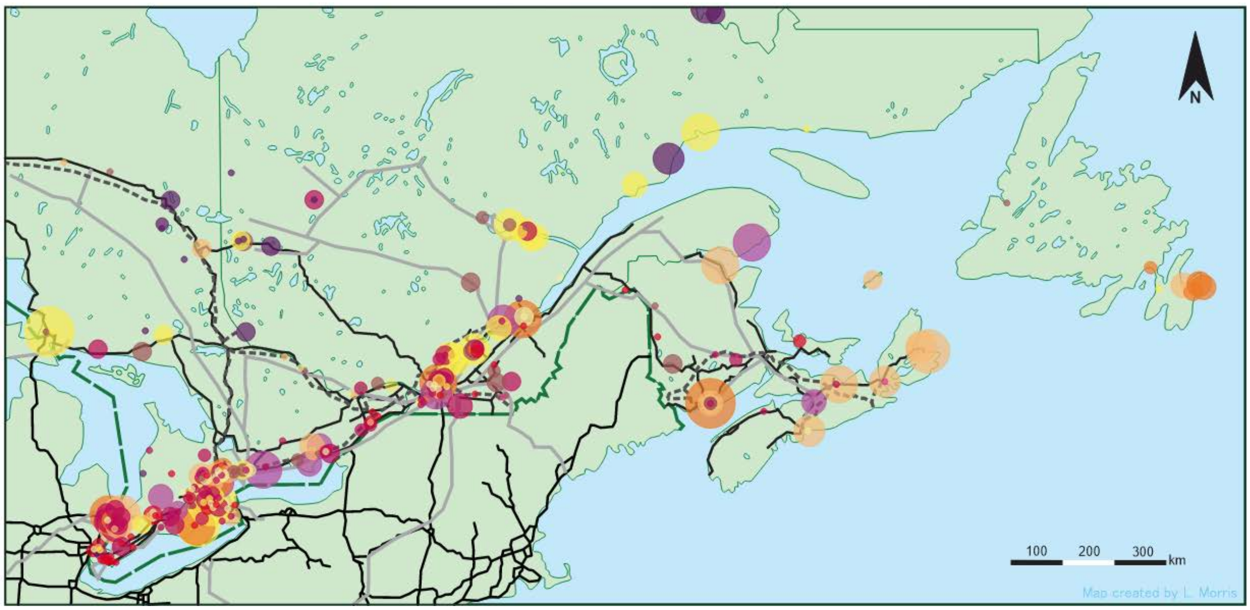

CARBON SOLUTIONS FOR EASTERN CANADA

RECORD OF THE 2023 CARBON NEUTRALITY FORUM AND ASSOCIATED MATERIAL

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EXECUTIVE SUMMARY

This paper was created as a follow-up to the Carbon Neutrality Forum, hosted in April 2023 and funded by Natural Resources Canada. Following the range of presentations given during the event and the information collected from academics and industry professionals, this report serves as both a review of the forum, as well as a depiction of the current situation when it comes to reducing Canada's carbon emissions and potential and feasible courses of action.

Throughout human history, as societies evolve and improve, our actions have been contributing to a shift in the natural order of the earth. From the advent of agriculture, the age of industrialization, advancements in technology, and exponential population growth, there is no doubt about the impact we have made on the globe. While much of this progress is seen as essential for the development of humanity, some of the negative influences – pollution, deforestation, greenhouse gas (GHG) emissions – have been compounding into significant issues. Our emissions in particular have been of rising concern as of late, as GHGs such as methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) absorb and trap heat within the atmosphere, leading to rising global temperatures. As temperature is intrinsically connected to numerous earth processes and cycles, the effects had on sea level, agriculture, and general quality of life could be catastrophic if not dealt with.

The global average surface temperature has risen nearly 1 °C since the 1970s, an increase that is typically seen on a scale of thousands if not millions of years. Studies show that if we continue doing business as usual, temperatures could continue to rise by another few degrees by 2100, drastically altering the condition of life on earth. The most reasonable approach to lowering global temperatures, or merely keeping them from rising further, would be to reduce human induced GHG emissions.

In 2021, Canada's GHG emissions totaled 691 Mt of CO_2 equivalent (~550 Mt of which are solely CO_2), while the eastern side of the country accounted for 50 Mt CO^2 of that total (depicted in Figure 1), with the most significant levels being derived from oil & gas developments, cement plants, and metal manufacturing and processing. With hopeful emission reduction targets in place both federally and provincially for 2030 and beyond, it's apparent that action is needed to change our approach to energy usage, manufacturing, and our relation to the land we reside within. While emission amounts vary between nations due to differences in levels of industrial and technological development, we can only be responsible for dealing with our own emissions; and as one of the most advanced countries in terms of economy and technology, with the means to address the issues head on, Canada should be setting the precedent for making progress in the fight against climate change.

While there are a number of emerging approaches to reducing CO_2 emissions, whether it be to scale down emissions directly at the source or sequestering carbon that is already present in the atmosphere, the idea of carbon capture, utilization, and storage (CCUS) is the main focus of this report. CCUS details the process of capturing carbon from point sources such as metal manufacturing and cement plants, transporting to point of use or storage, potential utilization in enhanced oil recovery or recycled into products, and eventually storage, either in specialized containers or within suitable subsurface geological formations.

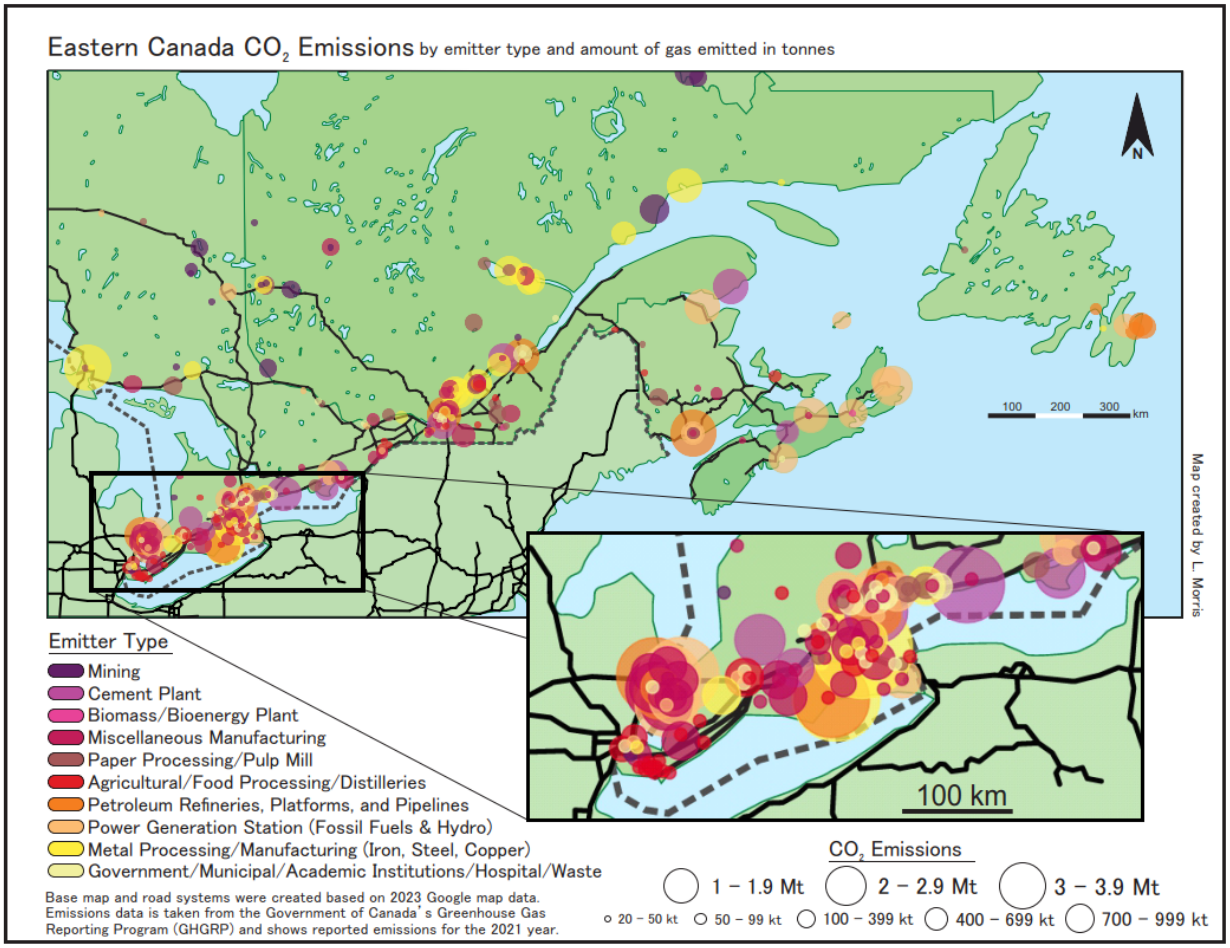

Figure 1: Annual CO_2 emissions of eastern Canada, classified by emitter type and emissions in tonnes per annum. Inset shows zoom view of southern Ontario, the most heavily condensed cluster in the region (data from GHGRP, map created by L. Morris).

In terms of reducing emissions at the source, industry is being pushed to transition away from fossil fuel-based energy generation and turn to renewable sources to power operations. While this transition will eventually be a necessity, without enticing incentives and/or punishing penalties, the replacement of existing, operational infrastructure would be an unfavorable change. In addition, ample renewable resources would have to be secured, and with the number of industries poised to transition, there may not be enough renewable energy to go around. Many renewable sources are intermittent and require battery-type storage to collect excess energy, raising the concern of further emissions from the creation and upkeep of these major batteries. As decisions are still being made at an industry level on how to manage future emissions, evidenced technologies to pull existing CO_2 from the atmosphere are the reasonable next step to make while energy sources are being transitioned.

For CO_2 sequestration, a number of innovative technologies have been and are being developed, with CCUS having produced more evidentiary results through extensive testing and pilot projects than other novel techniques to date. As there have been more active projects displaying the concepts of CCUS, and perceived risks have had a chance to be taken into account during operations, this technology may have the best chance of being implemented on a larger scale compared to newer, less tested ideas.

CCUS projects are becoming more prevalent globally, with significant movement in Norway, the Netherlands, and the USA. Norway's Langskip initiative, which includes an onshore storage site with a planned capacity of 1.5Mt annually, began development prior to any regulatory framework being put into place; while a seemingly risky decision has actually put them in the ideal place for contributing to the creation of new policy as it aligns with the project at hand. While maintaining a strict and lengthy licensing process to ensure safety in all aspects, the Netherlands is currently developing two CCUS projects to help put them on track for a 50% reduction in emissions by 2030. As the largest emitter in the western hemisphere, the US is supporting CCUS development through upgraded incentives and updated eligibility to remain competitive; alongside a potential CCUS consortium of petroleum industry giants focused offshore in the Gulf of Mexico, the US is poised to be a western leader in CCUS technology implementation. While many of these projects and associated policies are still under development, positive advancements displayed by nations at the forefront of CCUS growth serve as favorable indicators that similar projects and regulations could be successful if put into effect in eastern Canada.

The issue at the forefront of the forum was the need for a regulatory framework surrounding carbon-based emissions reduction technologies and methods, both federally and provincially. There are a number of obstacles to overcome while putting a regulatory framework into place; emerging technologies, the Canadian economy (especially when it come s to investing in proposals), existing policy, and public perceptions must all be taken into account. The resulting regulatory framework must adequately address all policy gaps to promote successful projects; monitoring, measurement, and verification (MMV) of viability of the site in question, intricacies regarding pore space within geological formations fit for storage, licensing processes for the industry side of the equation, and the assumption of liabilities.

Despite the best efforts of a handful of industry members and governmental bodies, we are not currently conquering the conflict that is climate change. Nominal progress has been made towards a more environmentally sustainable society, but not enough to slow our projected rise to a global warming of 1.5°C above pre-industrial levels, even with the previous worldwide deceleration due to the pandemic. Real change, at an accelerated rate, is desperately needed to reach our climate goals and transition into a future that is beneficial for society, the environment, and everything in between.

To reduce CO_2 emissions in eastern Canada through CCUS methods, the following actions are proposed:

- Creation of a regulatory framework for onshore and offshore geostorage that covers the main issues currently being faced: MMV of site viability, pore space ownership, industry licensing, and assumption of liability.
- Determination of sites with suitable storage capacity and characterization of the subsurface and associated risks.
- Development of test sites to initiate early injection projects and ascertain future feasibility.
- Establish the most suitable transportation type and route, while remaining conscious of emission outputs.
- Organize a public outreach & education plan to inform on technology, potential effects, and successful examples, while moving away from commonly held misconceptions.

INTRODUCTION

On April 19th and 20th 2023, the Carbon Neutrality Forum was held at Dalhousie University thanks to generous funding from Natural Resources Canada (NRCan). Organized by members from the Basin & Reservoir Lab at Dalhousie University, the Nova Scotia Department of Resources and Renewables, and Net Zero Atlantic, the Carbon Neutrality Forum hosted participants both in person and online from domestic and international backgrounds. The forum was created with the aim of helping the provincial and federal governments, along with industry and academia, develop the best practices and review the latest technical developments on reducing emissions and related impacts.

Contributors presented topics ranging from emerging technologies and methods for carbon sequestration, provincial progress on the road to net-zero emissions, lessons learned from countries leading the charge, and the social, political, and economic interconnectivity when it comes to achieving our climate goals. Due to Chatham House Rules being in place for the duration of the forum, the majority of the information presented in this paper will not be referenced to a single source, individual or organization.

While several emissions-reduction approaches were touched on, including bioenergy, hydropower, and geothermal, carbon capture, utilization, and storage (CCUS) was at the forefront of the discussion. CCUS projects operate with the goal of capturing carbon dioxide emissions from the atmosphere or directly from emitters, subsequent transport requirements, potential use for enhanced oil recovery and other CO_2 recycling methods, and eventual long-term storage, specifically within subsurface geological formations.

Provincial perspectives were shared in terms of ongoing projects, current policies, and potential for the future. BC, ON, NS, and NFLD have been considering the viability of geological storage of CO_2 in available saline aquifers and reservoirs previously containing hydrocarbon deposits. Alberta is leading the charge with a number of active and planned CCUS projects including the newly operational Alberta Carbon Trunk Line. Saskatchewan has also ventured into the realm of CCUS, with the Weyburn project that started in the 90s and has sequestered millions of tonnes of CO_2 to date, as well as a storage testing site created to measure and monitor conditions and provide evidence of project feasibility. Quebec is noted as a bit of an outlier, with a total ban on oil and gas which includes permits for carbon capture, the province will be sticking with their proven hydropower source well into the future.

International perspectives were shared from Norway, the Netherlands, the UK, and the USA. Norwegian presenter discussed the Langskip and Northern Lights projects, as well as the development of the Norwegian Continental Shelf project. For the Dutch, there are two offshore CCUS projects nearing an official start date, as well as an incredibly detailed licensing process to take note of. The UK is also working on project development in northeast Scotland, facing similar challenges as Canada regarding regulations. As with many things, comparison to the US is unavoidable; in the case of incentives, the US is providing much more financial and regulatory support to proposed CCUS projects.

Based on the information presented at the forum, alongside additional research completed through sources provided by presenters and publicly available data, comes this report detailing the current issues we're facing in the race to reduce carbon emissions, and the potential solutions available for implementation, specifically as it relates to eastern Canada.

The main sections of this report are classified as follows: 1) general concepts, detailing the general ideas, concepts, and technologies as they relate to carbon emission reduction, 2) perspectives from each province on current developments and known potentials, 3) perspectives from countries leading the charge in carbon reduction technologies, alongside regulations and incentives that could be drawn from, and 4) current issues with policy, monetary factors, and public perceptions, and potential solutions. While there is a variety of information presented across a wide geographic range, the intent is to use those global examples to create a regional resolution to the circumstances we current face in eastern Canada.

GENERAL CONCEPTS

Carbon Capture, Utilization, and Storage (CCUS)

Climate change and global warming have been growing issues for decades as we learn more about how society's habits are impacting the earth in many ways. While all greenhouse gases (GHGs) have some effect on atmospheric warming, not all are created equal. Compared to other GHGs like nitrous oxide, methane, and fluorinated gases, carbon dioxide (CO_2) may not be the most severe constituent, but it is the most abundant gas with the greatest longevity in the atmosphere. CO_2 is also a relatively safe gas as it is non-toxic at low levels and non-flammable, so there is low risk of negative impacts regarding its sequestration. These features are why CO_2 is the focus of emerging technologies in the combat against climate change.

CCUS technology was developed as an approach to handle carbon emissions in a way that reduces the anthropogenic influence on our atmosphere while also putting to better use the emissions captured. Typical technology could include the capture, transport, use, and storage of CO_2 emissions.

The first step in the carbon sequestration process is capture, where CO_2 is trapped to prevent it from being released into the atmosphere, which is typically done directly at the point source of emissions. The capture aspect in practice tends to target large emitters, such as petroleum refineries, fertilizer facilities, and cement plants, as they provide large, steady amounts of emissions to work with, and it helps offset their impact. These types of industries are sometimes demonized for their emission statistics and contributions to climate change, so finding an endpoint that isn't the atmosphere for at least some of their emissions may help their image, reduce the impact of emissions taxes, and encourage them to adopt cleaner processes.

Once the CO_2 is captured, it must be transported to either the point of use or the place of storage. Details on modes of carbon transportation will be discussed further in the following sections.

There are multiple uses for sequestered CO_2, some of which can be considered as recycling. It can be used for addition into carbonated beverages, the creation of dry ice, and assistance in chemical conversion processes for numerous industries. Perhaps the most frequent use of captured CO_2 is for enhanced oil recovery, where pressurized CO_2 is injected into oil wells with the intent of forcing remnant petroleum out of tight pore spaces and other hard-to-reach areas within a petroleum reservoir. This is a common practice with established CCUS facilities, as many are situated within existing oil fields due to the similarities in required infrastructure.

The final step in the process is storage, which can be either temporary or permanent depending on the intended use. Temporary storage could be within pipelines or specially designed facilities, somewhere within a CCS site system where it can be easily moved around or sent off for use in industry. Longer term temporary storage includes innovative solutions such as injecting CO_2 into cement products. A more permanent solution would be injection into suitable geologic formations, which is discussed in detail in the next section.

While there are many potential solutions that can be integrated to aid on the path to carbon neutrality, CCUS was the technology at the forefront of the Carbon Neutrality Forum 2023.

Geostorage

Geostorage refers to storing CO_2 within appropriate subsurface geological formations, as opposed to within manmade facilities or pipelines. In order for a geological formation to be successful, the appropriate parameters must be assessed; those requirements include capacity, containment, storage efficiency, and monitoring.

There are a number of rock types that have potential suitability when it comes to CO_2 storage, including depleted oil and gas reservoirs, aquifers, salts, basalts, and unmineable coal seams. Along with the type of rock comes structural forms that can aid in achieving the storage requirements, such as traps including domes and anticlinal structures, as well as sealing layers and faults. Sites that have already undergone exploration or exploitation for petroleum resources tend to be some of the most suitable choices, as the strata have already been proven to hold oil and gas, and development activities related to the subsurface (like wells and boreholes, containment facilities etc.) are typically already in place, and have already seen regulatory oversight. Although some wells would prove useful for access to the subsurface, many would have to be plugged to prevent seepage of gases out of the reservoirs.

