The Bowman Centre For Sustainable Energy

Bowman Centre for Sustainable Energy Report: **Where is the 'net' in Net-Zero?**

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Abstract

The pressing issue of climate change is one that cannot be ignored. The Canadian government and leading Canadian businesses have made across-the-board commitments to reach Net-Zero carbon emissions by 2050. However, there are concerns that relying solely on policy instruments such as the purchase of carbon credits, or technology solutions such as hydrogen fuel and carbon capture and storage (CCS), may not be enough to achieve this goal. This report, titled **"Where is the 'Net' in Net-Zero,"** provides an evaluation of Canada's progress towards Net-Zero and investigates the varied levels of ambition and effectiveness in businesses' Net-Zero action plans. Our research will determine the importance and feasibility of implementing technology solutions, such as renewable energy sources, improving energy efficiency, converting to electric vehicles, and capturing and storing carbon emissions. Our research also considers the exemplary leadership of certain Indigenous communities and municipalities in their initiatives to reach Net-Zero. The findings of this report are intended to inform and engage readers in the efforts to reach a Net-Zero economy and advance the mission of the Bowman Centre for Sustainable Energy to achieve a sustainable energy future for Canada.

Introduction

The Bowman Centre for Sustainable Energy is a federally incorporated non-profit think-tank. Associates of the Bowman Centre have lived and worked across Canada. In the spirit of peace and friendship, we honour the Anishinaabek of the Three Fires Confederacy, on whose traditional territory our Sarnia, Ontario office is in.

We have commissioned the research by Queen's University on which this report is based. The research team completed their work in April 2023. This report has had additional review and slight revisions by several Associates of the Bowman Centre for Sustainable Energy.

For governments, companies, and people across the world, the continuous problem of climate change continues to be a very troubling subject. Canada has adopted a strong stance in resolving this ongoing issue while being one of the major contributors to world emissions. Numerous Canadian businesses have made the commitment to achieve Net-Zero carbon emissions by 2050 in recent years. However, there are concerns that these promises might not be supported by efficient action plans.

One strategy used by businesses to get to Net-Zero energy usage is the purchase of carbon credits. By supporting environmental initiatives that reduce carbon emissions, they can use these credits to offset their carbon emissions. However, relying solely on carbon credits is not enough to achieve Net-Zero. Credible carbon credits are hard to come by, and many of the initiatives that produce them do little to reduce emissions.

According to research, many of Canada's leading industries have committed to becoming Net-Zero by 2050. However, their action plans vary in terms of ambition and effectiveness. As an illustration, while some sectors have concentrated on buying carbon credits, others have pledged to reduce emissions by a specific proportion. Additionally, some businesses have neglected some areas of their operations in favor of prioritizing others, such as supply chain management or renewable energy.

Companies need to take a complete approach that includes technology solutions if they want to achieve Net-Zero. Implementing renewable energy sources, improving energy efficiency, converting to an electric vehicle, and capturing and storing carbon emissions are a few of the options. These solutions call for large financial outlays as well as modifications to conventional company models.

Mission and Goal

This report's goal is to provide a thorough evaluation of Canada's progress toward 2050's goal of Net-Zero carbon emissions. The research focuses on the pledges made by Canadian businesses to accomplish this goal and the support provided by carbon credits for these endeavours. The research shows the varied levels of ambitions in these plans through a review of Canada's leading industries and their Net-Zero action plans. The research also investigates different technical solutions to get to Net-Zero, highlighting their significance in making real strides toward a Net-Zero economy.

Methodology

Evidence Gathering

The following list describes and defines the various activities the team will conduct to determine the feasibility of Canada's current Net-Zero ambitions.

1. Define Canada's top industries: The first step is to define Canada's top industries, who are likely to be the biggest contributors to greenhouse gas emissions in the country. These include Oil and Gas, Commercial Banking, Mining, Groceries, Transportation, Agriculture, and Shipping.
2. Identify top companies in each industry: Once the industries have been identified, the next step is to identify the top companies operating in each industry. This can be done through research and review of industry reports and publications, analyzing industry rankings, and looking at companies' financial performance.
3. Review the Net-Zero plans released in the reports of those firms: After identifying the top companies in each industry, the next step is to review the Net-Zero plans released in the reports of those firms. This involves analyzing the scope, timeline, and targets of each plan, as well as the specific measures and technologies proposed to achieve those targets.
4. Define the Canadian government's Net-Zero commitment: The next step is to define the Canadian government's Net-Zero commitment, which is the national target to achieve Net-Zero emissions by 2050. This includes analyzing the policies, regulations, and incentives put in place by the government to support the transition to a low-carbon economy.
5. Determine if Canada's firms/producers align with those goals: Once the government's NetZero commitment has been defined, the next step is to determine if Canada's firms and producers align with those goals. This involves analyzing whether the Net-Zero plans released by the firms are consistent with the national target, and whether the companies are taking steps to reduce their emissions and transition to a low-carbon economy.
6. Identify whether Canadian industry Net-Zero plans are feasible given current technical solutions available: After analyzing the Net-Zero plans of the companies, the next step is to identify whether those plans are feasible given the current technical solutions available. This involves analyzing the viability of the proposed measures and technologies, and whether they can realistically achieve the emission reduction targets.
7. Identify whether Canadian industry Net-Zero plans are feasible given economic viability of solutions available: In addition to technical feasibility, it's also important to consider the economic viability of the solutions proposed in the Net-Zero plans. This involves analyzing the

costs and benefits of the proposed measures and technologies, and whether they are financially feasible for the companies to implement.

8. Identify alternative solutions, areas for political involvement, and areas for future research: Finally, the methodology includes identifying alternative solutions that could be explored to achieve Net-Zero emissions, areas where political involvement may be necessary to support the transition, and areas for future research to improve the feasibility and effectiveness of current Net-Zero solutions.

By following these steps, the methodology can provide a comprehensive and detailed analysis of the feasibility of current Net-Zero solutions being pursued by Canadian governments and industries.

Scope 1, 2 and 3 Emissions

For Net-Zero to be achieved, the entire value chains of Canadian industries will need to be assessed. In the context of corporate sustainability reporting, "Scope 1, 2, and 3" refer to the different categories of greenhouse gas (GHG) emissions that companies report on. Scope 1 emissions refer to direct emissions from sources owned or controlled by the reporting company, such as emissions from a company's own fleet of vehicles, manufacturing processes, or buildings, such as from heating and cooling systems. For instance, a manufacturing company's Scope 1 emissions would include emissions from its own machinery and equipment, such as the combustion of natural gas to generate heat and steam for its production processes. These emissions include those from combustion of fossil fuels in boilers, furnaces, and vehicles, as well as emissions from chemical reactions in production processes.

Scope 2 emissions refer to indirect emissions from the generation of purchased electricity, steam, heating, and cooling consumed by the reporting company. This category covers emissions that occur outside the company's boundaries but are a result of the company's activities.

Scope 3 emissions refer to all other indirect emissions that occur in a company's value chain, including both upstream and downstream activities. These emissions are generally the most difficult to quantify and report on, as they can come from a wide range of sources, including suppliers, customers, and transportation. Examples of Scope 3 emissions could include emissions from the production of raw materials used in a company's products, emissions from the transportation of goods to and from a company's facilities, or emissions from the use and disposal of a company's products by customers. For instance, a clothing retailer's Scope 3 emissions could include emissions from the production of cotton used in its clothing, as well as emissions from the transportation of its products from factories to retail stores and from retail stores to customers' homes.

1.0 Current Net-Zero Plans

1.1 Scope of this report

To clarify the scope, this discussion focuses solely on Net-Zero plans and not on other sustainability topics such as biodiversity and waste disposal, and while most industries may benefit from a more comprehensive approach, additional research may be necessary. Any unreferenced conclusions regarding the overall industry are a comprehensive overview from all reviewed ESG Reports in the industry.

1.2 Government Action Plan

The Canadian Federal Government's current climate action plan is centered around the commitment to achieving Net-Zero emissions by 2050, which is enshrined in the Canadian Net-Zero Emissions Accountability Act passed on June 29, 2021. The plan includes several key measures, such as the Net-Zero Accelerator Fund, which provides $8 billion to large emitters to help reduce their emissions. Additionally, the plan includes a voluntary "Net-Zero Challenge" for firms to join, although there are no strict regulations in place. The plan is guided by the Net-Zero Advisory Body, which provides advice to the Minister of Environment and Climate Change [1]. The 2030 Emissions Reduction Plan is also an integral part of the government's climate action plan, with a goal to reduce emissions by 40-45% by 2030 from a 2005 baseline [2]. The full plan is available on the government's website, which outlines specific measures and policies aimed at achieving the Net-Zero target, such as investing in clean energy, electrification of transportation, and retrofitting buildings to reduce energy consumption.

1.3 Oil & Gas Action Plan

The Oil Sands Pathway to Net-Zero project is an initiative by six of Canada's top oil sands producers, namely Cenovus, Canadian Natural, ConocoPhillips, Imperial, MEG Energy, and Suncor, to achieve Net-

Zero emissions by 2050 [3]. The project focuses on investing in carbon capture and storage, as well as other technologies, to reduce emissions from the oil sands industry. The project aims to achieve its goal through a three-phase approach, with the first phase being carbon capture from 2020 to 2030. The second phase, which is slated for 2030 to 2040, focuses on improving efficiency in oil sands production processes. The final phase, from 2040 to 2050, focuses on emerging technologies to further reduce emissions [4]. Notably, the project does not include Enbridge or Parkland, two of Canada's largest energy infrastructure and refining companies [5][6]. With that in mind, both companies have individual goals for Net-Zero by 2050 outlined in their ESG reports. As it stands, the Oil Sands Pathway to Net-Zero project represents a significant step towards decarbonizing Canada's oil and gas industry, which is a significant contributor to the country's greenhouse gas emissions.

Through the Pathway Project and individual initiatives, Oil and Gas companies have promised a complete reduction in Scope 1, 2, and 3 emissions through carbon capture technology [7], which will require extensive investments in infrastructure and research [8]. The success of these projects can be evaluated by reviewing the ESG and Financial Reports of leading Oil and Gas companies.

While this project is a significant stride towards Net-Zero, it requires that participating companies maintain their promises and do not mislead the public. Cenovus stated, “in fact, we’ve reduced overall emissions intensity by over 23 per cent between 2012 and 2019,” which may suggest that the company is making significant progress in reducing its greenhouse gas emissions [3]. However, this statement may be misleading because it focuses on the emissions intensity, or emissions per unit of output, rather than the total amount of emissions produced. In most cases, the total emissions may have increased even if the emissions intensity per unit of production has decreased.

The term "emissions intensity" is commonly used in the ESG Reports of the oil and gas industry without providing a clear explanation of what it means [9]. This lack of clarity can make it difficult for investors and the public to differentiate between companies that are truly making progress in reducing their emissions and those that are merely using misleading metrics to create a positive impression. Similarly, all Oil and Gas companies refer to the inclusion of Indigenous peoples in decision-making but provide limited details into the specific processes that Indigenous decision-makers are being included in, and what difference their voices make to the projects undertaken.

To avoid greenwashing, it is important for companies to promote transparency and provide clear and comprehensive information about their environmental performance, including both total emissions and emissions intensity.

1.4 Commercial Banking Action Plan

The Canadian banking industry has made significant strides in recent years to develop and implement Net-Zero plans in response to growing concerns over climate change. The major banks in Canada have committed to achieving Net-Zero by 2050 or sooner and have taken steps to guide their clients in transitioning to more sustainable practices.

All major Canadian banks are members of the UN Net-Zero Banking Alliance, which aims to transition the operational and attributable GHG emissions from their lending and investment portfolios to align with pathways to Net-Zero by 2050 or sooner [10]. Within 18 months of joining, the banks are expected to set 2030 targets (or sooner) and a 2050 target, with intermediary targets to be set every 5 years from 2030 onwards [11].

The banks' first 2030 targets will focus on priority sectors where they can have the most significant impact, such as the most GHG-intensive sectors within their portfolios. Further sector targets will be set within 36 months. Additionally, the banks will annually publish absolute emissions and emissions intensity in line with best practices. Within a year of setting targets, they will disclose progress against a board-level reviewed transition strategy setting out proposed actions and climate-related sectoral policies [11]. However, Canadian banks, like Royal Bank of Canada (RBC) and TD-Bank, have used their presence in the UN Net-Zero Banking Alliance to veto proposals for increased regulations.

RBC and other major Canadian banks have faced scrutiny over its Net-Zero plans due to their involvement in the oil sands industry [12]. While these banks have committed to transitioning to a low-carbon economy, there have been concerns over the banks’ sub-sector exclusions in target setting and their significance to emissions. In the fifth column of the image below, taken from RBC’s Net-Zero Report, you can see a variety of data exclusions. More research should be conducted on the extent of these sectors, as they are not further explained in the Report [13].

