Pathways to net zero greenhouse gas emissions in New Brunswick

Report prepared for New Brunswick's Climate Change Secretariat

Summary

Both New Brunswick and the federal government have established a target of achieving net zero greenhouse gas (GHG) emissions by 2050[1,2]. Such a target implies reducing emissions to as close to zero as possible while counter-balancing any remaining emissions through carbon dioxide removals from the atmosphere.

This study builds on previous net zero work conducted by Navius Research for New Brunswick's Climate Change Secretariat and aims to:

1. Account for the shifting policy environment, including release of the federal Emissions Reduction Plan and New Brunswick's 2022 Climate Change Action Plan.
2. Conduct a detailed assessment of options for decarbonizing electricity supply in New Brunswick.
3. Explore the potential for non-energy related GHG abatement in the province (for example, in agriculture and waste) and carbon dioxide removals.

Approach

This study employs Navius' gTech-IESD modeling framework and considers the following scenarios for implementation of GHG policy in New Brunswick:

- **Current policy scenario.** This scenario includes currently legislated provincial and federal policies, such as a federal carbon price rising to $170/t CO_2e by 2030 and the Clean Fuel Regulations.
- **Emissions Reduction Plan (ERP) scenario.** In addition to currently legislated policies, this scenario includes (1) the policies announced in the federal Emissions Reduction Plan and (2) New Brunswick's commitment to installing 400 MW of small modular nuclear reactors by 2035.
- **Net zero scenarios.** In addition to all policies listed above, climate mitigation ambition is scaled up such that New Brunswick achieves net zero GHG emissions by 2050. Net

[1] Province of New Brunswick. 2022. Our pathway towards decarbonization and climate resilience: New Brunswick's Climate Change Action Plan 2022-2027. https://www2.gnb.ca/content/dam/gnb/Corporate/Promo/climate/climate-change-action-plan.pdf

[2] Canadian net-zero emissions accountability act. S.C. 2021, c. 22. https://laws-lois.justice.gc.ca/eng/acts/c-19.3/fulltext.html

zero is defined as emissions within the province, as tracked by the National Inventory Report, being offset by negative emissions (for example, from land use, land use change and forestry, LULUCF). Due to the limited state of research into the potential for nature-based solutions in the province, net zero is represented as a reduction in modeled emissions to three different levels - <1 Mt, 2 Mt and 5 Mt CO_2e in 2050 – with the assumption that these residual emissions will be offset.

Insights for policymakers

This study provides eight key insights for policymakers seeking to decarbonize New Brunswick's economy.

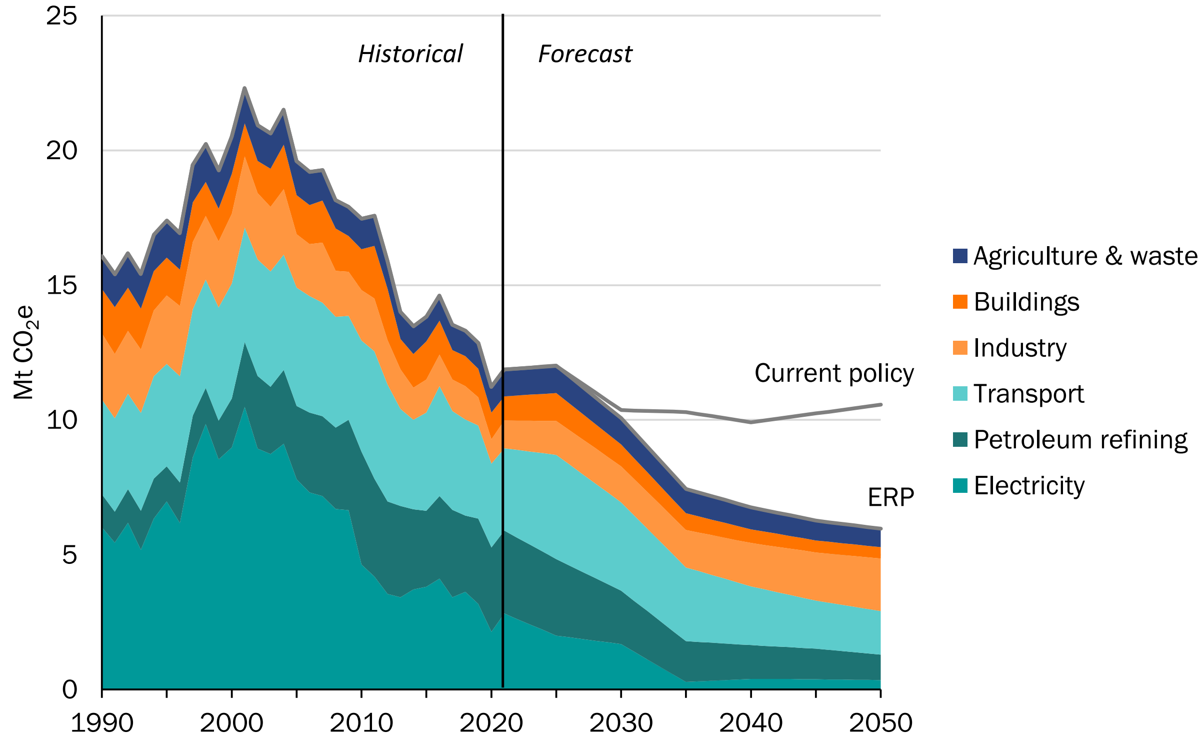
1. New Brunswick's emissions are reduced by 4.6 Mt by 2050 under the ERP scenario.

The modeled ERP policies reduce emissions by 2.9 Mt in 2035 and 4.6 Mt in 2050 (relative to the current policy forecast). This results in provincial emissions of 7.4 Mt in 2035 and 6.0 Mt in 2050 (see Figure 1). Reductions are concentrated in electricity, transport and industry due to policies like the Clean Electricity Standard and zero-emission vehicle (ZEV) mandates for light, medium and heavy-duty vehicles.

2. The gap to net zero is large and requires strong policy to overcome.

Under the ERP scenario, the gap to net zero is 6 Mt in 2050. The implication is that strong and compulsory policies are required to close this gap. These policies would entail an effective carbon price of over $350 dollars (2020 CAD) per tonne by mid-century (i.e., a carbon price of that level or a comparable suite of regulatory policies that achieve the same effect).

Figure 1: New Brunswick's GHG emissions to 2050 in the ERP scenario

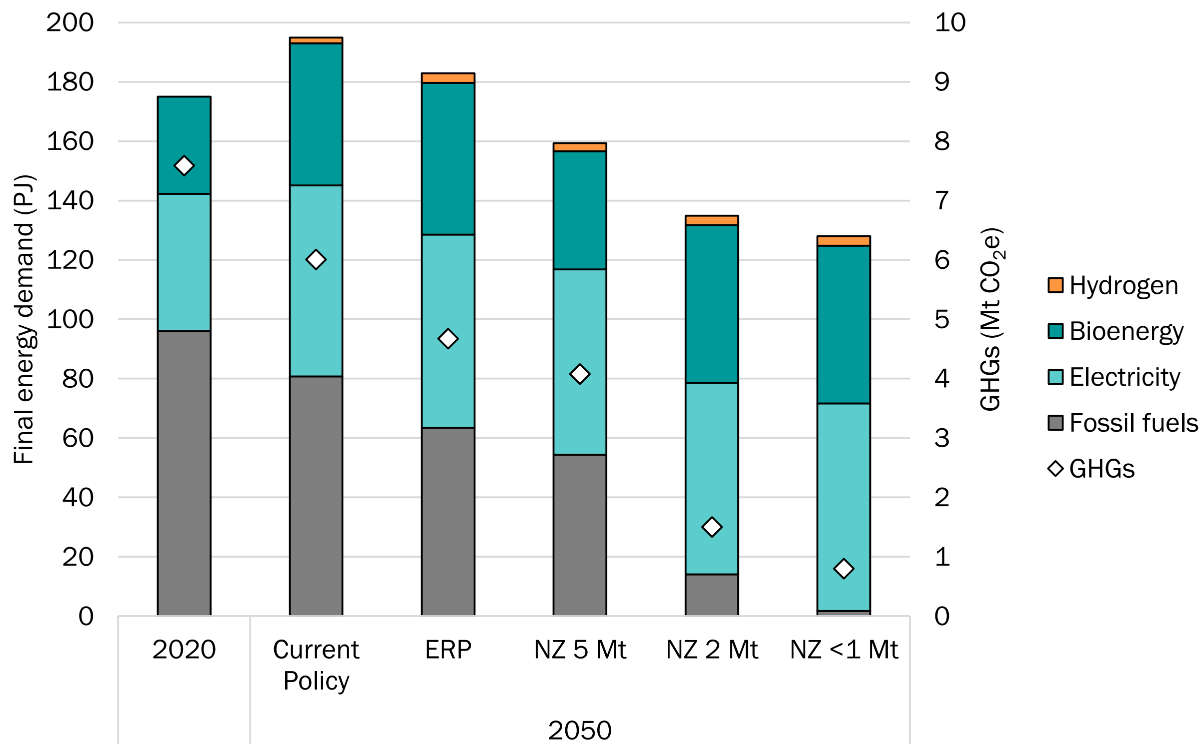


3. All pathways to net zero result in growing demand for low carbon energy – including electricity, bioenergy, and hydrogen – to offset reduced reliance on fossil fuels.

Energy consumption changes substantially under all net zero pathways examined in this analysis (see Figure 2):

- **Electricity** consumption grows from about 46 PJ in 2020 to between 62 and 70 PJ in 2050. Electrification is a key action for decarbonizing many sectors of the economy, including buildings, light and medium-duty vehicles and manufacturing.
- **Bioenergy** consumption grows from about 33 PJ in 2020 to between 40 and 53 PJ in 2050. This includes liquid biofuels (used in transport) and renewable natural gas and solid biomass (used in buildings and industry).
- **Hydrogen** consumption grows from negligeable amounts in 2020 to around 3 PJ in 2050. Hydrogen is produced domestically via electrolysis and is primarily used in heavy-duty fuel cell vehicles.

Figure 2: Final energy demand and GHG emissions in New Brunswick by scenario



4. New Brunswick's demand for low carbon energy can be met through a combination of domestic production and imports.

In a net zero future, growing demand for low carbon energy represents an opportunity to boost domestic supply, which increases under all simulated net zero scenarios:

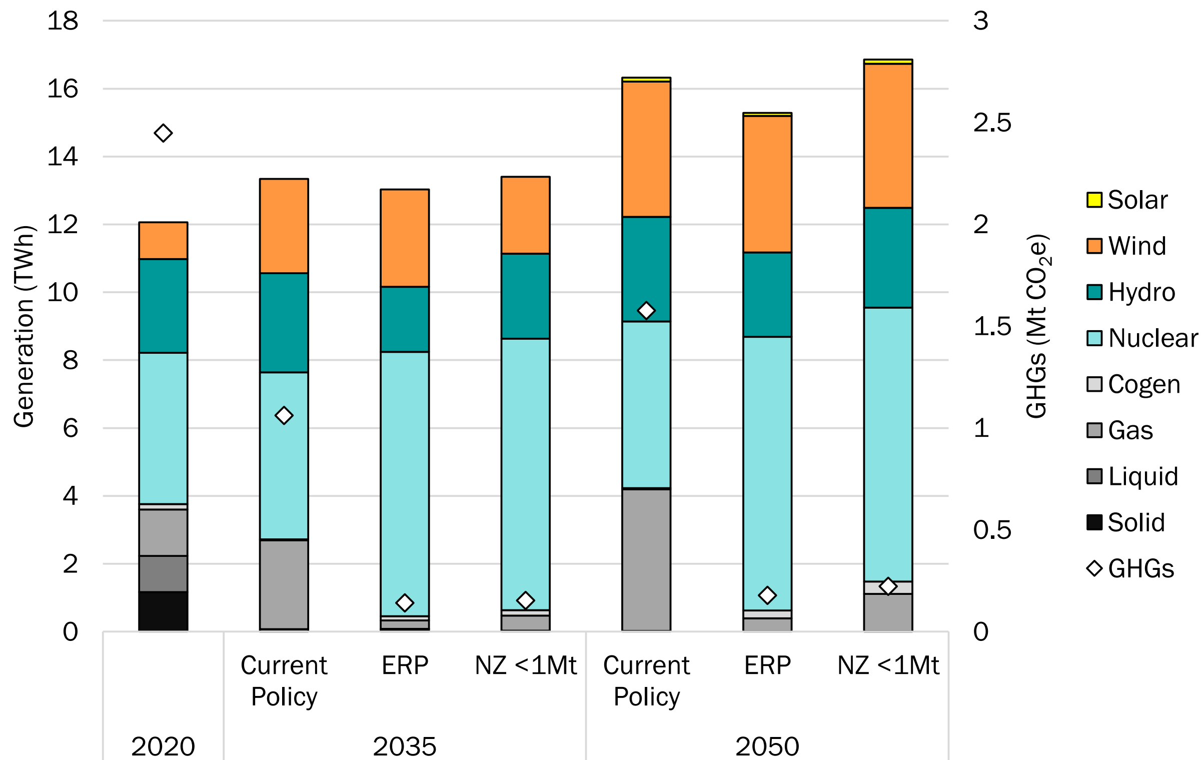
- **Electricity** production grows from 43 PJ (12 TWh) in 2020 to over 60 PJ (17 TWh) in 2050. At the same time, the method of producing electricity changes substantially (see below).
- **Bioenergy** production in all forms expands. This includes the supply of solid biomass from agriculture and forestry operations, as well as the potential emergence of new sectors supplying liquid and gaseous renewable fuels.
- **Hydrogen** production grows from a low starting point to over 3 PJ. This supply is exclusively met via domestic production using electrolysis.