However, with natural geologic formations comes natural risks. Interfering with complex subsurface relationships can provoke changes in uplift, deformation, microseismic events, geothermal gradients, and well leakage. For governments and society at large to recognize and support geostorage, sedimentary basins and other associated geologic formations must be derisked.

Many of the appropriate rock types for CO_2 injection are sedimentary in nature, as sedimentary rocks like sandstone are to some degree porous and permeable, and it is the pore space between the grains that will be holding any injected gas. For an area to be deemed suitable for CO_2 storage, the volume of the pore space in the area must be assessed, but this pore volume is already filled with brine or local accumulations of oil and gas. These natural pore fluids will need to be displaced to accommodate large-scale CO_2 injection.

There are complications in accessing pore space volume with suitable capacity for geostorage. The first is channeling, where the rock has some beds, joints, or faults of high permeability along which the CO_2 will flow preferentially, disallowing access to beds of lower permeability and thereby losing available pore volume. The second is viscous fingering, which refers to the instability that arises when a low-viscosity fluid (CO_2) is injected into a porous medium saturated with a higher viscosity fluid (brine); the injected fluid "fingers" through the medium, rather than efficiently displacing the brine, losing useful pore volume for storage. The next is gravity override: CO_2 is buoyant compared to brine so it will rise to the top of the reservoir, losing access to the lower pore volumes. Finally, there is the capillary blockage effect where injected CO_2 cannot enter a small pore throat because of the resisting brine- CO_2 surface tension; this means that the pore volumes in all the rocks of low permeability (small pore throats) are not available for storage.

Another barrier is regional pressurization; unless the reservoir is connected to distant outlets for brine, as more CO_2 is injected the reservoir will become increasingly pressurized, and the ability to inject declines as pressure builds. This will cause hydraulic interference that limits the proximity of adjacent injection wells, and will constrain the total CO_2 volumes that can be injected over a long time interval. Considering these barriers, there is much to consider when assessing a formation for storage suitability and long-term capacity.

For geological storage to become a commercially viable option in the eyes of the government and investors, they will need reasonable estimates and feasible statistics on the required parameters. Proposals for regional quantification, mathematical modeling, scenario analysis, best injection strategy, stochastic analysis, optimal strategy, and field verification should all be considered as we continue to push towards geostorage opportunities. Once geological formations have been characterized for CCUS, the technical and economic requirements of a project, and its social and environmental impact, can be assessed.

CO_2 Transport

When it comes to the transportation of sequestered CO_2, the destination will be to the point of use or the place of interim storage. There are four main forms of potentially suitable transportation with varying features to factor in.

It must be emphasized that the need for both technical feasibility and competitive commercial viability ensures that a full CCUS value chain for offshore projects will likely utilize all elements in various combinations optimized to create a collection system tied into individual emitters. These sites would be mostly concentrated in an urban industrial setting, feeding storage and/or a hub on land, tied to a bulk transportation system to reach a marine hub with storage and/or throughput to offshore injection sites.

Trucks could be used to transport small volumes of gas. Modern truck transport includes containerized pressure vessels scaled to meet standard container specifications (TEU) to allow a seamless transfer between truck, rail car, and container ships. Specifications and regulations already exist or could be further adapted for specific CCUS needs. The incremental scale at which CO_2 is captured and stored on a broad range of urban industrial sites will vary greatly, so the distance needed to transport CO_2 from a point source industrial emitter to industrial consumers (utilization) will tend to be small given industrial municipal zoning and the tendency for facilities to optimize supply chain transport distances and costs. One advantage to adapting emitters to containerized pressure vessels would be smaller Brownfield engineering and retrofit costs (compared to retrofitting regional gathering lines across an urban industrial setting); since the opportunity and direct costs of shutting down major urban centers including transportation arteries to install dedicated pipelines could be significant, and small facilities may take a long time to fill a single container on-site while larger emitters might have multiple units being filled over the same period. Most if not all industrial plants requiring CCUS retrofit could adapt existing transportation infrastructure and Transport Canada regulations. The scalability of containerized CO_2 at the plant scale makes road transport attractive for gathering from point sources in an urban area and moving CO_2 relatively short distances. One challenge is that each truck can only move a single unit at a time and larger plants with greater emissions to manage may require considerable truck traffic which adds to logistical challenges and increased emissions. It may also present the greatest risk, in terms of road accidents.

DNV and others are already exploring the potential of adapting tanker solutions used for compressed natural gas to CO_2. Low and medium pressure solutions are handled under the existing regulations, while DNV is exploring a solution utilizing high pressure transport vessels, a route which does not currently meet existing regulations. Containerized CO_2 transportation requiring purpose-built units may be feasible for upstream and midstream transportation to collection hubs and potentially to onshore injection sites, but transportation to an offshore injection site is more likely to require bulk transport by purpose-built vessel. Port hubs supplied by containerized units brought by truck and rail would require loading facilities servicing specialized vessels. Alternatively, hub facilities can be supplied by pipeline and port hubs can supply offshore injection sites by subsea pipeline.

The competitive value proposition for rail is scalability, where multiple tank cars can sit on a siding at a plant until there are enough to be moved economically. Rail connectivity exists at most large plants. The rail system in Canada is extensive and links major centers to port facilities with loading and unloading infrastructure and storage yards until sufficient volume exists to either load a vessel with containers or offload to a bulk CO_2 carrier, depending on the offshore injection facility design and operations. While road transport is limited to a single TEU per vehicle, rail achieves economies of scale with trains of potential hundreds of TEU's and the ability to move and track individual rail cars anywhere in North America. In addition, Transport Canada already regulates transportation of liquid and gas by rail. North America's rail transportation system allows hinterland expansion and potentially imports of CO_2 for sequestration from jurisdictions lacking viable storage capabilities but are connected by rail. Rail is also a relatively low carbon emissions solution compared to truck transport.

The most effective means of transporting large volumes is by pipeline. Despite the primarily negative public perception regarding pipelines, especially the construction of new pipelines, they remain a highly reliable source of transport for gases. It has the lowest cost per unit for large volumes and is relatively low maintenance. While the pipeline parameters may make it the most efficient means for moving sequestered CO_2 to injection sites, it would be challenging to have a new pipeline approved by the governing body and local populations. That said, the engineering and construction jobs associated with a CO_2 line and its ultimate role and potential impact on Canada's emissions targets may mitigate some of the negativity surrounding oil and natural gas pipelines. Two scenarios, that may both be part of a single project, are onshore and offshore pipelines.

Onshore pipelines may be supplied by multiple point sources with laterals tied into a single transportation corridor, or may be sourced by truck or rail to a hub location where it makes technical, environmental, social, and economic sense to optimize the project by using a pipeline for bulk transport. Pipelines often run through multiple jurisdictions and require considerable consultation with a range of communities and stakeholders. The potential for considerable delays during the environmental assessment and consultation process can impact the commercial viability of a project. Proposals for modern oil and gas pipelines in recent years show how challenging it can be to gain the necessary approvals. Its role in meeting climate change targets may soften the resistance, but requires public education and project promotion from the earliest stages. Fiscal considerations such as pipeline tolls in the form of carbon credits applied to CO_2 throughput may increase community support as a buffer to the Government of Canada's carbon tax which makes CCUS economically feasible. Offshore pipelines for CCUS projects have been explored in multiple foreign jurisdictions and offer the possibility of using existing technology and expertise to provide a direct link to an offshore injection platform or fully subsea injection site. The commercial viability of stand-alone projects remains uncertain compared to the economic advantages of CO_2 injection for enhanced oil recovery (EOR), where boosting production contributes to the overall project return on capital invested in subsea CO_2 pipelines.

Hydrogen

Interest in hydrogen gas for use in electricity generation has been on the rise, as when it is produced using suitable methods, water is the byproduct opposed to the gases created through combustion of fossil fuels. As it is a different energy type than what the grid is accustomed to, our current systems and networks are not ready to take on hydrogen as a commonly used resource. Energy pipelines, meters, surface or subsurface storage systems, turbines, and pumps are known to not be suitable for 100% hydrogen fuel. Testing of typical appliances is underway to determine the optimal concentration of hydrogen fuel to be used with existing infrastructure and equipment, for example in a CH_4/H_2 blend. Current data suggests that 20-30% hydrogen blended with natural gas is compatible with existing components used in power generation, suggesting this is the first step in integrating hydrogen into the fuel portfolio for power generation.

Although we may be getting closer to reducing emissions by using gas blending methods, there are still risks and limitations to the approach. As the gases are combined, the energy density per volume is decreased but the velocity within the pipe increases, a trade-off of sorts. When hydrogen under pressure diffuses into certain materials like steel, the metal can become brittle and increase risk for cracking, which could be an issue in a system made mostly of steel goods under pressure. For various end-user appliances, especially kitchen stoves, water heaters, and heating systems, would a change in fuel source, one that the appliance was not originally designed for, affect its operation and level of risk?

Despite moving closer to realizing the potential of hydrogen fuel through gas blending, there are still risks and limitations to the approach. The interaction of hydrogen with different metals, the key components of piping systems and storage tanks, can lead to brittle failure, especially under pressure. Further scientific and materials engineering research is required to understand containment and transport requirements for the safe and sustainable long-term adoption of hydrogen fuel. It holds considerable potential for motive transport in fuel cells in addition to larger scale power generation, but much more research is needed to ensure it is a viable, safe alternative, and to understand the extensive retrofits required in our energy systems to successfully adopt and integrate hydrogen into the energy mix of the future.

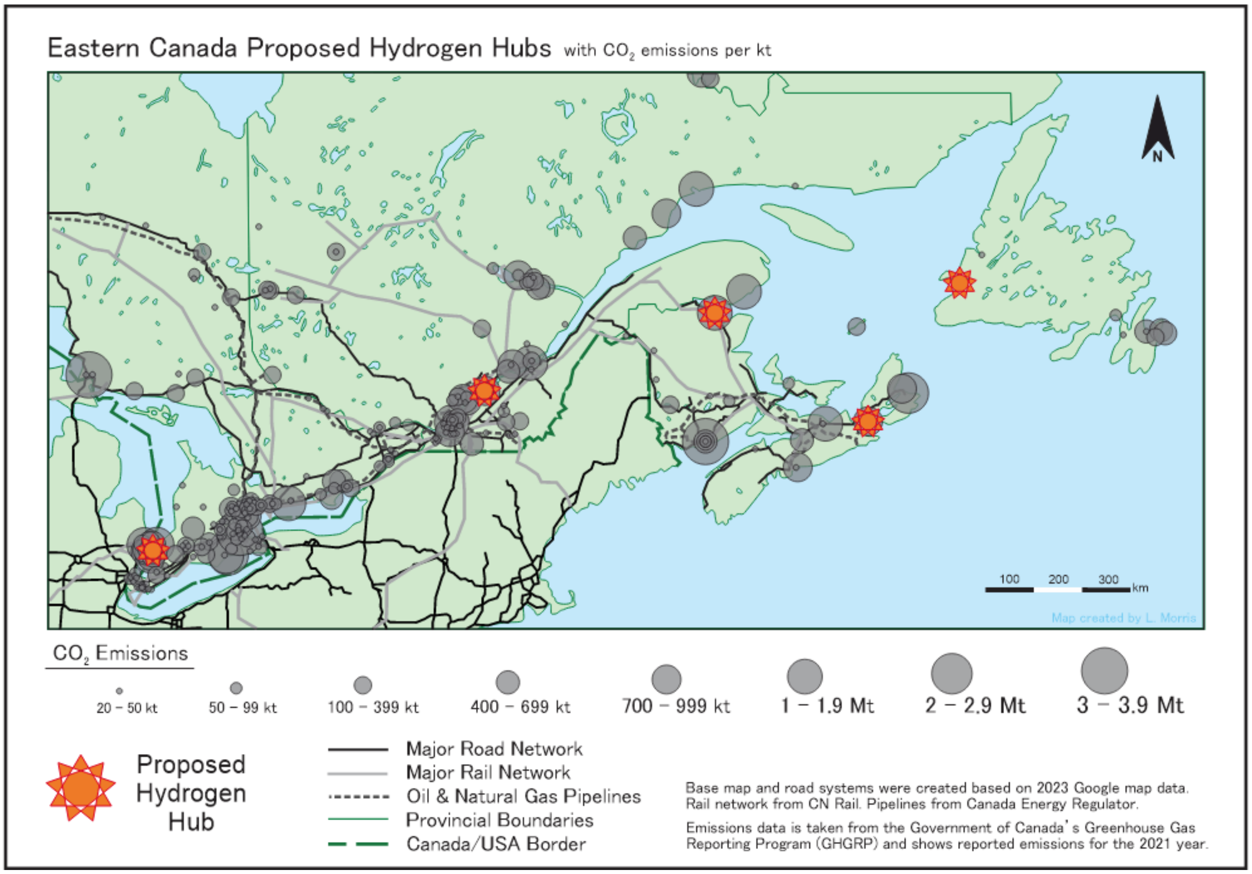

Figure 2: Annual CO_2 *emissions of eastern Canada, classified by emitter type and emissions in tonnes per annum (grey), alongside proposed hydrogen hubs in the region (emissions data from GHGRP, map created by L. Morris).*

Provincial Perspectives & Projects

British Columbia

The Pacific-coast province is working towards their carbon neutrality goals by assessing the geological storage potential for CO_2 in subsurface bedrock. A new geological atlas for the province has been recently published, created from repurposed historical maps for the purpose of identifying regions with the highest carbon storage potential. From these maps and further exploration, the northeastern region seems to have the best opportunity for the province. Northeastern BC appears to hold the greatest promise.

The region in question may already have the right combination of factors to be a successful hub for CO_2 sequestration and storage. A good number of point emitters including oil & gas processing, paper and pulp mills, power generation, and mining operations are currently stationed and operating in the area. Subsurface data and infrastructure from legacy oil and gas projects include tens of thousands of wells which would assist in the assessment of CCUS potential. To date the greatest potential is thought to lie in saline aquifers and depleted natural gas reservoirs.

Considering the area has already been exploited for petroleum resources, the geologic structure of the subsurface is well known and well recorded in terms of industry involvement. The province has been producing oil and gas from Devonian-Cretaceous reservoirs, as well as experiencing unconventional development in shale gas reservoirs in the past decade. Based on their knowledge of the geology of the area and the presence of a thick stratigraphic column, the provincial focus is primarily on saline aquifers and depleted gas reservoirs as they seem to have the most potential for large-scale storage.

The subsurface geology of various fields is known from the context of petroleum exploration and development activities of the past, but the porosity, permeability and seals associated with hydrocarbon reservoirs may be inadequate for CO_2 storage and must be reassessed through that lens. While theoretically the entire pore space that was once filled with hydrocarbon gas could be injected with carbon dioxide, effectively that amount would be reduced by an estimated 15%, which may raise questions of potential. And with all sedimentary rocks, there lies an element of heterogeneity that may complicate things. There exists a wide range of porosities and permeabilities, relationships between the two factors, and variability in the lateral extent of these strata.

Alberta

Albertan CCS projects have been operating successfully in the province for decades and have amassed a considerable body of operational data. The Quest project, originally established by Shell Canada with several partners and funding from provincial and federal sources, is one of the world's first commercial-scale CCS projects (>1,000,000 tonnes CO_2/year). CO_2 from the Scotford upgrader east of Edmonton has been pipelined 90km to Boyle, Alberta, since 2015, where it is injected into sandstones of Cambrian age at a depth of about 2 km beneath a superb continuous salt bed that serves as a regional seal. It has provided 8 years' worth of injection records and associated monitoring data, all published on an Alberta government website. The longevity and success of the Quest project is a positive indication of what is able to be accomplished in the realm of CCUS, and will hopefully promote the development of similar projects. In fact, there are several CO_2 storage projects proposed for the same general region northeast of Edmonton, and the permitting process for these is currently underway.

Another project, the Alberta Carbon Trunk Line (ACTL), described as "the world's newest, integrated, large-scale carbon capture, utilization, and storage system", became fully operational mid-2020. The project makes use of two CO_2 sources on the north end of the system (Northwest Sturgeon and Nutrien Redwater, a refinery and fertilizer plant respectively) and transports the gas downpipe for use in enhanced oil recovery. The 240 km long pipeline has the capacity to gather, compress, and store up to 14.6 million tonnes of CO^2 per year, an order of magnitude larger than the Quest Project. The facilities were designed to be efficient as possible; recovery points and compression stations are placed near each other to lessen transport distances, impact on emitters is minimized with flexibility in containment processes, and the pipeline supports multiple storage sites.

Like the rest of the country, there are a number of limitations to progress on getting to carbon neutral. The main roadblock to implementing projects such as CCS or geothermal energy development is insufficient data to support the theoretical proposals. Investors require greater certainty in reservoir performance to consider risking the necessary capital for additional projects, though improved confidence is driven by robust legislation and regulatory pathways to ensure projects are economically feasible and the public interest is protected.

While geothermal may be one of the best routes for achieving net zero by 2030, Alberta's geothermal potential does not necessarily align with its population centers or power grid. Considering Canada's cold climate, geothermal development for heat and power would make sense; however, the expansive geography and dispersion of the population is not overly favorable for heating projects because heat cannot be transported very far. This means that geothermal energy adoption must be tailored to local community economic development projects where grid connection is not feasible, or connecting to the grid where it is. The advantage of geothermal energy is that it offers a long-term energy source that can increase the attractiveness of small communities with the ability to offset Canada's northern climate with greenhouses or other small businesses whose off-grid energy supply may reduce the demand for fossil fuels.

Saskatchewan

Alongside Alberta, Saskatchewan was one of the first provinces to explore the realm of CO_2 capture and storage. The Weyburn project, in a region formerly used for oil extraction, was developed in the late 90s after initial drilling was completed in anticipation of a need for carbon storage. Collecting waste emissions from Saskatchewan power stations and a synfuels plant out of North Dakota, not only is this site used for simple storage, but the injected CO_2 is also used for enhanced oil recovery. Weyburn has stored about 40 million tonnes of CO_2, driving the recovery of 100 million barrels of oil that otherwise may not have been accessible, and it remains the world's largest anthropogenic CO_2 sequestration project.

Aquistore is a Saskatchewan-based project from the Petroleum Technology Research Centre (PTRC), to measure, monitor, and verify the safe and workable solution of storing carbon in underground aquifers. After almost two decades of experience with CO_2 storage monitoring, formerly through the Weyburn-Midale Project, the PTRC launched Aquistore. Their goal is to demonstrate that CO_2 storage in deep saline aquifers is a feasible venture, to provide a baseline example for those considering their own CCS projects, and to develop and improve monitoring technology leading to better outcomes in terms of project management and repository use. The project is research-oriented, with annual injection volumes about one tenth those of the Quest Project. Currently, after several years of injection, the basal Cambrian sandstone reservoir holds approximately 550,000 tonnes of CO_2 provided by the nearby SaskPower Boundary Dam Power Station.

As a testing Facility, Aquistore has several features a typical CCUS site may not possess. Most injection wells require layers of tubing strings and casings, providing the opportunity to include a variety of sensors within the well, such as pressure and temperature monitors. Alongside borehole measurements, monitoring methods include an extensive geophone array helpful in building realistic models for long-term projections. Soil testing and other environmental metrics are collected regularly to assure system integrity and exercise risk management. They also assess the effect of injection variability on the infrastructure as well as in the aquifer being used for storage. Challenges include temperature differences, inconsistent injection rates, and salts falling out of solution and filling pore space which alters the effective porosity and reducing the permeability, thus impairing injectivity. The Quest Project experiences similar phenomena, and periods of injection of warm fresh water have been implemented to dissolve the precipitated salts and flush them farther from the injection wellbores.