	Emission Scope[4] Inclusion	2030 Target (as % reduction from 2019 baseline)	2030 Target (as the portfolio measurement)	RBC 2019 Baseline	Sub-Sector Inclusions & Exclusions	Metric Used	Unit	Scenario Used
Oil & Gas	Scopes 1, 2	**35% reduction**	**4.9** g CO_2e/MJ	**7.6** g CO_2e/MJ	**Include:** Upstream, downstream, integrated **Exclude:** Midstream, services	Physical Emissions Intensity	g CO_2e/MJ	Canada ERP[5]
	Scope 3	**11 - 27% reduction**	**61.1 - 50.2** g CO_2e/MJ	**68.6** g CO_2e/MJ			g CO_2e/MJ	IEA[6] NZE[7,8]
Power Generation	Scope 1	**54% reduction**	**156** g CO_2e/kWh	**340** g CO_2e/kWh	**Include:** Electricity generation **Exclude:** Clients involved in transmission, distribution, non-generation	Physical Emissions Intensity	g CO_2e/kWh	IEA NZE
Automotive	Combined target for Scope 1, Scope 2 & Scope 3 tank-to-wheel	**47% reduction**	**102** g CO_2e/km	**192** g CO_2e/km	**Include:** Manufacturing,[9] financing **Exclude:** Retail motor vehicle loan, new vehicle dealer, trucking rental and leasing, railway, and other[10]	Physical Emissions Intensity	g CO_2e/km	IEA NZE

Figure 1: RBC Report table discussing sub-sector exclusions in various industries [12.

Per RBC, the transition to Net-Zero emissions in the Canadian economy requires significant investment in the electricity sector, including a shift to renewable and non-emitting sources [12]. Canadian banks have extensive experience in the sector and have committed to providing strategic advice to power generation companies, and other necessary clients. However, beyond references to consultations and investments, the discussion of pathways to Net-Zero is minimal and lacks any technical details.

Overall, the Net-Zero plans of the Canadian banking industry are a positive step towards addressing climate change. By committing to Net-Zero targets and taking concrete actions to transition to more sustainable practices, the banks are helping to drive change across the industry and support the global transition to a low-carbon economy.

1.5 Mining Action Plan

In many cases, Net-Zero is not mentioned in the ESG Reports of major Canadian mining companies [14]. With that said, some stand out as sustainability leaders in the industry, outlining their specific plans to reaching Net-Zero. For example, both Teck Resources and Barrick, among others, have committed to reaching Net-Zero by 2050, with various commitments to meet beforehand [15] [16].

These commitments include reducing “emissions intensity,” reducing total emission in Scope 1, 2, and 3, increasing the use of zero emission vehicles, and prioritizing investments in the sustainable transportation of assets [16].

However, tracking emissions across the mining value chain presents various challenges, and scope 3 emissions are a significant portion of mining emissions across all businesses. A recent McKinsey analysis concluded that the international mining industry is indirectly responsible for 28% of global emissions [17]. As a significant contributor to global mining projects, Canada’s businesses must lead the charge on increasing transparency by designating clear reporting of clean energy investments, official releases of what is being included in Scope 1, 2, and 3 emissions reporting, and plans for transitioning to the green transportation of extracted materials and equipment [14].

1.6 Supermarkets and Groceries Action Plan

Like many other industries, the grocery sector is committed to reducing its carbon footprint. Loblaws is one of Canada’s largest grocery store chains and is a large contributor to the grocery industry’s GHG emissions. In recent years, the company has made significant commitments to sustainability, which included a goal to reduce corporate carbon emissions by 30% by 2030 [18]. The company was able to reach this target in 2020, due to projects in energy management, equipment conversions, and refrigerant action plans. It is recognized that decomposition of food waste in landfills produces around 4% of the national greenhouse gas inventory [19]. Loblaws was also able to reduce food waste sent to landfills by 90% over the last six years through partnerships with local food rescue partners.

Loblaws plans to create a long-term roadmap that includes achieving Scope 1 and 2 Net-Zero emissions for the company’s operational footprint by 2040. The company also plans to achieve Scope 3 Net-Zero emissions by 2050 [20]. The action plan includes initiatives to ensure that all plastic waste is reusable or recyclable by 2025 and eliminate food waste sent to landfills and move to a zero-emissions truck fleet by 2030.

Despite promising numbers with reducing landfill waste, only little action has been done on ensuring plastic waste is reusable and a move to a zero-emission truck fleet. Plastic reduction in hangers, vegetable packaging, straws and stir sticks have been the only means of reduction. Loblaws has also only committed to purchase 15 new electric trucks, while maintaining the zero-emission fleet would require 350 zero-emission vehicles. Nonetheless, actions are being taken, but the speed and efficiency with which it is being done may be of concern.

1.7 Transportation Action Plan

Canada's transportation industry contributes a large amount of Canada's GHG emissions year over year. Automobiles and light trucks accounted for 11% of Canada's total greenhouse gas emissions in 2018 [21].

Canada's federal government has set new sales targets and requirements to reduce and eliminate emissions within the transportation industry. As part of their 2030 Emissions Reduction Plan, new light duty zero-emission vehicle sales will reach 100% by 2035, with mandatory interim targets of 20% by 2026, and 60% by 2030 [22]. The government is mandating that 35% of new medium and heavy-duty vehicle sales be zero-emission by 2030. Further regulations will require 100% of new medium and heavy-duty vehicle sales to be zero-emission by 2040. Further projections estimate that this initiative would result in 1.2 million zero-emission vehicle sales in 2030 for a total of 4.6 million zero-emission vehicles on the road by the same year.

Similarly, the Canadian government is also looking towards the aviation industry with the "Canada Aviation Climate Action Plan 2022-2030". The action plan consists of four key factors which includes reducing aircraft emissions, improving operational efficiency, developing sustainable fuels, and investing in green infrastructure. The plan is to reduce emissions intensity by 30% by 2030, (as compared to 2019 levels) and to achieve Net-Zero emissions by 2050 [22]. To achieve these goals the government will instigate regulatory measures, research, and development in fuels, and begin partnerships with industry leaders. The plan also emphasizes international cooperation and commits to working with global partners to address current emissions within the aviation industry.

1.8 Agriculture Action Plan

Canada's agriculture industry is a significant source of greenhouse gas emissions, making this industry a critical target in the country's efforts to achieve Net-Zero emissions by 2050. In recent years, 10% of Canada's greenhouse gas emissions are from crop and livestock production, which excludes emissions from the use of fossil fuels or from fertilizer production [23]. A detailed analysis of Canada's increasing annual GHG emissions from the agricultural industry from 1990-2019 was conducted [13]. The study, undertaken by the National Farmers Union, provided key insights into the emissions, as well as the targets required to reduce GHG emissions by 2050 [24]. It is important to note that since 1990 to 2019, the overall emissions have increased from 67 megatons of CO_2 to 84 megatons of CO_2 in 2019. While there are many different aspects that contribute to the overall emissions from these time periods, the main contributors are direct emissions from farm fields (carbon dioxide) and emissions from nitrogen fertilizer production facilities (mostly carbon dioxide, but also nitrous oxide). To reduce Canada's emissions within this sector, the industry has developed a plan to achieve Net-Zero emissions. This includes improving nutrition management, reducing the use of nitrogen fertilizers, enhancing soil health, adopting low-carbon energy sources, and improving technologies in agriculture.

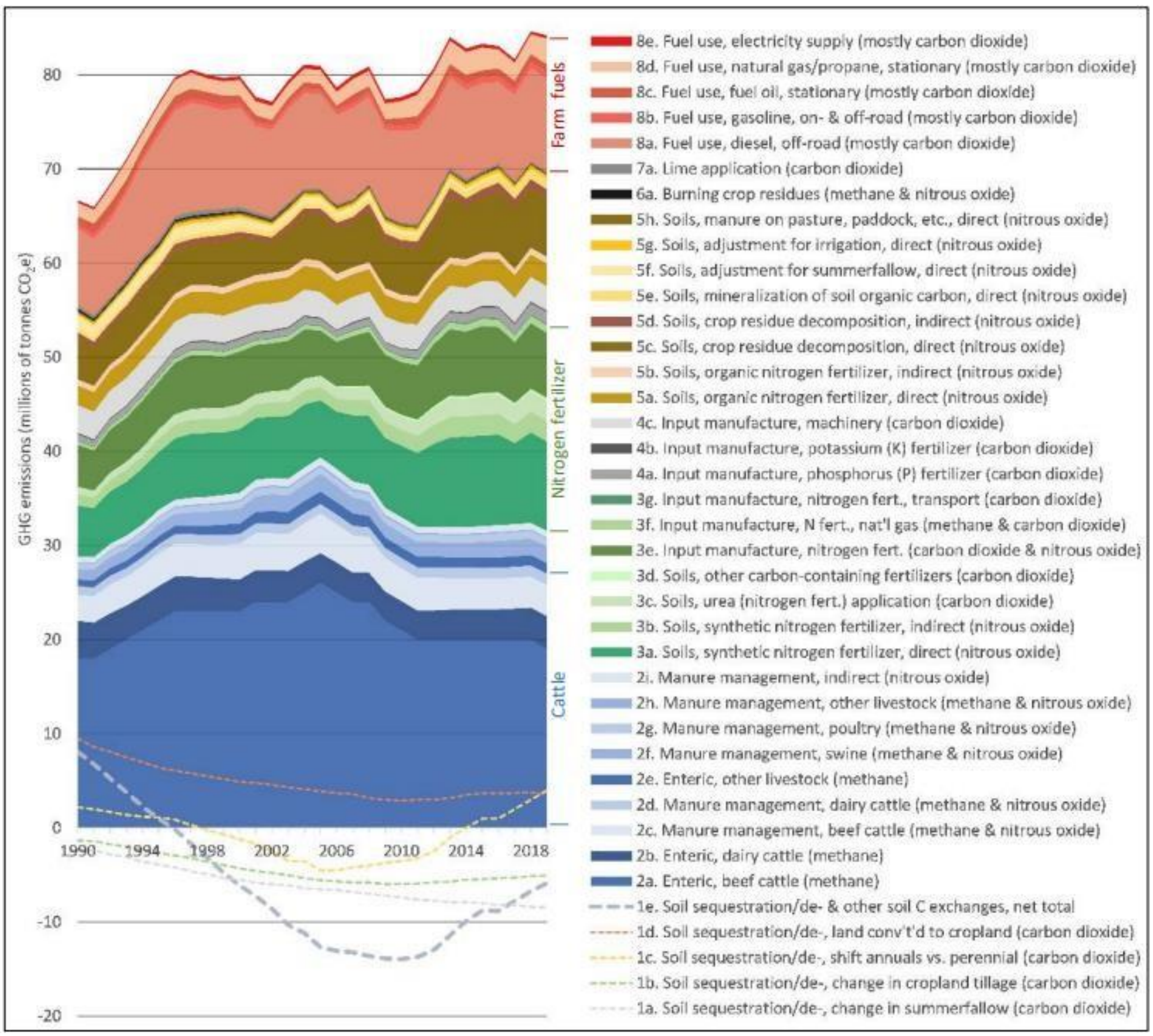


Figure 22: Comprehensive and detailed understanding of Canada's agriculture emissions from 1990-2019

With these solutions, Canada has committed to reduce economy-wide GHG emissions by at least 40% by 2030 and to reach Net-Zero emissions by 2050. Specific to agriculture, Canada has committed to collaborate with farmers and the industry to reduce fertilizer emissions to 30% below 2020 levels by 2030. Furthermore, the government has also pledged to reduce methane emissions from livestock production as part of a larger objective by decreasing overall methane emissions to 75% below 2012 levels by 2030 [24].

1.9 Community Leaders and Engagement

Walpole Island First Nation, located in southwestern Ontario provides an excellent example of an action-oriented community. They have developed an ambitious plan to achieve Net-Zero emissions by 2025. This plan includes installing renewable energy systems, retrofitting existing buildings, infrastructure, and public transit for energy efficiency, and reducing waste through community programs. The community has also implemented a sustainable land-use plan to protect their natural resources and preserve traditional cultural practices.

Other Indigenous communities across Canada have also made commitments and significant progress towards Net-Zero. For instance, the T'Sou-ke Nation, located in British Columbia, is the first Indigenous community in Canada to achieve Net-Zero in electricity consumption through the installation of solar panels, wind turbines and micro hydro systems [25].

Another example is in the United States, where the city of Berkeley, California, has implemented strict energy efficiency standards for all new buildings and requiring all existing buildings to undergo energy retrofits. Additionally, the city has committed to powering all municipal facilities with 100% renewable energy by 2030 [26].

These initiatives by Indigenous communities and local municipalities demonstrate that by prioritizing sustainability and collaboration, it is possible for Canadian municipalities and communities to drive Net-Zero initiatives by removing their reliance on Oil and Gas and other unsustainable value chains.

2.0 Greenwashing

2.1 Defining Greenwashing

Greenwashing is when a company conveys false or misleading information about the environmental impact of their products or business operations. It is usually done by making an unsubstantiated claim, using misleading labels or distracting you with positive environmental branding and images. It is an attempt to capitalize on the ever-growing market for environmentally sound and sustainable products and practices.

2.2 Greenwashing in the Industry

Companies, industries, and governments engage in greenwashing to fulfill their requirements for sustainable solutions without changing their current practices. For example, the fossil fuel industry has frequently portrayed itself as environmentally friendly, with concepts such as "clean coal" and natural gas as sustainable energy sources. Nonetheless, certain industries are easier to recognize as engaging in greenwashing tactics [27].

For example, in 2015 Volkswagen was caught for cheating emissions tests on their diesel vehicle line. The company was heavily fined, and their reputation was severely damaged. Volkswagen later tried to restore their image by claiming to produce eco-friendly cars, but it was discovered that they were still manufacturing polluting vehicles.