5. Renewables and storage are the safest bet for meeting most new electricity demand in New Brunswick, alongside any planned nuclear capacity additions.

In the ERP and net zero scenarios, electricity emissions fall to close to zero by 2035, due to the proposed federal Clean Electricity Regulation and in line with Action 7 of New Brunswick's Climate Change Action Plan. The following technologies, fuels and actions allow New Brunswick's demand for low carbon electricity to be met in these scenarios (see Figure 3):

- **Renewables.** Wind accounts for most electricity capacity additions in the net zero scenarios. Generation from wind quadruples, from 1.1 TWh in 2020 to over 4 TWh in 2050. A more modest amount of solar is deployed, though this could be greater depending on the future cost and performance of solar PV.
- **Nuclear.** Generation from nuclear increases by 3.6 TWh due to the deployment of 400 MW of small modular reactor (SMR) capacity by 2035 and the replacement of Point Lepreau's capacity (660 MW) in the 2040s, in line with current provincial plans. If new and replacement nuclear capacity is not developed substantially greater deployment of renewables is expected.
- **Renewable natural gas.** Renewable natural gas accounts for about 70% of gaseous fuel consumption in the net zero scenarios (6 PJ annually) and is used to generate 0.7 TWh of electricity annually. It is sourced from waste-derived biogas produced in New Brunswick as well as imports and can be used in conventional turbines without modification.
- **Battery storage.** Combining renewables with electricity storage can enhance system reliability and reduce costs. In the net zero scenarios, between 8.5-15.5 GWh (700-1,000 MW) of storage is deployed by 2050. This includes both short duration storage (i.e., 4-hour lithium-ion batteries) and longer duration storage (i.e., flow batteries).
- **Imports.** Net imports roughly double over the forecast period, from 1.6 TWh in 2020 to over 3 TWh in 2050.

Figure 3: Electricity generation in New Brunswick by scenario



6. Non-energy emissions can be reduced in New Brunswick but likely not eliminated.

The net zero scenarios see a reduction in non-energy emissions from about 1.5 Mt today to between 0.6 to 0.8 Mt by 2050. Key actions to reduce non-energy emissions include landfill gas capture and/or organic waste diversion, elimination of hydrofluorocarbons and the use of anaerobic digestors in agriculture. The potential and cost of technologies and practices to reduce remaining non-energy emissions (largely soils and enteric fermentation in agriculture) is uncertain.

7. Carbon dioxide removals (CDR) are required to counterbalance residual emissions from hard-to-decarbonize sources.

Carbon dioxide removals (CDR) refer to the removal of carbon from the atmosphere and storage underground, in plants and soil, in oceans or in products (e.g., cement). To achieve net zero emissions in New Brunswick, CDR is necessary to counterbalance residual emissions.

CDR can take many forms, from new technologies to land management practices. Broadly speaking, CDR options include:

- **Natural solutions** that use photosynthesis to remove CO_2 from the atmosphere and store it in wood and soil. The potential for nature-based solutions in New Brunswick is uncertain. A study by Nature United[3] provides the only known estimate for the province, identifying 0.89 Mt of annual reduction potential through actions such as salt marsh restoration and avoided grassland conversion. This value should be interpreted with caution because uncertainty is high and not all actions lead to negative emissions.
- **Technological solutions** that accelerate or mimic natural processes to remove CO_2 from the atmosphere. **Direct air capture** (DAC), although not yet commercialized, features prominently under all net zero scenarios simulated for Canada (up to several hundred Mt annually by 2050). For New Brunswick, DAC could be important to offset agricultural and other hard-to-decarbonize sources of emissions, whether or not the CO_2 is captured or stored within provincial boundaries.

8. New Brunswick's economy can continue to grow while achieving net zero.

The provincial economy grows in all scenarios, although it grows less quickly if the province reduces emissions to net-zero. Growth is lower in the net zero scenarios because firms and households incur additional costs adopting low carbon technologies and fuels (this analysis does not account for the benefits of avoided climate change).

While achieving net zero imposes costs on some sectors, it also benefits others. In particular, the electricity sector receives a boost in all net zero scenarios due to the electrification of various activities across the economy and higher demand for electricity. Other sectors also stand to benefit, such as bioenergy and hydrogen production.

[3] Drever, C. et al. 2021. Natural climate solutions for Canada. Science Advances 7 (23). www.science.org/doi/10.1126/sciadv.abd6034

Opportunities for future research

This analysis highlights a few areas of study that warrant more research, including:

- Defining a policy approach for meeting provincial net zero and other objectives.
- Evaluating the impacts of announced federal policies on New Brunswick as more details emerge about how they will be implemented.
- Monitoring the development of emerging low carbon technologies and fuels, such as electric batteries, hydrogen fuel cells and small modular nuclear reactors.
- Quantifying the emissions reduction potential and cost of nature-based solutions in New Brunswick.

Contents

1. Introduction

1.1. Background

Both New Brunswick and the federal government have established a target of achieving net zero greenhouse gas emissions by 2050[4,5]. Such a target implies reducing emissions to as close to zero as possible while counter-balancing any remaining emissions through carbon dioxide removals from the atmosphere.

New Brunswick is therefore interested in understanding potential pathways to achieving deep levels of decarbonization consistent with net zero. This information can help decision makers identify the most promising options for reducing greenhouse gas emissions.

This study builds on previous net zero work conducted by Navius for New Brunswick's Climate Change Secretariat[6]. It employs Navius' gTech-IESD modeling framework that has been applied to explore the impacts of climate policy in New Brunswick, through various analyses for the New Brunswick Climate Change Secretariat, as well as to understand pathways to net zero nationally and for multiple jurisdictions across the country.

---

[4] Province of New Brunswick. 2022. Our pathway towards decarbonization and climate resilience: New Brunswick's Climate Change Action Plan 2022-2027. https://www2.gnb.ca/content/dam/gnb/Corporate/Promo/climate/climate-change-action-plan.pdf

[5] Canadian net-zero emissions accountability act. S.C. 2021, c. 22. https://laws-lois.justice.gc.ca/eng/acts/c-19.3/fulltext.html

[6] Navius Research. 2021. Pathways for decarbonizing New Brunswick's economy: Report prepared for New Brunswick Climate Change Secretariat.

1.2. Objectives

This study builds on previous net zero work conducted by Navius Research for New Brunswick's Climate Change Secretariat and aims to:

1. Account for the shifting policy environment, including release of the federal Emissions Reduction Plan and New Brunswick's 2022 Climate Change Action Plan.
2. Conduct a detailed assessment of options for decarbonizing electricity supply in New Brunswick.
3. Explore the potential for non-energy related GHG abatement in the province (for example, in agriculture and waste) and carbon dioxide removals.

1.3. Report structure

The report is structured as follows:

- Section 2 provides an overview over the modeling approach and scenarios.
- Section 3 explores the technology, fuel and other transformation that could enable New Brunswick to achieve net zero.
- Section 4 conclusion.

Additional information and references are provided in the appendices.

2. Approach

This section provides an overview of the approach used to conduct this analysis. It is structured as follows:

- Section 2.1 introduces Navius' modeling toolkit.
- Section 2.2 outlines policy assumptions and simulated scenarios.

More detailed information about the models and assumptions is provided in the appendices.

2.1. Navius' modeling toolkit

Navius used the gTech-IESD model to characterize New Brunswick's energy-economy, where each component of this model brings its unique strengths:

- **gTech** provides a comprehensive representation of all economic activity, energy supply and use, and greenhouse gas emissions in Canada and the US, including simulating New Brunswick as a distinct region.
- **IESD** provides insights into the optimal way of supplying the electricity demand simulated by gTech, capturing sector-specific dynamics such as hourly variability in load and supply options.

Both of these models simulate future outcomes (e.g., technology adoption, energy use, greenhouse gas emissions, economic activity and household consumption) as a function of fundamental inputs and assumptions related to economic growth, energy prices, technology costs and policy.

The components of the model are introduced below.

2.1.1. gTech

gTech is Navius' proprietary modeling software designed to simulate the impacts of government policy and other external developments on both technological adoption and the broader economy.

As a technologically detailed computable general equilibrium (CGE) model, gTech balances supply and demand for commodities and factors of production (capital, labour) by varying prices. This price-driven balance of supply and demand is applied to energy commodities, where all energy/fuels must be produced and the supply of energy commodities (e.g., refined petroleum products in New Brunswick) is a function of demand in other jurisdictions.

In addition to representing key economic transactions within an economy, gTech includes explicit representation of technologies and fuels. The technology granularity is sophisticated enough that it includes everything from vehicles to refrigerators to ways of refining oil. gTech allows policymakers to gain a reliable, quantified understanding of the impact of different policies and policy combinations on technology and fuel choice, energy consumption, GHG emissions and broader economic indicators such as GDP, industrial competitiveness and household welfare.

gTech is well suited for quantifying the greenhouse gas and economic impacts of policy and carbon constraints in New Brunswick (and the rest of Canada) because it:

- **Provides a detailed accounting of low carbon technologies and fuels that can reduce greenhouse gas emissions.** In total, gTech includes over 400 technologies (e.g., electric vehicles, industrial heat pumps, anaerobic digestors, LED bulbs, building enclosures and furnaces) across over 100 end-uses (e.g., light-duty vehicles, industrial process heat, manure management, lighting, building heating, etc.). gTech represents technologies that are available or are likely to become available in the coming decades. The cost of key emerging technologies is subject to economies of learning, as the cost is contingent upon the scale of adoption.
- **Simulates how firms and consumers make decisions in the real world, describing likely outcomes rather than prescribing financial cost-optimized solutions.** This is important because technological choice – the decision by a consumer to select a specific technology – is often driven by factors that go beyond financial cost. As an example, few people would buy an SUV instead of a smaller car if their only concern was the cost. In the real-world, preferences have an important impact on energy consumption and GHG emissions.

- **Accounts for all substantive existing provincial and federal policies, including how they interact.** New Brunswick's greenhouse gas emissions are influenced by many provincial and federal policies. Accounting for the combined impact of these policies is crucial for developing reliable forecasts. For example, electric vehicle adoption is influenced by ZEV mandates, financial incentives, clean/low carbon fuel standards, fuel economy regulations and carbon pricing.

More information about gTech is available in Appendix A: "gTech", starting on page 38.

2.1.2. IESD

Electricity systems are unique energy systems because electricity markets are highly sensitive to short-term variations in the system. For example, total electricity system costs are largely a function of single hours of the year in which renewable resources operate below typical capacity and electricity consumption is high. Representing these short-term variations is critical to simulating the integration of existing and new variable renewable electricity resources with other conventional and low-carbon electricity supply.

Furthermore, a model with short-term dynamics is critical for understanding how electricity supply will interact with existing electricity demand and potential new electricity loads such as vehicles, electricity storage and dispatchable hydrogen production. It is very difficult to understand the impact of a policy that requires deep GHG reductions from the electricity sector, like the proposed Clean Electricity Regulations, without including short-term dynamics.

Navius' Integrated Electricity Supply and Demand model (IESD) is a capacity addition and dispatch model, meaning that it simulates how utilities across Canada build capacity and use that capacity on an hourly basis to satisfy changing electricity demand. IESD is capable of simulating North America's electricity systems under a variety of policy and economic conditions.