As one of the largest CCUS industrial research and testing facilities, Aquistore plans to focus on comprehensive monitoring and measuring project performance and promoting associated technology. Future plans include expansion under a commercial operating license, modeling other prospective aquifers and reservoirs for future development, and expand as a CCUS hub in Saskatchewan. The participation of partners from six other countries bodes well for furthering CO_2 storage in sedimentary basins elsewhere in the world.

Manitoba

Manitoba generates nearly 100% of its power from clean hydro and is focused on energy efficiency and biomass. It has implemented a 'made in Manitoba' approach to achieving its emissions goals and has provided subsidies to its citizens to counter the inflationary challenges associated with the federal carbon tax. The province has many industrial emitters including agriculture, manufacturing, mining, and forestry, though it has an advantage in an early reliance on clean hydro for power generation.

Ontario

Ontario's large geographic area and population, combined with it being the hub of the Canadian manufacturing and distribution, has created an abundance of emitters and a significant challenge in terms of the volume and percentage of Canadian emissions. Emissions come from manufacturing, cement plants, automotive sector plants, paper, forestry, refining, and much more. Ontario lags only Alberta in terms of tonnes CO_2 equivalent generated, most of which is from extensive industrial activity in the southern part of the province. Manufacturers and utilities emit 25 MT/yr of CO_2, which is approximately half of the total before Ontario Power Generation shut down its coal-fired power plants in 2012. The biggest emitters are steel and cement plants, oil refineries, and gas-fired power plants.

Ontario's geological CO_2 storage potential lies primarily in saline Cambrian aquifers north of Lake Erie. Other potential in depleted oil and gas reservoirs include the Innerkip gas field, Cambrian sandstones and Ordovician carbonates but these are penetrated by a large number of legacy wells. The cost and work associated with plugging hundreds of legacy wells may not be worth the benefit of using those reservoirs as CO_2 storage. The most prospective part of the Cambrian could entail offshore (lake) operations and is situated on a corridor with considerable, diverse land use associated with Lake Erie's watershed, unfortunately resulting in strict project requirements and challenging approval processes that may not align with Canada's emissions commitment schedule. Furthermore, the distribution of emitters does not align well with the optimal potential sites of injection and storage, requiring considerable transportation infrastructure. The timelines for getting a full CCUS project through development and approvals to a point where they are ready to inject do not fall in line with the 2030 targets, unless they plan on fast-tracking 10+ years of work, which is unlikely.

Ontario could be a potential candidate for offshore sequestration in partnership with the Atlantic provinces. Considering most emitters are in the Great Lakes region, transport through the St. Lawrence

Seaway to offshore east coast CO_2 storage injection sites could be a feasible option. Even smaller emitters that are further north than the population core could transport emissions via road or rail access to hubs or ports that would send the larger quantities out to the Atlantic.

At present, there is no regulatory framework to guide geological CO_2 storage in the province, although the recently passed Bill 46 does permit CO_2 injection for sequestration and enhanced oil recovery. The lack of policy on CCUS projects paired with the hesitancy to begin exploratory drilling and testing will only further delay any progress being made in the CCUS realm, likely leading to the province favoring alternative methods for decarbonization.

Québec

In 2022, the government of Québec banned oil and gas development in the province alongside a mandate to shut down any existing drilling sites within the following three years. While this is largely seen as a win for the fight to reduce emissions, the permit revocation for petroleum projects includes those issued for carbon storage proposals, effectively banning any development regarding CCUS. Although, considering the likely issues surrounding transport and geological storage opportunities, Quebec does not hold the potential for successful, large-scale CCS ventures, regardless of any policies in place.

Despite not being able to complete CCUS projects within the province, an indirect approach to carbon capture technology development centered around the creation of AI models is in the works. Based on a large dataset of detailed simulations, the models would calculate the cost of CO_2 capture for all major emitters. Knowing the costs and benefits of a specific project could provide preliminary details in the quest for more funding and promote proposals being put into place.

Currently the province is looking more towards the organic side of things. Bioenergy CCS (BECCS) would take the emissions available from pulp and paper mills specifically, to store and produce power and steam. This approach could have the potential of generating negative emissions, possibly offsetting sectors less prone to decarbonization.

Alongside these newly proposed developments, the province remains a leader in global hydroelectric power production. With a major reliable renewable clean energy resource like water, the infrastructure and policy already in place, and a positive perception for both the public and the private sector, hydropower should be considered Québec's best way forward along the path to carbon neutrality.

New Brunswick

The geologic potential in New Brunswick is largely unsuitable for CO_2 geostorage or geothermal ventures. Many regions consist of metasedimentary and crystalline bedrock, which along with the in-situ petroleum systems have low porosity and permeability, would not be conducive to successful CO_2 storage. Also, areas with tectonic compartmentalization and extensive faulting present barriers to large-scale site implementation and would require comprehensive derisking.

Geothermal potential is limited by regionally low geothermal gradients, characteristic of New Brunswick. To access appropriate temperatures to exploit the geothermal potential for electrical power, drilling would have to extend at least five kilometers deep, raising project expenditures and risking geothermal energy production becoming unfeasible.

Despite the bulk of the province being relatively unsuitable for geothermal, there remain several offshore areas that may have storage potential. The North Mountain Basalt in the Bay of Fundy, as well as deep aeolian sand deposits in the Gulf of St. Lawrence off the coast of Gaspé, may have the porosity and stratal thickness needed for potential storage solutions. Questions arise regarding the prospectivity of the geology in these areas, and regulations regarding CO_2 storage offshore are not yet in place. In addition, offshore territorial limits with neighboring provinces would need to be clarified with respect to subsurface rights, and a federal-provincial regulator would need to be established to provide oversight on any activities related to offshore CCUS. Pipelines, costs, and public perception also remain barriers, and currently there is no activity in the province related to CO_2 storage.

In 2020, the Atlantic Loop was proposed, a project to link the energy grids of Québec, New Brunswick, Nova Scotia, and Newfoundland & Labrador. The interconnected transmission grid would see power generated from nuclear, tidal, wind, and hydro stations shared between the four provinces, expanding and strengthening existing energy structures. The proposed plan would have benefitted Nova Scotia especially, as the province struggles with a high percentage of electricity generated from coal, the import of cleaner energy from other provinces would help achieve targets much faster. As of October 2023, the original proposal was modified significantly with only New Brunswick and Nova Scotia moving forward with expansion plans. Estimated costs of the full project, alongside significant increases in energy rates for consumers and uncertain energy commitments from Québec prompted the alteration of the plan, with NB and NS focused on eliminating coal-powered generation through whatever means possible. While full funding for the proposal is still unclear, any progress towards a cleaner grid is a step in the right direction.

Nova Scotia

Nova Scotia may be a small province, but it has big plans to achieve carbon neutrality. With a goal of having 80% electrical power from renewable sources by 2030, initiatives are underway to reduce emissions, develop wind energy, pursue tidal power development, access more hydro power, increase accessibility of solar panels through incentives, encourage adoption of electric vehicles, and strategies to decarbonize industry by pursuing CCUS. Nova Scotia's Climate Change Plan for Growth is based on four guiding principles: Netukulimk (in short, the human side of things), sustainable development, a circular economy, and equity.

By 2019, over half of Nova Scotia's electricity generation was from coal and coke, while power rate increases are facing heavy resistance from property owners and industry as production costs rise proportionally. To be sustainable, power generation must provide affordable electricity in a province already struggling with inflation, affordable housing, and health care challenges. As a region that has run off dirty fuel since its inception, even if the province can achieve its 80% renewables target in the next 7 years, achieving that last 20% by 2050 will be challenging. Power generation cannot be entirely from intermittent sources, so a replacement for coal and coke will need to be found, the generation infrastructure retrofitted or replaced to support new fuel types, or power purchase agreements from other provinces such as the Fixed Link to Newfoundland and Labrador's Lower Churchill Falls. One setback has been the huge cost overruns and delays. The existing power grid is also dated and unlikely to be adequate for the new loads, requiring further extensive investment, and all these massive additional future costs must be passed on to the rate-payer while maintaining affordable power rates. After years of provincial cap-and-trade carbon pricing, Ottawa will impose the federal carbon tax on Nova Scotians this year, raising gas prices by over 10c overnight and further driving inflation for the population. The pressure put on the province from these taxations will serve as further incentive for NS to reach their goals and transition to renewable, but at what cost?

Considering the 80% renewable energy goal, renewables will continue to grow and gradually replace fossil fuels. The speed of that transition, however, may be insufficient to achieve 2030 targets as major concerns accompany massive renewable energy implementation: intermittency and variability characterize solar, wind, and tidal power provision. This would bring up the point of excess storage, which may involve transport, all of which may not be desirable for those committed to the projects. There is also the issue of space and location, which can end up being a substantial use of land, something we don't have an excess of in Nova Scotia. There have also been growing cases of pushback by landowners who have had adjacent forests, which naturally sequester CO_2, cut down for solar farms.

Nova Scotia has great potential to harness the power of the highest tides in the world, conveniently located within the Bay of Fundy. While there are several active tidal power generators, one major project has withdrawn from the area due to impassable regulatory barriers. Sustainable Marine Energy, a tidal power company collaborating with the non-profit Fundy Ocean Research Centre for Energy (FORCE), has been submitting applications for a tidal project in the Minas Passage for years, even receiving millions in investments from Natural Resources Canada for the project. Fisheries and Oceans Canada (DFO) has halted any progress on the basis of the project being high risk due to the underwater turbines' effects on marine life, especially for at-risk species present in the Minas Passage. Sustainable Marine Energy and the DFO could not come to an agreement on appropriate environmental monitoring procedures, resulting in the project being pulled. Government regulators and tidal power companies will have to get on the same page in the coming years if we are going to employ the massive potential of the Bay of Fundy's tides, perhaps our best renewable option in the transition from fossil fuels.

There are many critical questions that remain to be answered if the fuel mix is to be sustainable economically and socially as well as environmentally and a very short timeframe to address them. Since the ultimate goal is carbon neutrality as opposed to the elimination of all carbon-based fuels, a potential solution lies in CCUS.

Nova Scotia's offshore region, the Scotian Margin, possesses considerable geologic storage potential. While the Scotian Slope storage capacity is limited by lack of effective porosity and permeability in addition to overpressure issues, the Scotian Shelf displays characteristics more suitable for CO^2 geostorage, with an estimated potential of 100 Mt in storage capacity within depleted oil and gas fields. Appropriate CCS play elements can be identified in regions offshore, some fields exhibiting more potential than others. The offshore basins of interest have reservoir-suitable sediment compositions, specifically within the Upper and Middle Mississauga Formation, comparable to the fluvial-deltaic sandstones seen in the Blomidon and Wolfville formations onshore. The placement of the Scotian Shelf on a low latitude passive rift margin with aquifers found below regional mud-prone wedges promotes ample containment, and overpressure is mainly confined to the slope. Along with established permeability, levels of production, and direct data from cores, the region makes a compelling case of geostorage potential (Richards).

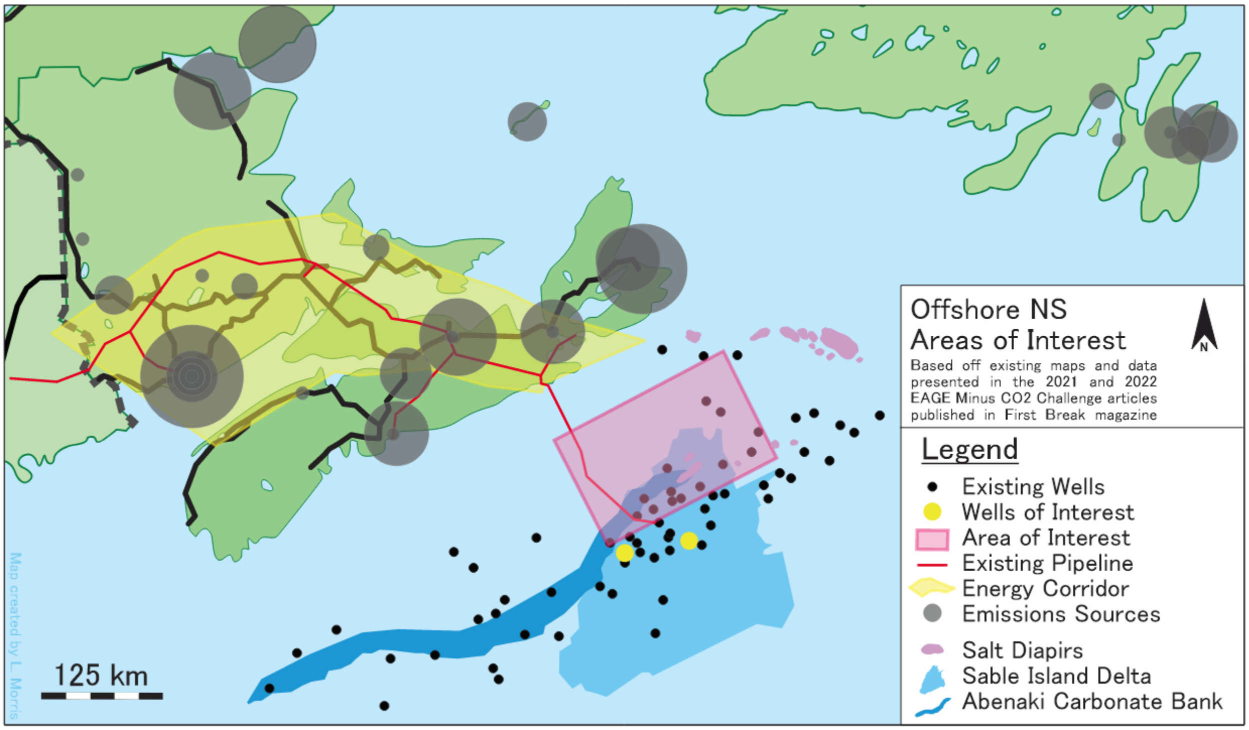

Figure 3: View of the Atlantic provinces with a focus on offshore Nova Scotia. Areas of interest for geostorage and energy-based solutions are highlighted: the yellow polygon covers the area referred to as "The Energy Corridor", a region with the best opportunity for onshore development based on the currently available resources and infrastructure; the pink box offshore depicts the suitable region for geostorage exploration based on available data; and the two yellow circles depict the drilled wells from depleted fields that would be best chosen for CO_2 *injection, Alma on the left and North Triumph on the right (Figure based off the Minus* CO^2 *Challenge Final Reports published in EAGE First Break; from 2021, Figures 4 & 7; from 2022, Figure 6; with assistance and permission from F.W. (B) Richards).*

Following interpretation of numerous data sets available regarding the offshore fields in question, the Alma and North Triumph fields are ranked highest in potential, with 30.7 and 14.5 Mt in estimated storage respectively; both fields are seen as single reservoirs within the Upper Mississauga Formation, lay at suitably shallow depths, and exhibit reasonable hydrostatic pressure. Compared to the complex depletion pressures and overpressure, low relief pools, and issues in drilling and subsequent CCS predicted for other offshore fields, Alma and North Triumph illustrate the first-choice fields for going forward with CCS development offshore Nova Scotia. Potentiality may also reside in deeply situated saline aquifers, although only modest model-based estimates have been provided so far. While an initial estimate of approximately 100-200 Gt in CO_2 storage potential within deep saline aquifers is quite encouraging, more reliable assessments are required to spur certainty: expert static and dynamic modelling (geospatial included), acquisition of new data (3D and 4D seismic), in-depth core analysis, probabilistic assessments, and a static resource atlas (Richards).

Based on these realistic estimates of offshore storage for Nova Scotia, there lies potential for a multi-phased commercial strategy to implement CCUS on the Scotian Shelf. Initial assessments can be made on several test wells (one to four), which upon confirmation of storage could then be followed by expanding the scope of drilled wells regionally (up to 100) and eventually intercontinentally (upwards of 100) in phases tailored to provincial and federal needs. Integration with existing energy infrastructure can be determined throughout the development process, as well as consideration of the "energy corridor" and how these resources can work in tandem (Richards).

Offshore subsurface resources and any related activities are jointly regulated by the federal and provincial Governments. The Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) will evolve into the Canada-Nova Scotia Offshore Energy Board with authority for activities related to renewable energy and, it is anticipated, CCUS, though the legislation mandating the powers of the Board is currently being written. All onshore components such as pipelines and plants are regulated by the Canada Energy Regulator (CER; formerly National Energy Board), which works together with the regulatory authority of the Impact Assessment Agency of Canada (IAAC) and other departments and agencies of government to ensure comprehensive oversight of all dimensions of offshore projects to ensure economic, social and environmental protection for Canadians. Overarching legislative authority and policy directives are provided by Environment and Climate Change Canada (ECCC).

Currently, there is a significant body of knowledge and experience associated with offshore projects on the Scotian Shelf which included developing a robust, world-class, and competitive regulatory regime linked to a competitive provincial fiscal framework of petroleum resources. No such framework exists for CCUS yet since the broad project elements necessarily required for CCUS resemble those of offshore natural gas development projects, but in reverse (extraction vs. injection). For this reason, the regulatory issues and processes for offshore gas development are likely to closely follow those required for the capture, transport and offshore injection of CO_2.

The strengths of offshore CCUS include an existing body of subsurface knowledge, trained and experienced professionals and researchers capable of undertaking geological assessments of potential formations including depleted reservoirs and saline aquifers, and considerable storage potential in each that has, at a basic level, been appraised. In addition, experience providing oversight on the design and construction of multibillion dollar offshore construction and associated onshore pipeline and facilities aligned with social and environmental impact at a federal and provincial level and provincial fiscal regime can provide guidance to a complex process that created thousands of jobs, knowledge transfer, a globally competitive offshore and onshore supplier community, research and development, and strategic investment. This certainty was needed for private sector investors to be able to gain internal sanction for development plans which would be the same for offshore CCUS project investors. Until a clear regulatory process exists, research into disparate elements of CCUS will remain siloed when multiple potential development scenarios should be undertaken concurrently with offshore characterization work. The potential for storing much of eastern Canada's CO_2 (from Ontario to Atlantic Canada) is enormous and likely holds the greatest potential for meeting Canada's emissions targets. Potential is always good, but it is how we transform that potential into robust projects that will matter most in the long term.

Prince Edward Island

Prince Edward Island is a small province with a primarily agricultural and fisheries economic base with limited industry. Energy efficiency improvements and tree planting combined with growth in wind energy have been helping the island province reach carbon neutrality. PEI may be affected by potential offshore energy projects undertaken by the neighboring provinces of Nova Scotia and New Brunswick in the Gulf of St. Lawrence, where sedimentary rocks of the Carboniferous Maritimes Basin might possess CCUS potential. Alternatively, the presence of salt structures might hold some promise for cavern storage for hydrogen fuel which could be produced from a favorable offshore wind regime. Any such projects would require the province's offshore boundaries with respect to those of neighboring provinces to be delineated with respect to offshore subsurface and energy rights, and a federal-provincial regulatory authority would need to be established.

Newfoundland & Labrador

Unlike many other provinces, Newfoundland & Labrador does not have a vast number of point emitters from which to capture CO_2. There are only a few stationary combustion sources on land; otherwise, any emissions suitable for capture would likely come from its multiple world-class offshore oil projects, and potentially ships.