In the natural gas industry, Shell has also been under scrutiny for participating in greenwashing activities by claiming to be a sustainable energy company, while their core business is still based on fossil fuels. Shell has invested in renewable energy, but it only accounts for a small portion of their business. Critics argue that Shell needs to do more to transition to sustainable energy to reduce their carbon footprint.

Coca-Cola and Nestle have also been accused of greenwashing. Coca-Cola claims to be a water-neutral company, which means that they replenish the same amount of water they use in their operations. However, activists and researchers argue that the company is still depleting water resources in water-scarce areas. Nestle has been accused of greenwashing by making claims that their products are environmentally sustainable, even though the company is responsible for massive plastic pollution. Nestle is one of the biggest plastic polluters globally, with millions of tons of plastic waste generated by their products.

In conclusion, it is important for consumers to remain vigilant and informed about greenwashing practices in various industries to ensure that they are making environmentally conscious decisions and holding companies accountable for their actions.

2.3 Greenwashing Regulations

The U.S. Federal Trade Commission (FTC) plays a role in protecting consumers by enforcing laws aimed at promoting a fair and competitive market. The FTC offers guidelines on how to differentiate real green products from those that are greenwashed. These guidelines include ensuring that packaging and advertising clearly and plainly explain the product's green claims, specifying whether the claim refers to the product, packaging, or just a portion of it, avoiding overstatement of environmental benefits, and substantiating claims of superiority over competing products.

Canada is also using similar measures to help reduce the effects of greenwashing of Canadian products. For example, the Competition Bureau is expected to focus on false and misleading environmental claims in advertising, particularly in the narrative of COVID-19. The bureau has already issued several warnings to companies that have made false or exaggerated claims about the environmental benefits of their products in relation to the pandemic.

Similarly, the Canadian Food Inspection Agency is expected to ramp up its efforts to monitor and enforce environmental claims on food packaging, particularly with respect to claims related to sustainable agriculture and production methods. The agency will also be working closely with other government departments and stakeholders to develop clearer guidelines and standards for environmental claims in the food industry.

Environment and Climate Change Canada will start enforcing the rules pertaining to dangerous substances, particularly about goods that make misleading or exaggerated claims about their environmental impact. The agency is anticipated to collaborate closely with other government agencies and interested parties to provide standards and rules that are more precise for environmental claims made in the manufacturing and industrial sectors.

2.4 Complexity of Greenwashing

While greenwashing is a serious issue that undermines the trust of consumers in purchasing sustainable products and services, it is also a complex topic that requires careful consideration. In some cases, companies may be accused of greenwashing even when they are genuinely trying to reduce their environmental impact. This can happen when their efforts fall short of what is expected by the consumers or when the message is not clear enough to communicate their intentions effectively.

Furthermore, many companies face challenges in adopting truly sustainable practices due to the complexities of their operations, supply chains, and regulatory environments. Many companies have standardized practices that require little to no change, but when new motives change the operations, the reluctance is evident. Making substantive progress towards sustainability requires significant investments of time, money and resources which can be difficult to justify in the short term.

Therefore, while it is important to hold companies accountable for their environmental projects and claims, it is also important to recognize that many companies are genuinely committed to helping the environment. Through promotion of transparency, collaboration, and improvements, companies and consumers can work together to make a more sustainable future.

3.0 Carbon Credit Feasibility

The feasibility of relying on carbon credits to achieve Net-Zero targets was studied from several angles. The following sections study the role carbon credits currently play in reducing global greenhouse gas emissions, current carbon credits policies and regulations, the quality and quantity of credits available, as well as shifting focus to adopting nature-based solutions that may bring us closer to achieving Net-Zero emissions.

3.1 Overview: What is a Carbon Credit and How is it Used?

Carbon credits are a form of permit that allows companies and governments to emit a specific amount of carbon dioxide or other greenhouse gases. The objective behind carbon credits is to establish a market-based solution to address environmental issues by placing a price on carbon emissions. These credits are aimed at reducing carbon emissions and mitigating global warming, with the funds generated from the sale of carbon credits financing clean energy initiatives and other projects that help to cut down greenhouse gas emissions [28].

The process of creating carbon credits involves investing in projects that reduce carbon emissions. For instance, a company can invest in renewable energy sources such as wind or solar power that lessen the amount of carbon emissions, which are then transformed into carbon credits [29]. These credits can be bought and sold on the carbon market, providing an incentive for companies and governments to invest in clean energy and other initiatives that reduce greenhouse gas emissions [29].

An example of a typical process for the creation and purchasing of carbon credits from a reforestation project is outlined below [30]:

1. A project developer owns a large plot of land in Ethiopia and plants several trees that are native to the region.
2. Project plans first need to be validated by a private carbon standard, at which point the project can be listed in the carbon registry. Once the project is ongoing, the project must be monitored and reviewed regularly by a verifying entity. The project is reviewed and validated by a private standard. The trees keep growing and absorb CO_2.
3. Credits are issued on a regular basis by the private standard after the emissions reductions are verified to have happened.
4. The project enters a phase of revenue generation as the credits issued to the developer can be sold to corporations and consumers through a broker or an exchange. Once sold to the end buyer, the credit is retired and removed from circulation.
5. Toward the end of the project life cycle, the trees reach a plateau of further growth, at which stage the project stops yielding credits.

One specific example of carbon credits is those generated from REDD+ projects. REDD, which stands for Reduced Emissions from Deforestation and forest Degradation, is a framework aimed at reducing greenhouse gas emissions caused by deforestation and forest degradation [31]. The primary objective of REDD+ projects is to conserve and restore forests via reforestation, thereby reducing greenhouse gas emissions and mitigating climate change. These projects provide incentives for forest conservation by compensating countries, communities, or individuals for their efforts to reduce deforestation and forest degradation [32].

REDD+ projects operate on a pay-for-performance basis, meaning that they compensate countries or communities based on their ability to reduce carbon emissions [31]. By providing financial incentives, REDD+ projects can promote sustainable forest management practices that protect forests and the biodiversity they support. The funds generated from REDD+ projects can also be used to support local communities by providing them with alternative livelihoods that do not depend on forest clearance or degradation [32]. In addition, REDD+ projects can help to preserve Indigenous cultures and traditional knowledge associated with forest management.

However, funding these projects may not actually lead to reductions in greenhouse gas emissions if the carbon offsets are not verified. To ensure that they are genuine, carbon credits are typically validated at the project level by a third-party verifier to ensure that the project from which they are generated meets certain standards. There are several global independent parties that validate and verify projects, but the most common is the Verified Carbon Standard (VCS), which provides a comprehensive set of rules and requirements to be certified that all offset projects must adhere to [33]. The VCS program is overseen by an organization called Verra (formerly Verified Carbon Emissions Standard), which is responsible for updating and maintaining the VCS rules to ensure their ongoing relevance and effectiveness [34].

3.2 Current Protocols and Regulations

This section of the report delves into the important policies and regulations related to offsets and how the federal/provincial system is involved in regulating the market. In 2019, Canadian Council of Ministers of the Environment (CCME) launched a pan-Canadian greenhouse gas (GHG) offsets framework as part of the Pan-Canadian Framework on clean growth and climate change [35]. The framework mainly focuses on the vital elements that need to be considered for the offset program design within federal, provincial, and territorial governments and guidelines. The offset program design includes:

1. Attainment of climate goals and clean economic development, encouragement of low-cost reduction through less attainable emission sources and sectors by carbon pricing.
2. Credibility and offering choices: Building confidence in the offsets to create value by incorporating practices to monitor GHG emissions and provide opportunities to regulated and voluntary emitters.
3. Program design: Define the program and offsets' purpose to avoid the investment barriers in the carbon reduction projects. Some of the major guidelines as per the framework are as follows [35]:

   i Eligibility Criteria: The criteria provided must include a clear definition of the project as defined by the sector with additional information about geographic boundaries and specific GHG types, and consideration of emissions that align with 1SO-15064-2 standard.

   ii Additionality: Any reduction that is caused by any kind of action beyond legal requirements and business-as-usual (BAU) expectations. Criteria states that the program should prevent these kinds of activities to maintain the fungibility of offset credits.

   iii Creating Period: The elements such as the normal adoption rate, respective industry standards, involvement of sequestration or non-sequestration of GHG emissions, timeline of the project are considered to address the validation of the offset credits. Although, the creating period could be extended or renewed if the project operates under standard conditions of the program.

   iv Leakage: Prior assessments and additional monitoring are conducted on the project to issue or accept an offset to the percentage of leakage that can cause shifting in emission and market effects.

   v Ownership: Requirement of adequate and legal information prior to the issuance of the offset and registration in the tracking system to avoid offset credits.

vi Offset Use: Required to follow the jurisdiction of the offset program and provide information to use the credit publicly. Prevention of usage of offset after "retirement" of the offset.

vii Enforcement: Establishment of provisions that align with carbon pricing program, throughout the tenure of the program- accuracy, correctness and material errors should be taken responsibility. Involvement of government and the reinforcement of the environmental integrity is highly essential.

As a part of the reduction plans by 2050, pricing carbon pollution is one of the ways to do it. There are two parts in the federal carbon pollution pricing system which includes, the flue charge which is a pollution price on fuel and the other Output-Based Pricing System (OBPS) which came into effect in July 2018 under the GHG pollution pricing act which is also known as federal backstop [36]. Here, polluters must pay for the environmental damage they cause and find alternatives that emit less pollution. The OBPS has set the standard emission based on the assessment of the risks to competitiveness and "Carbon leakage" for instance the risk of industries moving from one region to another to avoid paying the price on carbon pollution. The price of carbon pollution started at $20 per tonne of CO2 in 2019 and will gradually increase to $65 per tonne in 2023, with a review to determine if it needs to be increased even further. Industry facilities emitting 50,000 tonnes or more of CO2 per year are required to pay, small businesses and other sectors can voluntarily participate in the emissions reduction fund to finance their own clean technology projects. The system is designed to work alongside other climate change policies and programs and is expected to generate economic and social benefits. By reducing healthcare costs related to air pollution and creating jobs in the clean technology sector, everyone will benefit from reducing greenhouse gas emissions [37].

Under the OBPS, facilities that emit more than the government-set benchmark level of emissions must either reduce their emissions or purchase offset credits to cover their excess emissions. The offset credits can be purchased from other facilities that have reduced their emissions below their benchmark level or from approved offset projects in Canada or abroad. The price of offset credits is determined by the market and can vary depending on supply and demand. Therefore, the OBPS and offset credits are directly related in Canada's carbon pricing system for industries. The OBPS aims to incentivize facilities to reduce their emissions, and offset credits provide a way for facilities to comply with their emissions limits if they are unable to reduce their emissions sufficiently. The price of offset credits reflects the cost of reducing emissions through offset projects and can provide an additional financial incentive for industries to reduce their emissions. However, some of the drawbacks of the OBPS system includes [38]:

1. Complexity: The OBPS system adds more complexity to the carbon pricing system, as it requires businesses to report their emissions and demonstrate their compliance with emissions regulations.
2. Administrative Costs: The system also imposes additional administrative costs on businesses, which may affect their competitiveness.
3. Limited Coverage: The OBPS system only applies to certain industries and sub-sectors, and it doesn't cover process emissions, which restricts its effectiveness in reducing overall greenhouse gas emissions.
4. Uncertainty: The price of carbon emissions credits is subject to market forces, so businesses may face uncertainty and volatility in their operating costs.
5. Incentives for Innovation: Critics argue that the OBPS system may undermine incentives for businesses to innovate and invest in low-carbon technologies, as they can simply purchase emissions credits to meet their targets.
6. Equity: Finally, the OBPS system may raise concerns about equity, as it may disproportionately affect small businesses and low-income households that are more vulnerable to higher energy costs.

The OBPS is closely related to carbon credits because Federal system offset credits are one of the three types of credits in the OBPS, OBPS meets its compliance in three ways that includes paying charges at the given carbon price, which is rising by $15 each year. Additionally, by submitting surplus credits from a previous compliance year or purchased from another facility that outperformed its sectoral standard; and submitting offset credits — including federal offset credits or eligible provincial/territorial offset credits. Offset credits are generated from projects that reduce greenhouse gas emissions or increase stored carbon through activities that are not covered by carbon pollution pricing, such as waste or forestry. Based on the Pan-Canadian GHG framework the Federal GHG offset system regulation and Green House Gas Pollution pricing act were established in 2019 and 2022 respectively. The greenhouse gas offset credits that can be used by companies to offset their carbon emissions. The Greenhouse Gas

Offset Credit System aims to support Canada's clean and green economy by promoting projects that reduce emissions or remove greenhouse gases from the atmosphere, such as reforestation or conservation. The new system aims to provide market-based incentive to reduce GHG's to municipalities, foresters, farmers and indigenous communities and access to tradeable offset credit for every tonne of emission that they reduce in the atmosphere [39]. The system is also expected to create economic opportunities in rural and Indigenous communities by promoting sustainable land-use practices and supporting local businesses. Canada is currently on track to meet its target of reducing emissions by 40-45% from 2005 levels by 2030, but the offset credit system is seen as a key tool in achieving Net-Zero emissions by 2050. Additionally, the Canadian government has launched a set of protocols which provide flexibility to the people interested in reducing emissions to purchase the carbon credits, aiming to build a resilient and cleaner economy. For instance, municipalities, foresters, farmers, and Indigenous communities have an opportunity to access tradeable credits that reduce carbon in the atmosphere and enabling landfill operators to generate offset credits by repurposing the gas into energy such as boilers or engines. In the forthcoming days, the Government of Canada will launch new offset protocols based on agriculture and forest management. These protocols act as a comprehensive guide of mitigating actions of GHG emissions to manage and measure the emissions in different sectors.

