province meets its 2030 target of 10.9 Mt, it will have surpassed this by three megatonnes, making it net negative, meaning the negative emissions could be sold.

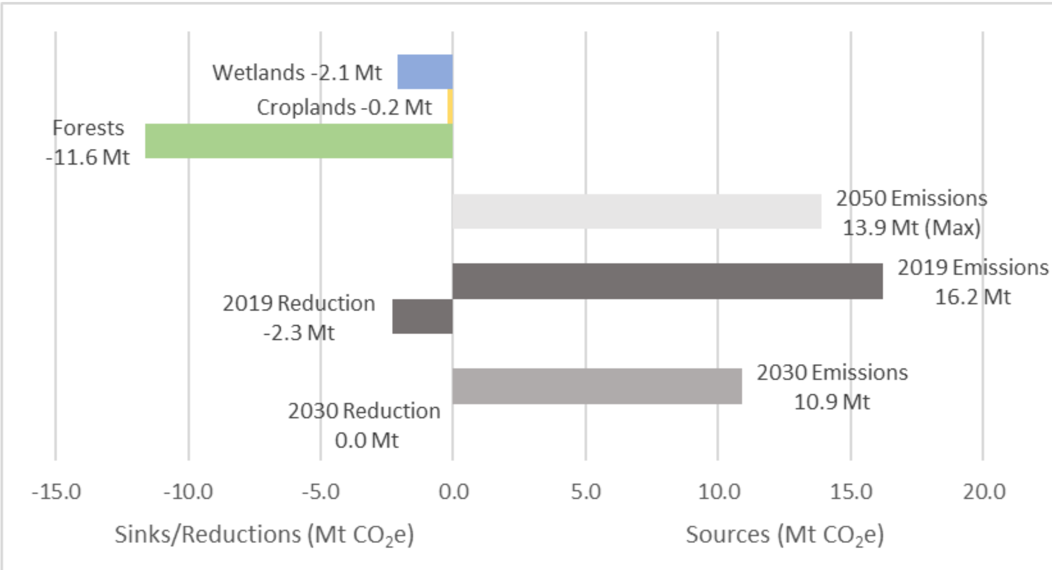

Figure 3: Emissions sinks and sources for the increasing sinks scenario

The three flux-strength scenarios were chosen to give an understanding of the size of the reduction the province would need to attain in 2050, depending on the state of the sinks. In the case of constant and increasing flux strengths, the province would have achieved net-zero by 2030 if the province's 2030 emissions target is met. However, even if the target is met, if the province's sinks weaken by 10% (something possible if extreme climate events become more likely and increase the threats to the sinks), the province will need to halve its 2019 emissions, requiring an additional three megatonnes of reduction from 2030 levels). The results are summarized in Table 2 of the report.

Table 2: Key results from the net-zero emissions scenarios to 2050

Sink Scenario	Projected total sink flux (Mt CO_2e)	Maximum allowable anthropogenic emissions (Mt CO_2e)	Required changes in anthropogenic emissions			
			2019-2050		2030-2050	
			Mt CO_2e	Percent	Mt CO_2e	Percent
Constant	-11.5	11.5	-4.8	-29%	0.0	0%
Increasing	-14.0	14.0	-2.3	-14%	0.0	0%
Decreasing	-7.9	7.9	-8.3	-51%	-3.0	-27%

The report concludes with a summary of the research.

Recommendations

The report makes seven recommendations:

1. *Conduct a complete and accurate biannual assessment of the province's greenhouse gas (GHG) fluxes of the biological sinks (such as forests, croplands, wetlands, and seagrass meadows)*.
2. *Measure, report, and verify the carbon-related impacts of the threats to Nova Scotia's biological sinks and conduct an economic and carbon flux assessment of the potential solutions to reducing the threats and vulnerabilities of the sinks*.
3. *Interim emissions reduction targets should be established*.
4. *Efforts should continually be made to reduce emissions beyond 2050*.
5. *Introduce tax incentives for carbon captured in natural sinks to promote the maintenance of our efforts to increase their carbon capture ability*.
6. *If the purchase of negative emissions is necessary, it must be sustainable*.
7. *Since biological sinks are at risk from extreme climate events, the province must research and if possible, develop its geological storage capacity*.

Final thought

As in our report on our report on the province's 2020, 2030, and 2050 emissions targets, we conclude with the question, if the province is unable to achieve net-zero by 2050, who pays, other than future generations?

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Introduction

In December 2015, world leaders agreed to the Paris Agreement. By November 2016, sufficient countries had ratified the agreement to bring it into non-binding force. Central to the Agreement is Article 2.1(a) which states:

> *Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change.*

In 2020, the average global temperature was approximately 1.2°C above pre-industrial levels. According to the Intergovernmental Panel on Climate Change (IPCC) models, in order to limit global warming to 1.5°C or have minimal increase over this temperature, the world must have reduced net anthropogenic CO_2 emissions to roughly 55% of 2010 levels by 2030 and achieved net-zero CO_2 emissions by 2050.

To reach net-zero emissions, a jurisdiction must balance its actual emissions from all emissions *sources* and any emissions *sinks* it may claim (typically a combination of changes in land use or forestry, or both, technologies for carbon capture and use or carbon capture and storage in geological structures, and emissions credits purchased in emissions trading systems):

$$Total\ Emissions = Emissions\ sources - Emissions\ sinks$$

It is important to note that reaching net-zero emissions does not necessarily require that all anthropogenic emissions are eliminated, it just means that the same volume of emissions that are released by a source are absorbed by sinks.

To reach net-zero emissions by 2050, CO_2 emissions must be both reduced (through the use of zero-emissions energy sources and potentially through energy efficiency measures) and removed (using CO_2 sinks).

In late 2020, Canada announced that it plans to achieve a 30% reduction in emissions by 2030 and net-zero by 2050.

Nova Scotia had legislated a 2050 net-zero target in late 2019 when the Legislature passed *An Act to Achieve Environmental Goals and Sustainable Prosperity*. Following on from this in October 2021, Nova Scotia's Minister of the Environment and Climate Change introduced the *Environmental Goals and Climate Change Reduction Act* to the Nova Scotia legislature. Clause 6 of the proposed legislation states:

> *The Government's targets for greenhouse gas emissions reductions are*

> *(a) by 2030, to be at least 53% below the levels that were emitted in 2005; and*
>
> *(b) by 2050, to be net zero, by balancing greenhouse gas emissions with greenhouse gas removals and other offsetting measures.*

Based on the 2030 goal in the Act, 2030 emissions should be at most 10.9 Mt CO_2e.

The Act is non-specific with respect to its 2050 target, allowing regulations to be established as required. However, given the importance of reaching net-zero by 2050 or sooner, the province should develop legislation that addresses how net-zero will be achieved, both through emissions reduction and sink protection, enhancement, and development.

This report takes a first step in addressing how Nova Scotia can achieve net-zero by examining the province's emission sinks.

The report evaluates Nova Scotia's current net emissions and estimates future net emissions. This is done through an analysis of Nova Scotia's existing carbon sinks and examining three different 2050 sink scenarios. The maximum allowable anthropogenic emissions to meet the net-zero target will be determined based on the projections of the sinks, providing clarity for the legislation and what is possible.

The report first reviews carbon sinks, their processes and, in some cases, technologies. Following this, a 2019 Nova Scotian baseline of known carbon sinks and the province's geological sequestration strength is presented along with the threats and vulnerabilites to those sinks and potential solutions to reducing the impacts of the threats. Once the baseline is established, the sinks will be projected under different scenarios to determine the maximum allowable anthropogenic emissions that still meet the province's climate targets. Finally, recommendations that were produced as a result of this research will be provided.

Sections of this report were used in a submission to the Province of Nova Scotia as part of public consultations regarding the Sustainable Development Goals Act.[1]

[1] The report, "An Analysis of the Greenhouse Gas Emissions Reduction Targets in Nova Scotia's Environmental Goals and Sustainable Prosperity Act of 2019", was submitted by Larry Hughes and Mark McCoy on 26 July 2021.

Review of Carbon Sinks

A sink is "any process, activity or mechanism which removes a greenhouse gas from the atmosphere" . Carbon dioxide sinks (also referred to as carbon sinks in this report) are sinks that remove CO_2. There are two kinds of carbon sinks: natural and artificial. Carbon sinks require the sequestration of the CO_2 they capture for an acceptable amount of time if they are to be considered for mitigating climate change. Ideally, the CO_2 would be sequestered permanently or for thousands of years. In this report, a natural sink is a carbon sink that captures CO_2 using processes that occur naturally on Earth.

If a sink is enhanced by humans, but its main process is naturally occurring, this report will consider the sink as natural. In this report, an artificial sink is a carbon sink that captures CO_2 using methods developed by humans. There are three natural sinks that are examined in this report which are relevant to Nova Scotia: forests, croplands, and wetlands. The artificial sink that is examined in this report is direct air capture in combination with carbon sequestration in geological formations. Finally, some other carbon sinks that were not the focus of this report will also be discussed. All monetary figures presented in this section are in 2019 USD.