Offshore Newfoundland has some of the most promising potential for CO_2 storage in the country. Its offshore area covers over 20 sedimentary basins, many of which have been exploited or assessed for oil and gas resources. While the region's CO_2 storage capacity still needs to be assessed, considering the petroleum development history, the region has the potential to be an "Energy Super Basin". Such a basin could provide abundant clean energy, provide hub-scale CCS opportunity, and access remaining petroleum resources as needed. CCUS provides the potential for offshore oil project emissions to be captured and reinjected for enhanced oil recovery, enhancing project productivity as well as storing project-driven CO_2 emissions. Its potential for storing emissions from onshore and other regions remains to be explored. The province has been supportive of efforts regarding CCS exploration, identification, and facilitation, including significant investment through the Offshore RD&D Fund.

While there is undeniable potential for CCUS offshore Newfoundland and Labrador, challenges remain along the road to provincial carbon neutrality. Large gravity based and floating production platforms were designed as 'fit for purpose' structures and sanctioned as such by the Canada-Newfoundland and Labrador Offshore Petroleum Board, a parallel authority to that of Nova Scotia. As such, an offshore CCUS federal-provincial regulatory roadmap developed for Nova Scotia would also provide general guidelines for Newfoundland and Labrador CCUS projects. Offshore structures that gain regulatory approval to be repurposed for CO_2 injection, typically for enhanced oil recovery which also serves to sequester CO_2, would still face complex and costly Brownfield engineering and associated offshore construction to adapt offshore processing across the province's multiple production platforms to capture, utilize, and store CO_2 in depleted fields and those still in production. In many instances it may not be technically or commercially feasible or must be integrated solely as prototypes. Additional research is required to assess Newfoundland and Labrador's offshore basins for dedicated CCUS versus utilizing CO_2 for enhanced recovery, which offers the commercial advantage of creating a revenue stream to offset capture and injection costs. Newfoundland and Labrador currently enjoys research credit by project operators under development plan agreements signed with the offshore regulator and the provincial government. This allows industry investment to lever government research program funding to assess offshore CCUS. As a result, Newfoundland and Labrador stands to see considerable advances in CCUS research including characterization of offshore basins and formations for CO_2 storage. The potential of the subsurface alone, however, does not offset the potential risk of offshore injection sites which, unlike the Scotian Shelf, are subject to iceberg impact and scour risk, stormy and low visibility conditions, and are a considerable distance from major emitters in-province and extra-provincial emission sources. This adds complexity to any potential expansion of the province's offshore CCUS potential beyond oil and gas industry-specific needs, and expanding to a national solution requires onshore transportation through neighboring provinces to port facilities that must travel a considerable distance to reach injection sites. That said, redevelopment of abandoned oil facilities provided reservoir characteristics are suited to CO_2 injection and storage might offer technical and commercial opportunities.

Regarding other potential renewable solutions, there remains some discussion on projects other than offshore carbon capture and storage. On the topic of wind energy, while the eastern coast receives such intense winds off the Atlantic that in theory could produce a great deal of power, the conditions are likely so extreme that regular wind turbines would not be suitable. With violent winds, heavy rains, large wave heights, saltwater spume, and ice impacts, the region would require turbines built for harsh conditions. Including the infrastructure needs and installation costs, wind farms offshore eastern and southeastern Newfoundland would be much more costly per kWh of energy provided than a typical wind farm setup on land. While the long distance to market from the offshore suggests considerable power loss along a subsea cable to shore, the potential of harnessing offshore power to generate hydrogen might support the creation of an alternative renewable energy source.

The potential of future LNG or CNG projects in Canada remains uncertain given the challenge of securing sufficient gas supply, particularly on the east coast, or the cost of developing stranded assets on the Labrador Coast. If such developments were to take place, or the potential to develop associated gas which has been reinjected to maintain oilfield formation pressures during production, there may be potential for offshore production with transport and reinjection of CO_2 to boost gas production and sequester CO_2.

Yukon, Northwest Territories, and Nunavut

Canada's north enjoys a small population, extensive forests, and a growing transition of off-grid communities to renewables from diesel and other fossil fuels. Some larger communities such as Whitehorse benefit from hydro power. The Canadian north and Arctic regions are disproportionately affected by climate change, which has an impact on traditional ways of life for many indigenous communities. Reconciliation efforts by the Government of Canada toward Canada's Indigenous peoples include greater transparency and a greater effort under Duty to Consult provisions under federal law with respect to projects that could potentially impact treaty rights. The Government of Canada's efforts to increase inclusion and transparency are reflected in changes to the regulatory framework formerly administered by the National Energy Board (NEB), which was replaced by the Canada Impact Assessment Agency (CIAA). Under broader scope of engagement for stakeholders, especially Indigenous peoples where, unlike projects reviewed and sanctioned under the NEB (which requires consultation only from stakeholders directly impacted by the project in question), CIAA opens the engagement process to all Canadians regardless of the project location. This suggests that while CCUS and other renewable energy projects may not necessarily take place in the north and Arctic, the potential impact of national scale transportation of CO_2, or the tying in of point sources from northern mines, mills, and other industrial or domestic operations will engage the territories. Duty to consult provisions, plus changes inherent in the CIAA regarding consultation, suggest that all projects need to consider a widely inclusive public education and consultation process.

Federal and International Perspectives & Projects

Canada

The Canadian 2030 Emissions Reduction Plan aims to reduce greenhouse gas emissions by 40% below 2005 levels by 2030 and achieve net-zero emissions by 2050. Proposed decarbonization routes include supporting negative emissions technologies to support CO_2 removal, producing low-carbon power and low-carbon hydrogen resources, and decarbonizing the largest industrial emitters. Although feasible projects have been proposed, there remain limitations and challenges impeding implementation: the regulatory gap, legislative barriers, cost reductions, and transport and storage regarding CO_2 sequestration must all be addressed in order to move forward.

There are multiple initiatives supporting the implementation of CCUS facilities and other carbon-reducing technologies, with the focus concentrated on technically enhanced solutions as opposed to nature-based schemes, while both are considered viable. The CCS Investment Tax Credit provides a range of tax credits available for investment into CCUS equipment and projects that aim to permanently store the captured CO_2. There is also the Net Zero Accelerator, an initiative that may provide billions in investments into large-scale industrial projects. Investments are divided across three key programs, 1) the decarbonization of large emitters, attempting to push industry to reduce emissions, 2) industrial transformation, promoting the development of new low-carbon processes, and 3) clean technology and battery ecosystem development, where the government hopes Canadian companies can capitalize on emerging technologies and become global leaders in the sector.

While the western provinces have been deemed suitable for CCUS in terms of emitter proximity to transportation and dedicated geostorage, Ontario and provinces to the east lack the same simplicity. Within the territories of Albertan oil and gas projects, emissions must only be transported short distances to depleted reservoirs or saline aquifers, while elsewhere in the country the point emitters do not match up so easily with suitable regions of dedicated geological storage, raising the issue of transportation. As most large emitters in eastern Canada are located in southern Ontario and Quebec (Figure 4), and the most suitable geostorage opportunities lie offshore Nova Scotia and Newfoundland & Labrador (Figure 3), it would be logical for emissions to be transported eastward for sequestration. Through the main transport route of the Great Lakes and St. Lawrence Seaway, captured emissions would travel on specialized container vessels for offloading at offshore injection sites. Considering ON and QC do not possess appropriate geological formations for CO_2 storage, other than in regions where development would be socio-politically unfeasible, and the lack of extensive emissions from NS and NFLD, the best course of action for eastern Canada would be interprovincial collaboration of this sort.

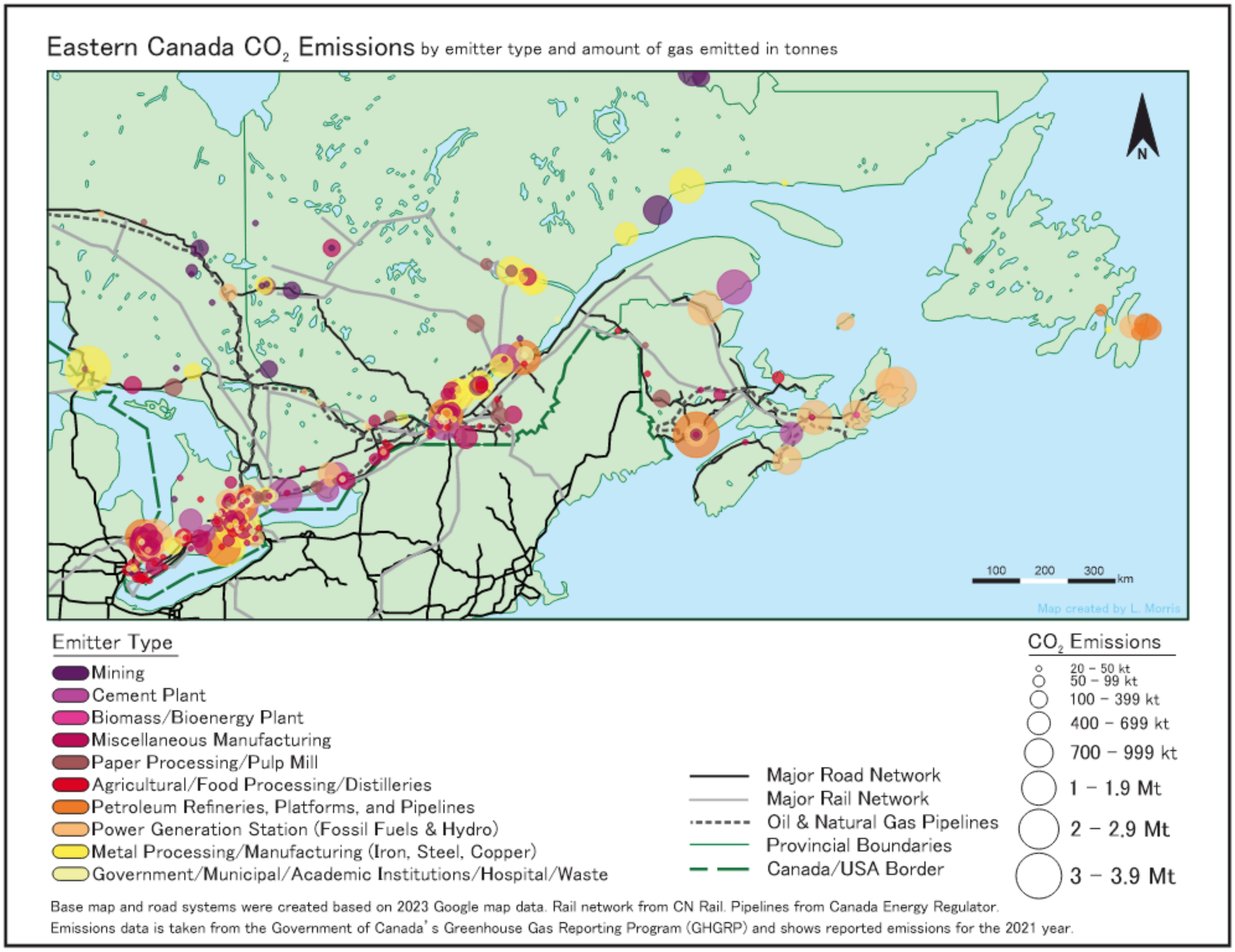

Figure 4: Annual CO_2 *emissions of eastern Canada, classified by emitter type and emissions in tonnes per annum. (Base map based on 2023 Google map data, emissions data available through the Government of Canada's Greenhouse Reporting Program (GHGRP), emissions from 2021; created by L. Morris).*

Time is beginning to run short in the race to implement appropriate technologies before the 2030 target deadline. For CCUS, it will take 3-8 years to confidently justify a geological CO_2 storage site, along with tens of millions of dollars to assess and validate the pore space volume and injectivity. Factors such as reservoir continuity, hydraulic interference, and effects of increased pressure must all be evaluated, requiring time and money to complete to the necessary standard. Pipeline construction to transport the captured CO_2 would take approximately four years to complete, which leaves only three years for assessments prior to the target deadline. In order to actually achieve the 40% less emission target for 2030, over ten years' worth of activity must be achieved in less than seven, a gargantuan task considering the slow progress made since the target was established.

In addition, once characterized, offshore pore space cannot be commercialized for CCUS without the typical 5-8 years it takes to design, construct, commission, and bring to steady state operations offshore projects that necessarily include onshore elements such as processing and storage facilities, as well as transportation networks such as pipelines. The short time available to meet Canada's emissions targets means multiple potential development concepts need to be engineered concurrently with offshore storage characterization efforts. That, in turn, requires a regulatory roadmap for CCUS.

The annual federal budget briefly addresses CCUS in regard to eligibility. As of 2023, only jurisdictions that have been determined to have appropriate regulations for ensuring permanent CO_2 storage are qualified to develop dedicated geostorage projects; Alberta, Saskatchewan, and more recently British Columbia qualify under these standards. Not only would this eligibility requirement disallow development offshore east coast, but it only permits permanent, dedicated storage, which would disqualify use of CO_2 in enhanced oil recovery. Since the petroleum industry is already at such a scale to easily handle integration of EOR methods, and depleted fields offshore would be some of the most promising regions for geostorage, the lack of eligibility presents a missed opportunity in the CCUS sector.

For major projects to move forward and support the common goal of eventually reaching net zero, both federal and provincial governments must commit to the implementation of pertinent, objective, and cooperative regulations and policies. Industry, federal, and provincial authorities must become unified to achieve the actions necessary to change our emissions output, and our future. In the adverse atmosphere of the world today, public perceptions have great influence on governmental affairs, impacting what is officially approved and what is even considered in the first place. Considering the growing negative stance against pipelines and all aspects of petroleum production, to get the public on board with CCUS initiatives an education campaign should be undertaken to increase public awareness of emerging low-carbon technologies, the effects they may have to the Canadian way of life, and why these proposals are so important.

Norway

Norway's plans to reach their target emissions reductions are underway with the introduction of the Langskip CCUS project in 2020. The nation has provided Langskip with $2M CAD in investments, covering approximately two-thirds of the project costs. Within the Langskip initiative is the Northern Lights project, which covers transport and storage aspects of the process. Northern Lights will collect emissions from neighboring countries and provide carbon storage as a service, making it one of few open-source carbon sequestration and storage projects. Nearby sources include cement factories, refineries, waste incineration facilities, biofuel/bioenergy plants, and direct air capture.

The transport aspect will be covered by a mix of pipelines and specialized ships that will work in tandem to collect captured emissions from numerous sources and inject them into suitable subsurface formations. New specialty ships will be built and powered by LNG energy with assistance from wind energy, reducing the expected emissions that come with industrial processes like ship building and transportation. They will be utilizing both onshore storage facilities and offshore geologic storage solutions, with the onshore site having a planned capacity of 1.5Mt annually.

In the past, Norway benefited from having a state-controlled oil and gas company working in concert with state-run applied research institutes. This allowed the deployment of new technology on oilfield projects, particularly in deep water, which was a competitive advantage compared to risk-averse international oil and gas producers who often balked at using unproven technology from major EPC contractors on large CAPEX offshore projects. This raises the potential for deploying new technology on CCUS projects with government mitigating risk through fiscal or other supports that allow prototypes to be fast-tracked into the marketplace.

The Norwegian Continental Shelf project is also in the works, aiming to create a "Sustainable Subsurface Value Chain" to balance energy security and accelerate the transition to a sustainable society. Its main action item is the assessment of sustainability within reservoir utilization with potential projects involving CO_2 and hydrogen storage, enhanced oil and gas recovery, and geothermal opportunities. With a strong focus on digitization and machine learning to use existing data to evaluate subsurface resources and their potential for storage, the current estimated storage potential of the Norwegian continental shelf is deemed to be upwards of 80 billion tonnes of CO_2.

Northern Lights is well located and may reduce the perceived risk threshold to catalyze further development in the CCUS sector in Norway, but it is not without limitations. There are no current standards of production or regulatory framework in place to establish standard oversight for CCUS, no clarity in market supply of CO_2, and a lack of clarity in qualification standards for the CCUS supply chain. While beginning a project when regulations have not been put into place may seem steeped in risk, in this case it's more of a proactive approach; with the demonstration project already moving forward, Langskip is able to contribute to the creation of the regulatory framework alongside government, in a way that aligns best with the project at hand.

Despite challenges and uncertainties, however, large scale CCUS developments like the Northern Lights project will be necessary to reach emission targets and the project partners are determined to make their first carbon capture and storage venture a success. The Norwegian government can consider it a proof of concept from which lessons learned can shape CCUS regulations and policy for future projects.

Netherlands

TNO (the Netherlands Organization for Applied Scientific Research) is the leading association when it comes to research and policy support on the energy transition (including CCUS) to the future energy system as well as the associated business, environmental and societal impacts.

In the Netherlands the 2022 level of greenhouse gas emissions was around 0.16 Gt (CO_2 equivalent), coming down from 0.23 Gt in 1990. With a 2030 aim of 50-55% reduction in emissions and a targeted decline to zero by 2050, the Netherlands will have to reduce emissions at an average rate of around 6 Mtpa, and CCUS is considered to take a significant part of that.

The potential for geological storage in the country is estimated as 10 Gt in depleted gas fields onshore (including the giant Groningen field) and offshore. However, for political reasons CO_2 storage onshore is not permitted. That leaves 1.6 Gt of offshore storage capacity to be used as an actual base for CCS development.

Storage potential offshore seems relatively promising, as it is close to large industrial emitters, Amsterdam and Rotterdam harbors, and can make use of existing platforms and wells. However, the busyness of the coast with major shipping lanes, stationed miliary, established and planned wind farms, and environmentally protected areas, will require careful and timely spatial planning, and strategy for abandonment or alternative re-use of these assets (e.g., for hydrogen storage).

There are currently two near-to-start CCUS projects, Porthos and Aramis. Porthos is a nearshore project 20 km offshore Rotterdam Harbor, with an estimated storage capacity of 37 Mt at an injection rate of 2.5 Mtpa, and first injection planned for 2024. Aramis will create a 20 Mtpa capacity trunk line for CO_2 transport from Rotterdam to the Dutch central offshore, the core area of storage capacity in depleted gas fields. From this crucial transport backbone, at least 0.4 Gt is estimated to be developed for CCUS.

Through TNO, companies can apply for the necessary licenses to begin CCUS project development as well as get an opportunity for funding. The Dutch regulation for a subsurface storage license is derived from the CCS EU Directive. Over 30 licenses are required to begin a project with full approval, which includes details on the storage plan, monitoring methods, risk management and corrective measures, financial security throughout the project's lifetime, and the closure plan upon completion. There is a one-stop-shop procedure in place to facilitate the licensing process. These required licenses verify that the interested parties take every factor into account to ensure the ultimate success of the project, as well as the positive impacts to the economy, the effective use of available assets, and contribution to the long-term goals for emissions reductions.

UK

Government in the United Kingdom has been providing incentives for those who plan and follow through on decarbonization projects such as carbon capture and storage. Currently, emitters are given tax breaks for participating in an active decarbonization project, and any differentials in storage costs are covered.

One up and coming UK project is Acorn, developed by Storegga and located in northeast Scotland. The Acorn project proposes CO_2 injection into depleted gas fields and saline aquifers, with the aim of storing around five million tonnes per annum by 2030, hopefully increasing that storage capacity to over 20Mt annually in the years following. Acorn sources its CO_2 from emitters in nearby St. Fergus and implements existing pipeline and terminals used for gas, allowing for multiple inputs of sequestered CO_2 along the line.