3.3 Strengths and Weaknesses of Carbon Credits

Carbon credits provide a venue for the total amount of emissions in the atmosphere to be reduced, even if investors cannot fully eliminate their own emissions. Examining the strengths and weaknesses of carbon credits provides insight as to what extent companies can rely on carbon credits to achieve Net-Zero emission by 2050. In this report, our team has specifically studied both the quality and quantity of carbon credits available to determine their role in achieving Net-Zero targets.

3.3.1 Overall Strengths

One advantage of using carbon credits is that it allows countries and organizations to act towards reducing their carbon footprint immediately, rather than waiting for expensive technologies to be developed or for regulations to be implemented. Carbon credits are currently available in quantities that can match demand, and purchasing credits is a relatively quick process – especially in comparison to the implementation of carbon capture technologies [40]. Additionally, carbon credits can often be purchased at a lower cost than implementing new technology or making major infrastructure changes, rendering it a cost-effective option for companies and organizations [29].

Another advantage of carbon credits is that they can help to incentivize the development of clean energy projects and sustainable practices in developing countries. Developing countries may have difficulty financing these projects on their own, but through the sale of carbon credits, they can receive funding and support for their efforts [29]. This can lead to a more equitable distribution of emission reduction efforts and ultimately help to encourage sustainable development in these regions.

The use of carbon credits can also help to create a market for emissions reductions, which can drive innovation and investment in new technologies and practices. As the demand for carbon credits increases, so too does the incentive to develop new and innovative ways to reduce emissions [41]. This can lead to the creation of new jobs and industries and could help to accelerate the transition to a low-carbon economy.

3.3.2 Carbon Credit Availability

Purchasing carbon credits is a valuable method used by corporations to address emissions that they are unable to eliminate. As efforts reduce the rate of global emissions increase, demand for carbon credits continue to rise, which leads to the following question: is the theoretical volume of carbon credits available sufficient to keep up with increasing demand?

BloombergNEF analysts estimate that 1,900 carbon offset projects issued credits from 2015 to 2020 with the four major registries. These projects created more than 344 million carbon offsets in 2021, an 86% increase from 2018 [42]. Carbon credit demand is projected to increase not only as we approach 2050, but as more companies commit to Net-Zero pledges. In 2020, the number of companies with Net-Zero targets doubled globally, from 500 in 2019 to more than 1,000 in 2020 [28].

The Taskforce on Scaling Voluntary Carbon Markets (TSVCM), in conjunction with the Institute of International Finance (IIF), estimates that demand for carbon credits could increase by a factor of 15 or more by 2030 and by a factor of up to 100 by 2050. These represent maximum bounds, not forecasts, as they represent total removal/sequestration requirements from climate modelling [30]. Overall, the market for carbon credits could be worth upward of $50 billion in 2030 – a significant increase from its value of $2 billion in 2021 [40] [43]. This corresponds to an annual global demand of up to 2.0 gigatons of carbon dioxide equivalents ($GtCO_2$) by 2030, compared to a 0.298 $GtCO_2$ demand in 2021 [40][44].

While the increase in demand for carbon credits is significant, analysis by McKinsey Sustainability indicates that demand in 2030 could be matched by the potential annual supply of carbon credits of 8 to 12 $GtCO_2$ per year [30]. Included in this is avoided nature loss (including deforestation); nature-based sequestration, such as reforestation; avoidance or reduction of emissions such as methane from landfills; and technology-based removal of carbon dioxide from the atmosphere [30]. This estimate was generated based on economic feasibility as land feasibility is difficult to address.

Using emission projections from the Global Carbon Budget 2018, McKinsey's *Global Energy Perspective Report* generated the following forecast for emission levels required to achieve the Net-Zero target [45] [46]. Assuming business-as-usual emissions, additional emissions reductions corresponding to an amount of 23 $GtCO_2$ are required by 2030 to be on target to achieve Net-Zero [30][46]. Assuming the previously stated maximum carbon credit volume of 12 $GtCO_2$ by 2030, the use of carbon credits would not be sufficient to reduce emissions to the Net-Zero target.

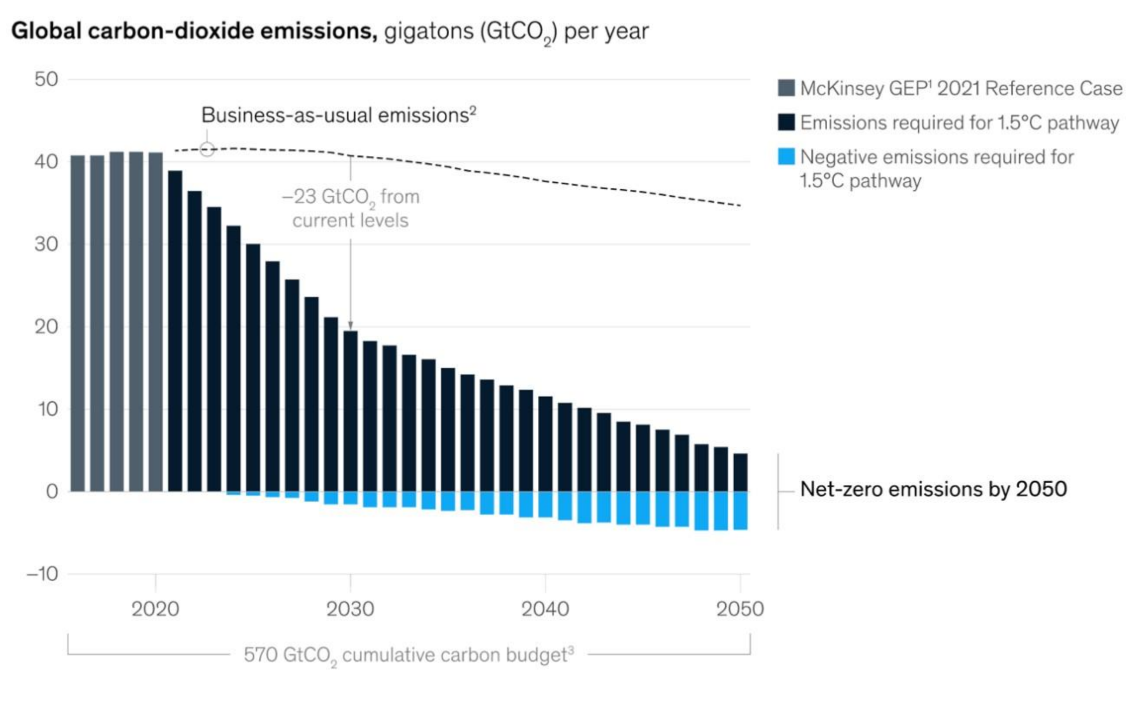


Figure 33: Global carbon-dioxide emissions, $GtCO_2$ per year [40]. The emissions required to be on track to achieve Net-Zero, indicated by the navy blue bars, are 23 $GtCO_2$ below projected emissions, indicated by the dotted line.

Although there is sufficient 'practical' supply to meet demand in 2030, several factors could make it challenging to mobilize and bring the entire potential supply to the market. These challenges include the following:

1. Rate of scale-up: The development of projects would have to increase at an unprecedented rate to achieve 8-12 $GtCO_2$ per year. If supply scales at the same rate it has done over the last 10 years, we will reach approximately 1 GtCO2 per year by 2030 [30].
2. Risk: For example, there is a risk that avoided nature loss is not sustained on a permanent basis due to threats such as fire or forest clearance [30].
3. Lack of financial attractiveness: Although offset project types are generally profitable, some are not financially attractive due to long lag times between investment and return [46].
4. Land availability: Over 90% of the potential supply of avoided nature loss and of nature-based sequestration is concentrated in a small number of countries in the Global South. This results in a high dependency on a small number of countries [47].

Once these challenges are accounted for, the estimated potential supply of carbon credits decreases to 1 to 5 $GtCO_2$ per year by 2030. This means that the maximum number of potential carbon credits produced in 2030 would only provide 21% of the emissions reductions required to achieve Net-Zero by 2050 [40] [30].

3.3.3 Carbon Credit Quality

These are not the only problems facing buyers and sellers of carbon credits. High-quality carbon credits are scarce because accounting and verification methodologies vary and are seldom well defined [40].

Reducing Emissions from Deforestation and forest Degradation, or REDD+ Projects, have often faced scrutiny when used as a source of carbon offsets. REDD+ is a multilateral framework for achieving climate change mitigation goals primarily by fostering forest conservation and the sustainable management of forests [32]. These projects earn carbon credits for independently verified emission reductions relative to the business-as-usual scenario (e.g., an estimation of emissions in the absence of the project). These reductions may arise by avoiding deforestation, reducing degradation, or increasing forest cover through reforestation activities [31].

Verifying emission reductions of REDD+ projects require consideration of how much of the reduced carbon emissions observed over the course of a project can be attributed to the project itself [48]. Estimating the impact of an intervention, such as REDD+, from observational data is inherently difficult because it relies on estimating what would have happened in the absence of the intervention.

Approximately 50 countries have ongoing REDD+ programs at various stages of development, and over 350 REDD+ projects have been initiated to date [32]. These are likely to have a range of success since they are subject to various driving forces of deforestation, forest degradation, deforestation prevention measures, and societal goals [48].

A study conducted by *West et. al.* at the University of Stanford in 2020 compared reductions in deforestation claimed by 12 REDD+ projects with estimates of actual reductions in deforestation after the fact. Results suggest that the accepted methodologies for quantifying carbon credits inflate the impacts of these projects on avoided deforestation and climate change mitigation [49]. Across all 12 projects studied, the authors found substantial differences between the deforestation baseline scenarios adopted by the REDD+ projects and the observed forest loss after-the-fact in their synthetic controls [49].

REDD+ carbon credits are distributed based on performance in the case of emissions reductions brought about by deforestation, as measured by comparison of realized forest cover to a baseline scenario created by projecting the forest cover anticipated in the absence of the REDD+ project [12]. As the regional economic and political situation shifts, these baseline scenarios frequently make unrealistic assumptions about the continuation of previous deforestation trends. These types of changes were observed in the Brazilian Amazon during 2004–2012, a period of sharply declining rates of forest loss, and during 2019, when deforestation soared again. Consequently, credits for reduced deforestation claimed by voluntary REDD+ projects in the Brazilian Amazon may have been the product, or partial products, of external factors rather than impacts REDD+ projects [49]. This can lead to a phenomenon titled “phantom credits” – purchasable offsets that are not linked to genuine carbon reductions.

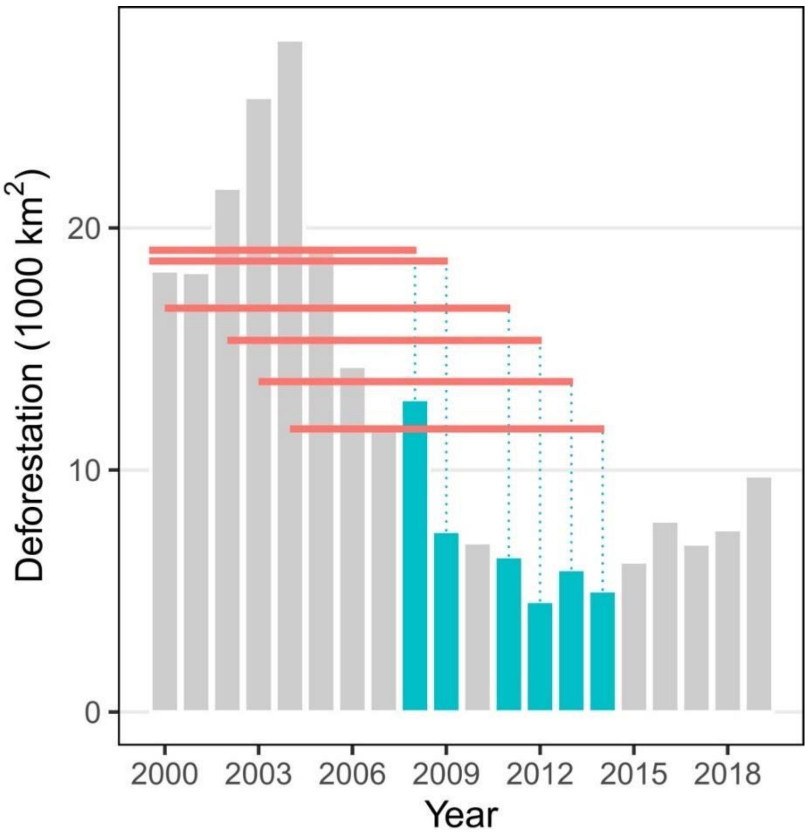


Figure 44: Annual deforestation in the Brazilian Amazon. The blue bars indicate voluntary REDD+ project start dates. The red lines illustrate 10-y deforestation averages prior to project implementation, commonly adopted as projects' before [49].