IESD is linked to gTech to provide enhanced representation of electricity sector dynamics. These dynamics are important in the context of climate policy, given the electricity sector's direct contribution to GHGs and the potential for end-use sectors to reduce their GHGs by electrifying. gTech provides IESD with a forecast of annual electricity consumption by end-use and other inputs (e.g., carbon credit prices, willingness to pay for electrolytic hydrogen). IESD takes these inputs, defines the hourly electricity demand, and solves for how that demand is satisfied.

IESD is the ideal tool for exploring different electricity sector pathways because it accounts for:

- **Hourly electricity consumption.** The supply of electricity must be perfectly timed to match demand in every hour of the day and in every day of the year. This poses a challenge because neither electricity consumption nor electricity production is consistent over time. New Brunswick must be able to supply enough electricity to balance demand at all times, through an ever-changing combination of domestic generation and imports.
- **Hourly generation profiles.** Different sources of power are available to meet demand in any given hour. Some generation units can be made available upon demand, such as combined cycle gas turbines, but others cannot. For example, generation from wind resources is only possible when the wind is blowing. Likewise, generation from solar photovoltaics is only possible when the sun is shining.
- **Identifying the potential and limits of emerging technologies.** IESD can anticipate the potential for variable renewable electricity (VRE) resources and determine opportunities to integrate them into the grid (e.g., through storage or utility-controlled charging) because IESD represents the short and long-term dynamics important to accurately capture the electricity system. Additionally, IESD can simulate the potential for hydrogen production through electrolysis via curtailed renewable energy and other sources.

More information about IESD is available in Appendix B: “IESD”, starting on page 52.

2.2. Policy assumptions and model scenarios

The scenarios simulated for this project vary against two dimensions: 1) the ambition of greenhouse gas policy and constraints and 2) assumptions about the cost and availability of emerging low and negative emissions technologies and practices.

2.2.1. Climate mitigation ambition

The analysis considers the following options for implementation of greenhouse gas policy and constraints in New Brunswick:

- **Current policy scenario.** This scenario includes currently legislated provincial and federal policies, such as a federal carbon price rising to \$170/t CO_2e by 2030 and the Clean Fuel Regulations. A full list of simulated policies is provided in Appendix C: "Current and announced policies", starting on page 61.

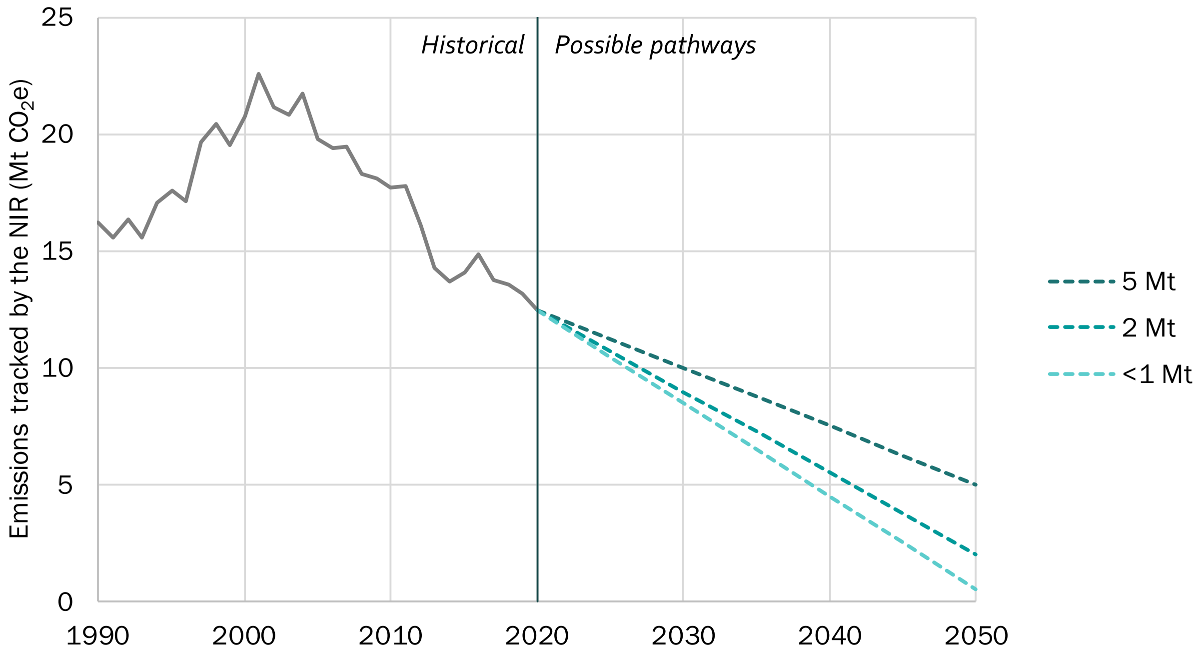
- **Emissions Reduction Plan (ERP) scenario.** In addition to currently legislated policies, this scenario includes (1) the policies announced in the federal Emissions Reduction Plan (ERP) and (2) New Brunswick's commitment to installing 400 MW of small modular reactors by 2035.

  Please note that uncertainty exists about how many ERP policies will be implemented. The Appendix provides details about the simulated policies and key assumptions.

- **Net zero scenario.** In this scenario, climate mitigation ambition is scaled up such that New Brunswick achieves net zero greenhouse gas emissions by 2050. Net zero is defined as emissions within the province, as tracked by the National Inventory Report, being offset by negative emissions (e.g., from Land Use, Land Use Change and Forestry).

  Due to the limited state of research into the potential for nature-based solutions in the province (please see Section 3.5), net zero is represented as a reduction in modeled emissions to three different levels: <1, 2 and 5 Mt CO_2e residual in 2050. The pathway to net zero is defined by a linear trajectory between New Brunswick's target in 2030 and the 2050 end point, as shown in Figure 4.

Figure 4: Emissions trajectories to net zero



*Emissions tracked by the National Inventory Report likely cannot be reduced to zero because no known abatement options exist for eliminating all sources of agricultural emissions. The implication is that these emissions would have to be offset via carbon dioxide removals.

2.2.2. Sensitivity analysis

A sensitivity analysis was conducted to examine the impact of uncertainty in factors beyond the Government of New Brunswick's control, including:

- The cost of emerging low carbon transport technologies (battery electric vehicles, hydrogen fuel cell vehicles and second-generation biofuels).
- The cost of electricity supply technologies (wind, solar PV, batteries) as described in Appendix B: IESD.
- The availability and cost of DAC as described in Section 3.5.2.
- The level of climate mitigation ambition in the rest of Canada and the US.

The sensitivity analysis resulted in a total of 63 simulations being conducted for this project. For simplicity, this report focuses on results associated with baseline assumptions.

3. Results

This section presents results from the analysis. It begins by examining emissions trends in response to current and announced policies to identify the potential gap to net zero in New Brunswick. It then reviews the transformation of technologies, fuels and activities along the pathway to net zero greenhouse gas emissions, including energy demand, energy supply, non-energy emissions and carbon dioxide removals. Lastly, it explores the implications of net zero for New Brunswick's economy.

3.1. Current trends

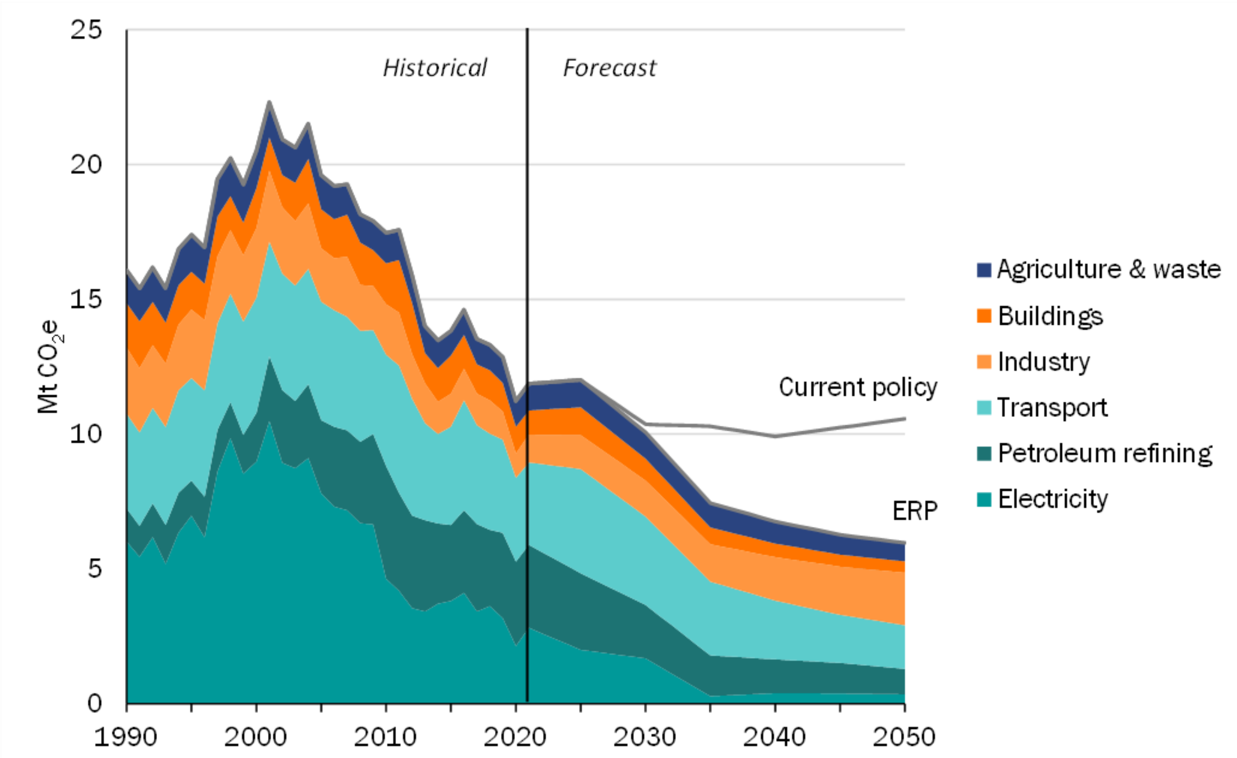
In response to current policies, New Brunswick's emissions decline to 10.4 Mt in 2030 and rebound somewhat through 2050 as existing policies run their course (see Figure 5). By 2050, emissions are 10.6 Mt.

The overall trend in emissions masks changes among sectors. Most notably, emissions from transport decline due to efficiency improvements of vehicles (as mandated by federal policy) and due to the adoption of zero emissions vehicles. Emissions from electricity also decline due to existing policies such as the coal phase out. On the other hand, emissions from manufacturing increase due to growing economic activity.

Under the ERP scenario, emissions are reduced by 0.3 Mt in 2030 and 4.6 Mt in 2050 (relative to the current policy forecast). This results in emissions of 10.1 Mt in 2030 and 6.0 Mt in 2050. Reductions are concentrated in electricity, transport and industry (due to policies like the Clean Electricity Standard and ZEV mandates for light, medium and heavy-duty vehicles).

The implication of these projections is that additional reductions would be required to achieve greenhouse gas targets in 2050. Below, we describe the changes in technology, fuel use and other factors that could allow that to happen.