For much of the public, injection into previously exploited oil and gas fields is more readily accepted as the storage capabilities are already proven from storing fossil fuels for millions of years. However, much of the UK's geological storage potential is in saline aquifers and salt deposits. Rather than attempting to find the "perfect" site in the eyes of the government, industry, and public, it was paramount to establish a project design early in the development process to understand exactly what parameters need to be met. Factors included the current regulatory environment, access to emitters and the question of local versus imported emissions, the necessary storage capacity of the geologic formation, and the estimated rates and variability of CO_2 injection and the effects it may have on the storage site in question. To be a successful decarbonization project, proponents must plan and adhere to their basis of design, engage with the government on regulatory matters in the initial stages, and engage in public hearings and community consultation processes.

USA

As the US is the largest emitter in the western hemisphere, emitting 6.3 billion tonnes of CO_2 in 2021, they have been making steady progress in reducing their emissions and promoting the implementation of cleaner technologies. They are moving ahead to address gaps in the regulatory framework when it comes to CCUS proposals, removing barriers and increasing frequency of permits granted, and attempting to reduce predicted bottlenecks associated with the chain of production.

The 45Q tax credit is an incentive program for CCUS projects that has been recently updated as part of the Inflation Reduction Act. The update included increases in incentives, which have an estimated coverage of around two-thirds of total costs for approved projects depending on the applications. Incentives of $85USD/t for permanently stored CO_2 and $60USD/t for CO_2 used in enhanced oil recovery, alongside the potential to stack the incentives with other credits and supports, place the US at a competitive advantage in the race to reduce emissions. These incentives are viewed as the guaranteed prices for carbon offsets generated for years to come, providing assurance that projects will see a return on investments. The update has also lowered the project eligibility to receive the tax credit to include smaller-scale projects, which has generated more investment in lower-cost proposals, resulting in a higher concentration of funded CCUS projects. These features of the 45Q tax credit are very promising for CCUS progress in the US and should be the standard in which other countries hold their policies to, should they want to remain competitive in the pursuit of decarbonization.

In April of 2020, the largest privately-owned energy company, ExxonMobil, announced the CCUS Innovation Zone, a proposed consortium of 14 companies (including Shell and Chevron) with the potential to become the largest global CCUS project. The project bid aims to design the main facility hub in Houston, collecting emitted gases from nearby oil and gas refineries and utilization in enhanced oil recovery prior to permanent storage within the deep subsurface offshore Gulf of Mexico. With a goal of storing an annual 50Mt by 2030, and hopes to double that goal to 100Mt per year by 2040, the proposed project will need an estimated $100B USD in funding to get underway.

While the CCUS Innovation Zone is not yet fully supported by the associated government bodies, ExxonMobil was the highest bidder on 69 blocks in the gulf for offshore CCUS. As one of the largest emitters in the country, ExxonMobil's initiative in developing technologies to offset their impact demonstrates a willingness to adapt to society's chancing sustainability expectations, and a commitment to positioning themselves as an industry leader in managing emissions.

CURRENT POLICY & THE PATH FORWARD

Regulatory Framework

The biggest barrier facing the CCUS industry in Canada is the lack of a regulatory and policy framework that establishes clear authorities, roles, and responsibilities of specific government departments and agencies at the federal, provincial, and municipal level. A seamless oversight is required to provide full protection to Canadians while establishing a clear process for private sector investors to follow in mitigating emissions in economically viable and environmentally sustainable projects.

Several complexities exist; the first is how to categorize CO_2 disposal. This challenge has been addressed in the short term by categorizing CO_2 injection as 'utilization' as part of enhanced recovery, yet the injection of CO_2 in the subsurface without associated operational (and economic) benefit has yet to be clarified in legislation in most provinces and at the federal level. Canadian provinces have regulatory authority over natural resources on land while the offshore is subject to joint federal-provincial regulation. The oversight on CO_2 injection and long-term storage is uncertain. The fact that it is not a natural resource, but a waste product from the use of natural resources and transported from other provinces (or even international sources) must be addressed, as must the monitoring of storage sites over an indefinite period. The transportation systems required to move CO_2 across provincial borders are regulated by federal Government departments and agencies, and on certain matters duplication of federal and provincial oversight can cause confusion and delay due to duplication of nearly identical but autonomous processes. Unnecessary delay adds time to project schedules which adds to project cost and reduces potential return on capital risked by private sector project proponents. Major projects involving the subsurface in other sectors such as mining and oil and gas can provide a degree of guidance to the framework issues facing a CCUS project. Issues specific to CO_2 capture and containment, transportation, and eventual storage can be addressed with overarching regulatory oversight related to potential economic, social, and environmental impact, what type of projects can be pursued, what processes they include, and where they are located. Without a defined legal precedent for CCUS ventures, industry and investors are stuck in lawmaker limbo where little can move forward without federal authorization first.

Ongoing Obstacles

There are a number of challenges facing the government when it comes to the creation of a regulatory framework or policies regarding emerging and evolving technology such as CCUS. These include considerations regarding technology, Canadian economy, existing regulatory pathways, and public perceptions, the last of which will be discussed later.

The first consideration is the technology itself; CCUS hasn't been and still isn't very common in the global sphere, making it unfamiliar territory for nearly everyone involved. There are few CCUS projects in proximity that can be viewed as examples, alongside the uncertainty that comes with unfamiliar technologies doesn't instill the most confidence. The technological techniques that are implemented in CCUS projects will have to be confirmed safe and supportive of the goal, and presented to the government in a way that promotes full understanding and confidence. In addition, offshore projects are complex and costly, and operators are highly risk averse, rarely deploying technologies on high CAPEX projects with long project lives that have not already seen rigorous proof of concept and extensive application. The race to meet 2030 and 2050 targets offers very little time to fully de-risk the deployment of new technology, especially where communities and the environment could potentially be impacted. Not to mention the costs of project development, typically multiple billions in CAPEX, are the responsibility of private sector operators who are necessarily risk averse for their shareholders.

Another hurdle is the effect on the Canadian economy which comes with two considerations; available government funding and the allocation of those funds, and how these CO_2-based solutions effect the consumer's relationship to energy consumption. On the investment side of things, the government and Crown corporations only have a set amount of funds to spend on a range of climate-change-related ventures which must be directed at creating strategic outcomes related to platform commitments, most of which are designed to leverage private sector investment to build science and technology capability and capacity, as well as short and longer-term employment. Some other proposed techniques regarding emission reduction may offer more fruitful, shorter-term solutions that require less government intervention to reach project completion, potentially making those ventures more feasible than the long-term nature of CCUS. On the other hand, implementing CCUS technology will change the energy industry, and ultimately how it will affect the population that relies on that energy. Increases in operating costs at power generation facilities, whether it be from implementing costly emissions reduction technologies or trying to offset penalties, may be pushed to the end-user, which does not aid in public perceptions given that energy costs in some jurisdictions are already hitting the ceiling of consumer affordability. There must be a way to balance the financial requirements of CCUS projects with the government climate change priorities, as well as the effect it has on the general populous, in a way that is mutually beneficial.

The final challenge to discuss is that of existing regulatory pathways, or the route that regulations must follow to eventually be authorized and confirmed into law. Like any regular business or corporation, there is a chain of approvals that must be followed for a project to be sanctioned by regulatory authorities, by having met the requirements that protect the public interest. As this issue deals with the approval of the government and involves a number of different aspects concerning numerous departments and levels of legislative power, there is no doubt that the creation and approval of a regulatory framework is a time-consuming and elaborate process. Despite any frustrations associated with the slow pace of regulatory and policy formation, it is certainly worth it if it ensures that stakeholders are fully consulted and contribute to ensure that what is intended to solve one challenge does not create new challenges in other areas. That said, most regulatory issues applicable to offshore CCUS are not sector-specific and have synergies with the regulations for offshore energy projects in which considerable experience has been amassed. It may seem like we are at a tipping point of the fate of our current environment and as if it will take too long for policies to be created to make a difference, but there is no time like the present to start things moving down the regulatory pipeline.

Filling in the Regulatory Gaps

There are a few key regulatory gaps that need to be addressed for the CCUS industry to make progress. Firstly, the fact of federal versus provincial legislation, and how the two should complement each other for stable and steady adherence by industry. An overarching federal regulatory framework must be established, a standard for provinces to base their policies off; provinces with existing legislation should update it to reflect the most recent federal consensus, and those without a framework in place that have opportunity for CCUS ventures should capitalize on the current circumstances and support the proposed projects with their policy. It must address regulations imposed on onshore CCUS projects, especially for areas that are under federal jurisdiction.

Currently, there are no regulations regarding the authorization for offshore CO_2 storage; in order for offshore projects to be legally feasible, numerous amendments to existing laws alongside new legislation must be created. In the interim, waste gas derived from offshore production, such as in Nova Scotia's legacy Deep Panuke natural gas project, is reinjected to maintain formation pressure and enhance recovery of hydrocarbons. That the permanent storage of CO_2 forms part of production operations today reveals an important link between the regulations covering existing operational processes for oil and gas production and those needed for stand-alone CO_2 injection. Enhanced recovery also establishes a revenue stream from the sale of incremental gains in production that otherwise would not accrue to a fully depleted reservoir or saline aquifer as a fully stand-alone CCUS project.

Offshore regulatory authority was established through the Canada-Nova Scotia Offshore Petroleum Accord Act and the Canada-Newfoundland and Labrador Offshore Petroleum Accord Act and associated implantation legislation. Joint regulation of Canada's offshore regions has an established precedent, including precedent for navigating regulatory issues on single province projects that jointly impacted both provinces. The decision to redefine the role of the offshore regulatory authority in Nova Scotia by creating the Canada-Nova Scotia Offshore Energy Board suggests that both levels of government anticipate strong synergies between regulating petroleum projects and other energy related projects including offshore CCUS. This would allow fast-tracking the development of a CCUS regulatory framework.

Offshore CCUS cannot proceed until all the elements, from capture through utilization to transportation and storage are integrated into a project concept. Doing so moves CCUS from various research silos to meeting the official definition of a project, allowing critical milestones to be set, a critical path established and a timeline that allows project net present value (NPV) to de determined. As with oil and gas projects, NPV compares the cost of developing a resource against the life of project revenue. In the same manner, private sector project proponents will consider the cost of designing and constructing a full cycle project and compare those costs to the life of field value of the total volume of CO_2 stored. This means that for any CCUS initiative to be considered as a feasible project, even when looking at multiple potential competing concepts, the development elements must be assessed in terms of time and cost, and compared to the revenue generated by total storage volume.

There are four main considerations when it comes to creating a new regulatory framework that fits the needs of CCUS projects and proposals. Monitoring, measurement, and verification (MMV) of viability of the site in question; characterizing pore space and other aspects of geological formations fit for storage; licensing processes for the industry side; and the assumption of liabilities.

Monitoring, Measurement, and Verification (MMV)

Monitoring, measurement, and verification standards are indispensable when it comes to carrying out a successful proposal. Verification of feasibility beforehand is especially important as the geological formation in question must be proved appropriate for storage. The subsurface site must be a formation with some sort of permeable pore space for the injected gases to reside in, whether it is the space between grains in a sedimentary rock, or within the cracks of fractures and faults in a more crystalline bedrock. The porous portion of the formation must also be sealed, typically by an impermeable cap rock or through structural traps, so there is little change of gas migration of the injected CO_2. One of the more readily available routes for CCUS is using depleted oil and gas fields as the geological formations would already have proven porosity, permeability, seals, and traps that held liquid and gaseous petroleum for millions of years; formations that in theory should have no issue holding injected CO_2. Measurement goes hand in hand with verification as testing is used to determine the viability of the site, including appropriate injection rates and effective storage capacity. To round off the feasibility trio, an effective monitoring strategy is critical to ensure that injection and containment meet or exceed modeled performance expectations, in order to maximize reservoir use and the life of the field. In order to be characterized sufficiently to proceed with project design and construction, a distinct MMV approach must be in place where the proposal components can be verified to the highest degree of certainty, and can continue to be monitored for the duration of the project to ensure standards are consistently met.

Other than the general geological requirements necessary for successful storage, there are other guidelines set by the Canadian Standards Association (CSA), as well as the opportunity to receive funding amounts exceeding $1B. Alongside the aforementioned competent sealing rock, any formation intended for CO_2 storage must be over 800m deep, should be as near to existing infrastructure as possible, and have little need for adaptations, including the plugging of existing wells. And while smaller portions of funding may be available for fewer specifications, in order to receive larger investments projects will need proof of concept through extensive testing including drilling, modelling of CO_2 migration potentialities, and the intentions to create a storage hub.

Pore Space Ownership

Pore space adequate for storing large volumes of CO_2 in geologic formations is the basis of subsurface CO_2 storage, so knowing who it legally belongs to is crucial to carbon storage. Pore space ownership is defined in only a handful of provinces with ownership vested at the provincial and territorial level, yet the decision to set aside the matter of federal versus provincial ownership of offshore mineral resources, including subsurface formation pore space, created joint regulatory federal-provincial authority over the offshore regions of Nova Scotia and offshore Newfoundland and Labrador. It is expected that much of the regulation of subsurface pore space would follow precedent of matters deemed similar to those of oil and gas production, and appropriate regulations would be drafted accordingly. Determination between federal or provincial ownership aligns with regulations coming into place, and which government ultimately has the authority to administer orders regarding CCUS projects, as whichever group owns the pore space should be the one responsible for imposing regulations.

Licensing and Liability

Alongside determining which governmental body owns the pore space and is responsible for creating regulations and providing oversight on their application, comes the licensing process and assumption of liability; essentially answering the question of who is ultimately culpable for providing a rigid regulatory framework at the beginning, surveying the project during its active phase, and dealing with any serious potentialities that could arise during or after the life of the project.

On the licensing side, provincial programs are already in place in Alberta and Saskatchewan, established from the alteration of existing legislation regarding industrial ventures such as petroleum extraction and mining. This is likely the simplest approach as it adapts existing regulations designed for the natural resource sector which is, on land, regulated by provincial governments to address a range of public interest matters closely resembling those associated with CCUS. The main advantage is that it doesn't involve the creation of an entirely new suite of regulations and allows the regulator to draw from the experience of adapting or adopting regulations along with lessons learned and established best practices from the extractive sector.

The assumption of liability may be a tougher issue. The company proposing a new project will be required to be compliant with regulations established by the province (or offshore regulatory board for offshore projects) with oversight and licensing provided by expert staff employed by the regulator. If regulations are not followed resulting in unfavorable outcomes, they would ultimately be responsible for avoidable errors. The challenge with CCUS being a fledgling industry is that it may be permitted to operate under regulations that could potentially be inadequate in the long run. This distinction between a depleted petroleum field and a filled CCUS field is a potential long-term risk for CO_2 storage and would need to be addressed by the licensing process where clear liabilities are established for both private operators and public regulators. There are countless risks involved in implementing unfamiliar technologies, but those risks substantiate the opportunities available surrounding CCUS, and the supply of related rewards dwindles with each chance not taken. To profit from CCUS ventures, both economically and environmentally, acceptance of liability must be resolved.

Chance for Success

A seamless and transparent regulatory process covering CCUS projects is imperative. It must offer a compelling argument that such projects can be profitable for shareholders and operate under a manageable level of risk to consider investing. The high risk of offshore oil and gas projects is often mitigated through farm-in partners. The 'single-portal' offshore regulatory authority in both Nova Scotia and Newfoundland and Labrador, and their multi-decanal experience regulating a wide range of exploration and development projects, provides a reasonable template for offshore CCUS. Even if some specific activities and concerns differ, the intent of regulations is protection for both the stakeholder and the public from economic, social, and environmental risks. Most modern regulations are performance-based rather than prescriptive, which could allow greater transferability of overarching sustainability and safety policy ends to CCUS. A phased approach to implementing new regulations may also be a practical concept, as it may take some of the pressure off the immense task of creating a new policy scheme and allow for evolution of laws alongside the progression of a project.

Regardless of the immense number of considerations that must go into the creation of a new regulatory framework for CCUS projects, the key to the successful creation of a new regulatory framework lies in a collaborative effort between governments, investors, and industry leaders. A trustworthy partnership between all those involved would be crucial to the success of proposed ventures, as sharing ideas, innovations, risks, and costs tends to be mutually beneficial in the long term.

The London Protocol

One potential offshore regulatory route comes from the UK: a global treaty signed in 1996, known as the London Protocol, intending to address the growing risk of marine pollution. The treaty provides guidelines for disposal of materials at sea, including intentional dumping or storage on or within the seabed of waste, or abandonment of industrial sites or equipment, but excludes expelling of waste from vessels and pipelines during normal operations. Rather than a list of materials that are not permitted to be disposed of at sea, the London Protocol adopted a "reverse list" referred to as Annex 1, which classifies materials that are permitted under the treaty.

The Protocol has undergone two amendments in regard to CO_2 storage; the first in 2006 where carbon dioxide was added to Annex 1 under the specific storage requirements of being within a subsea geological formation, the composition being of almost entirely CO_2 (as opposed to secondary gases), with no additional waste to be included in the process. The second amendment in 2009 lifted prohibitions dealing with import and export of CO_2 between other countries from subsea storage sites. Although these amendments essentially approve CO_2 storage offshore, environmental factors must still be considered; monitoring strategies, effects of injection and associated changes in pressure, impact of new infrastructure, and the possibility of disastrous leaks must be recognized and prepared for.

Canada has been associated with the London Protocol since its development, and has it implemented country-wide through the Canadian Environmental Protection Act (CEPA). Despite following the lead in marine pollution management, Canada has not sanctioned the 2006 and 2009 amendments into law leaving a wide regulatory gap for CCUS project potentialities. CO_2 is not listed on CEPAs Schedule 5 of approved waste materials for marine disposal for reasons unknown. The approval of these amendments could be the simplest first step in getting a regulatory framework in place as the basis is already enforced through CEPA and other nations have already adopted the revisions.

Investments

To put emerging technologies such as CCUS into place, it will require extensive funding as any large-scale industrial project would require. Government financial support in the form of grants, credits, incentives, and direct monetary contributions are the driving force behind research, development, and implementation of new industrial expansion. As of yet, government backing in the form of funding has not been sufficient to drive substantial advancement in the field. The costs of projects cannot be modeled unless a clear regulatory framework is established since any project design must be compliant. The private sector is a key player in any major energy project with many technology start-ups and small to medium size enterprises (SME's) developing the innovative technologies required on the road to carbon neutrality. Government programs can provide R&D funding, including the recent Natural Resources Canada CCUS fund of $319 M, as well as various fiscal incentives such as provincial Feed-in Tariffs or the federal Scientific Research and Experimental Development Tax Credit (SR&ED). Industrial benefits provisions for applied research under the federal-provincial Offshore Accord legislation provided research support under the provision that it be directly related to a specific development project offshore, the advantage being that such industry contributions could act as leverage for funding from government research programs. In addition, targeted R&D funding is available through provincial departments and agencies as well as not-for-profit entities including Petroleum Research Atlantic Canada (PRAC), Net Zero Atlantic, and others whose research focus and calls for proposals helps stimulate the R&D ecosystem. The industry chiefs leading the charge on establishing these CCUS projects need confirmation that the ventures will be subsidized, whether it be from the government or other investment organization, lest R&D be halted completely before construction can even begin.

One of the consistent challenges faced in Canada is that R&D funding is largely driven by government and academia with limited connection to commercialization. As a catalyst for industry research, it can help private sector invest in innovative startups and attract attention to SME's attempting commercialization, yet multinational corporate partners take a measure of control over intellectual property (IP) rights and manage the R&D function out of the corporate head office which is often not within Canada. As such, innovation is often at arms' length to corporate R&D centers. Many smaller companies prefer to license or sell their IP which can move its commercial market distribution out of Canada. This is not necessarily negative since it offers the potential for achieving prototype field testing and mainstream commercial deployment in a much larger market space sooner.