The study conducted by *West et al*. found no systematic evidence that the certified carbon offsets claimed by the voluntary projects in their sample, which make up 13% of current active REDD projects, are associated with additional reductions in deforestation in the REDD+ areas beyond the background reduction in deforestation achieved in the Brazilian Amazon over the same period [49]. Deforestation was consistently lower in the REDD+ project site than in the synthetic control site in only 33% projects studied. The study highlighted a specific case in which 40% of the 50,000 tradable carbon offsets issued by the project were not genuinely linked to quantifiable carbon offsets [49].

These projects examined in *West et al.*'s study was geographically limited to the Brazilian Amazon. Hence, these results do not imply that all well designed and implemented voluntary REDD+ projects will fail to achieve their objectives. Various other studies, however, have found similar results using different methodologies.

A study performed by Simonet and Ezzine-de-Blas for the American Journal of Agricultural Economics found, from a sample size of 40 active REDD+ projects, that 42.5% of the projects examined had negligible impact on deforestation when compared to baseline deforestation rates, and in some cases were found to increase forest degradation rates [32]. Additionally, a nine-month investigation performed by *The Guardian* in conjunction with the German non-profit investigative journal *Die Zeit* analyzed satellite imagery from dozens of Verra-approved projects to determine the true effectiveness of curbing emissions. They found that, on average, the predicted deforestation rates used by Verra – forecasts compared to the projects' present levels of forest protection to calculate the emissions reductions achieved by the project – were inflated by up to 400% [50]. When comparing Verra's predictions with the scientists' results, the journalists found that approximately 94% of the credits generated from already validated projects were not linked to genuine reductions in greenhouse emissions [50].

Critics of REDD projects have expressed concerns that deforestation or emission baselines might be intentionally inflated by companies seeking to financially benefit from the sale of credits. This practice not only fails to effectively offset greenhouse gas emissions, but also imposes an indirect cost on authentic climate change mitigation efforts by undercutting the price of their credits [51]. Whether or not this practice is intentional, carbon credits have been shown to fail in achieving the scale of greenhouse gas emissions for which they are intended. They will likely not be able to reduce emissions sufficiently to achieve Net-Zero emissions by 2050 unless global emissions are reduced drastically from the source [52].

3.4 Adopting Nature-Based Solution

According to World Resource Institute, incorporating high quality nature-based solutions to offset credits are essential as one of the mitigating actions to reduce the emissions.

3.4.1 Blue-Carbon

As we learned from the carbon credits section that alone carbon credits will not be sufficient to reach the Net-Zero target by 2050. To achieve the target, nature-based solutions play an important role in Canada to mitigate and adapt the climate change. Canada is known for its rich coastal biodiversity as it has the world's longest coastline with 25% of the world's total wetland and 80% of the Carolian forest. These ecosystems especially can absorb and store carbon from the atmosphere. One such project that Canada is focusing on is Blue Carbon. Blue carbon is defined as the carbon that is captured and stored in water-based ecosystems. As per the 2020 data, Canada's carbon emissions to the atmosphere should be between 296 mega tonnes and 333 mega tonnes of GHG to reach the set target by 2030. Saving the marine ecosystem is essential because if the ecosystem is destroyed or degraded it will emit carbon rather than hold 1.7 million tonnes of carbon by 2030 (equivalent to almost 3.4 million barrels of oil). This project can generate high-quality nature-based credits [53]. The further sections provide in-depth understanding of carbon sequestration by ocean ecosystem.

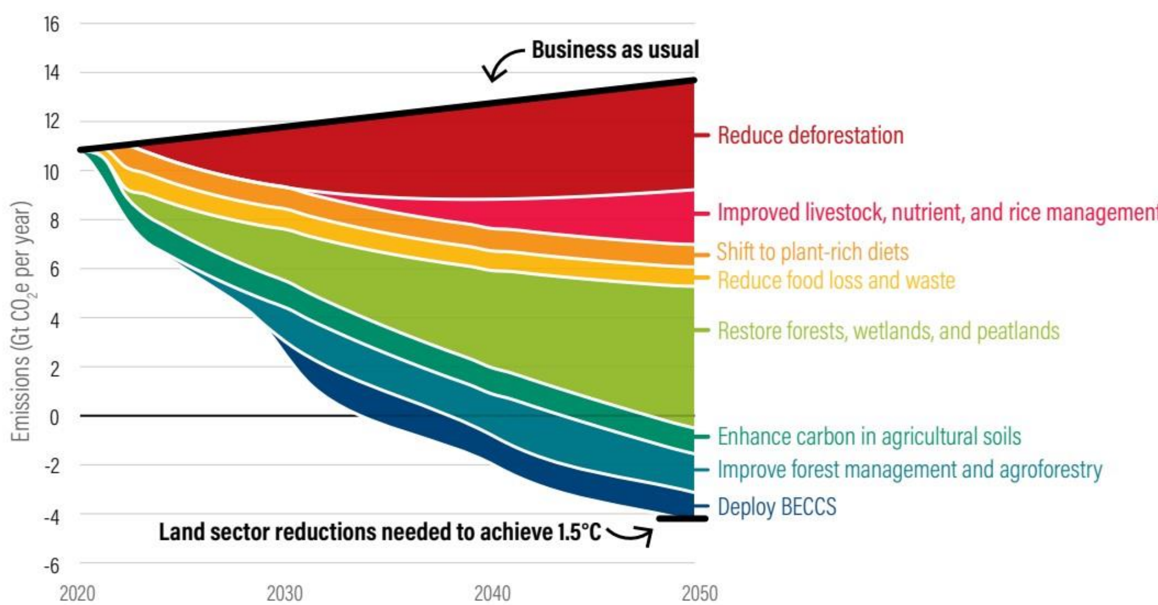
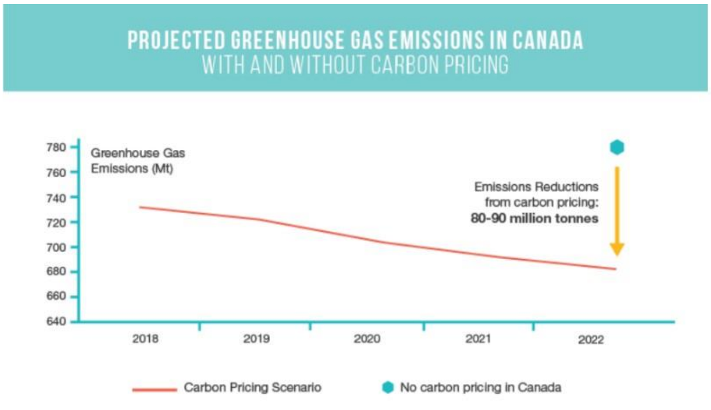


Figure 5 5: Impact of nature-based solutions on the reduction of emissions [54].

3.4.2 Economic Considerations

According to the analysis by the Government of Canada, carbon pricing is one of the most efficient and the cheapest (cost-effective) way to reduce the carbon pollution. According to 2017, it was analysed that carbon pricing could reduce 80-90 million tonnes in 2022 which is almost equivalent to 23-26 million cars off the road and 20-23 coal-fired power plants a year [55].



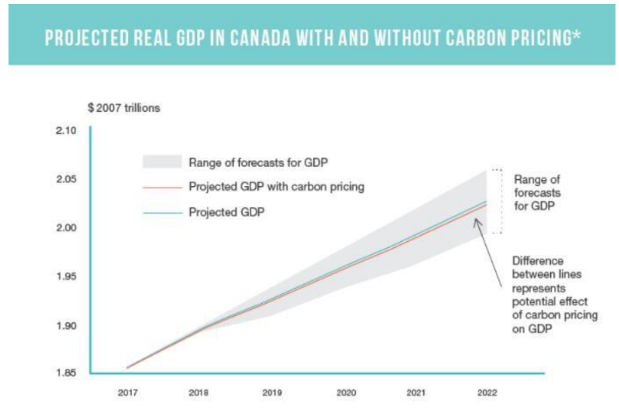


Figure 67: Projected GHG emission with and without carbon pricing from 2022 [28].

Figure 76: Carbon Pricing impact on GDP [28]. 2018-

With respect to the country's economy, the GDP growth remains strong along with long-term opportunities in clean technology. Although, the impact of the carbon pricing is dependent on the adoption of different methods of its pricing system by different jurisdictions- a direct price, cap and trade system or a hybrid. As we can observe from the below graph that a carbon pricing scenario is presented by the red line which starts at 727.8 million tonnes of GHG in 2018, then declined to 680.9 million tonnes in 2022. The blue dot represents the value in the absence of carbon pricing system which is 770.5 million tonnes of GHG. For instance, British Columbia was able to reduce 5-15% emissions along with a positive growth of 17% of GDP and there was a drop of gasoline demand in 2007-2014. However, as the figure 5 illustrates, there is less impact on GDP, however, if the carbon pricing is adopted in all the provinces and territories, it can have significant benefits on the economy.

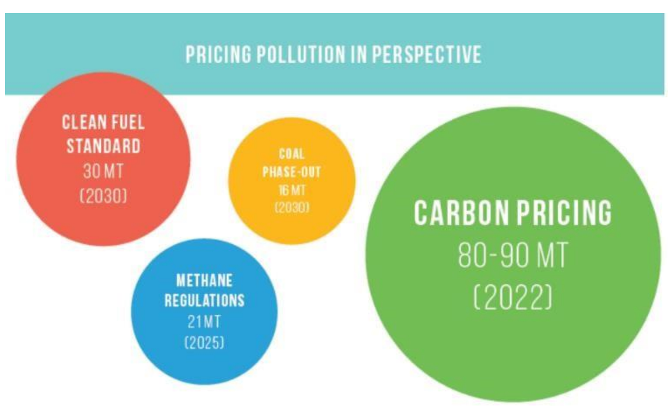


Figure 88: Ability of the carbon pricing relative to other measures [28].

4.0 Technical Solutions

The following sections describe technical solutions, including alternative fuels such as hydrogen and carbon capture, sequestering, and storage. The sections describe the reduced emissions that are associated with the solutions and analyzes the technical and economic feasibility of each solution. Additionally, potential advancements in the future are discussed in each section.

4.1 Hydrogen Solutions

Hydrogen is the most abundant element on the periodic table. It is a versatile, highly energized gas that may be used as a fuel source for many different industries, such as heating, transportation, oil and gas, mining, and energy production [21]. Graphene or carbon nanotubes can be used as physical storage media for hydrogen, or it can be kept as a super-cooled liquid or compressed gas. Hydrogen emits water vapour into the atmosphere rather than CO2 and is similar to natural gas [21]. Although it can be consumed in combustion processes, hydrogen fuel cells are most frequently employed to generate energy. By mixing hydrogen and oxygen atoms in an exothermic process, hydrogen fuel cells generate both electricity and heat [21]. This process takes place on an electrochemical cell that is similar to batteries. The most commonly used methods to produce hydrogen include the electrolysis of water, biological production through the fermentation of biomass, and through thermal processing with a steam methane reformer [56]. Each of these production methods have certain pros and cons and result in varying amounts of scope 1, 2 and 3 greenhouse gas emissions. Hydrogen can be safely stored in underground caverns but is difficult to transport long distances due to its low volumetric energy concentration.

4.1.1 The Colour Spectrum of Hydrogen

Hydrogen is defined with a colour depending on the way that it is produced, and the quantity of carbon associated with its production. The vast majority (96%) of hydrogen produced globally is generated from fossil fuels [57]. Grey Hydrogen is produced by extracting hydrogen straight from hydrocarbons typically natural gas in a steam methane reformer (SMR) or coal gasification process. Steam methane reformers function by reacting high temperature steam with natural gas or petroleum under 3-25 bar pressure in the presence of a catalyst to produce hydrogen [57]. This process involves the production of carbon monoxide that is then converted to CO_2 that is generally emitted into the atmosphere. Grey hydrogen results in approximately 11 tonnes of scope 1 $_{CO2}$ emissions per tonne of hydrogen produced [57]. Methane can also be produced as a by product of steam methane reforming which is 86 times more potent than CO2. On average 0.90 grams of methane are produced per MJ of energy produced from the hydrogen [57].

Blue Hydrogen on the other hand is also produced using an SMR process, however a portion of the subsequent CO2 that is produced is sequestered to reduce the emissions. Currently there are only two blue hydrogen production facilities in the world, one of which is in Canada [57]. This CO2 is sequestering directly from the SMR or other flue gas that is produced. The CO2 captured from the flue gas can be recycled back into the process by providing heat and pressure to drive the process [57]. The carbon captured can also be stored in aquifers or underground. Currently not all the carbon produced can be captured and fugitive methane production and other CO2 equivalents are not captured in blue hydrogen production. Studies have found that on average blue hydrogen production could have an 85% capture rate directly from the SMR process and a 65% capture rate for the energy to drive the SMR process [57]. The energy to power the carbon capture and indirect up stream CO2 emissions results in approximately 40 g of CO2 per MJ of energy emitted compared to 77.4 g CO2 per MJ for grey hydrogen. However, 95.4 g of CO2eq/MJ from methane are produced compared to 77.4 g CO2eq/MJ for grey hydrogen [57]. Using this data, the total emissions from blue hydrogen was found to be only 12% lower than grey hydrogen. Another concern with blue hydrogen is that carbon capture adds a significant cost to the process and carbon utilization is currently limited and permanently storing the carbon is challenging [57].