Figure 5: New Brunswick's greenhouse gas emissions to 2050

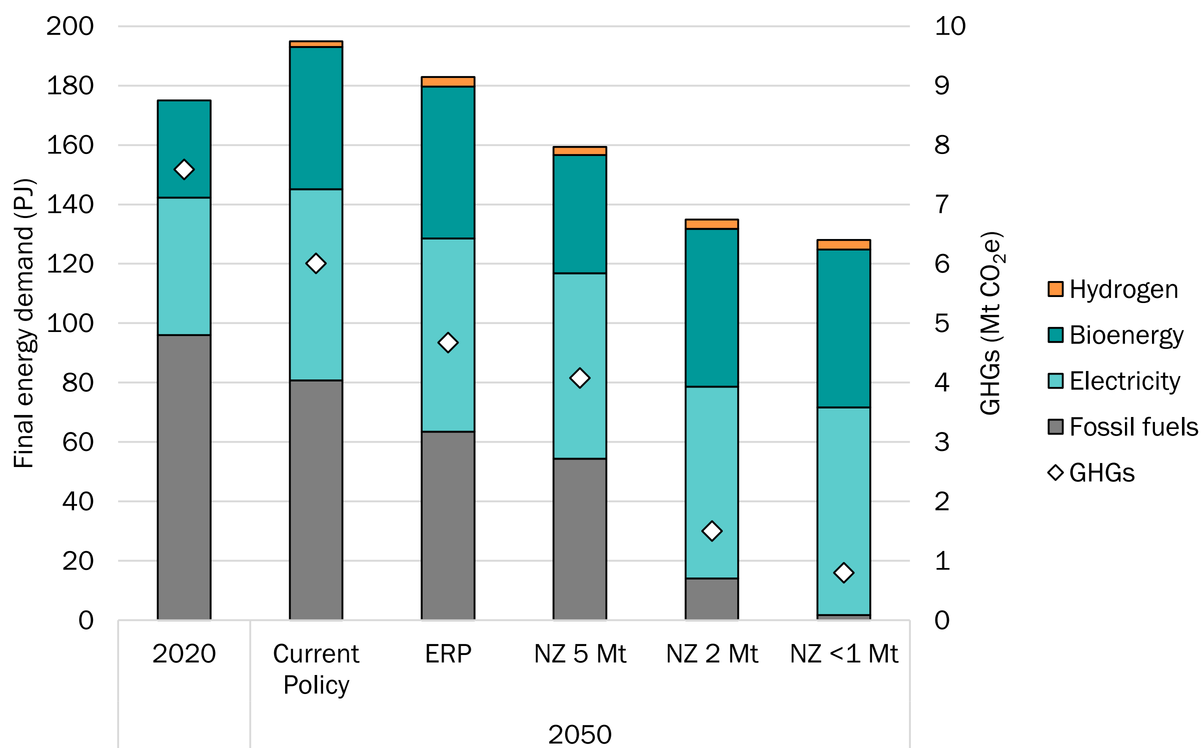


3.2. Energy demand and emissions

The net zero pathways result in the displacement of fossil energy use with multiple low carbon energy carriers, including electricity, bioenergy and hydrogen (see Figure 6):

- Electricity consumption grows from about 46 PJ in 2020 to between 62 and 70 PJ in 2050. Electrification is a key action for decarbonizing many sectors of the economy, including buildings, light and medium-duty vehicles and manufacturing.
- Bioenergy consumption grows from about 33 PJ in 2020 to between 40 and 53 PJ in 2050. This includes liquid biofuels (used in transport) and renewable natural gas and solid biomass (used in buildings and industry).
- Hydrogen consumption grows from essentially zero in 2020 to around 3 PJ in 2050. Hydrogen is produced domestically via electrolysis and is primarily used in heavy-duty fuel cell vehicles.

Figure 6: Energy consumption and emissions



The extent of the reduction in fossil energy use depends on the amount of offsets that are available. When emissions tracked by the National Inventory Report (NIR) are constrained to less than 1 Mt, fossil energy consumption declines to essentially zero. On the other hand, when NIR-related emissions are constrained to 5 Mt, some fossil energy consumption remains by 2050. This scenario implies that these emissions would have to be offset by carbon dioxide removals, which are discussed in Section 3.5.

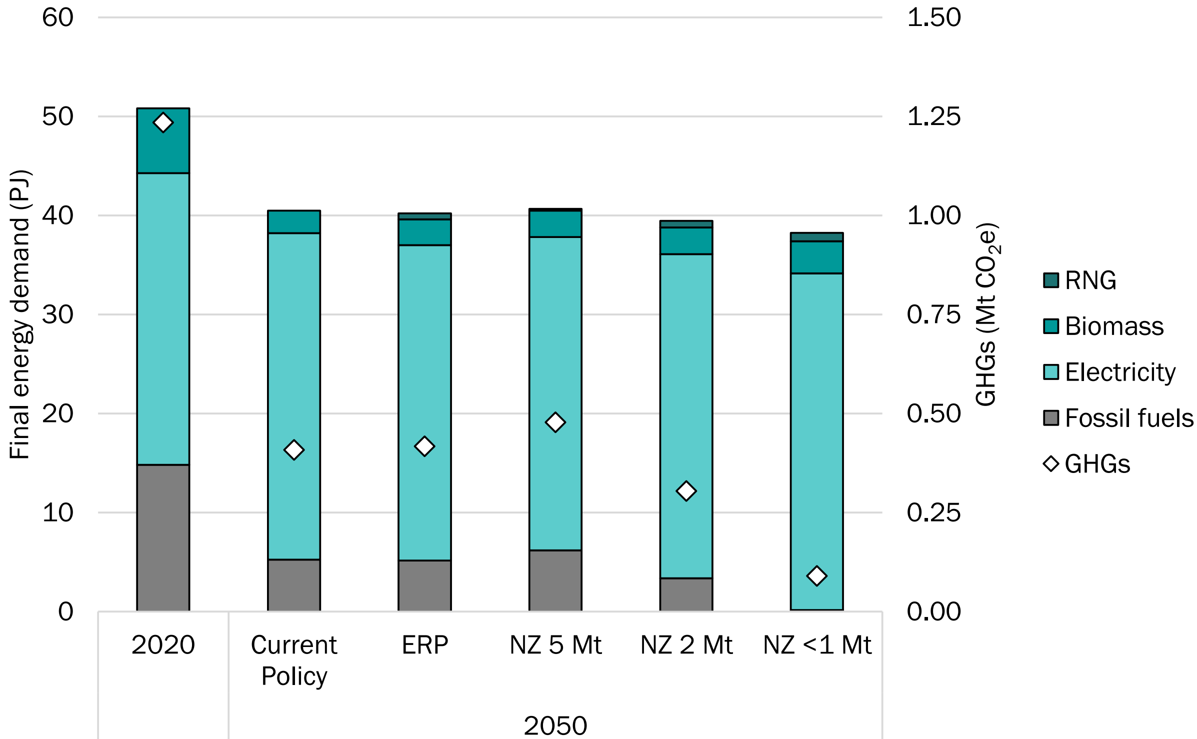
This section focuses on the technology and fuel transformation that is required to achieve net zero across three broad categories of energy demand sectors, including buildings, transport and industry (including agriculture, forestry and construction).

3.2.1. Buildings

Buildings accounted for 0.8 Mt of emissions in 2020 (of which 0.5 Mt are from residential buildings, while the remaining 0.3 Mt are from commercial and institutional buildings). These emissions mainly arise from the combustion of oil, natural gas, and propane for space and water heating. Additional but less significant emissions are due to the release of hydrofluorocarbons from air conditioning systems.

Figure 7 shows how fuel consumption in buildings changes between 2020 and 2050 under various scenarios.

Figure 7: Building energy consumption and emissions



This analysis finds that:

- **The electrification of space and water heating, especially using heat pumps, is the most important pathway for decarbonizing buildings.** A growing number of households and businesses across New Brunswick are switching to electric heating options due to energy savings, convenience and (in the case of heat pumps) the ability to provide cooling in summertime.

  The transition to electric heating accelerates under net zero, with electricity consumption rising to between 32 PJ and 34 PJ in 2050, up from 29 PJ in 2020. The increase in electricity consumption is moderated by the fact that (1) heat pumps are more efficient than conventional technologies and (2) the efficiency of other electricity consuming equipment, such as cloth dryers and lighting, and building shells increases over time through natural retirement of old equipment and replacement with newer, more efficient technologies.

- **The use of renewable fuels, such as renewable natural gas, can displace fossil energy use in remaining conventional equipment.** Consumption of renewable natural gas rises to around 1 PJ by 2050. While it accounts for a relatively small share of building energy consumption, its ability to be used without modifying conventional heating equipment and pipeline systems means it could be helpful for decarbonizing buildings that haven't been electrified.

Renewable fuels could also potentially be used to displace emissions from buildings oil-fired equipment. However, this analysis finds that most oil furnaces are retired by 2050. In addition, the cost of liquid biofuels suitable for use in oil furnaces is likely to be expensive relative to electrification.

- **Biomass offers an alternative low carbon heating option, but its potential adoption is uncertain.** Biomass heating through wood stoves or pellet furnaces is generally considered a zero-carbon heating option. While it may be cost competitive with other heating options (especially fuel oil), its use is determined in large part by preference rather than cost. For example, some households readily prefer wood stoves due to the intangible benefit they derive from them. Conversely, other households would much prefer to avoid chopping wood or re-stocking pellet supplies.

- **Hydrogen is not a cost-effective option for decarbonizing buildings in New Brunswick.** While hydrogen could potentially be used to provide space and water heating, it requires special equipment and changes to transmission and distribution infrastructure. Coupled with the high cost of hydrogen (which would likely be produced from electricity anyway), using electricity directly to heat buildings is a more economical decision.

- **Improvements in thermal efficiency can reduce energy use, but if building heating is provided by zero carbon sources does not reduce emissions.** Thermal shell efficiency improves in the current policy and ERP scenarios but does not improve further under net zero. This finding highlights the fact that additional shell efficiency improvements are a more costly abatement action relative to electrification. In fact, decarbonizing space heating equipment reduces both the incentive and the effect of reducing emissions by improving shell efficiency. If a building is heated electrically, improving its thermal shell efficiency has no impact on direct emissions. Put another way, the abatement cost of shell efficiency improvements to such a building are infinite. In addition, use of more efficient space conditioning equipment such as heat pumps further reduces the financial incentive of increasing shell efficiency, as the incremental reduction in energy use and energy cost declines.

3.2.2. Transport

Transport accounted for 3.4 Mt of provincial emissions in 2020. Most of these emissions (3.0 Mt, or 90%) were from the combustion of refined petroleum products (gasoline and diesel) in vehicles. Remaining emissions are associated with marine transport (0.2 Mt), railways (0.1 Mt) and aviation (0.1 Mt).

Given their importance, this section focuses on pathways for decarbonizing vehicles. The most promising options for decarbonizing other transport modes have some overlap with those discussed here, especially renewable fuels and hydrogen.

Figure 8: Transport energy consumption and emissions

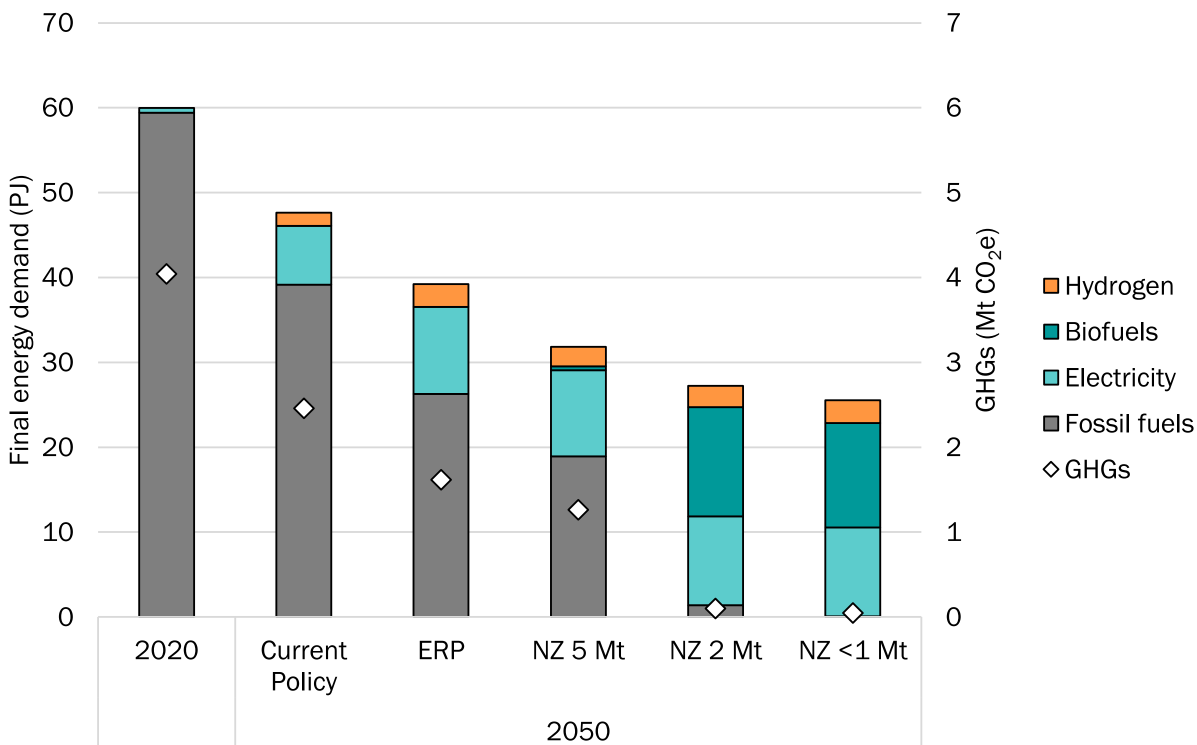


Figure 8 shows how fuel consumption in transport changes between 2020 and 2050 under various scenarios:

- **The adoption of plug-in electric vehicles is the most important action for decarbonizing light and medium-duty vehicles.** Electricity consumption increases under all net zero scenarios, from less than 1 PJ in 2020 to around 10 PJ in 2050.