The Canada Infrastructure Bank (CIB) is a federal Crown corporation tasked with providing financial support to a variety of infrastructure projects within the priority sectors of clean power, public transit, green infrastructure, broadband, and trade & transportation. As a partner to governments, Indigenous communities, and private investors, the CIB has $35 billion in capital in reserve support for projects that fit their priorities in both short- and long-term schemes.

While the CIB is certainly willing to fund projects relevant to the priority of clean energy, industry will have to demonstrate the validity of their proposals. Validating their proposals requires research and testing which requires funding up front. This can be impractical since, without advance funding, materials, and operational support needed to start a project cannot move forward. Yet, investors require some demonstration that the work has moved forward and produced some preliminary results that serve as a basis for financial backing that can provide companies with sufficient working capital to move the research forward at the initial stages.

If looking for a standard to base government support off of, taking a note from our neighbors to the south would be a good start. The 45Q tax credit, updated through the Inflation Reduction Act, has government investment covering nearly two-thirds of the total costs of an approved CCUS project, while Canada's current incentives cover less than twenty-five percent. The price of carbon offsets from successful projects are guaranteed for another decade at least for the US, while uncertainty abounds regarding future revenue for Canadian projects which is undoubtably a big risk for those looking to invest. These stark differences in tax credit approach have left us at a competitive disadvantage in the CCUS market, something to be considered while generating new policies.

CCUS ventures are long-term and typically require an integrated approach to capture, transport, usage, and storing of CO_2. That integration frames the individual research silos into a value chain that could, in the future, be a project workflow. These aren't single-time investment opportunities, they are industry-shifting developments that will require ongoing support, and ultimately patience, as projects advance through their strategic plans.

Public Perception

With all the talk regarding industry and government, the importance of public perception is often thrown to the wayside. Of course, industry holds the ideas, and the government holds the power to sanction projects based on those ideas, but public support is integral to seeing projects approved and put into operation. The actions that have been taken in the past couple of decades regarding climate change have occurred because the government has led public education initiatives to help the population understand the issue and its impact, resulting in support for mitigation measures from research expenditures to fiscal initiatives such as a carbon tax.

Like many emerging scientific concepts, education is key for acceptance of novel theories such as CCUS. Although public perceptions on carbon capture and storage technologies are not currently well known, one may assume they fall in line with ideas surrounding decarbonization strategies and the fight against climate change. However, impressions that equate CCUS technology with petroleum extraction and use of fossil fuels have the potential to negatively impact attitudes toward and acceptance of carbon capture and storage. Mentions of pipelines and injecting gases into the subsurface without context can immediately set an unfavorable tone within the public while certain groups will take a negative stance that cannot be overcome with additional educational efforts.

Educational endeavors towards a positive public perception must be conscientiously planned to demonstrate the innovative nature of CCUS and the potential for success on the path towards reducing our emissions and achieving net zero. The general idea of carbon capture, transport, utilization, and storage should be clearly communicated to society at the earliest stages, considering past experience in other jurisdictions when delays allowed inaccuracies and misinformation to become established before science-based material could be presented, resulting in the failure of the project. The regulations and safety procedures CCUS projects are required to follow must be presented to establish that common concerns have been considered and will be appropriately dealt with. The differences between what is known about existing processes and impacts of fossil fuel exploitation and the proposed development of CCUS technology must be classified plainly, alongside the concept that although the two share much in common such as geological formations capable of storage and use of pipelines in gas transport, they are not one in the same and result in two distinct outcomes.

While the public uncertainty towards CCUS initiatives may stem from larger environmental concerns regarding the petroleum industry and unknown technologies, for many, especially for those not necessarily interested climate-related news, the main concern is financial in nature. With increasing rates on nearly everything, from fuel costs to grocery prices and housing hikes, Canadians cannot afford additional increases on their power bills or further inflated taxes. When faced with reports of implementation of novel technologies and this intense need for decarbonization, it doesn't take much to realize the immense costs associated with the creation of new infrastructure and investing in renewable energy sources. And based on decades of price increases, it is not unreasonable to believe the costs of becoming carbon neutral will be offloaded to the end-user. Someone could be incredibly knowledgeable about CCUS and renewables and the important role they play in the energy transition, but when faced with potential difficulty to afford life's necessities, that is where their concern will lie no matter how idyllic the climate plan may be.

In the past, approaches to climate action have been largely individualistic; choosing reusable options over single-use plastics, push towards electric vehicles, monitoring energy and water usage, all things to reduce our "carbon footprint". For many, these relatively simple actions felt like tangible options for dealing with the climate crisis, thoughtful responses that made folks feel better about their influence on the environment. However, as time went on and more information came to light, individuals turned their focus to the industrial side of things, processes that could emit the same amount of CO_2 in a single day as a person would in their entire lifetime. Now, people are looking for the big industry players to take accountability for their own emissions. If CCUS initiatives are the way these emitters plan to reduce their impact, and the costs are still being passed down to the lowest rung on the ladder, it will reinforce the negative stance the public has of industrial emitters and put carbon neutral technologies at a further disadvantage. Keeping energy needs affordable for the average Canadian must be kept at top priority, lest the public eye and its influence on society veer away from the few opportunities to make change.

Despite the best efforts of a handful of industry members and governmental bodies, we are not currently conquering the conflict that is climate change. Nominal progress has been made towards a more environmentally sustainable society, but not enough to slow our projected rise to a global warming of 1.5°C above pre-industrial levels, even with the previous worldwide deceleration due to the pandemic. Real change, at an accelerated rate, is desperately needed to reach our climate goals and transition into a more sustainable energy future.

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Sincerest acknowledgements to the following colleagues for providing initial comments and suggestions and helping mold the paper into its final form: Bill Richards, Maurice Dusseault, Richard Jackson, Jaap Breunese, and George Kovacic.

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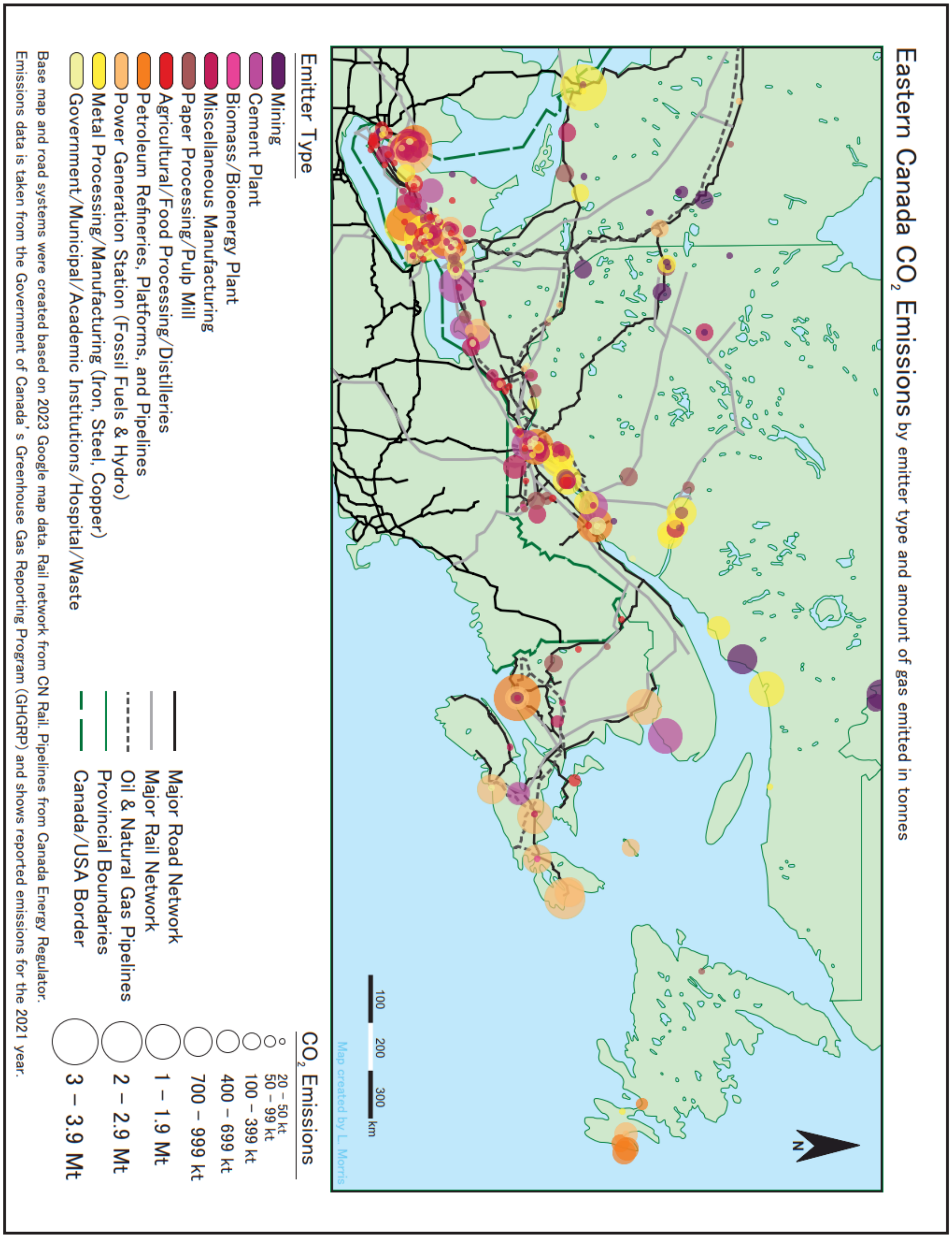

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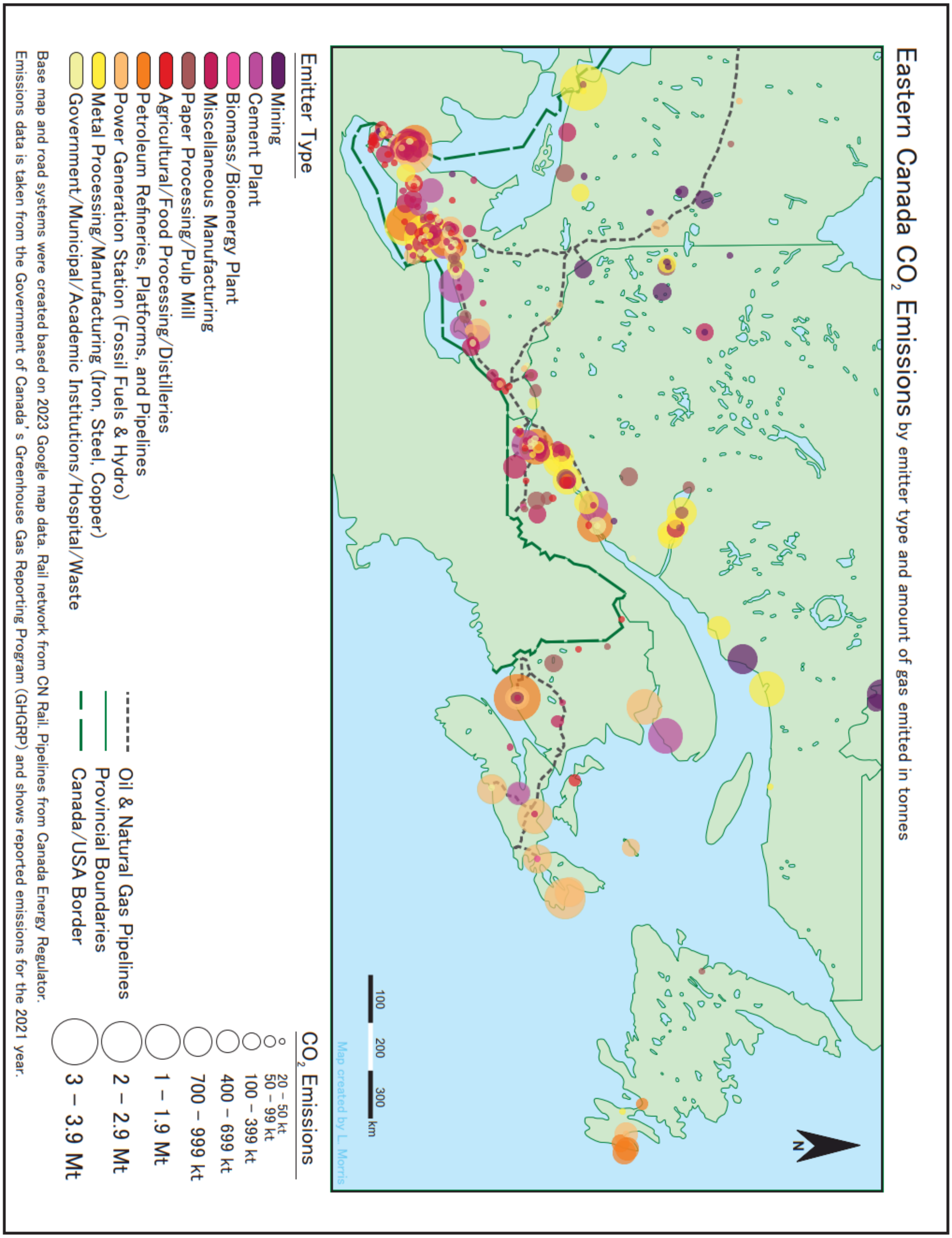
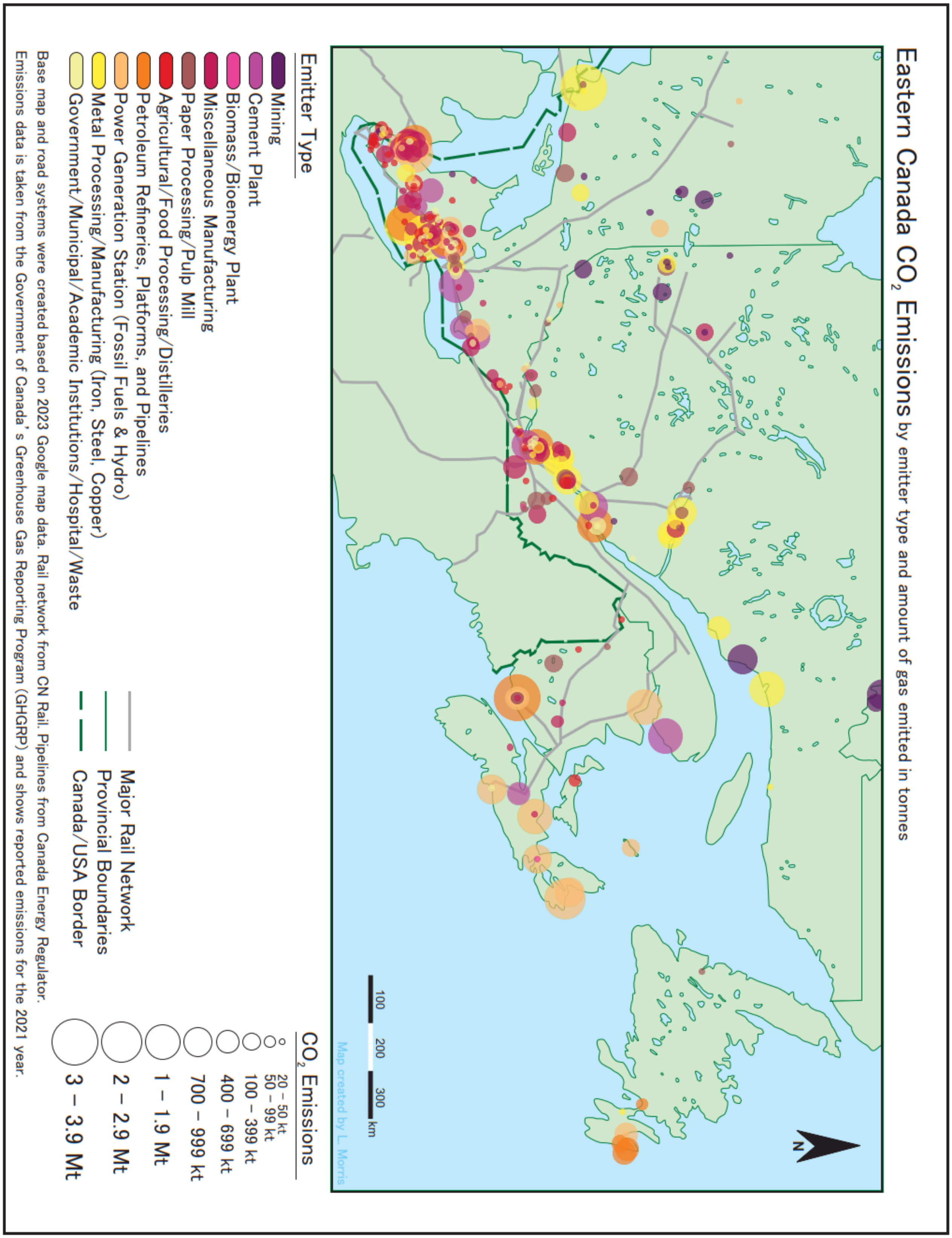
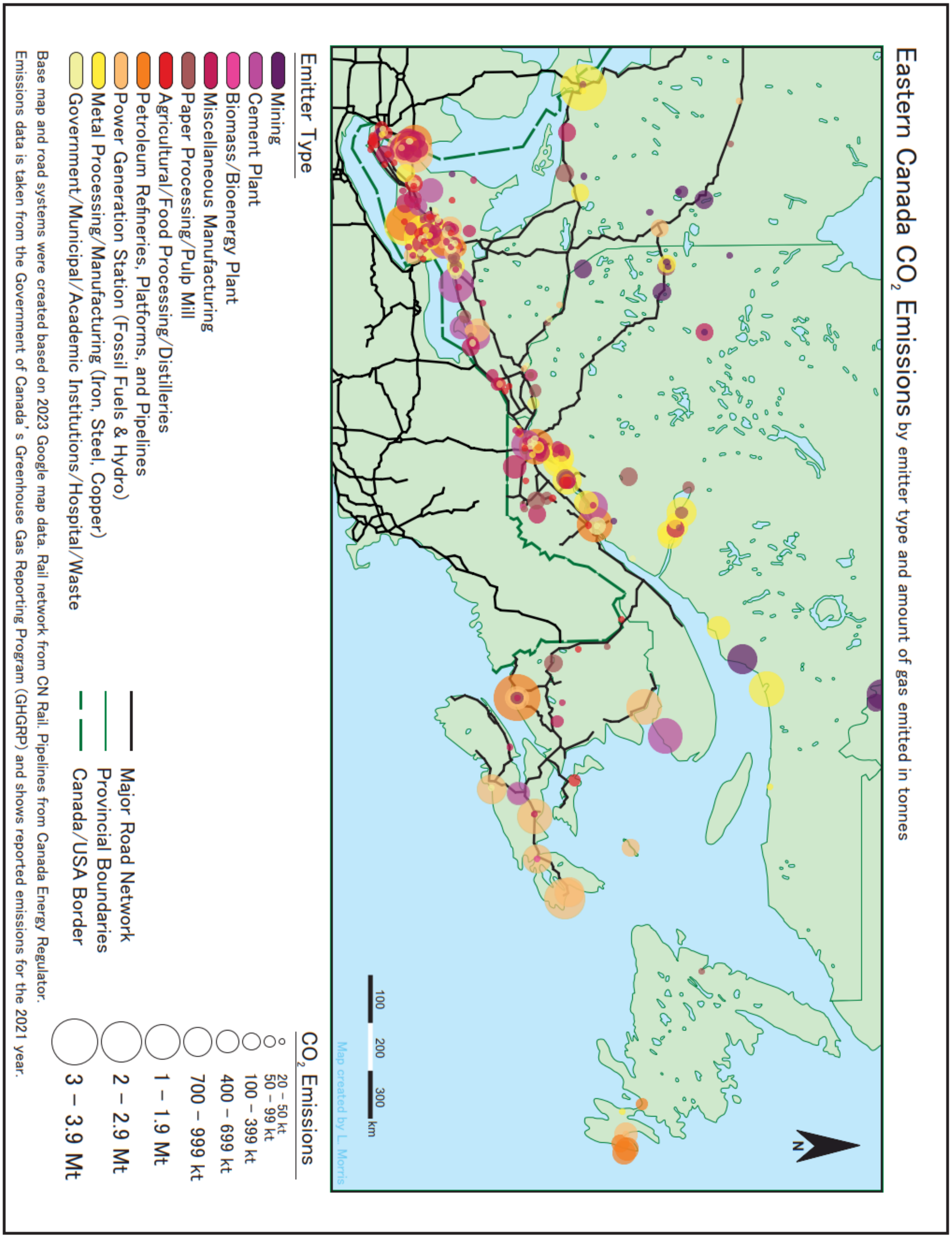