Green hydrogen is produced by the direct electrolysis of water and has practically negligible scope 1 emissions [58]. It is ideally powered by electricity from renewable energy sources. The electrolysis process involves the splitting of the water molecule into hydrogen and oxygen using an electrolyser. Electrolysers function similarly to fuel involving an anode and a cathode with an electrolyte and results in oxygen being formed on the anode side and the transfer of electrons to the cathode where pure hydrogen is produced [58]. Currently the Ontario electricity grid has a carbon intensity of 32 kg per

MWh meaning green hydrogen is expected to produce 1.5 tonnes of scope 2 emissions per tonne of green hydrogen produced [57].

Pink hydrogen also involves the electrolysis of water, however instead of being powered by renewable electricity it is powered by nuclear energy. Nuclear energy is currently experiencing a revival as a carbon free source of energy [59]. Alongside electrolysis nuclear can be used in a process known as a thermochemical cycle which involves harnessing the high temperatures created by nuclear fission to split water into oxygen and hydrogen [59].

The remaining colours are defined in Figure 9.

Figure 99: Colour spectrum of hydrogen production [60].

4.1.2 Hydrogen Transport and Storage

Hydrogen is a promising energy storage medium for a low-carbon future due to its high energy content and the limited emissions associated with using it. However, there are challenges regarding the storage and transport of hydrogen. While hydrogen has a high energy per mass, its low ambient temperature density results in a much lower energy per unit volume than traditional fuels such as gasoline [61]. As a result, high energy density storage methods are required for transport and long or short-term storage.

Hydrogen can be stored physically as a gas or liquid. Storing hydrogen as a gas requires high-pressure tanks, typically ranging from 350-700 bar. Storing hydrogen as a liquid requires a cryogenic tank because the boiling point of hydrogen is -252.8°C at atmospheric pressure [61]. Alternatively, hydrogen can be stored on surfaces through adsorption or absorption.

The Hydrogen and Fuel Cell Technologies Office (HFTO) has set targets for energy and cost efficiency for hydrogen storage systems. These targets include a 1.5 kWh/kg system (4.5 wt.% hydrogen), a 1.0 kWh/L system (0.030 kg hydrogen/L), and a $10/kWh ($333/kg stored hydrogen capacity) [62]. These targets are important for the development of cost-effective and efficient hydrogen storage solutions.

Hydrogen fuel cell vehicles require enough hydrogen to drive more than 300 miles with relatively quick and easy refueling. To meet this driving range, 5-13 kg of hydrogen is required in light-duty vehicles. 700 bar is the chosen onboard storage pressure for the first vehicles that are being put on the market, while 350 bar is the chosen pressure for buses and larger duty vehicles. [61]. Hydrogen fuel powered vehicles currently rely on compressed gas in a large-volume, high-pressure vessel.

HFTO's short-term pathway is to use compressed gas storage using advanced pressure vessels made with fiber-reinforced material that can operate at 700 bar. The long-term pathway includes cold or cryo-compressed storage, or material-based hydrogen storage including sorbents, chemical hydrogen storage materials, and metal hydrides. These carriers can be novel liquids or solids and deliver the hydrogen by hydriding a compound during production and then dehydriding it at the point of delivery [61]. Metal hydrides and reversible hydrocarbons are examples of carriers used for this purpose. The hydrogen atoms bond to the metal hydrides, which allows them to be stored at closer to room temperature without compression, when the hydrogen is used heat is added and the hydrogen is released [61]. These advanced storage methods have the potential to increase the energy density of hydrogen storage systems and make them more cost-effective and practical for widespread use. A breakdown of the physical and chemical storage methods is summarized in Figure 10.

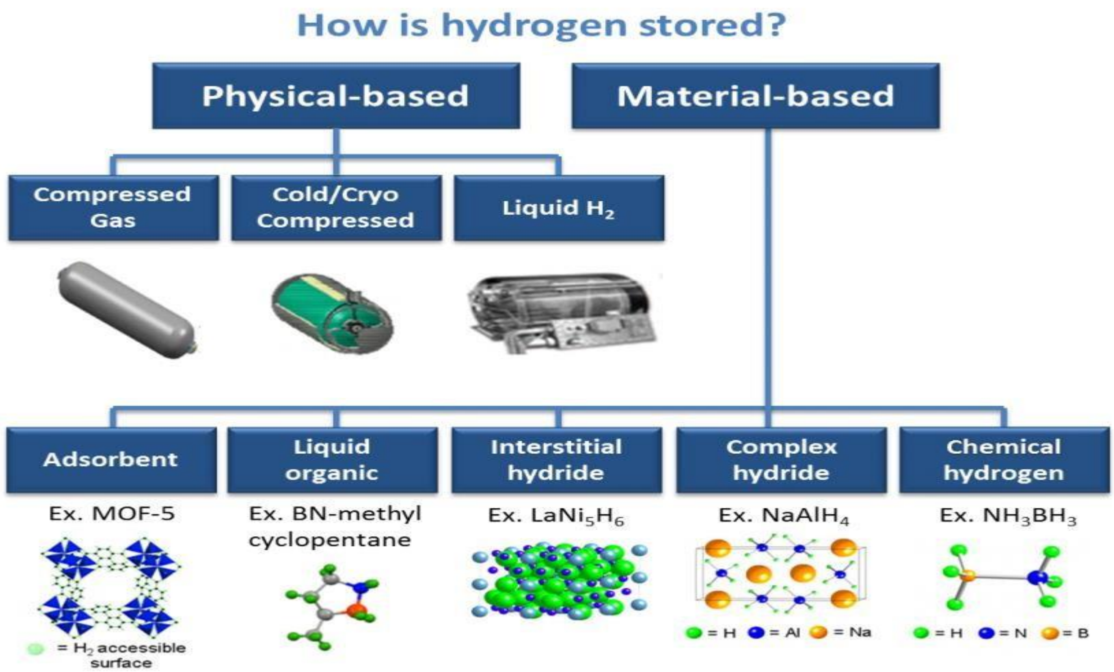


Figure 1010: Hydrogen storage methods [61].

4.1.3 Hydrogen Delivery

Hydrogen is transported from production to its point of use through pipelines, cryogenic liquid tanker trucks, and gaseous tube trailers. Large-scale applications are underway to transport hydrogen through chemical carriers that store hydrogen in a different chemical state as described in the section above.

Transporting, storing, and delivering hydrogen are costly due to its low volumetric energy density, resulting in energy inefficiencies. Liquefying and storing hydrogen alone requires approximately 30-40% of its energy content. Hydrogen deployment is being developed to store the hydrogen at 350-700 bar and dispense it at 10 kg/min [61]. On-site hydrogen production can save money on transportation costs. Pipeline delivery is required in cases where the hydrogen cannot be produced on site, however, is more capital intensive. The existing natural gas pipes must be significantly retrofitted to be able to transport hydrogen. The diameter of the pipes must be made at least 50% greater in diameter to achieve the equivalent energy transmission rate as natural gas [63].

The most efficient means of producing hydrogen in the long run is through large-scale, centralized plants that use pipeline distribution networks. Currently pipeline shipment and dispensing add an estimated cost of $0.96/kg H2, which is essentially equal to the cost of production [63]. This cost is much higher than today's gasoline dispensing and distribution costs, at $0.19/gal.

Despite these challenges, there is hope for the future to reduce the cost using chemical carriers and cryogenic tanks and to improve the efficiency of hydrogen reformers and electrolytic generators to reduce the production costs.

4.1.4 Hydrogen Economy in Canada

Hydrogen can be produced today at costs ranging from $1.22 to $1.03/kg H2 from natural gas, and from coal at $1.03 to $0.96/kg H2 with and without carbon sequestration, respectively [57]. The cost of green and pink hydrogen produced from electrolytic processes is currently 2-3 times greater than grey and black hydrogen. Pipeline shipment and dispensing add an estimated cost of $0.96/kg H2, as mentioned in the previous section [57]. The table below compares the current and future costs of hydrogen in terms of production, storage, and distribution. As well as the efficiency of each method. As one can see the production of hydrogen from steam methane reformers is the most efficient and cost-effective method, however it produces the most CO2. The current cost is $1.99/kg and it is expected to decrease to $1.62/kg in the future [57]. Carbon capture adds approximately an 8% increase in cost. The onsite production of hydrogen from natural gas is more expensive and less efficient at $3.51/kg [57]. The production of hydrogen from electrolysis is significantly more expensive at $6.58/kg, however the price is expected to drop to $3.53/kg in the future [57]. For comparison in Canada the cost of the production and distribution of gasoline is approximately $1.12/gal which is equivalent to $0.39/kg. *All the dollar amounts in the section above are in US dollars and have changed slightly since the article was written.

TABLE 4-1 Estimated Cost of Elements for Transportation, Distribution, and Off-Board Storage of Hydrogen for Fuel Cell Vehicles—Present and Future

Case	Production Costs ($/kg)	Distribution Costs ($/kg)	Dispensing Costs ($/kg)	Total Dispensing and Distribution Costs ($/kg)	Total Costs ($/kg)	Total Energy Efficiency (%)
Centralized Production, Pipeline Distribution						
Natural gas reformer						
Today	1.03	0.42	0.54	0.96	1.99	72
Future	0.92	0.31	0.39	0.70	1.62	78
Natural gas + CO_2 capture						
Today	1.22	0.42	0.54	0.96	2.17	61
Future	1.02	0.31	0.39	0.70	1.72	68
Coal						
Today	0.96	0.42	0.54	0.96	1.91	57
Future	0.71	0.31	0.39	0.70	1.41	66
Coal + CO_2 capture						
Today	1.03	0.42	0.54	0.96	1.99	54
Future	0.77	0.31	0.39	0.70	1.45	61
Distributed Onsite Production						
Natural gas reformer						
Today					3.51	56
Future					2.33	65
Electrolysis						
Today					6.58	30
Future					3.93	35
Liquid H_2 Shipment						
Today		1.80	0.62	2.42		
Future		1.10	0.30	1.40		
Gasoline (for reference)	$0.93/gal refined			$0.19/gal	$1.12/gal	Well to tank: 79.5%

Note: The energy content of 1 kilogram of hydrogen approximately equals the energy content of 1 gallon of gasoline. Source: National Academy of Engineering. 2004. The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs. Washington, DC: The National Academies Press. https://doi.org/10.17226/10922.

The Future of Hydrogen

By lowering CO2 emissions in the industrial, energy, and transportation sectors, hydrogen has the potential to help Canadian industry achieve their Net-Zero emissions targets. One of the top 10 producers of hydrogen in the world right now is Canada. According to studies, Canada can supply up to 30% of its energy needs from hydrogen and replace 50% of its current reliance on natural gas [62]. This will allow for the annual elimination of about 190 megatons of CO2 equivalent emissions. To achieve these objectives several challenges must be surmounted [62]. These obstacles include, efficiency, cost of production, transportation, and storage and safety concerns. Currently, green hydrogen, produced through electrolysis using renewable energy, costs between two to three times as much as grey hydrogen, derived from fossil fuels [64]. Retrofitting existing pipeline infrastructure for hydrogen transport will also be a significant challenge. Safety concerns due to hydrogen's explosive nature and its lower efficiency compared to natural gas are other potential barriers.

Significant investment in hydrogen infrastructure, including pipelines and tankers capable of moving large amounts of hydrogen, will be required to meet the potential demand for hydrogen. Additionally, research and development of chemical carriers to transport and store hydrogen on chemical carriers can significantly reduce the distribution costs. Companies in Canada, such as Air Products, Brookfield Renewable, Enbridge, and Northland Power are some of the leading investors in the hydrogen economy [64].

In the future, it is anticipated that Canada will move away from hydrogen made from fossil fuels. According to reports, only two-fifths of the hydrogen generated in Canada by 2050 would come from fossil fuels; the rest will be produced through electrolysis [29]. Compared to the existing output, which derives more than 95% of its energy from fossil fuels, this is a substantial improvement. Additionally, research has revealed that blue hydrogen may be more harmful than beneficial, given the status of carbon capture technologies today. Compared to utilizing natural gas, coal, or diesel oil directly for heating, the carbon footprint of blue hydrogen, which is made from fossil fuels using carbon capture and storage technology, is more than 20% higher [62]. This emphasizes the importance of transitions towards green hydrogen.

4.2 Carbon Capture Solutions

Carbon capture technology has been developed and researched for many years, with the first capture sequestration site in the US in 1972 [65]. There are many different types of carbon capture solutions, and they can be largely categorized into two main categories of carbon sequestration: biological carbon capture and deep saline aquifers.

4.2.1 Biological Carbon Capture

The first type is the biological carbon capture method, this includes any natural biological carbon capture device such as trees, marsh lands, peat bogs, etc. These types of carbon capture methods are a sustainable and effective way of storing capturing and storing carbon from the atmosphere with minimal negative impacts on the surrounding environment [66].

4.2.1.1 Deep Saline Aquifers

An aquifer is an underground area of permeable rock and material which can contain or allow the flow of water. Some aquifers are important sources of potable water or water for agricultural uses. Saline aquifers contain water that is too rich in salts and minerals to be used for drinking or agricultural purposes.