  Despite being the dominant energy source for transport in New Brunswick, electricity consumption is relatively low compared to current fossil energy use. This reduction in energy use is due to the high efficiency of electric motors compared to internal combustion engines. For example, typical energy efficiency ratios (i.e., which are used to compare the energy use for different vehicle technologies and fuel types) for battery electric vehicles range from four to five.

By 2050, most light-duty vehicles (over 95%) and medium-duty vehicles (81%) are plug-in electric in the ERP and net zero scenarios. The deployment of these technologies helps comply with proposed federal policy, which requires that 100% of light-duty vehicle sales are zero emission by 2035, and 100% of medium and heavy-duty sales are zero emission by 2050 (based on feasibility).

- **Drop-in renewable fuels don't require any modifications to be used in existing transport vehicles, though further innovations are required to produce these fuels at scale.** Under the net zero scenario, bioenergy is the second most important energy source for transport after electricity. Bioenergy, including conventional biofuels (e.g., biodiesel and ethanol), hydrogenation derived renewable diesel (HDRD) and second-generation biofuels, displaces all remaining fossil energy in the gasoline and diesel pools.

  While conventional biofuels like ethanol and biodiesel are widely produced today, using them in their pure (i.e., non-blended) form requires significant modifications to existing engines and results in poor cold weather performance. A more promising option for decarbonizing liquid fuel use is "drop-in" fuels that are fully interchangeable with petroleum-derived products. These fuels require no change to fuel transport and distribution, nor of internal combustion engines.

  Hydrogenation derived renewable diesel (HDRD) accounts for virtually all current global production capacity of renewable drop-in fuels. Because the feedstocks for this fuel are ultimately limited (i.e., vegetable oils and animal fats), New Brunswick's ability to secure enough supply under any scenario of global or North American decarbonization may be constrained.

  In the future, "second-generation" biofuels like renewable gasoline and diesel that are produced via thermochemical processes (pyrolysis or gasification) offer the potential to boost supply while being less constrained by feedstock availability. The feedstocks used for these production pathways include lignocellulosic biomass (e.g., agricultural and forestry residues), algae, wastewater or dedicated energy crops like switchgrass. At present, thermochemical conversion is mostly limited to pilot and demonstration facilities.

- **Hydrogen fuel cell technology may be attractive for decarbonizing heavy-duty vehicles, trains and ships.** Hydrogen consumption for transport grows from essentially zero in 2020 to between 2 and 3 PJ in 2050.

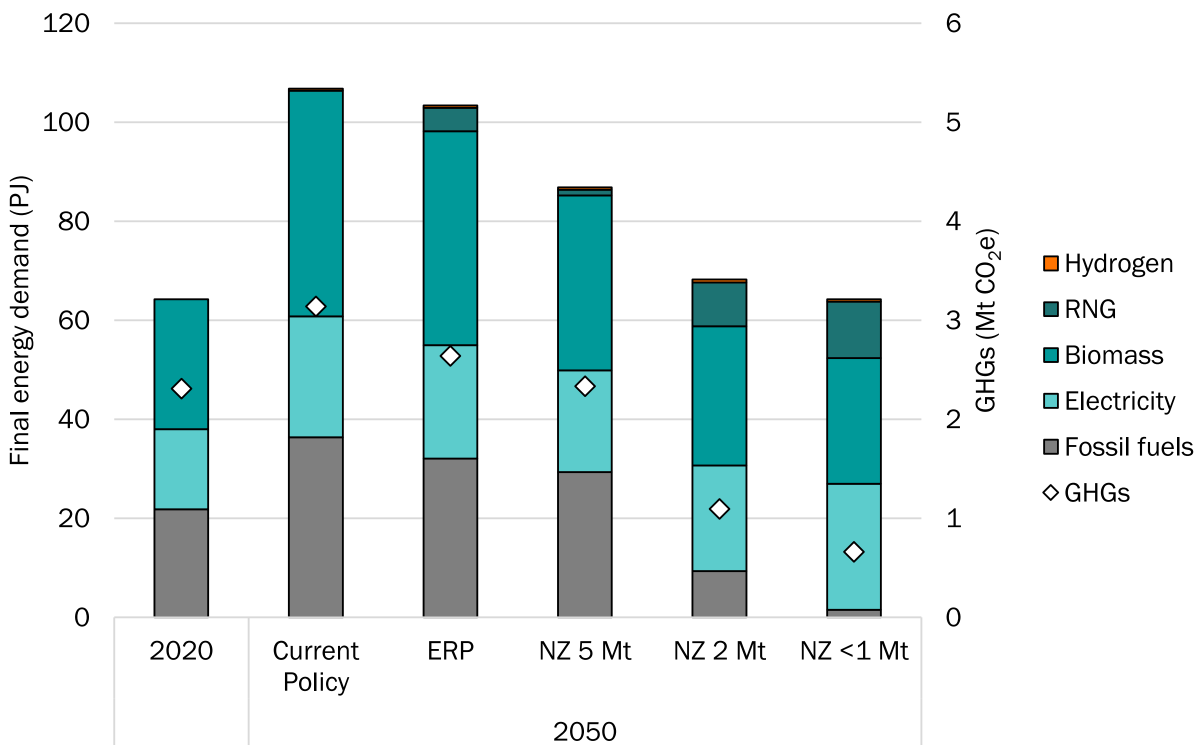
The use of hydrogen as a transport fuel requires developments on both the energy supply and demand side. On the supply side, hydrogen can be produced via electrolysis on a distributed basis (i.e., small scale production at individual refueling stations). Section 3.3.3 reviews hydrogen production.

Hydrogen may be particularly attractive for difficult-to-electrify transport modes including long-haul trucking, rail and marine. By 2050, hydrogen fuel cell vehicles account for 27% of heavy-duty vehicles on the road in the ERP and net zero scenarios.

3.2.3. Industry

Industry (including heavy industry and light manufacturing, construction and forest resources[7]) accounted for 1.1 Mt of emissions in 2020. These emissions are associated with the combustion of fossil fuels to provide heat and power required in the production of various products such as pulp and paper, food, lime, and gypsum. In addition, lime production results in process emissions associated with the calcination of limestone (though these emissions are relatively small, at around 0.02 Mt).

Figure 9: Industrial energy consumption and emissions



[7] Petroleum refining and other sectors associated with energy supply are not included here.

Figure 9 shows how fuel consumption in industry changes between 2020 and 2050 under various scenarios:

- **Biomass remains the dominant source of low-carbon energy due to its use in the pulp and paper sector.** As fossil energy use declines under the net zero scenarios, biomass accounts for an ever-greater share of industrial energy use.

- **Electricity consumption increases under all net zero scenarios.** Electricity consumption grows from 16 PJ in 2020 to between 21 and 25 PJ in 2050. In particular, we note that industrial heat pumps are an attractive option for decarbonizing low temperature heat production. This technology can provide low-grade process heat requirements, suitable for use in food and other light manufacturing. It accounts for close to 40% of low temperature heat supply by 2050 under net zero.

  Heat pumps are generally more costly to install but reduce energy costs. In the scenarios in which New Brunswick achieves net zero, industrial heat pumps meet virtually all low temperature heating requirements. Electric boilers can be used to provide higher temperature heat.

- **Renewable natural gas use displaces fossil energy use in more difficult to electrify applications.** Renewable natural gas consumption grows under all net zero scenarios, from zero in 2020 to between 1 and 11 PJ in 2050. Combustion of RNG (and biomass) is helpful for providing high temperature process heat required by industry. As with its use in other sectors of the economy, RNG has the benefit of being able to be used in conventional equipment without modification.

  Lastly, we note that biofuels and hydrogen use, which is more limited than the other fuels listed here, are predominantly associated with motive applications in mining, agriculture, forestry and construction. For further discussion of transport, please see Section 3.2.2.

3.3. Energy supply and emissions

As described above, achieving net zero requires the use of multiple low carbon energy carriers, including electricity, bioenergy and hydrogen. This demand is met via a combination of domestic production and imports.

In the net zero scenarios, domestic production of electricity, bioenergy and hydrogen increases:

- Production of electricity grows from 43 PJ (12 TWh) in 2020 to 60 PJ (17 TWh) in 2050. At the same time, the method of producing electricity changes substantially, with a reduction in the use of fossil fuels in favour of renewables, nuclear and bioenergy.
- Production of bioenergy in all forms expands. This includes the supply of solid biomass from agriculture and forestry operations, as well as the potential emergence of new sectors supplying liquid and gaseous renewable fuels.
- Production of hydrogen (as an energy carrier, not a feedstock) grows from a low starting point to over 3 PJ. This supply is largely met via electrolysis.

While the supply of low carbon fuels grows, production of refined petroleum products (RPPs) in New Brunswick falls under all net zero scenarios. It is particularly sensitive to the level of emissions reduction effort in the rest of North America (as opposed to policy in New Brunswick), which influences demand for RPPs.

Below, we discuss the production of each low carbon energy carrier in turn.

3.3.1. Electricity

The electricity sector plays an important role in all pathways to net zero. Not only must the sector decarbonize itself, but it must also supply greater amounts of electricity to enable electrification across buildings, transport and industrial sectors.

Under net zero scenarios, electricity generation increases from 12 TWh in 2020 to around 17 TWh in 2050[8]. Figure 10 and Figure 11 provide additional detail about how electricity capacity and generation change under the current policy, ERP and net zero scenarios.

Even the current policy forecast implies big changes for New Brunswick's electricity sector. Emissions decrease from 3.5 Mt in 2020 to 1.6 Mt in 2050, driven by various factors including policies (especially the coal phase-out), economics (the high cost of generation from oil compared to declining costs of renewables and storage) and geography (which limits the availability of natural gas).

---

[8] TWh are used for electricity because it is a common metric, while PJ are used for other sectors. One TWh equals 3.6 PJ.

In the ERP and net zero scenarios, emissions fall to close to zero by 2035, due to the proposed Clean Electricity Regulation. The following technologies, fuels and actions allow New Brunswick's demand for low carbon electricity to be met in these scenarios:

- **Renewables.** Wind accounts for most capacity additions under net zero scenarios. Generation from wind quadruples, from 1.1 TWh in 2020 to over 4 TWh in 2050. A more modest amount of solar is deployed, generating over 0.1 TWh in 2050, though this could be greater depending on the future cost and performance of solar PV.
- **Nuclear.** Generation from nuclear increases by 3.6 TWh due to the deployment of 400 MW of small modular reactor (SMR) capacity by 2035 and the replacement of Point Lepreau's capacity (660 MW) in the 2040s, in line with current provincial plans. Nuclear power is attractive because it provides firm power. If new and replacement nuclear capacity is not developed – SMRs may or may not be commercially viable by the early 2030s – substantially greater deployment of renewables is expected.
- **Renewable natural gas.** Renewable natural gas accounts for about 70% of gaseous fuel consumption under net zero scenarios (6 PJ) and is used to generate 0.7 TWh of electricity annually. It is sourced from landfills in New Brunswick as well as imports (please see Section 3.3.2). Renewable natural gas can be transported through existing natural gas pipelines and used in conventional turbines without modification.
- **Battery storage.** Electricity storage makes renewables more attractive and reduces the need for thermal capacity. Under net zero scenarios, between 8.5-15.5 GWh/700-1,000 MW of storage is deployed by 2050. This includes both short duration storage (i.e., 4-hour lithium-ion batteries) and longer duration storage (i.e., flow batteries).
- **Imports.** Net imports roughly double over the forecast period, from 1.6 TWh in 2020 to over 3 TWh in 2050. The expansion of interties, not explored in this analysis, could further facilitate greater imports of low carbon electricity, particularly hydro from Québec and Newfoundland.