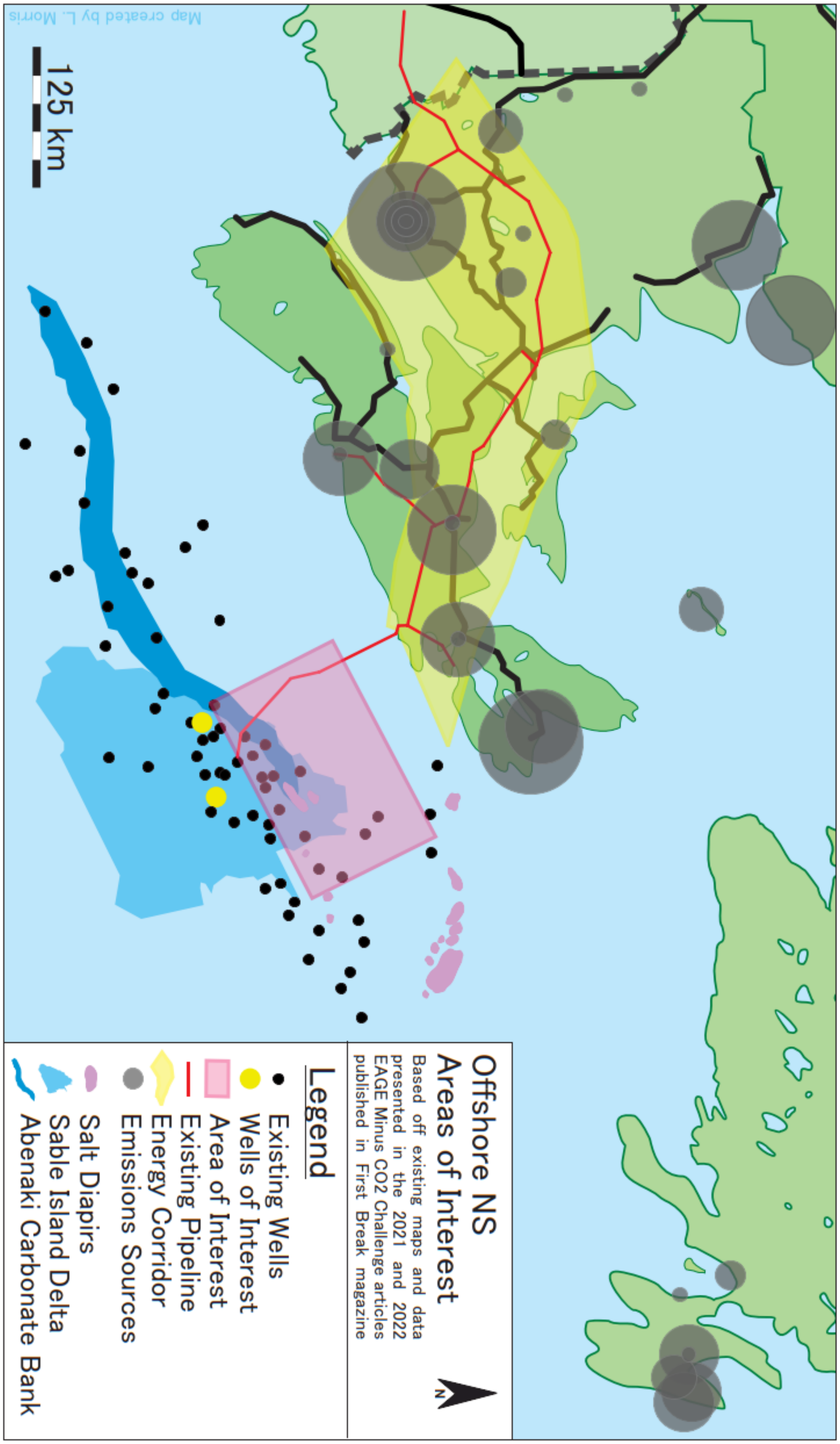
Eastern Canada CO_2 Emissions by emitter type and amount of gas emitted in tonnes, version with pipelines only.



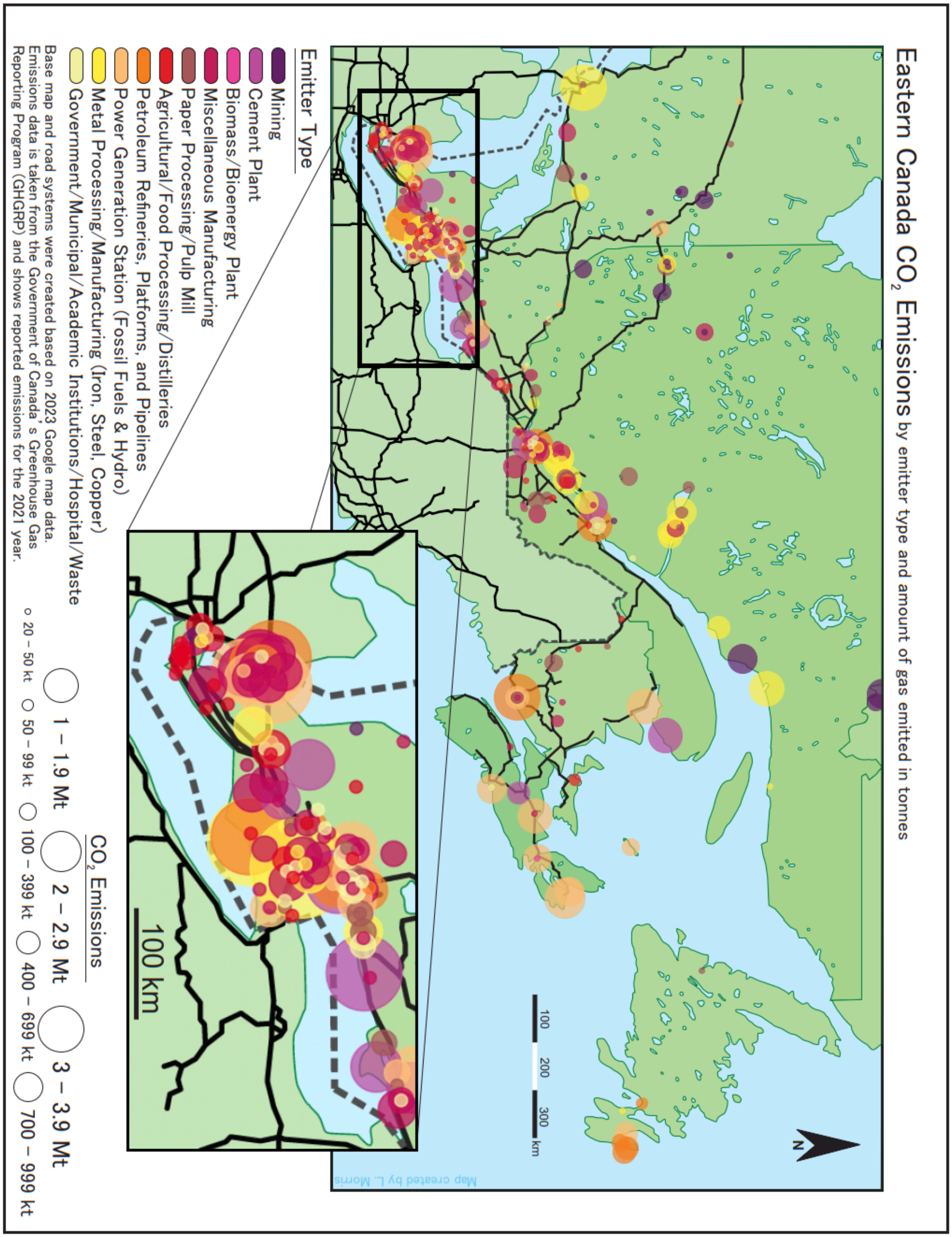
Eastern Canada CO_2 Emissions by emitter type and amount of gas emitted in tonnes, version with rails only.



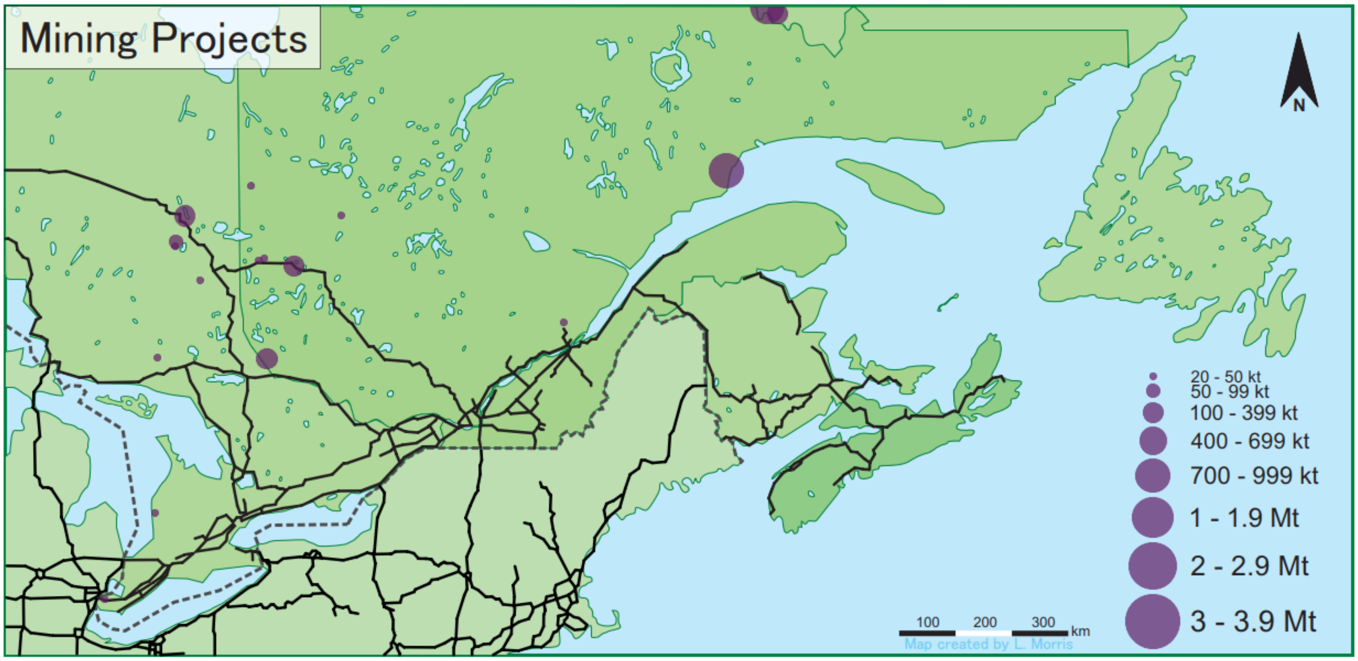
Eastern Canada CO_2 Emissions by emitter type and amount of gas emitted in tonnes, version with roads only.



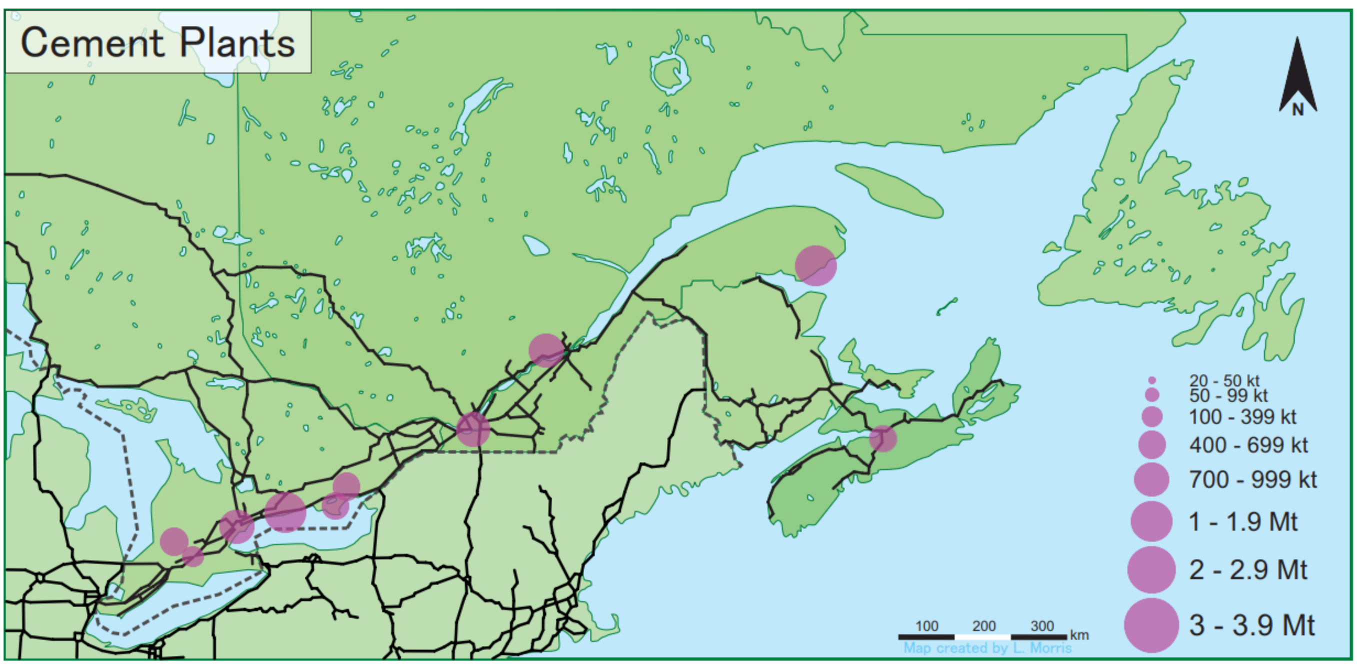
Offshore NS Areas of Interest, complete version.



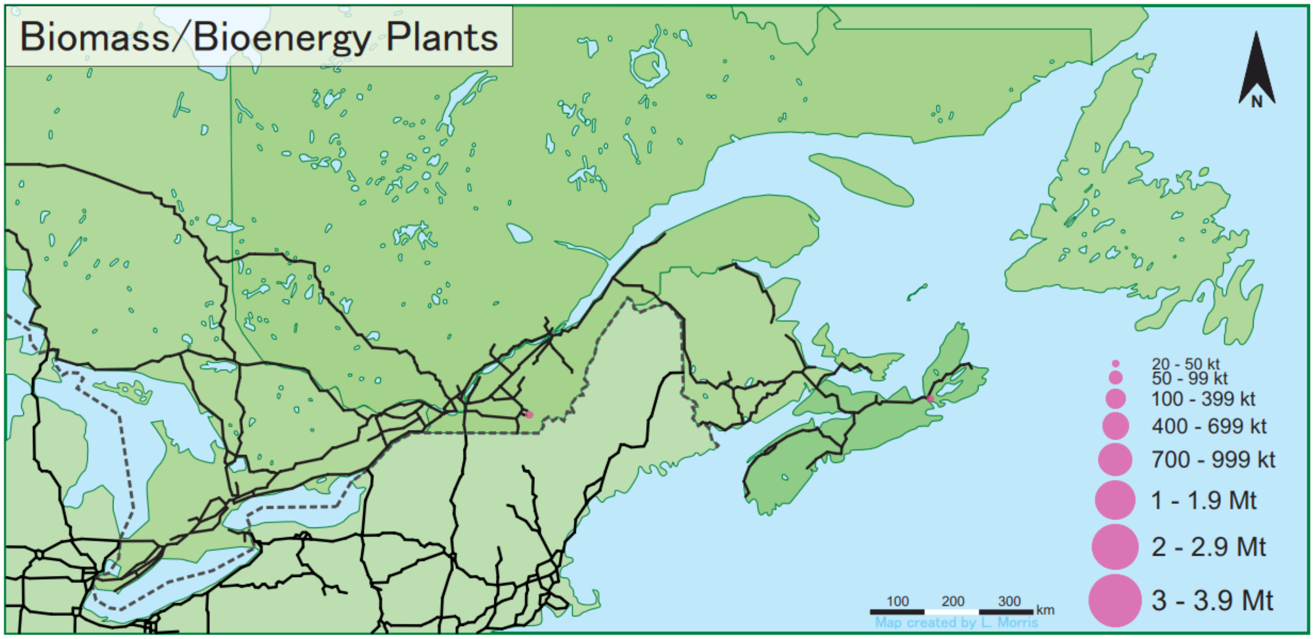
Eastern Canada CO_2 Emissions by emitter type and amount of gas emitted in tonnes, complete version with inset focused on southern Ontario.



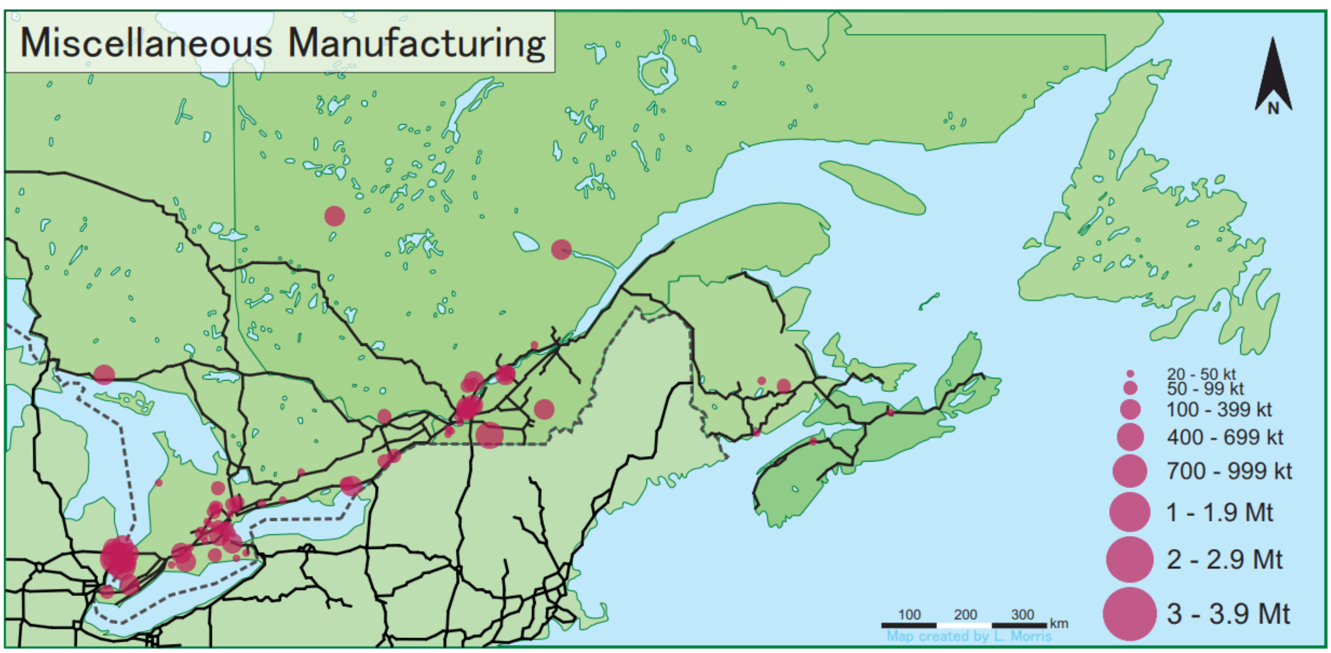
Eastern Canada CO_2 Emissions from Mining Projects.