Forests, Croplands, and Wetlands

The land sink was the largest carbon sink available globally in 2019. This subsection of the report will examine how forests, croplands, and wetlands work as carbon sinks, their ability to capture and sequester carbon, and the advantages and disadvantages to them working as carbon sinks.

How it Works

Various forms of vegetation absorb carbon dioxide from the atmosphere through direct contact. Aquatic plants obtain CO_2 through contact with CO_2 in water, air, or both (if not fully submerged). Plants use photosynthesis to uptake CO_2 and some is released back to the atmosphere through respiration. The retained CO_2 is eventually converted into materials for the structural material of the plant, such as bark or leaves; this is how carbon is stored in plants, and when vegetation dies, it decomposes and begins to release the carbon that it stored. When plant products burn, such as in wildfires or intentional burning. The soil that vegetation is in can also contain a significant amount of the carbon in a vegetated area in the form of soil organic matter (44% of forest carbon is stored in the live vegetation and 45% of forest carbon is stored in the form of soil organic matter).

Three major areas of vegetation for carbon sinks are forests, croplands, and wetlands. There are various proposals on how best to capture carbon by managing these three areas of vegetation, such as coastal blue carbon and terrestrial carbon removal and sequestration (TCRS).

Coastal blue carbon is a carbon capture and sequestration (CCS) method that involves tidal wetlands and seagrasses capturing carbon and storing it in the structural material of the plants as well as burying plant organic carbon in their soils. Tidal wetlands can expand both along the sea floor and vertically (they must expand vertically at the same or greater rate of rising sea levels), potentially increasing the amount of carbon they can capture and sequester. Most of the organic carbon collected in tidal wetlands is a product of the wetlands themselves. While coastal blue carbon is a natural process, with human involvement, its ability to capture and store carbon can be improved through measures such as restoring coastal wetlands; improving the carbon storage of coastal areas by burying high-carbon materials that were not made in the coastal ecosystems in them; managing coastal wetlands in such a way that allows their area to increase with rising sea levels and that increases or maintains the rate at which organic carbon is buried over time; and preventing wetlands from being drained.

TCRS is a CCS method that involves land-based plants capturing CO_2 and storing it in the structural materials of the plants as well as storing carbon in the soil. Increasing the amount of carbon stored in forests requires planting and preserving more carbon-dense trees, or protecting more trees from being lost (through natural death, harvesting, or fire), or both. Increasing the amount of carbon stored in soil requires adding more plant matter to the soil, decreasing the decomposition rate of soil organic matter into CO_2, or both. As with coastal blue carbon, TCRS is a natural process, but humans can improve its ability to capture and store carbon. Various practices of TCRS can be divided into the types of the land that they are used on, such as forests, grasslands, and croplands. Some forestry practices include avoiding deforestation; afforestation and reforestation; management of forests to restore and maintain their health, and increase their growth; increasing the time before harvest of trees to maintain the carbon capture ability of the trees; and preserving more harvested wood and wood products (a developing practice which may improve carbon/CO_2 removal). These practices have the potential to increase carbon capture and reduce CO_2 emissions associated with wood products. In terms of grassland/cropland practices that help remove and reduce CO_2 emissions, they can be divided into two categories: conventional (already established) and frontier (developing). Some conventional grassland/cropland practices are including trees in agricultural land and management techniques such as not tilling the ground as frequently or at all before planting crops (the CCS ability of tilling practices varies based on the climate and soil characteristics). Some frontier grassland/cropland practices include: adding biochar (solid carbon by-product resulting from the biomass-to-fuel process) to soil to store carbon and increase crop productivity; placing high-carbon surface soils deeper underground and low-carbon soils near the surface to allow more carbon to be absorbed and potentially increase the amount of time carbon remains in the soil; and modifying current agricultural plants to increase the amount of carbon sent to the plant roots.

Carbon Capture Ability

The global land sink captured an estimated 11.50 GtCO_2 in 2019, which is approximately 27% of the global CO_2 emissions, while land-use changes were responsible for 6.60 Gt of global CO_2 emissions. The potential annual global CCS ability and CO_2 capacity of coastal blue carbon with the technology and knowledge in 2019 was 0.13-0.80 GtCO_2/y and 8-65 GtCO_2. The potential annual CCS ability and CO_2 capacity of TCRS practices with the technology and knowledge in 2019 was 5.5-12 GtCO_2/y globally and 660-1215 GtCO_2 globally, respectively. There are significant variations in the carbon absorbed by the land between years, with variation reaching as high as 4.62 GtCO_2/y in the previous decade. This variation is connected to changes in temperatures and stored water in tropical regions, and can result from weather events.

There are multiple factors that affect the carbon capture ability of vegetation and the land sink. The amount of carbon absorbed by vegetation on the land is believed to increase when higher atmospheric CO_2 concentrations increase photosynthesis, causing more plant growth and thus, more carbon to be stored, and when forests reclaim former agricultural land. While increased CO_2 allows for plants to grow more, plants are still limited by other materials that may not be as plentiful to grow. It has been recently found that globally, the effectiveness of 86% of terrestrial ecosystems at capturing CO_2 is decreasing. The vegetation sink can be divided into two categories: vegetation that quickly acts to reach equilibrium with the CO_2 in the atmosphere and the vegetation that is not in equilibrium with the CO_2 in the atmosphere. Types of vegetation that fall into the first category are leaves and small roots, whereas those that fall into the second category are live wood and long-lasting, land-based dead organic matter. Should the CO_2 concentration in the atmosphere decrease over a century, the land is predicted to remain a carbon sink due to the absorption of CO_2 by the vegetation that does not reach equilibrium with the atmosphere, despite the vegetation that releases CO_2 during this time. When more CO_2 is removed from the atmosphere, the effectiveness of vegetation as a carbon sink will decrease. In a business-as-usual scenario, it is predicted that the land carbon sink will become a land carbon source as a result of factors such as plants lacking resources other than CO_2 to grow and the death of forests to high temperatures and drought. The removal of the trees through methods such as harvesting, natural death, or fire affects the carbon capture ability of trees. Also, due to changes in albedo when conducting afforestation/reforestation at high latitudes, the result is an overall increase in temperature even after taking into account the temperature decrease from the emissions reduction from trees.

Advantages/Disadvantages

Some advantages to coastal wetlands are that they help to protect coasts during storms, provide homes for wildlife, and reduce the strength of waves. Coastal blue carbon practices can also reduce the flood risk to humans by reducing the population of regions that are becoming more prone to flooding. Another major disadvantage to coastal blue carbon is that there is risk that the practices used, such as shoreline modification, will ultimately harm the coastal ecosystem. Some advantages to TCRS practices are that the practices can be viewed as repairing damage done to the ecosystem, they may improve ecosystem diversity, and improve soil quality. A significant disadvantage to these practices is that there might be competition for land with other economic needs, such as food production, so what is technically possible for carbon capture may not be necessarily feasible. Another major disadvantage is that the effects of the practices can be reversed by methods such as harvesting, where the carbon that was stored gets released. One final disadvantage to some terrestrial practices is that adoption rates for some of these practices are low, preventing the effects from being realized. The estimated costs to implement the CO_2 removal practices of coastal blue carbon and TCRS span a relatively small range. The cost for coastal blue carbon burial is estimated to be \$10/t CO_2 and the cost for TCRS is estimated to range \$15 to \$100/t CO_2.

Direct Air Capture

As the name suggests, direct air capture (DAC) technology captures CO_2 from the air. While DAC is not a sink by itself, the combination of DAC with carbon sequestration in geological formations is a carbon sink. DAC has the potential to provide significant carbon capture abilities. This subsection examines how DAC works, the ability of DAC to capture carbon, and its advantages and disadvantages.

How it Works

In a DAC system, air is pulled from the atmosphere into an air contactor where CO_2 is removed from the air. DAC systems are carbon capture systems; they do not store CO_2. At present, DAC systems can capture CO_2 using liquid solvents or solid sorbents.

Carbon Engineering's DAC systems use a liquid solvent in the form of a KOH solution and capture 75% of the CO_2 passing through their DAC system. The liquid solvent DAC system uses an aqueous solution of KOH as well and can capture 75% of atmospheric CO_2 passing through the air contactor at an ambient concentration of 400 ppm. In the liquid solvent DAC system, there are five further processes, including causticizing, calcinating, slaking, clarification and filtering, and air separation of O_2, where the KOH is recovered, and high-concentration CO_2 gas is produced. The following are the reactions for the different processes:

$$2KOH_{(aq)} + CO_{2\,(g)} \rightarrow H_2O_{(g)} + K_2CO_{3\,(aq)} \text{ (Air Contactor)}$$

$$K_2CO_{3\,(aq)} + Ca(OH)_{2\,(aq)} \rightarrow 2KOH_{(aq)} + CaCO_{3\,(s)} \text{ (Causticizer)}$$

$$CaCO_{3\,(s)} \rightarrow CaO_{(s)} + CO_{2\,(g)} \text{ (Calciner)}$$

$$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2\,(aq)} \text{ (Slaker)}$$

Not only is KOH recovered through these processes, but materials for the various processes are recovered throughout the system reactions shown above.