Figure 10: Electricity capacity by scenario, 2020, 2035, 2050

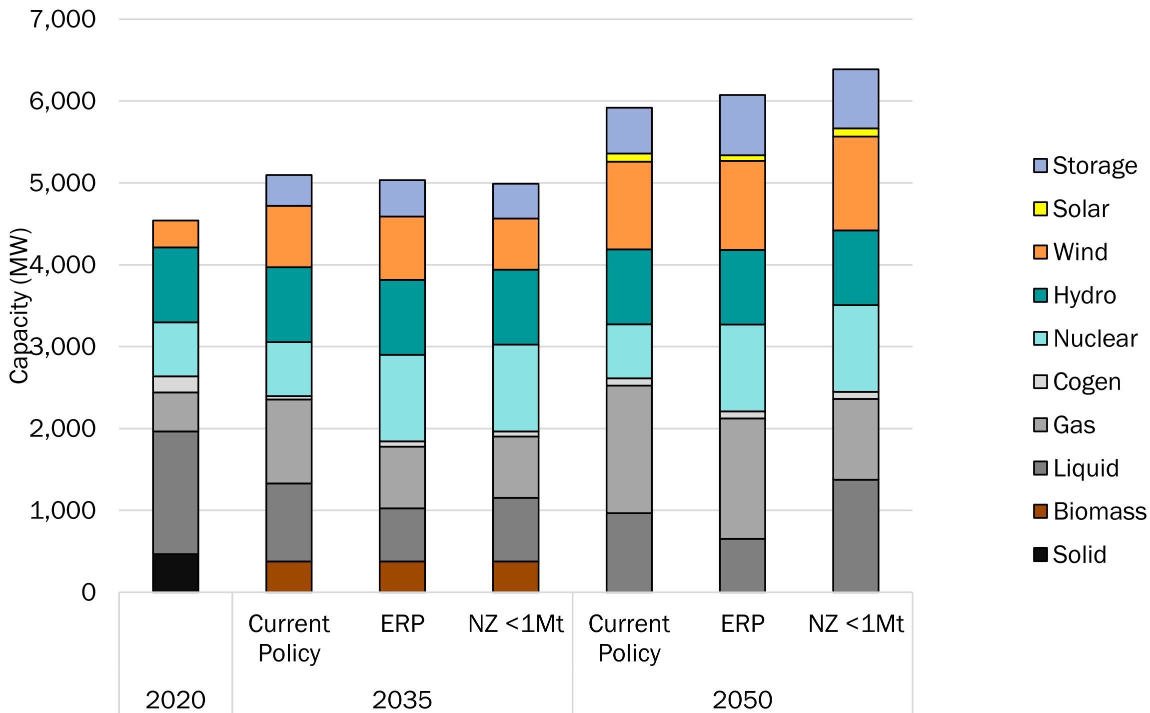
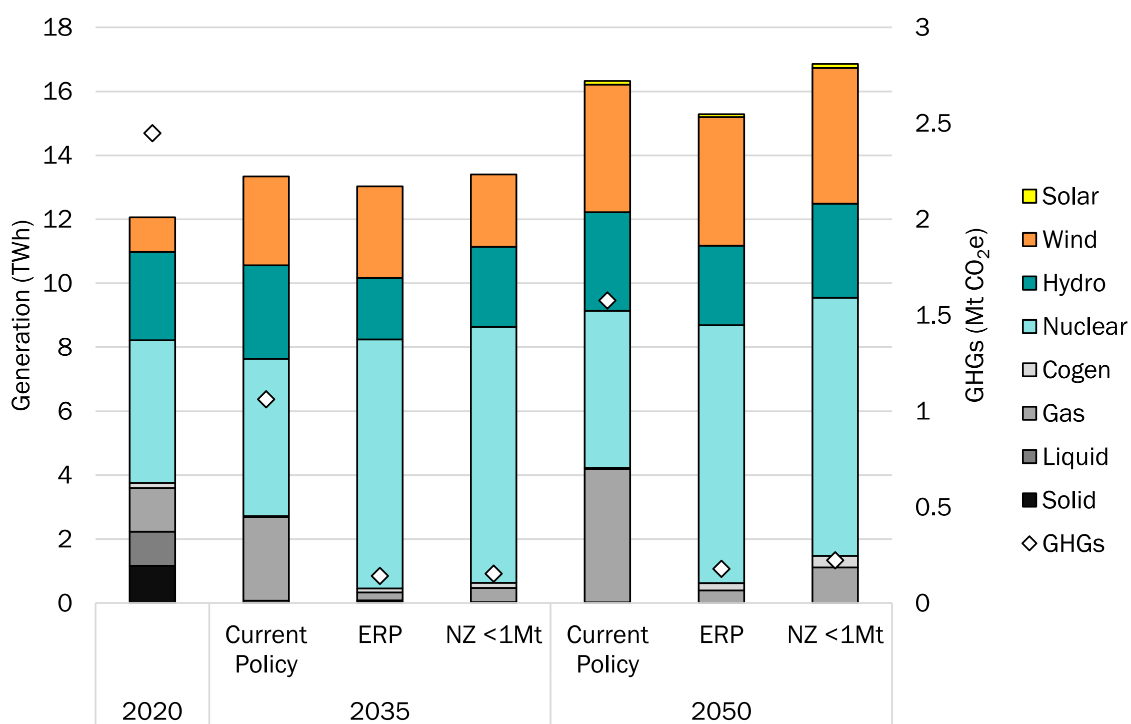


Figure 11: Electricity generation and emissions by scenario, 2020, 2035, 2050



Despite the development of new low carbon sources of electricity described above, we note that thermal capacity offers value to New Brunswick, even in a low carbon future. While oil capacity decreases somewhat over the forecast period, gas capacity increases. By 2050, thermal capacity is comparable to that installed today.

Thermal capacity remains valuable for maintaining system reliability and can be consistent with deep decarbonization when capacity utilization is low, renewable fuels are used (e.g., RNG) and/or remaining emissions are offset (see section 3.5).

Additional low carbon options for meeting electricity demand beyond those considered in this analysis include:

- **Greater renewables and storage deployment.** For example, the low renewables cost scenario leads to 260 MW of additional storage by 2050. Additionally, we note that if solar capacity factors improve (they were held fixed for this analysis), solar could cost-effectively play a larger role in cost-effectively meeting New Brunswick's electricity needs.
- **Greater nuclear deployment.** Nuclear capacity could be deployed beyond the 1040 MW (Point Lepreau plus 400 MW of SMRs by 2035) assumed in this analysis. On the other hand, SMRs may or may not be commercially viable by the early 2030s and their costs are highly uncertain.
- **Carbon capture and storage.** This technology may be attractive if opportunities for geological storage exist in the province. We note that the combustion of RNG, coupled with carbon capture, could allow the electricity sector to have negative emissions.
- **Load shifting.** Dispatchable load provides an opportunity to "shift" electricity consumption from periods of peak load or low capacity factors for renewables. The effects of dispatchable load are twofold. First, it can shift electricity consumption to periods of greater availability of renewables. Second, it can move consumption away from peak load. In both cases, it manages intermittency by reducing the amount of available capacity needed to meet an expected or actual peak in demand.

3.3.2. Bioenergy

Bioenergy is an important pathway for decarbonizing multiple sectors of the economy. Most significantly, drop-in renewable fuels, such as hydrogenation-derived renewable diesel, allow conventional transport vehicles to decarbonize without engine modifications. In addition, renewable natural gas and solid biomass can help decarbonize industry, buildings and electricity.

Growing demand for bioenergy represents an opportunity to boost domestic supply, which increases under all net zero scenarios:

- Liquid bioenergy manufacturing grows to as much as 25 PJ in 2050. Depending on the scenario, this accounts for between as much as half of New Brunswick's needs for biofuels.
- Gaseous bioenergy (i.e., renewable natural gas or RNG) production is constrained by feedstock availability, with <1 PJ being generated from landfills and anaerobic digestors. Remaining RNG is imported from agricultural and waste sources in the U.S., where feedstock availability is much greater.
- The supply of solid biomass from the forestry and agriculture sectors remains an important energy source for paper manufacturing and other industrial sectors.

Domestic production of bioenergy, combined with imports, allows for the complete decarbonization of liquid and gaseous fuels in New Brunswick:

- Conventional biofuels (e.g., ethanol and biodiesel) are blended at relatively small amounts, limited by the need to modify vehicle engines to accommodate stronger blends.
- Hydrogenation-derived renewable diesel (HDRD) is a drop-in fuel produced from inedible fats or vegetable oils, such as canola. It is the dominant fuel used to decarbonize the diesel pool.
- Second-generation biofuels (i.e., renewable gasoline and renewable diesel produced through thermo-chemical conversion of grassy and woody materials such as forestry and agricultural waste products) are also drop-in fuels and account for the remainder of the liquid fuel pool in the net zero scenarios.

3.3.3. Hydrogen

Hydrogen is a low carbon energy carrier which is helpful for decarbonizing transport modes which are challenging to electrify, most notably heavy-duty vehicles, rail, marine and potentially some air travel.

Unlike most other low-carbon energy carriers, demand for hydrogen is exclusively met via domestic production. This reflects the fact that as a low-density and highly explosive fuel, shipping hydrogen is expensive.

Domestic production of hydrogen (as an energy carrier) increases from essentially zero in 2020 to around 3 PJ by 2050. It is produced via electrolysis, a process in which electricity is used to split hydrogen and oxygen from water. This method is consistent with production on a distributed basis (i.e., small scale production at individual refueling stations).

Alternative supply options generally rely on centralized production at scale, such as steam methane reforming of natural gas combined with carbon capture and storage (which requires suitable geology) and biomass gasification (which requires technological developments).

Please note that this analysis focused on options for reducing GHGs in New Brunswick and did not consider the potential for exporting hydrogen outside of North America.

3.4. Non-energy emissions

Most of New Brunswick's GHG emissions are associated with the supply and use of energy. However, about 1.5 Mt arise from non-energy sources, including waste, industrial processes and product use, and agriculture (Figure 12).

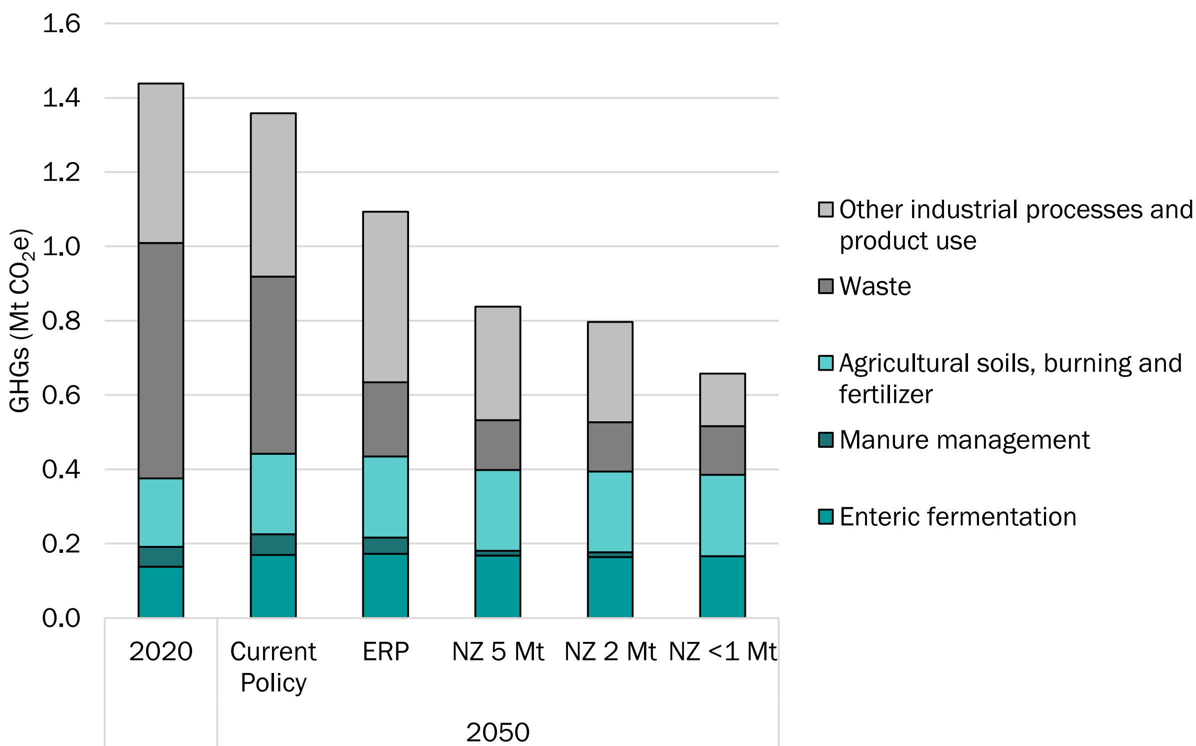
This analysis finds that non-energy emissions can be reduced but not eliminated:

- Waste emissions are reduced by up to ~80% (relative to today's levels) by capturing biogas and combusting it to provide electricity and/or heat.
- Other industrial processes and product use emissions are reduced by ~70%, largely by reducing use of hydrofluorocarbons.
- Agriculture emissions (from non-energy sources) remain relatively stable. Manure management emissions can largely be eliminated by using anaerobic digestors, but

the potential to reduce agricultural soils and enteric fermentation emissions is uncertain.