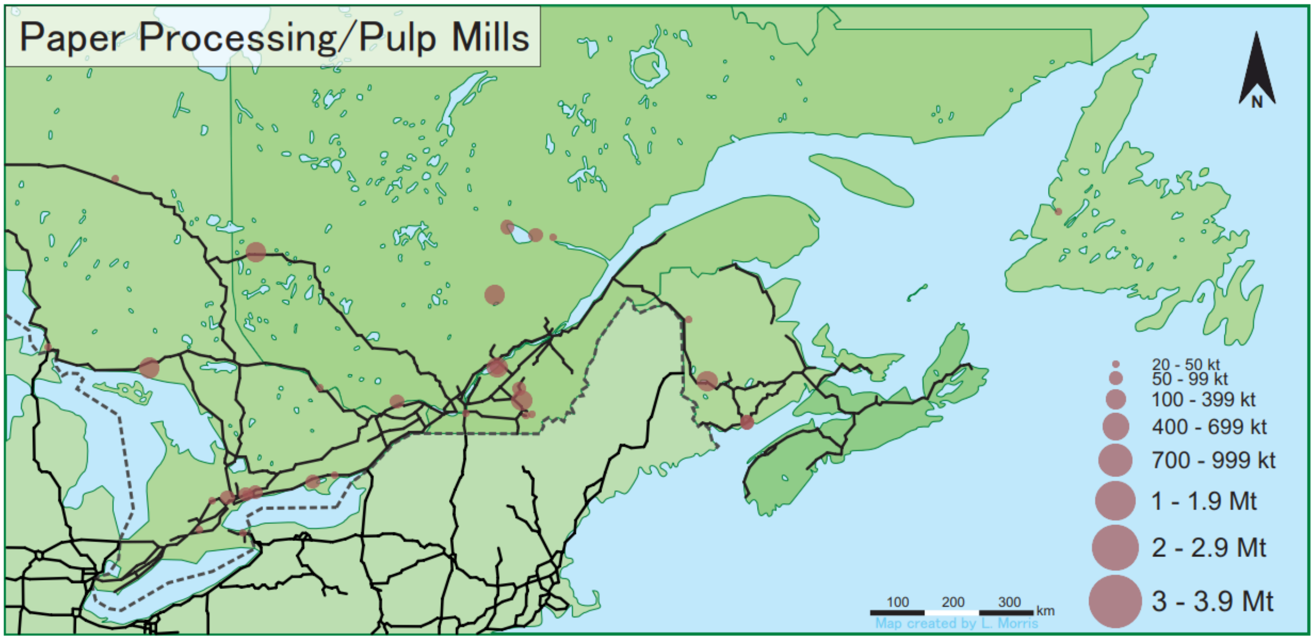
Eastern Canada CO_2 Emissions from Cement Plants.



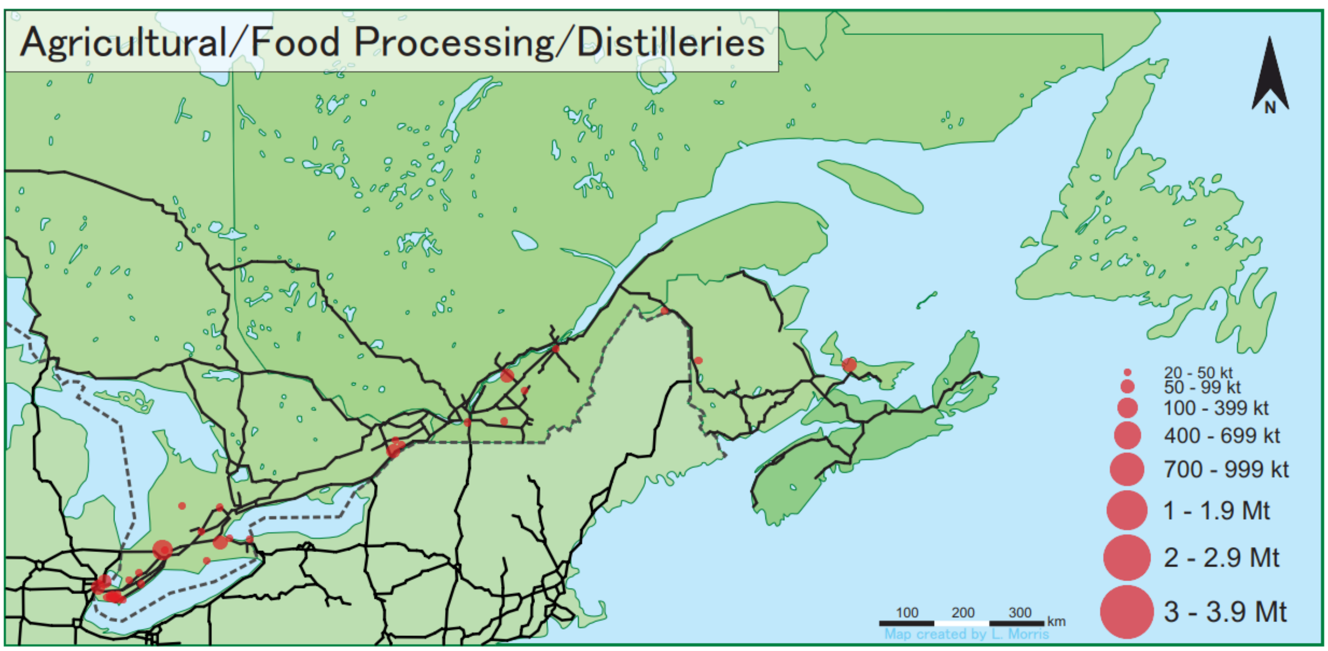
Eastern Canada CO_2 Emissions from Biomass/Bioenergy Plants.



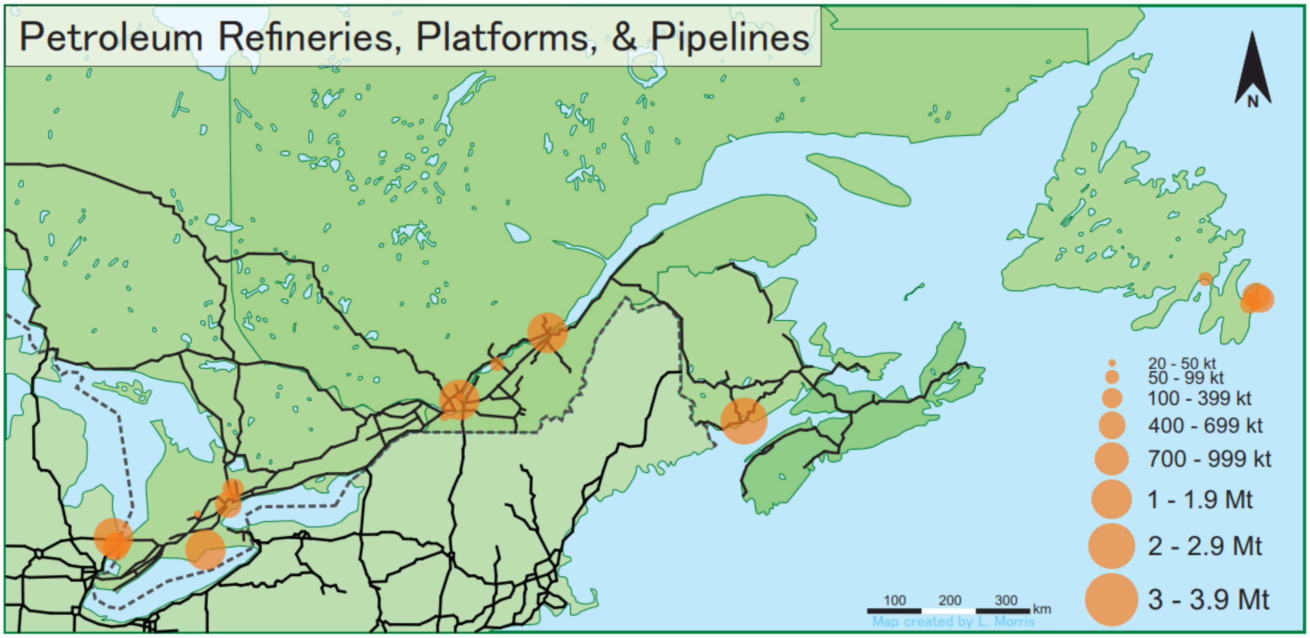
Eastern Canada CO_2 Emissions from Miscellaneous Manufacturing.



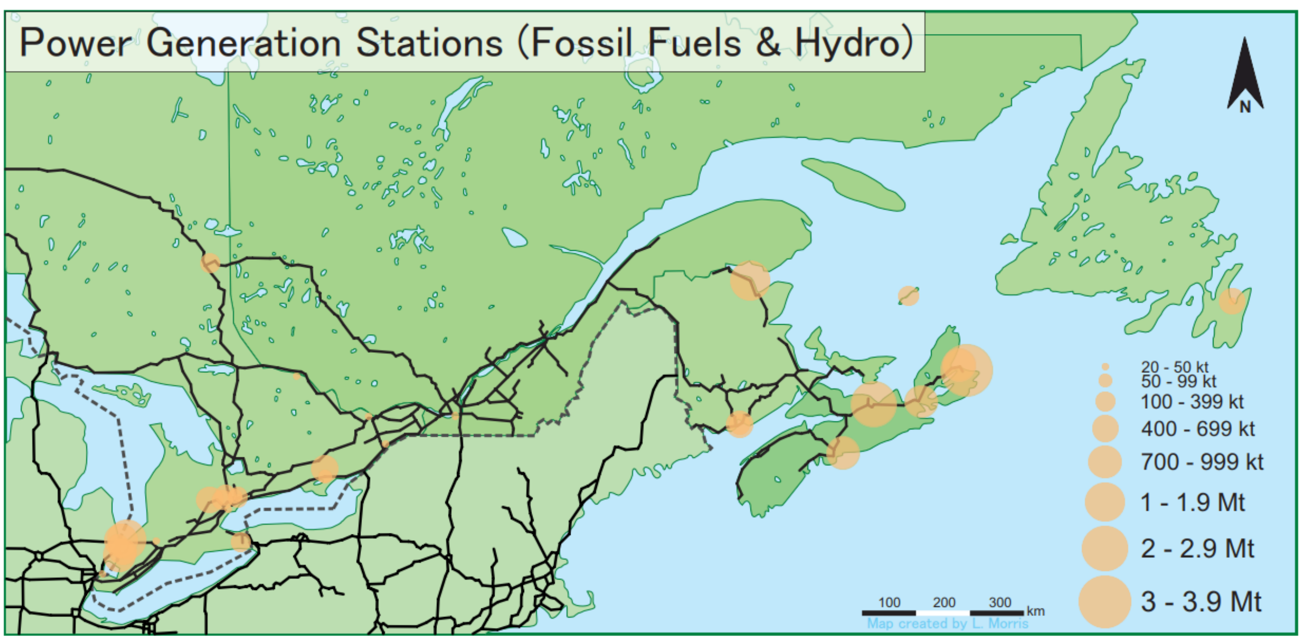
Eastern Canada CO_2 Emissions from Paper Processing/Pulp Mills.



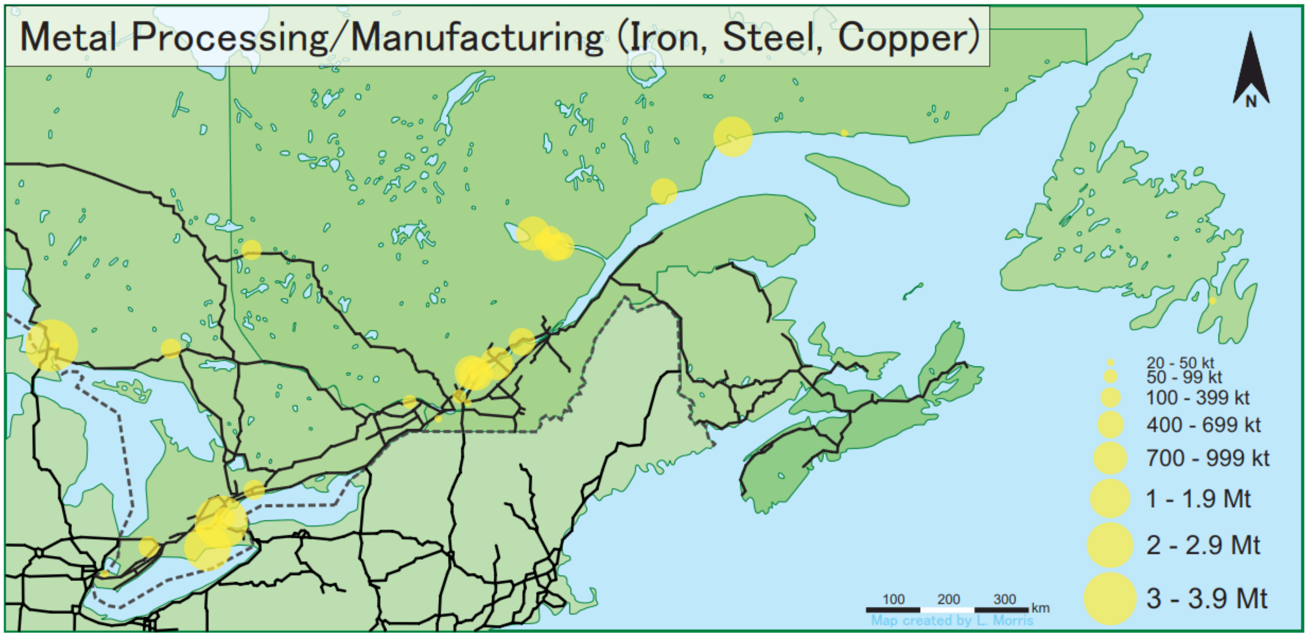
Eastern Canada CO_2 Emissions from Agricultural/Food Processing/Distilleries.



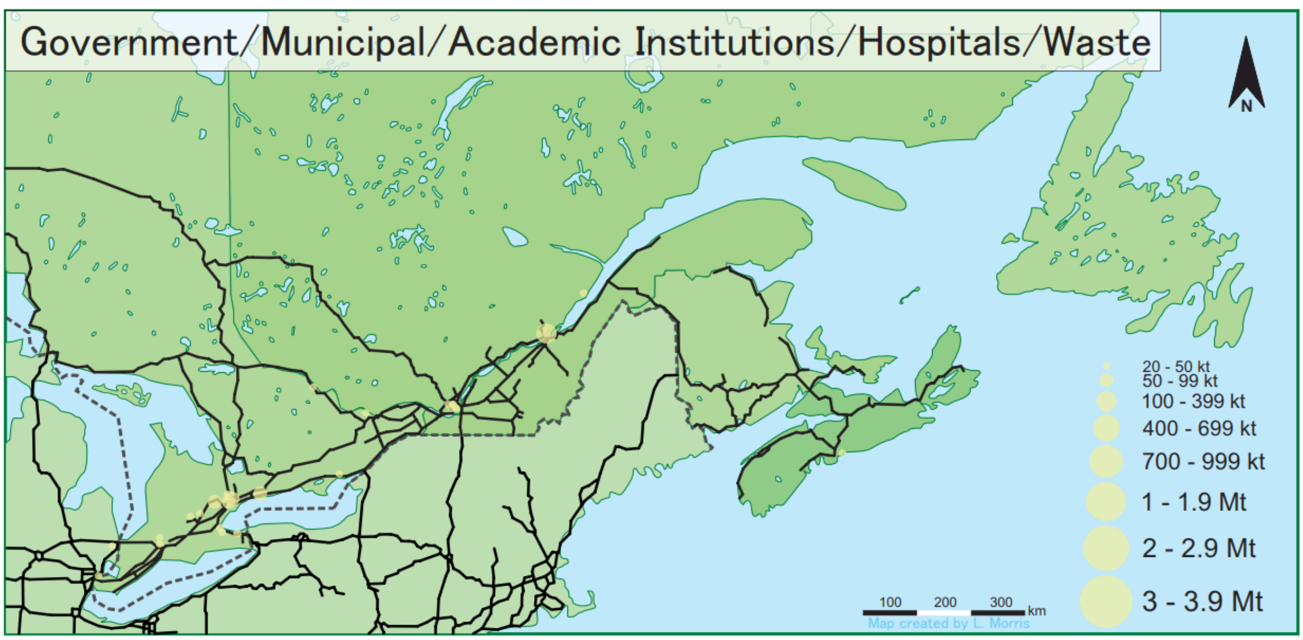
Eastern Canada CO_2 Emissions from Petroleum Refineries, Platforms, and Pipelines.



Eastern Canada CO_2 Emissions from Power Generation Stations (Oil, Gas, Coal, and Hydro).



Eastern Canada CO_2 Emissions from Metal Processing/Manufacturing (Iron, Steel, Copper).



Eastern Canada CO_2 Emissions from Government/Municipal/Academic Institutions/Hospitals/Waste.

APPENDIX B – ENERGY UNITS & CONVERSION TABLE

ENERGY	**MJ**	**KWh**	**BTU**
1 MJ is = to ….	1	0.278	947.8
1 KWh is = to …	3.6	1	3412
1 BTU is = to …	105.5	29.3	1

For Canada and the USA, the average annual household electricity consumption rates range between 9000-12000 KWh.

Appendix C – Glossary of Terms

ACRONYM	TERM
ACTL	Alberta Carbon Trunk Line
BECCS	Bioenergy Carbon Capture & Storage
CAPEX	Capital Expenditure (capital expense)
CCS	Carbon Capture & Storage
CCUS	Carbon Capture, Utilization, & Storage
CEPA	Canadian Environmental Protection Act
CER	Canada Energy Regulator
CIAA	Impact Assessment Agency of Canada
CIB	Canada Infrastructure Bank
CNG	Compressed natural gas
CNSOPB	Canada-Nova Scotia Offshore Petroleum Board
CSA	Canadian Standards Association
DFO	Fisheries and Oceans Canada
ECCC	Environment and Climate Change Canada
EOR	Enhanced Oil Recovery
EPC	Engineering, procurement, and construction
FORCE	Fundy Ocean Research Center for Energy
GHG	Greenhouse Gas
Gt	Gigatonne
IAAC	Impact Assessment Agency of Canada
IP	Intellectual Property
LNG	Liquid Natural Gas
MMV	Monitoring, Measurement, Verification
Mt	Megatonne
NEB	National Energy Board
NPV	Net Present Value
NRCan	Natural Resources Canada
PRAC	Petroleum Research Atlantic Canada
PTRC	Petroleum Technology Research Centre
TEU	Twenty-foot Equivalent Unit
TNO	Netherland Organisation for Applied Scientific Research