In DAC systems that use solid sorbents, air is brought into contact with a solid, CO_2-adsorbing material which captures the CO_2 on its surface. The material is then heated, or placed in a vacuum, or both which releases the CO_2 from the material at which point it can be processed for sequestration. The CO_2-adsorbing material is then cooled to begin capturing more CO_2.

Once CO_2 is captured through either type of DAC system, it must be stored; for example, in geological formations.

Carbon Capture Ability

The carbon capture ability of DAC is mainly constrained by finances rather than technical constraints. The sequestration of the CO_2 that is captured by DAC systems does have limitations in the form of feasible geological sequestration locations and safe storage capacity. DAC systems can be constructed anywhere, but the infrastructure and resources to operate DAC systems must be in place as well, potentially limiting DAC locations. The energy that is required to run the DAC systems could be obtained from renewable and/or non-renewable sources, the use of renewables increasing the net CO_2 capture ability of the DAC system and the use of non-renewables decreasing that ability. To increase the net CO_2 capture ability of DAC systems, non-emitting energy sources should be employed.

If natural gas was used as a thermal energy source for liquid solvent DAC, the system could absorb the CO_2 produced by the combustion of the natural gas while also absorbing as much atmospheric CO_2 as possible. This reduces the volume of atmospheric CO_2 that can be captured. The employment of power sources at the location of the DAC system has the potential to be limited by land availability. If there are multiple air intake points, it is important to place them such that the air being pulled in by the air intakes at each point has an ambient concentration of CO_2, allowing for optimal carbon capture.

Advantages/Disadvantages

The major advantages of DAC are its potentially large annual CO_2 capture abilities and relatively small land usage to achieve those ends. Also, DAC allows for CO_2 product at various purities to be sold to the market. The most significant disadvantage to DAC is that it is presently an expensive technology for CO_2 removal, with average costs ranging from roughly \$90/t to \$900/t of net CO_2 captured.

The limited deployment of DAC systems has resulted in a lack of data for analyses to help policymakers understand the costs of negative emissions through DAC systems that are required to meet the climate goals of the Paris Agreement. One advantage is that it does not seem to be a lack of fundamental understanding of the technology that is slowing its uptake.

Some disadvantages of DAC include the significant reduction in local CO_2 concentrations may have a detrimental impact to local ecosystems; potential chemical emissions from solid sorbent DAC systems may harm the environment; more research needs to be conducted into water production and use in DAC; and to reach large scale CO_2 capture via DAC, a significant amount of money needs to go towards research and development. Another significant disadvantage of DAC systems is that they are not carbon sequestration technologies themselves – they need another method to store the carbon they capture to be useful. Looking past 2050, it has been recently found that DAC could decrease the costs of meeting international climate targets, but doing so would require up to 25% of worldwide energy in 2100; this is a significant potential disadvantage.

Carbon Sequestration in Geological Formations

Carbon sequestration in geological formations (CSGF) is an artificial carbon sink support method that works with bioenergy with carbon capture and sequestration (BECCS) and DAC by acting as the storage method. Here we examine how CSGF works as a carbon sink, the ability of CSGF to sequester carbon, and the advantages and disadvantages to CSGF working as a carbon sink.

How it Works

CSGF is a primary CO_2 storage method for both BECCS and DAC systems. This technology is simply a storage method for the CO_2 that other technologies capture. Captured CO_2 must first be compressed into a supercritical fluid before it can be sequestered, allowing for more CO_2 to be stored. The fluid is then pumped into an underground geological formation for long-term storage. The formation must be deep enough that the underground pressure and temperature causes the fluid to stay compressed and supercritical. The geological formations that can be used for CSGF must have porous rock that fluids can pass into and their tops must be sealed by rock that is difficult or impossible for fluids to pass through. Due to the density of supercritical CO_2 in relation to fluids that fill the rock pores, the CO_2 will rise to the top of the rock formation and be stored permanently if there are no leakage pathways; sedimentary rocks can be used for CSGF.[2] Some reservoirs for CO_2 storage include depleted oil/gas deposits and deep saline aquifers – both onshore and offshore locations. One method of CSGF injects CO_2 into oil/gas reserves to increase extraction while also storing CO_2, a process referred to as enhanced oil/gas recovery. To increase the trapping ability of CO_2 in the underground reservoirs, multiple methods can be implemented, such as CO_2 (or carbon) mineralization.

Carbon Storage Ability

By 2019, major saline aquifer CSGF projects sequestered individual amounts between 0.3 and 1.2 Mt CO_2/y. The potential global CO_2 capacity of saline aquifer CSGF given the knowledge and technology in 2019 was 5,000 to 25,000 Gt CO_2. Enhanced oil recovery projects can be carbon sinks provided that substantially more CO_2 is injected into the reservoir per barrel of oil produced.

One factor that affects the ability of CSGF to store CO_2 is the potential for leaks in the CO_2 reservoir. Leaks could be the result of cracks in the low permeable rock. If the sequestration site is not near the capture site, transportation will be required to the sequestration site, potentially resulting in CO_2 emissions (i.e., transportation on a ship burning fossil fuels). Consequently, the net CO_2 captured and sequestered could decrease. Ideally, sequestration sites would be near to the location of carbon capture to avoid transportation costs and potential emissions. It is important to note that there is a maximum sequestration rate for CO_2 in CSGF that is capped where unsafe pressure build-up in a reservoir is not reached. An important factor which limits the CO_2 sequestration capacity of CSGF is that injecting CO_2 into reservoirs can result in a build-up of pressure that may cause seismic activity or break the reservoir seal. Once stored in the reservoir, unless there is leakage, the CO_2 will remain in the reservoir for an indefinite period.

Advantages/Disadvantages

The most significant advantages of CSGF are: it has a large potential CO_2 storage capacity; there is a significant amount of research and experience with CSGF; and storage of CO_2 is permanent provided there are no leaks. Additionally, the cost of CO_2 sequestration is very low at \$7 to \$13/tCO_2. Major disadvantages of CSGF include implementation of CSGF may result in further seismic activity; leakage of the CO_2 reservoir may contaminate groundwater; it requires a significant amount of research to scale up CSGF and

[2] Professor Grant Wach, Dalhousie University, personal communication, 23 June 23, 2021

guarantee its safe and consistent application; and a sequestration site may not necessarily be near high-emissions sources. Given the use of CSGF in enhanced oil recovery, another advantage of CSGF is that the oil industry could play a role in carbon sequestration should it make sense to do so, improving their oil extraction. Another significant disadvantage to CSGF is that, depending on a country's laws, it may not be explicit who is financially liable for CO_2 reservoirs long after a sequestration project has ended; this has been a major contributor to preventing large-scale deployment of CSGF. Another barrier to scaling up CSGF is the potential issue of gaining permission to conduct CSGF under lands that are owned by potentially many people, which expends time and money.

Other Sinks

Other sinks which were not examined in relation to Nova Scotia, but which may have carbon capture potential for the province include bioenergy with carbon capture and sequestration (BECCS) and carbon mineralization. BECCS is a mix between an artificial sink and a natural sink while carbon mineralization is a sink following a natural process. In their respective subsections, how the technologies work will be explained and their global carbon capture potential will be provided.

Bioenergy with Carbon Capture and Sequestration

Generally, BECCS is the process in which CO_2 is captured from the air via growing vegetation, the vegetation is used in bioenergy power plants, CO_2 is captured from the power plants, and CO_2 is then stored in geological formations. As explained above, plants capture CO_2 via respiration and store it in the materials that constitute the vegetation. While some carbon can be stored in the soil at this step, the sequestration of carbon for BECCS is focused on geological formations.

Some other methods of BECCS are: the vegetation is fermented into fuel and CO_2 from the fermentation process is captured and sequestered; and the vegetation is converted to fuel and the biochar product of this conversion is sequestered in soil as in the TCRS practice. Sources that could be used for BECCS include: energy crops grown on marginally productive cropland (of which there is a substantial amount globally); forestry plant residues; crop plant residues; and organic waste from cities. When biomass is collected from the source, it must then be transported to a consumer (including industrial consumers) for conversion into its next product (i.e., fuel, energy, or biochar, or all three). If the product is fuel, that fuel must be transported to the consumer, adding CO_2 emissions to the atmosphere which BECCS can absorb. It is important to note that emissions will vary depending on the mode of transportation as well as the distance travelled. The biomass can be converted to various products (such as heat and fuel) using multiple methods that fall under thermochemical or biological classifications, such as pyrolysis, fermentation, gasification, and simply combustion.

When biomass combustion is used for thermal or electrical power, CO_2 is produced and the methods for capturing this CO_2 are typically no different than the developing methods for CCS in a fossil fuel power plant. Some methods in which power plant CO_2 emissions are removed are where CO_2 is separated either before or after combustion. One technology of CCS used in fossil fuel power plants is CO_2 scrubbers, which remove a net of 80% to 90% of CO_2 emitted by the plant when including the extra energy and emissions for running the scrubbers. Once the CO_2 is captured from these processes, it can be sequestered in geological formations. When biomass is converted to fuel, carbon can be stored in biochar which can be added to soil for sequestration as well as a potential benefit to the productivity of the land.