The sections below explore the options for reducing non-energy related emissions. Overall, these options are less well understood and defined than those for reducing energy related emissions. The implication is that some sources of non-energy emissions would likely need to be offset to achieve net zero.

Figure 12: Non-energy emissions



3.4.1. Agriculture

The options for reducing agricultural emissions in New Brunswick are less well understood than for energy-related emissions. Therefore, this discussion is mostly qualitative. The only mitigation option for agriculture explicitly simulated in this analysis is the adoption of anaerobic digestion to reduce manure management emissions. Insufficient information was available to parameterize abatement options for enteric fermentation or agricultural soils.

This section draws on work from British Columbia, which found that non-energy related agricultural emissions could be reduced by 13% in 2030 (relative to what they otherwise would have been).[9] We note that many of the options for reducing emissions examined in the BC study are likely to be available, to some extent, in New Brunswick. However, the abatement potential and cost are uncertain as much depends on the types of agriculture (e.g., which crops are being grown) and local soil conditions. Therefore, any references to BC data are provided for general context only.

Table 1 summarizes potential abatement options available for reducing different types of non-energy related emissions that were included in the BC study. We discuss these options below.

Table 1: Potential abatement actions in agronomy and livestock

Abatement action	Enteric fermentation	Manure management	Agricultural soils	LULUCF
Agronomy				
4R nutrient management			X	
Cover crops			X	X
Nitrification inhibitor			X	
Plant woody perennials & preserve forests				X
Livestock				
Cattle feed additive	X			
Rotational grazing	X			X
Anaerobic digestion		X		
Manure composting		X		

Agronomy

Options for reducing emissions associated with agronomy include:

[9] Navius Research. 2021. Informing a strategy for reducing agricultural greenhouse gas emissions in British Columbia. Report prepared for the Investment Agriculture Foundation. https://www.naviusresearch.com/publications/greenhouse-gas-emissions/

- **4R nutrient management.** Improving the accuracy of nitrogen fertilizer application can reduce N_2O emissions from agricultural soils. Best management practices include applying (1) the right amount of fertilizer from (2) the right source at (3) the right time and to (4) the right place. The abatement potential and cost are highly dependent on the nature of the crops and soils in question. In the BC analysis, the potential abatement ranged from 0.03 to 0.12 t CO_2e per hectare annually, at a cost of $158/t to $264/t.

- **Cover crops.** Cover crops are planted to cover the soil rather than for the purpose of being harvested. They can reduce greenhouse gas emissions by increasing soil organic carbon and decreasing N_2O emissions. This action could reduce emissions from both agricultural soils and LULUCF emissions. The abatement potential and cost are dependent on crop and soil type. In the BC analysis, the authors estimated a reduction of 1.63 t CO_2e per hectare annually at a cost of between $24 and $38/t.

- **Nitrification inhibitor.** Nitrification inhibitors can be added to fertilizers to supress the nitrification process in soil and reduce N_2O emissions. The BC analysis considered a specific type of nitrification inhibitor, dicyandiamide (DCD) for field crop production. The cost of this abatement action ranged from $259/t to $329/t and reduced emissions by 0.08 to 0.16 t CO_2e per hectare annually, depending on the crop type.

- **Plant woody perennials.** This action is best included as part of the discussion of nature-based solutions in 3.5.1, but we mention it here for completeness (it was within scope of the BC study). Woody perennials such as trees and shrubs can mitigate greenhouse gas emissions by sequestering atmospheric CO_2. As trees and shrubs grow, their rate of sequestration increases until they reach maturity, after which the carbon remains stored until they die or are cut down. In the BC study, this mitigation action included planting woody perennials as (1) vegetive buffers on cropland (i.e., along farm field edges) and (2) riparian buffers (i.e., waterways).

Livestock (enteric fermentation)

Options for reducing livestock emissions associated with enteric fermentation include:

- **Feed additives.** Feed additives can reduce methane associated with enteric fermentation. For example, 3-nitrooxypropanol (3NOP) is a synthetic compound which inhibits methanogenic bacteria from performing the final step of methane production in livestock's rumen. Analysis for BC found that this could reduce enteric fermentation emissions by 1.1 kt CO_2e per 1000 head of cattle annually at a cost of between $8 and $58/t.

- **Rotational grazing.** Rotational grazing is the practice of circulating livestock through multiple, separate paddocks. Compared to continuous grazing in a single paddock, rotational grazing can increase vegetation growth and soil organic carbon. Analysis for BC found it could reduce emissions by 1.1 t CO_2e per hectare annually (roughly split between a reduction in enteric fermentation and LULUCF emissions), at a cost of between $16 and 33/t.

Livestock (manure management)

Options for reducing livestock emissions associated with manure management include:

- **Anaerobic digestion.** Organic residues such as manure and crop residues can be used to create renewable natural gas through the process of anaerobic digestion. Anaerobic digestion captures manure emissions and therefore reduces livestock emissions. Captured methane is then turned into renewable natural gas (RNG) and can displace natural gas elsewhere in the economy. While the combustion of RNG leads to carbon emissions, it is produced from a waste product that would have otherwise been released into the atmosphere as methane. Methane has about 30 times higher global warming potential than carbon dioxide over a 100-year time period.

- **Manure composting.** Composting is an alternative manure storage method to reduce greenhouse gas emissions. Specifically, aerobic composting reduces the amount of CH_4 produced by anaerobic decomposition of organic matter.

The net zero pathways in this analysis feature a complete elimination of manure management emissions due to the adoption of anaerobic digestors.

3.4.2. Waste

Waste accounted for 0.7 Mt of emissions in 2020. Most of these emissions (86%) are associated with landfills, in which the decomposition of organic matter generates methane.

Under net zero scenarios, waste emissions decline to a negligible amount due to the capture of methane, which is then used as an energy source (renewable natural gas) in other sectors of the economy, including electricity generation. Section 3.3.2 provides further information on the amount of RNG produced from landfills under net zero.

We note that another option for mitigating waste emissions is organic waste diversion. This option was not included in this analysis.

3.5. Carbon dioxide removals

Carbon dioxide removals (CDR) involve removing carbon from the atmosphere and storing it in geological, terrestrial, or ocean reservoirs, or in products.

To achieve net zero, CDR is necessary to counterbalance residual emissions. For example, all pathways considered by the IPCC's most recent Assessment Report that limited global warming to 1.5 °C with no or limited overshoot required significant global use of CDR, on the order of 20-660 Gt CO_2e over the 21st century.[10]

CDR can take many forms, from new technologies to land management practices. Broadly speaking, CDR options include:

- Natural solutions that use photosynthesis to remove CO_2 from the atmosphere and store it in wood and soil.
- Technological solutions that accelerate or mimic natural processes to remove CO2 from the atmosphere.
- Ocean solutions that facilitate ocean carbon removal systems.

Below, we discuss two options that may be available to help New Brunswick achieve its net zero greenhouse gas targets: natural solutions and direct air capture (a leading technological solution). Ocean-based CDR offsets could also become available in New Brunswick, though they are outside the scope of this project and are not discussed further[11].

[10] IPCC, 2022: Summary for Policymakers. In: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001

[11] World Resources Institute. (2022). Ocean-based Carbon Dioxide Removal: 6 Key Questions, Answered. Available from: https://www.wri.org/insights/ocean-based-carbon-dioxide-removal

3.5.1. Natural solutions

Natural CDR solutions include a suite of protection, improvement, management and restoration actions in forests, grasslands, agricultural areas and wetlands.

A 2021 study by Nature United provides the most comprehensive assessment to date of the mitigation potential from these types of actions in Canada[12]. Its scope is "nature-based solutions", which encompass pathways to reduce GHGs as well as those that sequester additional carbon in living organisms and soils. In total, it identified 105 Mt of annual offset potential from land-use and forestry measures by 2050, albeit with a large range of uncertainty. This result has been used to guide assumptions in national net zero analyses for Canada[13].

The Nature United study provides a regional breakdown for some, but not all, pathways. Those quantified for New Brunswick are shown in Table 2 and total 5.02 Mt annually. However, this amount is not representative of natural CDR potential because it includes avoided fossil fuel emissions.

Specifically, the improved forest management pathway (totalling 4.13 Mt of annual reduction potential) includes the implementation of three activities: old forest conservation, enhanced regeneration of trees growing post-harvest and improved wood utilization. The most significant of these activities is the last one, which includes the GHG benefit of switching from fossil fuels to biomass for electricity generation. The other components (old forest conservation and enhanced regeneration) play a much smaller role in the mitigation potential identified for New Brunswick.

Removing the improved forest management pathway, most of which is not contributing to potential negative emissions, leaves an annual reduction potential of 0.89 Mt. Of this, salt marsh restoration and avoided grassland conversion account for most of the emissions potential.

This value should be interpreted with caution:

- First, uncertainty is high.

[12] Drever, C. et al. 2021. Natural climate solutions for Canada. Science Advances 7 (23). www.science.org/doi/10.1126/sciadv.abd6034

[13] For example, see: Navius Research. 2021. Achieving net zero emissions by 2050 in Canada: An evaluation of pathways to net zero prepared for the Canadian Climate Institute. https://www.naviusresearch.com/publications/climate-choices-net-zero/

- Second, emission benefits are measured relative to a baseline (i.e., they may or may not be truly "negative"), which could reduce the emissions benefit shown.
- Lastly, there are natural carbon solution pathways for which provincial estimates weren't available, which could increase the emissions benefit shown.

Table 2: Natural carbon solution mitigation potential in New Brunswick reported in Nature United study

Pathway	Mt CO_2e annually
Improved forest management	4.13
Salt marsh restoration	0.51
Avoided grassland conversion	0.3
Cover crops	0.04
Nutrient management	0.01
Reduced tillage	0.01
Restoration of forest cover	0.01
Riparian tree planting	0.01
Total	**5.02**

Source: Nature United. 2021. Canada NCS Mapper. https://www.natureunited.ca/what-we-do/our-priorities/innovating-for-climate-change/natural-climate-solutions/

3.5.2. Direct air capture

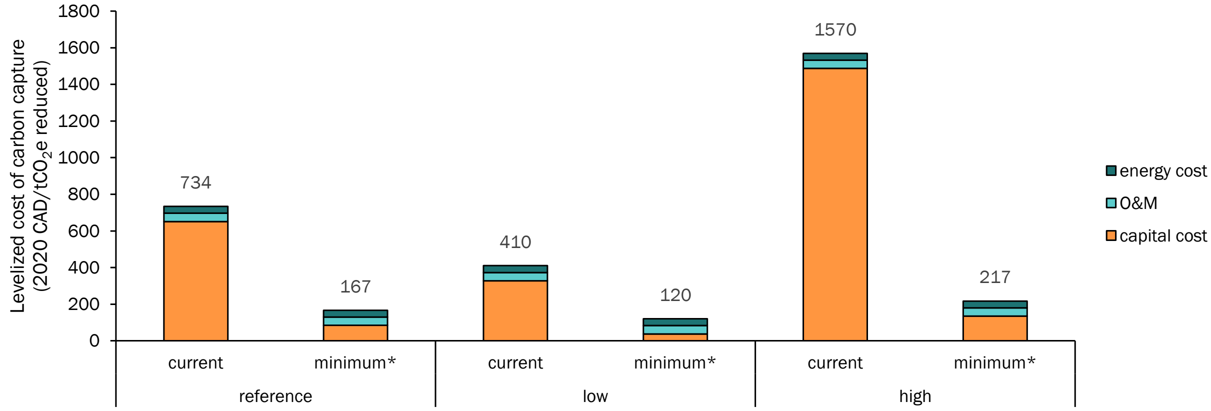
Direct air capture (DAC) uses chemical reactions to pull CO_2 out of air. When air moves over these chemicals, they react with and trap CO_2. Captured CO_2 can then be injected underground for geological sequestration or used in various products, such as concrete. DAC can also be used to produce synthetic fuels, which could be carbon neutral (though not negative).

According to the International Energy Agency, there were 18 direct air capture plants operating around the world as of late 2022. While most of these plants are for testing and demonstration purposes, plans for a total of eleven more facilities are now in advanced development[14].

Figure 13 summarizes estimates of the levelized cost of carbon capture from DAC, which are used to parameterize the technology in gTech. Costs today are relatively high (over $410/t), reflecting the emerging nature of this technology and its current low level of deployment. However, boosting the deployment of DAC could bring costs down to between $120/t and $217/t in the future.