Once carbon has been captured from the atmosphere it must be stored somewhere to permanently remove it from the atmosphere. One of the most viable solutions for this has been researched as deep saline aquifers. There are many aquifers in various places around the world, however, to be a viable solution for carbon storage and to minimize the chances of emissions and leakage of carbon from the atmosphere, the aquifer must consist of a largely porous medium, allowing for vertical fluid transmission amongst the aquifers. Other conditions that must be met are that the aquifer must be at least 2 kilometers or greater below the surface of the earth to ensure the safe storage and ensured containment of the injected carbon [67]. To assess the viability of an aquifer, deep geotechnical and geochemical analysis of the aquifer must be performed to gather data that will allow for accurate modelling of the fluid performance and movement in the aquifer. As the carbon is injected into the aquifer, the density of the fluid increases and creates vertical movement within the aquifer, if not properly modelled and calculated this movement can result in large pressure variations inside the aquifer, potentially leading to geological damage and fractures that could allow for the release of the injected carbon from the aquifer. This modelling data can assess the performance of the aquifer and dictate the rate at which the carbon could be injected into the aquifer, and at which rate the aquifer could potentially absorb the sequestered carbon [67].

Another consideration to assess the viability of an aquifer is the geological location of the aquifer. A large factor in determining the viability of an aquifer is the ability to transport the sequestered carbon from a sequestration site to the deep saline aquifer for storage. Therefore, aquifers that are created near or by Oil and Gas extraction sites or power generation sites are often preferable as injection sites as the carbon can be directly sequestered from the operation and reinjected into the aquifer [67].

With the developing research of deep saline aquifers and the ability to accurately model the fluids performance and dynamics inside the aquifer, the rates at which carbon can be injected into the atmosphere has been estimated. It is between 40,000 and 10,000 gigatons of carbon per year between the largest aquifers studied and the smaller ones that have been examined [67].

Some of the dangers and risks that have emerged with the use of deep saline aquifers is that often the upper layers of the aquifer are used as water sources for many geological areas in the world. However, due to the nature of the aquifer, there are many layers of fluid stored in the aquifer and as the salinity of the water increases, the density of the fluid increases and therefore the segregation of the fluids is quite dramatic. With the drinkable and useable fresh water often rising to the top of the aquifer to be used by civilians, and the deeper layers of the aquifer are often significantly more saline than seawater and unusable for use, with the exception of use as a carbon sink to store captured carbon from the atmosphere [67].

4.2.1.2 Peat Bogs

Peat bogs are an area of land that are often waterlogged lands with stagnant standing water in a dense slurry with decomposing organic matter. As the organic matter is deposited and grows on top of the lower layer of peat, the peatland deepens and as the deeper layers of the peat bog have higher pressures, more consistent temperatures, and an acidic nature, can all increase the rate of decomposition and storing the carbon from the matter in perpetuity [68]. Due to the composition of the peatlands, they are often not viable areas for biodiversity and development, very few species are specialized enough to live in the acidic environment of a peat bog. As the plant matter decomposes and sinks deeper and deeper into the peat bog, the water level increases and completely captures the partially decomposed organic matter in the fluid and forms peat. Once, the peat is completely isolated from the oxygen source, the decomposition is ultimately halted and the carbon in the organic matter is permanently stuck in the peat slurry [68].

As far as utilizing peat bogs as a viable solution for carbon capture and sequestration, it is very difficult and often non-viable to attempt to inject carbon that has been sequestered from the environment into the peat bog as it is a difficult substrate to hold the carbon and absorb it as it would be in an engineered fluid or in a saline aquifer. However, the way that peat bogs can be used as carbon sinks is to preserve the carbon within the organic matter that can be deposited into these peatlands. The peatlands can confine any emissions from organic decomposition and are effective at holding this carbon in [68]

In the world peatlands are very abundant and lush areas of land, however there are many areas in the world and countries that are planning the destruction and actively demolishing and draining these peatlands for development or alternative usage. However, as these peatlands are drained and the fluid from the land is removed from the lower levels of the peat bogs, the oxygen from the atmosphere can penetrate deeper into the layers of peat and resume the decomposition of the organic material in the bogs, thus increasing the carbon and methane emissions from the areas that have been destroyed [69].

4.2.1.3 Tropical Forests

There are many different types of forests and their abilities to capture and sequester carbon from the atmosphere is dependent on the climate in the forest and the biodiversity and biological composition of the life in the forest. The first type of forest that will be evaluated and explained is the tropical forest. The tropical forest is defined as a forest that is bound longitudinally between the tropic of Cancer and the tropic of Capricorn [68]. The tropical forest often receives more than 100 inches of rainfall per year, therefore allowing for very lush and dense brush and growth in the forest. Due to the density and abundance of organic matter in the tropical forest, there are often many layers of a tropical forest that are capable of storing and capturing carbon at different levels of the atmosphere. In total, tropical rainforests are calculated to store near one quarter of the carbon on earth, therefore they are a very important carbon sink in the global stage of carbon capture and sequestration [68].

Due to the combination of their forest density, and the abundance of rainfall throughout the year, the tropical forest can provide large carbon capture effects, however they are also responsible for a large cooling potential in the surrounding areas and the ability to manage the atmospheric temperature around them serving as a large heat sink for the areas. The vegetation is high in water content, and water has a high energy absorption potential therefore, a large amount of energy is required to change temperatures and climates in these areas. A large factor in their cooling abilities is also their ability to produce clouds and precipitation in other surrounding areas to further control the climate of these areas [68]. As these clouds form, they reflect the sunlight back out into space and reduce the total energy that is absorbed by the earth. This combined cooling factor is said to cool the entire globe by a full 1 degree Celsius.

These areas of relatively constant climate have allowed vast biodiversity and biological development in a wide array of organic vegetation as well as wildlife, creating a very biodiverse ecosystem with many tiers of complexity. As the forest grows and the layers of vegetation evolve, carbon is absorbed through the ground and from the air and stored in the biomass of the forest to prove as an effective carbon sink as well as a natural solution for the complex issue of carbon sequestration [68].

However, as global economies and government expansion projects in these regions hinder the increase of tropical forests. Over one third of the total tropical forest regions have been destroyed and is beginning to bring these forested areas to the tipping point of carbon absorption. As the forests are removed, the water table and distribution are disturbed, depositing excess water in some areas and causing landslides and localized flooding, and in other areas there are regional droughts. As these tropical forests are changing in landscape and the environment and conditions that they live in are being disturbed, the balance and rate at which the tropical forests are able to absorb and sequester carbon are also changing. The overall total rate at which tropical forests are able to absorb carbon is slowly decreasing, and the balance must be restored by other means, such as the boreal forest, which has been shown to have an overall increase in their carbon capture and sequestration rates as will be discussed below [68].

4.2.1.4 Boreal Forest

Boreal forests are the biome type that is typically found in North America and largely consists of deciduous and coniferous trees with a much smaller range of biodiversity and vegetation than the tropical forest biome. The risks that are associated with the boreal forest are very similar to the degradation of the tropical forests as they act as a carbon sink, as the temperatures of the globe rise, the boreal forests climate becomes increasingly drier and warmer [68]. Therefore, as the climate changes the conditions inside the forest, it becomes more susceptible to large scale forest fires which cause mass destruction in the forest. The boreal forest is similar to the tropical forest environment, as it stores carbon in the form of organic matter either in the roots of the trees and the soil beneath it, as well as in the biomass of its vegetation. This accounts for a large amount of carbon stored in the boreal forested regions. There are certain stands of boreal forest that are more resilient to forest fires and climate activated vegetation decomposition [68]. Forest stands that are typically over 60 years in age are considered legacy stands. These trees absorb more water to maintain a more consistent climate and are less likely to ignite in a forest fire [68].

As these boreal forests are burnt and/or destroyed by deforestation, the carbon that has been stored for centuries is released from the vegetation and organic matter. As the forest is destroyed, both the ability for the forest to absorb and sequester carbon from the atmosphere is reduced, as well it releases all of the stored carbon. As these forests are being destroyed internationally, the release of carbon from tropical forests has caused the boreal forest to increase in carbon absorption per hectare of forest. However, it is predicted that soon the boreal forest will reach a critical mass and no longer be able to absorb the increased carbon from the atmosphere and the carbon levels in these areas will begin to rise [68].

4.2.1.5 Temperate Forests

Temperate forests are defined as the region of forests that are between the polar regions of the boreal forests and the tropical forests surrounding the equator as explained above. These regions of temperate forests have gained this name as they are often between seasonal temperatures of -30C and 30C. They mostly consist of broadleaf deciduous trees. These trees often lose their leaves in the winter months and enter a hibernation period where the rate of carbon capture and sequestration vastly decreases for these months [68].

Temperate forests operate in very similar circumstances to the other categories. However, with the exception that temperate forests undergo a cyclical shedding of their leaves every year [68]. Therefore, as the trees have more leaves and increase their photosynthesis and production of sugars and energy for the tree, their carbon intake increases significantly. However, during the seasons of the year when the trees begin to lose their leaves, that excess carbon that is stored in the leaves is released to the forest floor where the leaves and organic matter form a layer of decomposing biomatter. As this layer of matter is covered by other layers of decomposing biomatter and goes deeper and deeper into the soil layer the carbon is permanently stored in the soil below the forest, similar to the functions of peatlands [68].

These forests are under the same duress as other types of forests as the land is being deforested for local developments, forestry products and changing climate conditions. These areas are not as susceptible to climate change caused forest fires and natural disaster events. However, as these forests are depleted, the carbon capture that is sequestered by the forest decreases and the local concentration of carbon increases therefore pushing the capabilities of the forested areas to a tipping point where they will no longer be able to sequester the carbon from the atmosphere [68].

4.2.1.6 Engineered Fluids Solutions

There are many applications for chemical uses and development in carbon capture and sequestration as carbon is naturally a chemical and its chemical nature and properties can be used to effectively and efficiently create ways to capture it before it is released into the atmosphere. One such chemical method is the use of ionic liquids in the presences of the flue gases released from carbon emitting combustion processes [70]. The chemical carbon capture procedure involves introducing ionic liquids in the form of liquified salts into the stream of flue gases and allowing the chemicals to freely interact. Ionic salts are by definition polar non-volatile liquids that can be used to line the insides of the combustion gas flues and maximize the interaction with the emissions and the amine salts. In previous iterations of the chemical carbon absorption, amines were used as they were effective at separating the toxic sulfur gases and molecules from the emission gases. However, amines are corrosive and volatile and degrade in potency and effectiveness over time, therefore making them difficult to implement in industrial settings as they must constantly be changed and maintained and the equipment that is required for their use quickly deteriorates and must be maintained frequently [70].

Therefore, the use of ionic engineered fluids is an area of research that is emerging to become a chemical alternative to flue gases carbon capture technology. The most common carbon capture method involves multiple stages and apparatus including the absorption column, stripper column and feed gas. This results in a carbon rich gas stream that is then sent to be sequestered and disposed of, as well as a carbon poor gas which is then released into the atmosphere. This process is effective at stripping the carbon from the flue gases and is an efficient method at capturing the carbon emitting from combustion events.

Some of the drawbacks of using this method, however, is the financial investment of implementing a carbon capture system in the facility and the working efficiency of the ionic liquids compared to the traditional amines. First, it is a large investment for a facility to purchase and implement the required equipment to effectively capture and sequester carbon from their emissions. Therefore, unless financially or politically pressured it is often too difficult to move an industry towards implementing green carbon capture and sequestration facilities in their operations. Another drawback is the efficiency of the ionic liquids when compared to the traditional amines capture. The ionic liquids have a lower working capacity than the traditional amines and therefore much more of the ionic liquids must be used to capture the same amount of carbon as the traditional amines. However, research is being currently performed to attempt to increase the working capacity of the ionic liquids by implementing task specific liquids, some that are specialized for chemisorption, and others that will specialize in physisorption [70].

Another drawback is the viscosity and the use of the ionic liquid when compared to the amine solvent and how it can be effectively implemented into the stripping and mixing towers. The rate of carbon absorption into the fluid is dependent on the rate of reaction between the gas and fluid, and therefore a function of the diffusivity of the carbon gas into the working fluid, therefore inversely proportional to the viscosity of the working fluid. Therefore, as the viscosity of the fluid increases, the rate of the reaction between the ionic liquid and the carbon rich gas is slower. However, the physical properties of the ionic liquid can be changed, hence engineered fluids, the rate of reaction and diffusivity can be changed and altered dependent upon the application [70].

This leads to the tuneability of the engineered fluids and their adaptability to any application regardless of exhaust gas temperature, pressure, ambient conditions, and chemical composition. They can be introduced in different phases to maximize different types of absorption, mixed with other chemicals to promote mixing a diffusion at different temperature ranges or pressure values. The chemical composition can be infinitely modified through the use of various procedures and techniques such as changing chain lengths, substituting radicals, mixing with other ionic liquids, mixing with water, amines, all with different results and optimized applications [70].

The industry of chemically engineered ionic fluids is a multi-billion-dollar industry and the development of an effective and efficient chemical carbon capture mixture would be highly beneficial in the capturing and sequestration of emissions through combustion generated flue gas emissions. This a widely diverse and promising sector of chemical development with substantial research to back the science and claims being made in the industry. The chemical absorptivity and diffusivity of carbon and carbon dioxide can be accurately modelled for a wide array of pressures and temperatures and therefore promotes the use of adaptable engineered fluids [71].