The potential annual carbon capture ability of BECCS with the technology and knowledge in 2019 was 3.5 to 15 Gt CO_2/y globally. Like DAC, the CO_2 capacity for BECCS methods that store CO_2 in geological formations is constrained by the space in geological formations to store CO_2 safely and feasible geological sequestration locations. The CO_2 capacity for the BECCS method that produces fuel along with biochar seemingly does not have capacity constraints. As discussed previously, the mode of transportation and the transportation distance for biomass can decrease the net CO_2 removal ability of BECCS to varying degrees. Truck transportation has the highest rate of CO_2 emissions per kg of biomass per km travelled, followed by train and then sea freight. A significant factor that affects the carbon capture ability of BECCS is carbon losses: for a bioenergy integrated gasification combined cycle power plant that uses CO_2 capture and sequestration and burns switchgrass, from the point of carbon capture in switchgrass to the point of sequestration of that carbon, over half of the original carbon can be lost. It is important to note that the combustion, degradation, and respiration of living things contribute to CO_2 and CH_4 emissions.

Carbon Mineralization

Carbon mineralization is a natural process that occurs when various kinds of silicates and rocks high in calcium or magnesium content are weathered. Natural carbon mineralization can capture 30 Gt CO_2 over a century. CO_2 can be stored as carbonates by reacting with the previously described materials. Some preferred types of minerals for carbon mineralization are mantle peridotite and basaltic lavas. Some of the mineralization reactions are shown below:

$$\mathrm{CaSiO_3 + CO_2 \rightarrow CaCO_3}$$

$$\mathrm{Mg_2SiO_4 + 2CO_2 \rightarrow 2MgCO_3 + SiO_2}$$

$$\mathrm{Mg(OH)_2 + CO_2 \rightarrow MgCO_3 + H_2O}$$

Humans can get involved with carbon mineralization to achieve two outcomes: sequestering CO_2 in carbonate materials or both capturing and sequestering CO_2 in carbonate materials – each outcome has methods that can be taken to achieve them.

For storing CO_2, three methods can be used: ex situ, in situ, and surficial carbon mineralization. For ex situ carbon mineralization, material used in the CO_2 to carbonate reaction is brought to locations of CO_2 capture where it is reacted with CO_2 in its temporary storage substance. For in situ carbon mineralization, CO_2 that is temporarily stored in fluids are passed through viable underground rock formations to react and store CO_2 in carbonate materials. For surficial carbon mineralization, CO_2 that is temporarily stored in fluids are passed over a high surface area of certain industrial waste products (such as mining tailings) or a high surface area of reactive rocks where CO_2 can react with the material. The method for both carbon capture and storage could use in situ or surficial mineralization along with surface water as the temporary storage substance for CO_2. CO_2 from the atmosphere will dissolve in surface water naturally, so the surface water for this carbon mineralization process acts as the carbon capture component.

There is a wide range and some unknown quantities for the carbon capture ability of the various methods of carbon mineralization, given the technology and knowledge of 2019. The known values for individual sequestration-only carbon mineralization methods could be as high as 32 Gt CO_2/y for annual CO_2 removal and as high as roughly one million Gt CO_2 for global capacity. Two potential limiters of the carbon capture ability of in situ carbon mineralization are that the pores of rocks could be clogged by carbonates, preventing further carbon storage, and that the reactions that produce the carbonate materials could form a layer that protects the reactants from further reacting, potentially slowing or stopping further carbon storage. Certain kinds of rocks have higher rates of carbonation, so their abundance (or lack thereof) is important to consider when choosing a rock for carbon mineralization. For surficial carbon mineralization, some industrial waste products do not contain much calcium or magnesium, thus reducing the carbon storage capability of this method.

Nova Scotia's Carbon Sinks Baseline

To develop emissions scenarios that extend decades into the future, it is necessary to establish a baseline of the province's current carbon sinks. This section examines Nova Scotia's forests, croplands, and wetlands as carbon sinks and Nova Scotia's geological sequestration potential. The baseline year is 2019 as it is the most recent year for which key data involved in this report is available, such as the annual GHG emissions for Nova Scotia.

Nova Scotia's Forests

According to the provincial Ecological Landscape Analysis (ELA) reports for Nova Scotia's eco-districts, which use data from 2015 and 2017, the total area of Nova Scotia's forests is approximately 4.3 Mha (found by summing the forest areas provided in the ELA report for each eco-district). Assuming that this area is the area of the province's forests in 2019 and using the ELA data it was determined that forests constituted approximately 78.3% of the land area of Nova Scotia in 2019; this makes the forests Nova Scotia's largest carbon sinks by land area. This subsection will discuss the ability of forests to absorb carbon as well as the threats to the forest and vulnerabilities to events that will impact this ability.

Forest Sink Ability

The average CO_2 flux (i.e., change in CO_2 emissions) of Nova Scotia's forests was approximately -9.38 Mt CO_2/y between 2013 and 2017 and approximately -9.06 Mt CO_2/y between 2008 and 2012. This report assumes that the change in these values is linear to get the CO_2 flux for the next five-year period (2018-2022), resulting in a CO_2 flux of approximately -9.70 Mt CO_2/y for the baseline year. The data used to determine this value were collected from permanent forest sample plots (PSPs) in the province. The PSP-based estimations show only change in carbon stocks between measurement periods. Therefore, if a given plot is harvested, it is assumed that all emissions associated with the harvested wood products are emitted entirely at harvest, which will lead to an overestimation of emissions from harvested wood products that store carbon for a longer period as they decompose.[3]

Additionally, forests and PSPs were stratified by ecoregion and it is therefore assumed that the sample plots share the same carbon capture characteristics of a given ecoregion. Moreover, emissions from dead organic matter only include coarse woody debris and standing dead trees (i.e., snags) and not litter, fine woody debris, dead tree roots, or soils, which will lead to an underestimation of emissions from forests due to the decomposition of these dead organic matter pools. The total net removal of carbon from forests and harvested wood products is likely overestimated by the PSP-based data.[4]

Given that the carbon capture value for Nova Scotia's forests is likely overestimated,[5] it is important to compare it to the carbon capture value of the forests of a jurisdiction that is geographically close to Nova Scotia. Maine is one such jurisdiction, with a forested area of 17.30 million acres (approximately 7 million ha) and Maine's forests captured an estimated average net of about 15.1 Mt CO_2e/y between 2006 and 2016 (value obtained by subtracting wood product emissions from net forest uptake and converting from carbon to CO_2e). From this data, the per hectare carbon capture of Maine's forests can be estimated to be approximately 2.16 t CO_2e/ha/y. Comparing the results from Maine's forests to Nova Scotia's over a similar period (2013 to 2017) which have an estimated net per hectare carbon capture of 2.17 t CO_2e/ha/y

[3] Dr. James Steenberg, Nova Scotia Department of Lands and Forestry, personal communication, 26 July 2021)

[4] Ibid.

[5] Ibid.

(from the 2013 to 2017 flux data for the province's forests and Nova Scotia's forested area from the 2019 ELA reports), suggests the estimate for Nova Scotia is reasonable.

Threats and Vulnerabilities

There are multiple threats to Nova Scotia's forests that could reduce their ability to capture and store carbon, such as drought, fires, pests, and strong weather events.

Some potential solutions to reducing the threat of droughts to Nova Scotia's forests are to thin or intentionally burn the forest to decrease the forest density and to promote trees that can resist the effects of droughts. The likelihood of droughts happening in Nova Scotia's future is likely given that there has been a drought of any intensity during six years of the last decade and that temperatures increase with global warming.

Reducing the threat of drought consequently reduces the threat of fires to the province's forests. The risk of potentially high-damaging fires can be reduced through management practices such as prescribed burning. The likelihood of forest fires happening in Nova Scotia's future is almost certain given that there have been wildfires reported every year for the past five years and that in the rapid emissions reduction climate scenario, the province's fire season is expected to get longer.

Pests, including new pests introduced from southern climates, are considered by the province to be the highest threat to Nova Scotia's forests; to reduce the threat of these pest, the province should prepare and research forest management practices to reduce the impact of the most likely pests on Nova Scotia's forests. To reduce the threat of pests that currently inhabit the province's forests, practices to reduce their impact which already exist (such as those meant to deal with the spruce beetle) should be used (if not currently practised) and research should be conducted to improve their effectiveness or to find more effective practices. A vulnerability of Nova Scotia's forests is the vulnerability of all spruce trees to the spruce beetle during spruce beetle outbreaks. The likelihood of new pests is almost certain since it is already occurring (i.e., the hemlock woolly adelgid was reported in Nova Scotia in 2017). The likelihood of spruce budworm infestations is likely to decrease in the future should temperatures at their southern limit rise; currently, certain spruce budworm infestations cause low amounts to significant amounts of damage to large quantities of spruce-fir forests in 30- to 40-year intervals. To reduce the vulnerability of Nova Scotia's forests to pest infestations, various forest management practices can be conducted, such as decreasing the number of a pest's host trees in a forest through thinning and predicting when and where pest infestations will occur so that action can be taken to prevent further infestation. An example of a practice that is currently implemented to reduce the potential of spruce beetle infestations is removing blown down trees from an area of forest.

Some other vulnerabilities of Nova Scotia's forests are the vulnerability of tall stands of mostly spruce or balsam fir to wind damage, and the vulnerability of shallow rooted trees to wind damage. In Nova Scotia, between 2008 and 2012, two softwood tree species that were among the highest in commercial populations were red spruce and balsam fir, and a hardwood tree species that was among the highest in commercial population was red maple. The trees listed all have shallow roots which means that the province's commercial trees with some of the highest populations in their respective category were vulnerable to wind damage and likely still are. A potential solution to reducing the vulnerability of the province's forests to wind damage would be to assess areas that are high-risk and ensure that the trees do not grow too tall (since some tall trees are more vulnerable to wind damage). The likelihood of strong weather events is almost certain since hurricanes hit Nova Scotia every seven years on average, while the likelihood of extra-tropical cyclones that have winds that could result in significant damage is almost certain since cyclones of this strength hit Nova Scotia roughly once every two years.

Other threats to the province's forests are: anthropogenic actions which help the forest sink can be undone deliberately (i.e., forest clearing) or through natural disturbances (i.e., fires or windstorms), thus reversing progress; and the potential to increase the amount of harvested wood to decrease emissions by replacing higher-emissions materials like steel and concrete with harvested wood products. To reduce the threat of actions that improve the forest sink being intentionally undone, a potential solution would be to produce legislation that "locks in" the action unless the scientific community decides, in the future, that the action is ultimately harmful to the forest sink. The increase in emissions resulting from an increase in the production of harvested wood products would have to be offset by increasing the net carbon uptake of the forest through various methods such as improved forestry management practices as well as afforestation/reforestation. A serious impact from climate change is potential changes in growing season length: while potentially longer growing seasons could increase plant growth, warmer temperatures could increase carbon loss from plant respiration enough to offset some of or exceed the carbon capture from the longer growing season, presenting a significant challenge.

Nova Scotia's Croplands

In 2011, the area of cropland in Nova Scotia was 280,889 acres, and the area decreased by 4.8% to approximately 267,406 acres (or 108,218 ha) in 2016. For the baseline year of this report, the cropland area will be assumed to be the same as the area in 2016. When comparing this value to the total area of Nova Scotia calculated from the data in the ELA reports, cropland constituted approximately 1.96% of Nova Scotia's land area in 2016. This subsection will discuss the ability of cropland to absorb carbon as well as the threats to cropland and vulnerabilities to events that will impact this ability.

Cropland Sink Ability

Due to insufficient data available about the ability of Nova Scotia's croplands to absorb or emit carbon, a coarse estimate was made. The most specific data provided regarding the carbon capture ability for cropland is the Land-Use, Land-Use Change, and Forestry (LULUCF) data for the Atlantic Maritime Ecozone (AME), which is that the cropland for this region released approximately 541 kt CO_2e in 2019. This value was scaled down linearly from the cropland data of the AME to the cropland data of Nova Scotia by using the ratio of the area of Nova Scotia to the area of the AME.[6] The result of this calculation is that Nova Scotia's croplands are a source of approximately 145 kt CO_2e/y rather than a sink in 2019. Due to the coarseness of this estimate, it does not provide an accurate depiction of Nova Scotia's cropland sink. Since it is relatively small in comparison to other sinks and sources, this inaccuracy does not have a significant impact on Nova Scotia's carbon sink baseline. Currently, there is no incentive for cropland owners to focus on carbon sequestration on their cropland.[7]

Threats and Vulnerabilities

Like the forests, there are multiple threats to Nova Scotia's croplands that could make them emit more carbon via degradation of the ecosystem's ability to capture carbon. Climate change could result in an increased quantity and strength of droughts that reduce the productivity of the cropland; this means that the plants on the cropland would not be absorbing as much carbon. To reduce the effect of droughts on crops, cropland, livestock, and forestry systems can be combined in various ways on one farm. A cropland management practice that can reduce the effects of floods and droughts on croplands is planting cover

[6] The area information reproduced in the calculations is a copy of an official work that is published by the Government of Canada and the reproduction has not been produced in affiliation with or with the endorsement of the Government of Canada.

[7] Professor Derek Lynch, Dalhousie University, personal communication, 30 June 2021

crops. Another effect of climate change is that it could increase pest infestations which may require the use of pesticides – the use of which could increase energy usage for their production and distribution and potentially GHG emissions depending on the energy source used. Efforts should be made to avoid the potential emissions connected to the production and distribution of pesticides or to capture them at source points. Another threat to the productivity and survivability of cropland plants is the potential introduction of salt water to cropland. To reduce the impact of salt water intrusion, various adaptation actions can be taken, such as adding gypsum to the soil and planting cover crops; however, these are only short-term solutions.

Nova Scotia's croplands have some vulnerabilities, such as having low-lying coastal cropland (e.g., parts of the Annapolis valley) being prone to saltwater intrusion as sea levels rise. To prevent the intrusion, sufficiently high dykes should be constructed or maintained, or both, in areas that are at risk of saltwater intrusion. Other vulnerabilities are that: Nova Scotia uses unirrigated farming, making the cropland susceptible to drought; the province's soils are coarse and sloped, making them vulnerable to erosion; and the soils are low in soil organic matter, reducing their water holding capacity and structure related to water infiltration capacity.[8] This reduction in soil health related to water infiltration and retention has multiple detrimental effects: it leaves the land vulnerable to both flooding and drought.[9] The adoption of cropland management practices that increase soil organic matter would decrease the risk of both flooding and drought.[10] Some potential examples of management practices to increase soil carbon would be to include trees on cropland and the planting of cover crops and diverse crop rotations to allow inclusion of some perennial crops.[11] Increasing the amount of soil organic matter in cropland soils would increase soil structure and thus, decrease erosion.[12]

The likelihood of droughts occurring in the province's future is already discussed in the Nova Scotia's Forests subsection of this report. If sea barriers are not constructed to prevent the sea from reaching inland, the likelihood of salt water intrusion is likely given the expected sea level rise and that Nova Scotia is slowly losing land. The likelihood of flooding occurring in Nova Scotia in the future is likely given that the annual precipitation is predicted to increase in the future and that more intense rainfalls are predicted.

Nova Scotia's Wetlands

According to the most recent provincial ELA reports for Nova Scotia's eco-districts, which use data from 2015 and 2017, the total area of Nova Scotia's wetlands is approximately 383 kha (found by summing the wetland areas provided in the ELA report for each eco-district. Assuming that this area is the area of the province's wetlands in 2019 and using the ELA data, it was determined that wetlands constituted approximately 6.9% of the land area of Nova Scotia in 2019; this makes the wetlands Nova Scotia's second largest carbon sink by land area. This subsection will discuss the ability of wetlands to absorb carbon as well as the threats to the wetlands and vulnerabilities to events that will impact this ability.

Wetland Sink Ability

A study of Nova Scotian wetlands examined 55 wetlands consisting of five kinds of wetland across the province during summer of 2017. One portion of the study was to determine the GHG flux from Nova

[8] Ibid. 15 August 2021
[9] Ibid. 15 August 2021
[10] Ibid. 30 June 2021
[11] Ibid. 15 August 2021
[12] Ibid. 15 August 2021

Scotian wetlands and it was determined that the wetlands emit an average of 1.46 t CO_2e/ha/y in the form of methane and capture 6.45 tCO_2e/ha/y in the form of CO_2e, resulting in an average net capture of 4.99 t CO_2e/ha/y. For this report, the net capture rate is assumed to be the same as the baseline year. With this assumption, the net capture rate along with the area of wetlands were used to calculate the net carbon capture ability of Nova Scotia's wetlands. The province's wetlands were calculated to be a sink of approximately 1.91 Mt CO_2e/y for the baseline year.

Threats and Vulnerabilities

From Australian research which has shown how climate change will affect the CO_2 and CH_4 fluxes in wetlands in certain climate change scenarios, we believe the most significant threat to the ability of the province's wetlands to absorb carbon is climate change. According to the Australian Department of Sustainability, Environment, Water, Population, and Communities and the Wetlands and Waterbirds Taskforce, these are potential changes to the GHG fluxes in wetlands:

- Warmer climates will accelerate the rate of production of carbon dioxide and methane from wetland soils, but may also increase primary production.
- Wetter climates will increase wetland surface areas and promote carbon sequestration and increased primary production, but may increase methane emissions.
- Drier climates will increase the oxidation of carbon stores but reduce methane emissions.