4.2.2 Artificial and Geological Carbon Capture

Another type of carbon capture category is the artificial carbon capture devices, these include anything from open air carbon scrubbers, artificially engineered liquids, and more, as described later in this report. There are many instances of artificial carbon capture structures and technologies that have been implemented around the world to varying degrees of effectiveness and efficiency. Some examples that are to be covered later in this report include, direct air capture systems, pre-combustion engineered fuels, and oxygenated fuel combustions, etc.

4.2.2.1 Direct Air Capture Towers

There are many different forms and iterations of direct air capture towers that depend upon the geographical location of the plant, as well as the atmospheric concentration of carbon in the atmosphere, which is the largest downfall with the implementation of direct air capture systems, versus flue gas carbon capture systems [72].

The first type of system is the aqueous direct air capture system, this system operates on chemical properties and reactions that allow for the capture of ambient carbon from the atmosphere. These systems often involve large intake fans that pull atmospheric air over a sheet of fluid that is often a potassium hydroxide working fluid that reacts with the carbon in the atmosphere and creates carbonate salt deposits in the working fluid that are then transferred into the tower for further procession. These salt structures then undergo a series of chemical reactions and processes that can return the potassium hydroxide solution back to its original form to continue the cycle, as well as producing pure carbon dioxide that can be used for various industrial purposes or can be stored and sequestered. This carbon dioxide is often sold back to industries that use carbon dioxide for reactions, cooling properties, or carbonation of fountain beverages [72].

Another form of direct air capture is the solid chemical system that employs many of the same chemical reactions and principles as the aqueous capture solution. However, in a solid-state form that allows it to operate at a slightly lower energy consumption than the aqueous systems. These systems suffer the same downfalls as the aqueous systems as their capture rates are limited by the geographical location of the capture system and the atmospheric content of carbon in the air that is intake into the system [72].

The final type of direct air capture systems that have been implemented in various locations around the world are much simpler solid particulate filter systems that use a series of particulate filters to capture chemicals and debris that is suspended in the atmosphere. One of the largest downfalls of the direct air capture systems is that they often operate in an energy deficit and therefore are difficult projects to get approved by local governments and municipalities, as well as industries as they are inherently not a profitable business model or solution [72]. However, these solid particulate filters operate on a much lower energy consumption level and therefore can be implemented into these situations at a much lower initial investment that other solutions. These systems operate by pulling ambient air through a series of particulate filters of varying degrees of size and density to filter and clean the air passing through the filter. These systems often only require vacuum fans and regular maintenance and cleaning to remove the carbon and particulate buildup from the filter elements periodically. However, there are examples of these systems that operate by using geological features and phenomenon to generate the required pressure differential to drive the fluid through the filter, and therefore operate on a nearly zero energy consumption and are very viable options for direct air capture solutions in the future [72].

4.2.2.2 Pre- Combustion Engineered Fuels

Pre-combustion engineered fuels is a way of altering the chemical composition of the fuel before it is combusted in the combustion chamber. This is an effective method at reducing the carbon output of fossil fuel combusting operations as it is able to change the composition of the fuel before it is converted to energy and by-products, so the by-products of the combustion are easier to separate and capture the carbon from. This is however, a very expensive procedure and is often only viable to be implemented by new energy and industrial projects [70]. However, due to the shift in carbon neutral and greener solutions for energy, there are not very many large-scale combustion and emitting projects that are being constructed that also are viable options for this technology to be implemented [70].

The way the technology works is to take the incoming fuel, often a hydrocarbon, and partially oxygenate the fuel at a high pressure to separate the fuel into various gases such as carbon dioxide, carbon monoxide, methane, and water vapor. Then as the fuel is returned to a lower pressure and temperature, the fuel composition shifts to return to a mixture of hydrogen gas, and water vapor mostly. Then the hydrogen gas is combusted as a clean combustion producing water vapor, and the un-combusted carbon products can be easily extracted from the combustion materials. This procedure is often referenced as creating a synthetic gas, or syngas, or synthesized gas as it is effectively generating an alternate fuel source from the hydrocarbon fuel source before the combustion and releasing the harmful carbon deposits from the combustion products before the actual combustion procedure occurs. This method is very effective at separating the hydrocarbons from the emissions; however, it is a very energy and infrastructure intensive solution that is largely unobtainable to retrofit to older facilities [70].

Some of the benefits of the gasification process is that many different types of fuels can be used to produce this synthetic gas for combustion, including biomass fuels, diesel, coal, and many more traditional fuels that are normally harmful to the environment upon combustion. There has been research performed by the United States Department of Environment and gasification sector to look into more potentially cost effective methods of producing the synthetic gas for clean combustion. However, the entrance fee into the gasification industry and its implementation into industrial facilities remains incredibly high and therefore, has been deemed currently as an unobtainable solution to producing clean combustion in a financially responsible way by many private industries still combusting hydrocarbons for energy harvesting [70].

4.2.2.3 Oxygenated Fuels Combustion Environments

The concept of using oxy-fuel primary combustion technology is to reduce the introduction of secondary hydrocarbons and unwanted species into the combustion process that are often present in atmospheric air. The concept of oxy-fuel combustion is to undergo the combustion process in an almost purely oxygenated environment to reduce the secondary species. The downfall of this method is that pure oxygen combustion often results in incredibly high exhaust gas temperatures which can also lead to the production of sulfur and nitrous oxides. Therefore, by altering the combustion parameters and the physical layout of the combustion reactor in the facility, the combustion products are redirected into the combustion chamber to effectively reduce the combustion levels in the chamber. This lowers the exhaust gas temperatures exiting the chamber, and by modulating the reflow of exhaust gas into the combustion chamber, the temperature or the exhaust gases and the system can be accurately controlled as well as the production of sulfur and nitrogen oxides can be controlled [70].

The benefit of this system is that it can be utilized in the combustion of almost any hydrocarbon as the working molecule in the combustion cycle that is introduced in the atmospheric air is the oxygen, therefore if the oxygen is supplied, the combustion can be better controlled and modulated as required to optimize the combustion for energy production and efficiency. It is a very adaptable technology that can be integrated into a wide variety of combustion plants and infrastructures as the required equipment and development is relatively minimal and the maintenance on the systems are relatively routine to the normal operation of the combustion plant [70].

However, the downfalls that are associated with this system is that a supply of pure oxygen is required. In some situations, if the combustion is occurring on a large scale, there is a sizeable requirement for oxygen which can be produce high operating costs for the facility and make it difficult for the facility to operate efficiently and financially responsibly [70].

5.0 Recommendations

5.1 Canadian Progress To-Date

Canada's greenhouse gas emissions action plan is a set of policies and initiatives which aim to reduce the country's greenhouse gas emissions, address the issue of climate change, and promote a sustainable, low-carbon future. The action plan has had many different iterations, with the most recent change being the Pan-Canadian Framework on Clean Growth and Climate Change, which was released in 2016 and updated in 2019.

There are six major factors that contribute to Canada's greenhouse gas emissions action plan which include carbon pricing, clean energy, energy efficiency, electric transportation, carbon capture and storage, and adaptation and resilience.

Canada has also committed to reducing its greenhouse gas emissions by 30% below 2005 levels by 2030 under the Paris Agreement. This target was set as a part of Canada's Nationally Determined Contribution (NDC) under the agreement.

The Pan-Canadian Framework on Clean Growth and Climate Change is Canada's plan to achieve its emissions reduction targets by the deadlines. Canada has also committed to reaching Net-Zero greenhouse gas emissions by 2050. This means that Canada will aim to balance its greenhouse gas emissions with removals and/or offsets by 2050, effectively eliminating its contribution towards global warming.

5.1.1 Recent Emissions Within Canada

Canada was unable to reach its emissions goal by 17% below 2005 levels by 2020. According to the latest data from Environment and Climate Change Canada, Canada's greenhouse gas emissions were 730 million tonnes CO2e in 2019, which is only 1% lower than 2005 levels [73]. This means that Canada fell short of its 2020 target, which would have required emissions to be reduced to 618 Mt CO2e.

It should be noted that the COVID-19 pandemic had a significant impact on Canada's emissions in 2020, leading to a reduction of approximately 11% compared to 2019 levels. While this short-term reduction was not achieved through the implementation of long-term sustainable solutions, it has shown how significant emission reductions are possible with changes in human behaviour.

Furthermore, Canada has updated its climate goals and pledged to reduce its greenhouse gas emissions by 40-45% below 2005 levels by 2030. The government has also introduced new policies and initiatives in clean technologies, and more regulations for emissions from industry and transportation sectors.

5.2 Feasibility of Carbon Credits

Carbon credits are a form of permit that permits companies and governments to emit a specific amount of carbon dioxide or other greenhouse gases. However, our studies concluded that the maximum market supply of carbon credits produced in 2030 would only provide 21% of the emissions reductions required to achieve Net-Zero by 2050 [40] [30]. High-quality carbon credits are also scarce because accounting and verification methodologies vary and are seldom well defined [40]. Ultimately, carbon credits will likely not be able to reduce emissions sufficiently to achieve Net-Zero emissions by 2050 unless global emissions are reduced drastically from the source.

5.3 Feasibility of Technical Solutions

There are many potential technical solutions that can reduce the global carbon output and concentration in the atmosphere. However, there needs to be a collaboration between carbon capture and sequestration projects with emissions projects to balance the volume of released carbon and emissions with the amount of carbon that can be pulled and removed from the environment. There are many solutions, both biological and artificial, that are viable solutions for removing the carbon from the atmosphere and store that carbon in permanent holding solutions, or reuse in useful industrial applications. However, these methods are only capable of capturing so much carbon. Therefore, the use of renewable or carbon neutral fuels such as Hydrogen must be used, and the infrastructure to make them a reasonable solution must be further developed and invested in to make them a viable solution.

There is still plenty of work that is required to make these technologies viable for use and implementation in the future, however the idea of developing solutions to remove carbon from the atmosphere is an important step in the right direction to move towards reducing the overall carbon output globally and becoming truly Net-Zero by 2050.

Biological solutions of carbon capture are abundant and readily available and should be fully used to maximize nature's capacity to capture and store carbon where possible, and artificial technologies should be implemented and developed as required. However, natural biological carbon capture solutions, such as forests and vegetation have a higher capacity to store carbon than artificial solutions of carbon capture technologies.

The use of biological features to store the carbon and reintroduce it into the environment is vast, and a viable option to reintroduce the carbon back into the ground and geological features that it was previously stored in. The research and development of surveying and mapping deep saline aquifers is poised to be a viable solution to sequestering large amounts of captured carbon in these geological features.

As stated previously and shown in the research of the report, the use of alternatives fuels such as Hydrogen should be considered and developed to reduce the overall carbon emissions in the atmosphere and allow the natural cycles of biological carbon capture cycles to bring the global level of carbon in the atmosphere back to a reasonable and sustainable level.

Overall, there has been applicable research from previous years to move us towards viable solutions for both reducing the amount of carbon in the atmosphere, as well as capturing the carbon that is currently in the atmosphere and storing it in geological and biological features. The progress is in the right direction, however further research and development of these technologies and infrastructure is required to make these technologies a viable solution to bring the world to a carbon Net – Zero by 2050.

6.0 Conclusion

This report provided a thorough evaluation of Canada's progress towards Net-Zero emissions. It investigated leading emitting industry's plans to reach Net-Zero by 2050 and the feasibility of these plans. Additionally, the report defined the concept of greenwashing and provided examples of the challenges of identifying a company's true sustainability metrics. The report then discussed the feasibility of carbon credits and offsets, along with the benefits of the Output Based Carbon Pricing System in Canada. Finally, the report investigated and summarized the benefits and challenges of alternative fuel sources such as hydrogen, and carbon capture technologies. The main findings of the report are the following:

1. Large industry changes are difficult to audit and will require robust regulation to take effect. However, smaller municipalities and indigenous communities, have made impressive strides towards local Net-Zero efforts with demonstrable results.
2. Carbon credits are not available in sufficient quality or quantity to be relied on as the primary way to reduce emissions to achieve Net-Zero by 2050.

3. A strategic focus on carbon offsets created by nature-based solutions in Canada is essential to reduce emissions and help Canada reach Net-Zero.
4. Pricing on carbon pollution is one of the most efficient and cost-effective ways to reduce GHG emissions while driving industry innovation.
5. Canada must transition towards producing hydrogen from renewable electricity and using cost effective methods to transport and store it in large quantities for hydrogen to be used as an alternative fuel source to replace emitting fossil fuels.
6. Canada must utilize the abundance of natural carbon capture resources available in the country to viably reach its Net-Zero goal by 2050.
7. The utilization of artificial carbon capture methods in Canadian industries will have a large impact on the nation's ability to achieve Net-Zero.

In summary, Canada and its industries must meet Net-Zero targets by 2050 to mitigate upcoming ecological catastrophe. Canada's industries react with the environment on a global scale and must act as leaders in the worldwide mobilization against climate change. However, with some of Canada's business leaders proving reluctant or ineffective in their efforts, it's up to local, provincial, and federal governments to ensure feasible and proven abatement methods are pursued such as those outlined in this report.

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