Dry and wet environments could be created by droughts and floods, respectively, potentially resulting in changes to the GHG flux of Nova Scotian wetlands. Before any solution is chosen to counter the effects of increased wetness or dryness, an assessment of the GHG fluxes from a wetland in its original state should be made along with an estimate of the GHG fluxes with the solutions applied. If a solution will have lower net emissions or be a greater net sink than the original state, then the solution should be applied. An example of a solution to counter the effects of wetland soil drainage (which may result from excessive dryness) would be to rewet the soil of the wetland. A potential solution to counter the effects of wet environments on wetlands would be to drain the excess water, though the ecological effects of such an action requires further research. Some threats to coastal wetlands are coastal erosion and "sea-level rise, where inundation will threaten the survival of the largely intertidal wetland plants". To control the erosion of coastal wetlands, sediments can be added to a region; for example,

> *If continued input of suspended sediment from rivers is sufficient for sediment accretion to keep pace with a steadily rising sea-level, then carbon dioxide emissions could decrease as the tidally-flooded coastal areas increase in area and plant population size and existing inundated carbon pools are buried even deeper – provided that such landward movement of intertidal areas is not prevented by coastal squeeze such as the presence of hard sea-defences and other infrastructure.*

Management practices should be developed and adopted to allow coastal wetlands to move inland with rising sea levels and to maintain the sink. A potential technological solution to impacts of rising sea levels is to use control gates to maintain the current tides into the future; however, this should be considered a last resort.

We believe that the greatest vulnerability of the wetlands carbon sink is that its GHG fluxes are influenced by its climate. This means that unless climate change is reversed, there are a couple measures that could be taken to reduce the impacts on the sink, notably to estimate the GHG fluxes under the new climate and attempt to modify the environment where necessary and possible (as described in the previous paragraph). The vulnerability of coastal wetlands is their location – they are susceptible to both coastal erosion and flooding from rising sea levels. The potential solutions for both issues are discussed in the previous paragraph.

The likelihood of droughts which may cause wetlands to dry was already discussed in the Nova Scotia's Forests subsection of this report. As noted in the Nova Scotia's Croplands subsection of this report, there is more annual precipitation expected in Nova Scotia's future which means that the province's wetlands could experience the GHG flux changes associated with a wet environment. The likelihood of sea level rise is considered by the IPCC to be virtually certain. The likelihood of coastal erosion continuing in the future is certain since it is considered an inevitable process.

Nova Scotia's Geological Sequestration Sites

While geological sequestration sites do not capture carbon on their own and as such, are not technically sinks, it is important to discuss them as they make up Nova Scotia's "natural" carbon storage capacity for artificially captured carbon. Nova Scotia has the potential to be an important location for CO_2 sequestration given the number of offshore sedimentary basins in the region, which have excellent potential for carbon sequestration.[13]

While work is being done to determine an estimate for the CO_2 sequestration potential in and around Nova Scotia, an estimate can be made for some potential sites that are known, namely the depleted offshore oil and gas fields.[14] For example, the volumes of oil or gas that were extracted from the Sable Offshore Energy Project, the Deep Panuke Offshore Gas Development Project, and the Cohasset-Panuke Project are 60 billion m^3, approximately 4.2 billion m^3, and 7.1 million m^3, respectively. Assuming that the volume that can be injected into the depleted reservoirs is equivalent to the volume that was extracted, that the density of supercritical CO_2 being injected into the reservoirs is 600 kg/m^3, and that the reservoirs can retain supercritical CO_2, the potential CO_2 storage capacity of Nova Scotia's depleted offshore oil/gas fields is approximately 38.5 $GtCO_2$. Given that Canada's total anthropogenic GHG emissions were 730 Mt CO_2e in 2019, this is a significant storage potential, equivalent to about 53 years' worth of Canada's 2019 anthropogenic GHG emissions.

Summary of Nova Scotia's Carbon Sinks

Nova Scotia has both carbon sinks and geological storage for potential CO_2 capture and storage. While other sinks do exist, such as carbon mineralization and seagrasses, they were not the focus of this report. Research to quantify these other sinks could be used to enhance the accuracy of the scenarios that will be provided in this. Of the three sinks examined, Nova Scotia's forests were found to be the largest sink by far, followed by the province's wetlands. Nova Scotia's croplands were estimated at present to be a source rather than a sink, though not a significant one in comparison to other emissions sources. Table 1 provides a summary of the 2019 baseline for Nova Scotia's carbon sinks.

Table 1: Nova Scotia's 2019 carbon sinks baseline summary

Sink	Potential
Forests	9.701 Mt CO_2/y absorbed
Cropland	0.145 Mt CO_2e/y released
Wetlands	1.911 Mt CO_2e/y absorbed

[13] Professor Grant Wach, Dalhousie University, personal communication, 23 June 23, 2021
[14] Ibid. 5 July 2021

The vulnerabilities, threats, and likelihoods of those threats must be taken into consideration when examining the net-zero scenarios. Policymakers need to understand the risks associated with the sinks when developing policy. It is essential that the quantities shown in Table 1 are kept up-to-date and accurate so that the state of the sinks can be measured and the net-zero goals can be adjusted accordingly.

2050 Net-zero scenarios

A jurisdiction's total emissions are the sum of its actual emissions from all emissions *sources* and any emissions *sinks* it may claim (typically a combination of changes in land use or forestry, or both, technologies for carbon capture and use or carbon capture and storage in geological structures, and emissions credits purchased in emissions trading systems):

$$Total\ Emissions = Emissions\ sources - Emissions\ sinks$$

When a jurisdiction reaches its net-zero target date, it will be in one of three states, determined by its total emissions:

$Total\ emissions\ = 0$: In this state, the jurisdiction's emissions sources are offset by its emissions sinks and the jurisdiction has achieved net-zero emissions.

$Total\ emissions\ < 0$: The jurisdiction is a net sink; after removing its own emissions, it still has "sink space" to remove additional emissions. The jurisdiction could, for example, use the space to attract industries from emissions intensive jurisdictions or sell the space as emissions credits to jurisdictions that are net emitters (see below). (As with the Covid-19 vaccines, there would always be the danger of jurisdictions hoarding emissions credits to force up the market price.)

$Total\ emissions > 0$: The jurisdiction's emissions sources exceed its sinks, making it a net source. If a jurisdiction in this state is required to achieve net zero, it should aim to maximize its decoupling and decarbonizing efforts before the net-zero target date. Since the total emissions exceed zero, it will be necessary to obtain emissions credits from jurisdictions that are net sinks. Such purchases will need to be made until the jurisdiction finds other, lower-cost sinks.

Achieving zero-emissions this way could be a costly exercise if there is a significant global demand for the carbon-removal process, as there may well be, given the number of organizations, regions, and countries pledging to attain net-zero by 2050.

In Nova Scotia's case, the province is committed to achieving net-zero emissions by 2050 .

This section considers three net-zero scenarios for the province in 2050 determined by the CO_2 flux strength: constant strength (the sink strength in 2050 is the same as in 2019), increasing strength (sink strength increases at different, evidence-based rates), and decreasing strength (the sink strengths decrease by 10% of the 2019 capacity per decade). (Emissions from Land-Use, Land-Use Change, and Forestry (LULUCF) are included in the greenhouse gas flux estimate for the province's croplands.)

Each scenario is described in terms of the total emissions sink strength (the sum of the forest, wetland, and cropland strength for 2050), the maximum permissible emissions in 2050 (the total sink strength), and the emissions reductions the province must make between 2019 and 2050 to reach the maximum permissible emissions.

Nova Scotia's 2019 emissions were 16.2 Mt CO_2e and are summarized by sector in Figure 1. If the province's 2030 emissions target is met, emissions are projected to decline to 10.9 Mt.

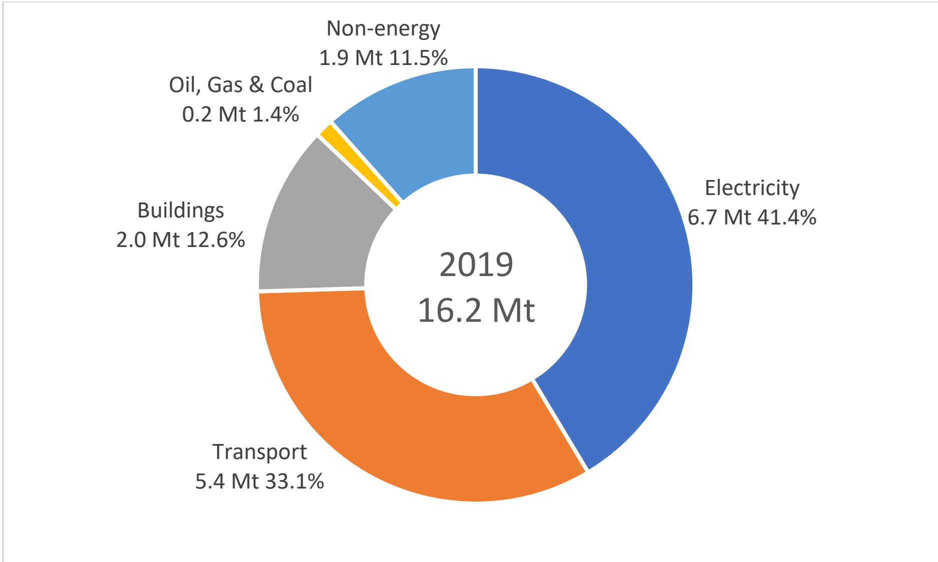

Figure 1: Nova Scotia 2019 GHG emissions by sector

Scenario 1: Constant Flux Strength

In the constant flux strength scenario between 2019 and 2050, the sink strength of Nova Scotia's forests and wetlands remains constant while croplands continue to act as a source. In this scenario (see Figure 2), the total sink strength in 2050 is 11.5 Mt CO_2e (sum of wetlands, croplands, and forest fluxes), to achieve net-zero, the province's emissions could not exceed 11.5 Mt CO_2e. The total required anthropogenic emissions reduction from 2019 is 4.7 Mt CO_2e or approximately 29% below 2019 levels. The province's 2030 emissions target of at least 53% below 2005 levels (about 10.9 Mt CO_2e), is about 0.6 Mt below the 2050 sinks, requiring no further reductions and making the province net-negative.

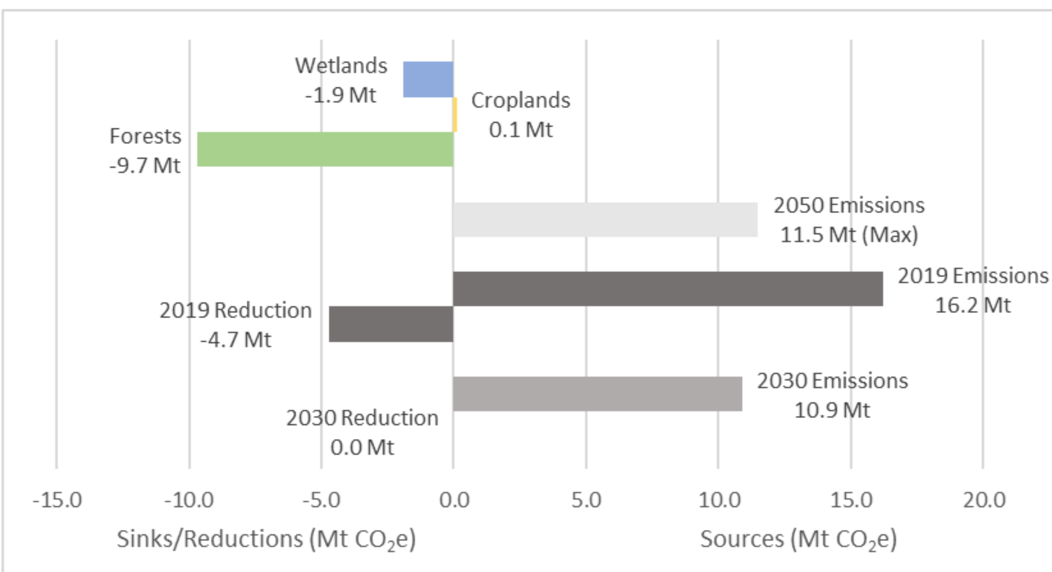

Figure 2: Emissions sinks and sources for the constant flux strength scenario

This scenario would probably be difficult to maintain, given the threats to and vulnerabilities of the sinks from climate change and anthropogenic activities.

Scenario 2: Increasing Flux Strength

In this scenario, sink flux strengths increase between 2019 and 2050, based on the following assumptions:

Forests: The forest sink CO_2 flux increases by 0.319 Mt CO_2 every five years (estimates based on data from Steenberg).[15]

Croplands: Improved cropland practices are fully implemented by 2050. The resulting changes in Nova Scotia's soil organic carbon are assumed to be the same as in the United States (0.36 t C/ha/y for cover crops, 0.14-0.18 t C/ha/y for improved crop rotations, and 0.33 t C/ha/y for no tilling). The increase in soil organic carbon is converted to CO_2 sequestered when calculating the CO_2 flux.

Wetlands: Net carbon sequestration rates remain constant and wetlands are restored so the sink increases by 4% of the baseline value every decade.

The increasing sinks scenario would be the most difficult scenario to achieve because the impact of the threats to and vulnerabilities of the biological sinks would have to be reduced while also increasing their carbon capacity.

By 2050, limited emissions reductions would have to take place to meet the 2050 goal of net-zero emissions (see Figure 3). The maximum anthropogenic emissions permitted in 2050 is 13.9 Mt CO_2e, a reduction of about 14% from 2019. The province would need to reduce its emissions by only 2.3 Mt from 2019 levels. If the province met its 2030 emissions target, it would be under the 2050 sinks by about 3 Mt, making the province net-negative and meaning it could, for example, sell its negative emissions. The main issue with achieving this scenario is ensuring that the sinks' strengths increase while their threats and vulnerabilities decrease.

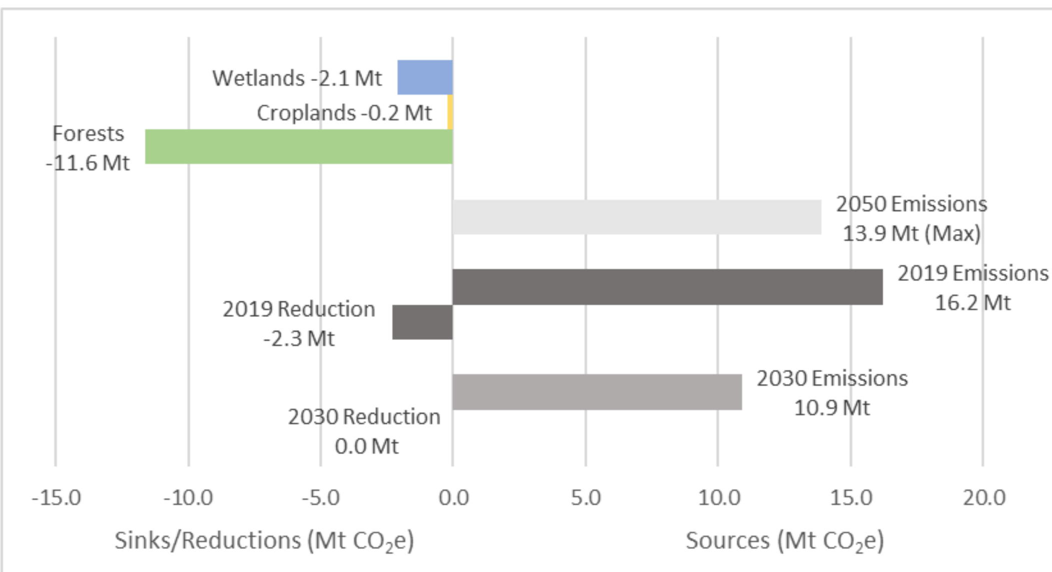

Figure 3: Emissions sinks and sources for the increasing strength scenario

[15] Dr. James Steenberg, Nova Scotia Department of Lands and Forestry, personal communication, July 2021

Scenario 3: Decreasing Flux Strength

In this scenario, the flux strength of the sinks decreases. With the growing threat of climate-related events, this scenario may be considered more plausible than either of the two previous scenarios. Should the sink strengths decrease, the degree to which they decrease may be hard to predict; however, in this scenario we assume the forest and wetland sink strengths decrease by 10% of the baseline value each decade, and for croplands, emissions increase by 10% of the baseline value each decade. As Figure 4 shows, the sinks remove a total of 7.9 Mt CO_2e. To achieve net-zero, Nova Scotians would need to reduce their emissions by 8.3 Mt CO_2e (a 51% decline) from the 2019 level, or by 3 Mt CO_2e (an over 27% reduction) from the 2030 level.

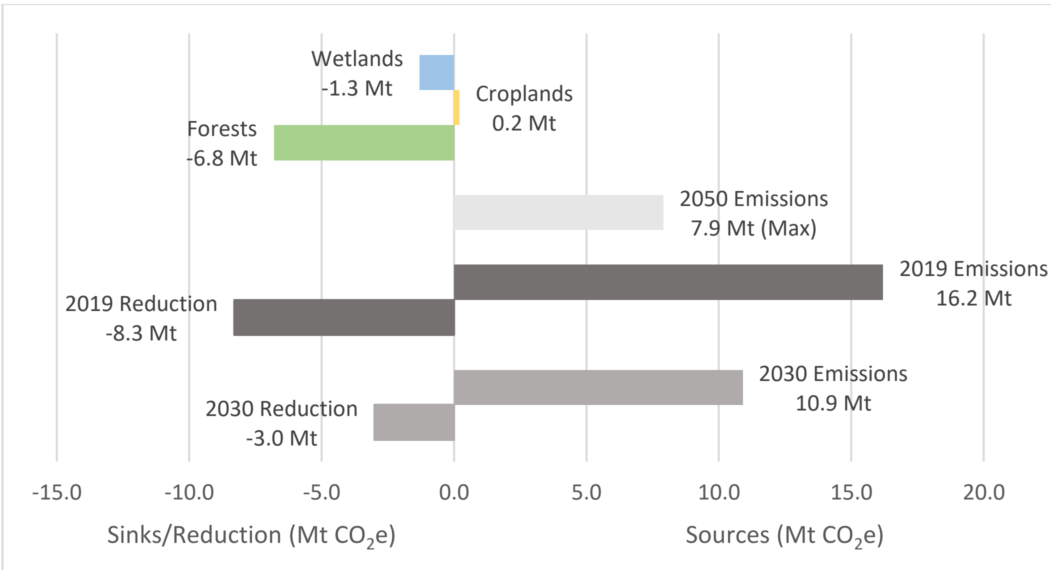

Figure 4: Emissions sinks and sources for the decreasing strength scenario

Summary

All the scenarios presented require some level of anthropogenic emissions reduction to achieve the 2050 net-zero emissions target. Table 2 details key information from the three net-zero emissions scenarios.

Table 2: Key results from the net-zero emissions scenarios to 2050

Sink Scenario	Projected total sink flux (Mt CO_2e)	Maximum allowable anthropogenic emissions (Mt CO_2e)	Required change in anthropogenic emissions			
			2019-2050		2030-2050	
			Mt CO_2e	Percent	Mt CO_2e	Percent
Constant	-11.5	11.5	-4.8	-29%	0.0	0%
Increasing	-14.0	14.0	-2.3	-14%	0.0	0%
Decreasing	-7.9	7.9	-8.3	-51%	-3.0	-27%

The anthropogenic emissions reductions from 2019 levels range from 14% to 51%, and the projected total GHG flux of all sinks in 2050 range from approximately -7.9 Mt CO_2e to -14.0 Mt CO_2e. The projected total

GHG flux of all carbon sinks in 2050 is always equal to the maximum anthropogenic emissions in 2050 for net zero to be achieved.

If Nova Scotia achieves its 2030 emissions target, the province would be net-negative in both the constant and increasing sink-strength scenarios. In the decreasing sink-strength scenario, additional reductions would be need to achieve net zero.

Both maintaining and increasing sinks could be a major problem given all the vulnerabilities of sinks and the threats they face, such as the threats of fires and pests to the forests. Preventing sinks from decreasing in strength any further than the assumptions made for the decreasing sinks scenario could also be difficult depending on the impacts of the threats to and vulnerabilities of the sinks. It is important to note that, for the decreasing sinks scenario, the maximum anthropogenic emissions will continue to decline past 2050 if the sink strengths decline as well. This means that efforts to reduce emissions should not be given up once 2050 is reached.

If Nova Scotia is unable to achieve the emissions reduction necessary to meet the 2050 emissions target, it will have to either purchase negative emissions from another jurisdiction or construct direct air capture facilities. The cost of direct air capture ranges from 2019 values of roughly $90 to $900 USD per net tonne of CO_2 captured. For this report, it is assumed that these prices are both the cost of negative emissions (through purchasing or direct air capture) and the sale price of negative emissions.

If the province needs to remove one Mt CO_2e of emissions to reduce its emissions to net-zero, the cost would be between C$120 million and C$1.2 billion. Alternatively, if the province sold one Mt CO_2e of negative emissions, its revenue would be approximately $120 million to $1.2 billion in 2019 CAD. At the maximum cost of roughly $900 2019 USD per net tonne of CO_2 captured, the cost or revenue could be significant, especially if there is more than one Mt CO_2e that needs to be removed or can be sold. Work should be done to maintain and increase the biological sinks while also reducing anthropogenic emissions so that negative emissions can be sold, providing another revenue stream to the province.

Conclusion and Recommendations

By 2050, Nova Scotia intends to reach net-zero emissions "by balancing greenhouse gas emissions with greenhouse gas removals and other offsetting measures". Since the province has yet to develop a plan to achieve either removals or offsetting measures, this report provides an estimated baseline of Nova Scotia's natural carbon sinks and its geological sequestration capacity and shows that Nova Scotia has significant carbon sinks and geological capacity in relation to its annual greenhouse gas (GHG) emissions.

The report explains the carbon capture potential of the province's sinks (forests, croplands, and wetlands) and the province's carbon storage capacity. It also examines possible threats to, and vulnerabilities of, the natural sinks, and considers potential ways of reducing the impact of the threats and vulnerabilities. Natural sinks, direct air capture, and carbon sequestration in geological formations are also described to give a better understanding of their concepts and carbon capture and sequestration potential.

Three different sink scenarios have been considered, developed on the assumption that between now and 2050, changes to the climate could affect the sinks. Using the province's 2019 emissions and estimated sinks as a baseline, three different sink scenarios (steady, increasing, and decreasing) were developed to determine the maximum allowable anthropogenic emissions to meet the 2050 net-zero target.

The minimum reduction from 2019 emissions levels to achieve net-zero depends on the changes to the province's sinks. If emissions levels remain steady at 11.5 Mt CO_2e, the province would need to reduce its emissions by about 4.8 Mt CO_2e or 29% from 2019 levels, slightly less than the province's 2030 emissions target requires. However, if the sinks are enhanced by various means each decade, by 2050 the sinks would remove about 14 Mt CO_2e and the Nova Scotians would only need to reduce their emissions by 2.3 Mt CO_2e or 14% from 2019 levels. In the case in which sinks flux strength is weakened by 10% a decade, Nova Scotians would need to reduce their emissions by 8.3 Mt CO_2e or 51% from 2019 levels. We should assume this last case is becoming increasingly likely.

If Nova Scotians are unable to achieve net-zero using emissions reduction programs or the sinks have insufficient capacity, the province would need to purchase negative emissions using direct air capture or emissions credits. The magnitude of the cost per Mt CO_2 was found to be about $120 million to $1.2 billion in 2019 CAD; however, if the province became a net-sink, it could sell the negative emissions.

Quite simply, the importance of the province's emissions sinks cannot be overstated if we are to achieve net-zero. The province must ensure that sinks remain protected or enhanced and geological sequestration be pursued. Net-zero must be maintained annually and in perpetuity.

To this end, we urge the province to adopt the following recommendations:

1. *Conduct a complete and accurate biannual assessment of the province's greenhouse gas (GHG) fluxes of the biological sinks (such as forests, croplands, wetlands, and seagrass meadows)*:
    - The assessment should be released as a publicly accessible state-of-the-sinks inventory report. Changes to the fluxes must be identified.
    - Each sink should be mapped and its GHG flux made available in a publicly available map. The associated data tables should be released with the map.
    - At a minimum, the following information should be supplied for each sink: location, area, annual GHG flux, and maximum annual GHG flux. This will provide better estimates of the maximum anthropogenic emissions for the 2030, 2050, and any interim targets. The data must be verifiable.

- Trends in the strength of the biological sinks should be monitored and appropriate action should be taken if the strengths decrease.

2. *Measure, report, and verify the carbon-related impacts of the threats to Nova Scotia's biological sinks and conduct an economic and carbon flux assessment of the potential solutions to reducing the threats and vulnerabilities of the sinks*:
   - Quantify the impacts on the carbon flux of any of the provincial biological sinks using known measurement, reporting, and verification techniques (MRV).
   - Conduct research into the potential solutions (including those presented in this report) to the threats and vulnerabilities faced by the sinks.
   - Evaluate the economic feasibility and changes to the carbon flux of potential methods to reduce the impact of the threats and vulnerabilities to biological sinks.
3. *Interim emissions reduction targets should be established*:
   - In addition to the legislated 2030 and 2050 targets, three interim emissions targets 2035, 2040, and 2045 will allow for changes to regulations to reduce the likelihood of overshooting net-zero.
   - These targets will provide emissions reduction reference points.
4. *Efforts should continually be made to reduce emissions beyond 2050*:
   - Net-negative global anthropogenic CO_2 emissions will need to be maintained annually and in perpetuity to prevent further increases in global temperature.
   - Reducing emissions so that net-negative emissions are achieved means environmental security if the sinks decrease in strength.
   - Maintaining net-negative emissions creates a potential revenue stream to the province and helps other jurisdictions reach their climate targets.
5. *Introduce tax incentives for carbon captured in natural sinks to promote the maintenance of our efforts to increase their carbon capture ability*:
   - Nova Scotia or the Government of Canada should provide tax incentives to managers of forests, croplands, wetlands, and seagrasses based on a per verified tonne of carbon captured. This incentive should be less than the annual cost-per-tonne for DAC; otherwise, it might be more financially reasonable to spend the government funds on DAC.
   - This will motivate land managers to manage their lands in a way to maintain or increase their carbon capture capacity.
6. *If the purchase of negative emissions is necessary, it must be sustainable*:
   - Achieving and maintaining negative emissions will require the province to budget for the purchase of emissions credits annually and in perpetuity.
7. *Since biological sinks are at risk from extreme climate events, the province must research and if possible, develop its geological storage capacity*:
   - The removal and long-term storage of existing atmospheric carbon using Direct Air Capture (DAC) is essential if global temperatures are to be maintained or, ideally, reduced by removing new and existing carbon from the atmosphere.
   - If properly managed, this could be a potential revenue stream for the province.

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