[14] International Energy Agency. 2022. Direct air capture. https://www.iea.org/reports/direct-air-capture

Figure 13: Levelized cost of carbon capture from DAC



*Future minimum costs are based on 1,557 Mt CO_2 of capture. Parameterization based on: Fasihi et al. (2019). Techno-economic assessment of CO2 direct air capture plants. Journal of Cleaner Production, 224, 957-980; Larsen et al. (2019). Capturing Leadership, Policies for the US to Advance Direct Air Capture Technology. Rhodium Group; Keith et al. (2018). A process for Capturing CO2 from the Atmosphere. Joule, 2, 1-22. Costs harmonized using a 15% discount rate, 30-year life, $27.13/GJ electricity price, and $2.64/GJ natural gas price (2020 CAD).

This analysis resulted in up to several hundred Mt of DAC being adopted in the scenarios in which Canada achieves net zero. In other words, DAC could be a significant component of a net zero strategy for Canada.

In New Brunswick, DAC would be sufficient to offset hard to decarbonize sources of emissions, including in agriculture and industrial processes. The implication of pursuing DAC as a net zero strategy is that New Brunswick's emissions (as currently tracked by the NIR) would have some positive value that would then be offset via DAC (likely operated in Alberta or Saskatchewan). Yet another option would be for New Brunswick to purchase DAC credits from other jurisdictions (e.g., outside North America, in locations with especially high renewable energy availability and geological sequestration potential).

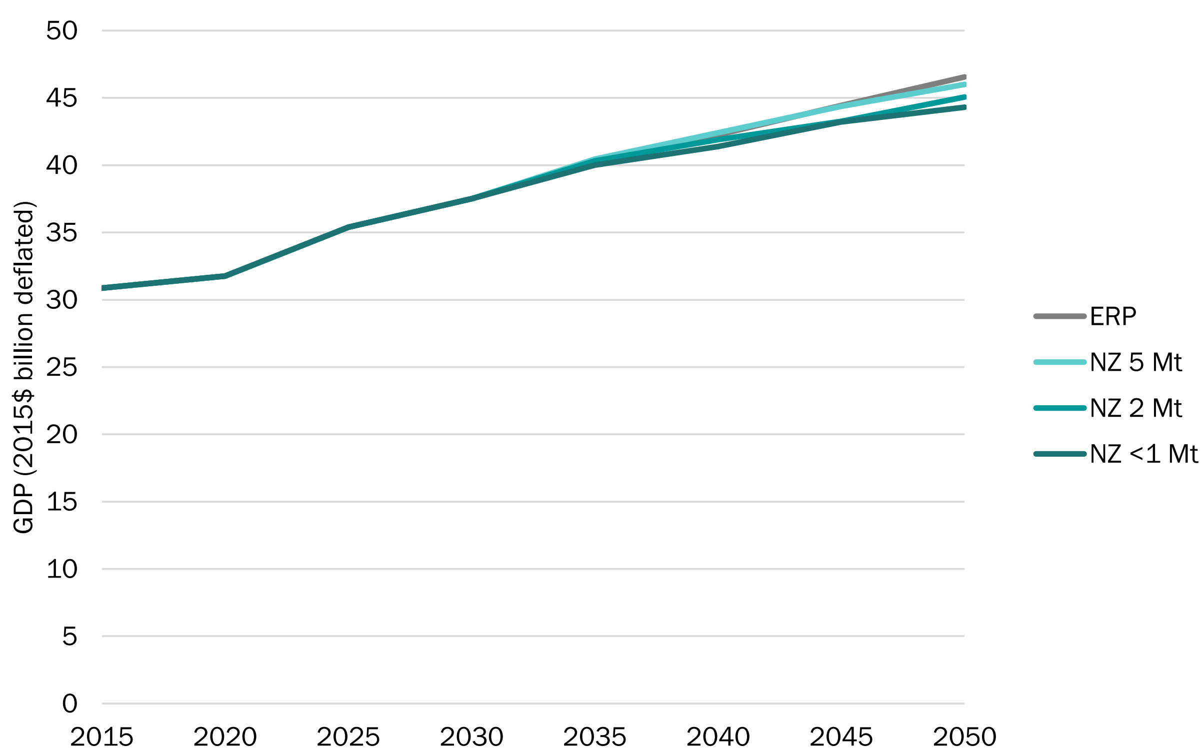
3.6. Economic impacts

New Brunswick's economy grows in all scenarios, although it grows less quickly if the province reduces emissions to net-zero (see Figure 14). Growth is lower in the net zero scenarios because firms and households incur additional costs adopting low carbon technologies and fuels.

By 2050, this reduction in growth means that provincial GDP is lower by 1.2% to 4.8% than it would have been without greater decarbonization effort (see Figure 15). The number of jobs is also lower, by between 2.6% and 4.5%. Nevertheless, GDP and jobs remain higher in 2050 than they are today.

While achieving net zero imposes costs on some sectors, it also benefits others. In particular, the electricity sector receives a boost in all net zero scenarios due to the electrification of various activities across the economy and higher demand for electricity. By 2050, the electricity sector increases provincial GDP by up to 0.6%. Other sectors also stand to benefit, such as bioenergy and hydrogen production (see Section 3.3).

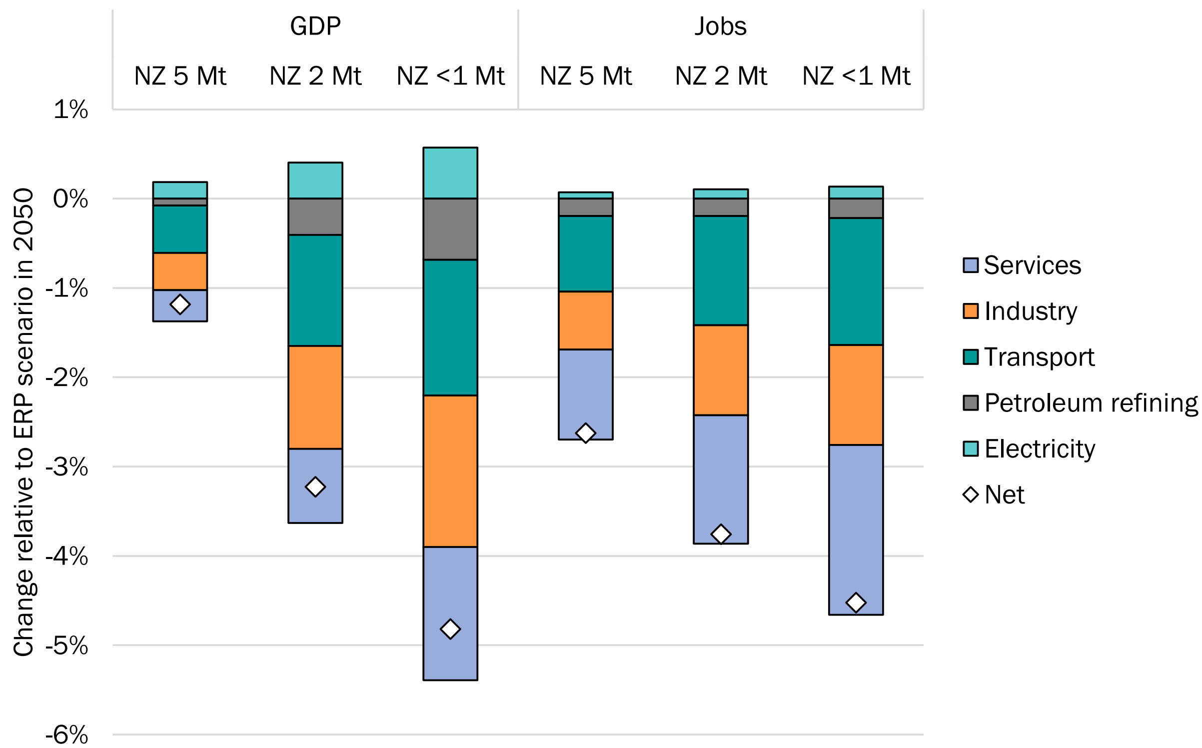
Figure 14: New Brunswick's GDP to 2050



The magnitude of GDP impact is uncertain and will depend on decisions made in New Brunswick (i.e., which policies will be implemented to achieve net zero) as well as factors beyond the province's control (e.g., the cost of emerging low carbon technologies and fuels, demand of hydrogen for export, etc.).

Please note that the economic impacts presented here do not account for the benefits of avoided climate change.

Figure 15: Impact of achieving net zero on GDP and jobs in 2050



4. Conclusion

This study examined how New Brunswick's GHG emissions may change in response to current and announced polices through 2050. It also explored how the province could achieve additional emissions reductions consistent with provincial and federal net zero commitments.

Provincial emissions are expected to continue declining due to a wide range of provincial and federal policies. Ongoing technological developments are also rendering low carbon technologies and fuels more attractive, from electric batteries to heat pumps.

In response to current policies, provincial emissions decline to 10.4 Mt in 2030 and rebound somewhat through 2050. If the modeled ERP policies are fully implemented, GHGs could decline further to 6 Mt in 2050.

Though strong policy would be required to fully decarbonize the province's economy, this analysis finds that achieving net zero emissions is achievable. It identifies a range of technologies, fuels and actions that, if adopted across the economy, would allow the province to meet its emissions targets.

All net zero scenarios examined in this analysis result in:

1. Substituting fossil energy use in buildings, transport and industry for low carbon energy including electricity, bioenergy and hydrogen. The level of substitution required depends on offset potential (see point 4 below) but conceivably involves the complete elimination of fossil energy use by 2050.
2. Boosting provincial supply of low carbon energy of electricity (from renewables and storage, as well as planned nuclear capacity additions), hydrogen (from electrolysis) and bioenergy (from agriculture and forestry operations as well as potentially new sectors supplying liquid and gaseous fuels).
3. Constraining non-energy emissions from waste, agriculture and industrial product and process use to the extent possible.
4. Offsetting residual emissions (likely to be at least 1 Mt due to hard to eliminate non-energy sources) by removing CO_2 from the atmosphere using natural solutions (e.g., salt marsh restoration) and/or technological solutions (e.g., direct air capture).

Consistent with other net zero studies in the Canadian context, this analysis finds that New Brunswick's economy can continue to grow while achieving net zero. Ultimately, the magnitude of GDP impact will depend on decisions made in New Brunswick (i.e., which policies will be implemented to achieve net zero) as well as factors beyond the province's control (e.g., the cost of emerging low carbon technologies and fuels, demand of hydrogen for export, etc.).

Opportunities for future research

This analysis highlights a few areas of study that warrant more research:

1. Defining a policy approach for meeting provincial net zero and other objectives. This analysis examines pathways to net zero in New Brunswick by simulating an economy-wide emissions constraint. It is not an analysis of policy options to achieve net zero in the province. For example, building electrification consistent with net zero could be brought about through carbon pricing, regulations, subsidies or other policies. Different policy approaches will have trade-offs in economic and other impacts.
2. Evaluating the impacts of announced federal policies on New Brunswick. Many federal policies have been announced, but there is uncertainty in how many of these policies will be designed and implemented. As more information becomes available, this analysis can be updated to determine how federal policy design choices will impact the province.
3. Monitoring the development of emerging low carbon technologies and fuels. This study relied on the latest available estimates for the cost and performance of emerging low carbon technologies, such as electric batteries and hydrogen fuel cells. It also considered uncertainty by conducting a sensitivity analysis that considers a range of potential future costs (though these results are not summarized in this report). These costs could be updated over time, especially for emerging technologies for which costs are particularly uncertain.
4. Quantifying the emissions reduction potential and cost of nature-based solutions. Little research has been conducted to quantify the emissions reduction potential and cost of nature-based solutions in New Brunswick. Additional work in this area would be important before relying on offsets as part of the province's net zero strategy.

Appendix A: gTech

gTech is a computable general equilibrium (CGE) model, and is unique among energy-economy models because it combines features that are typically only found in separate models:

- A realistic representation of how households and firms select technologies and processes that affect their energy consumption and GHG emissions.
- An exhaustive accounting of the economy at large, including how New Brunswick interacts with other provinces and the rest of the world.
- A detailed representation of liquid fuel (crude oil and biofuel), gaseous fuel (natural gas and renewable gas) and hydrogen supply chains.

Simulating technological choice

Technological choice is one of the most critical decisions that influence GHG emissions in Canada's economy. For example, if a household chooses to purchase an electric vehicle instead of a gasoline car, that decision will reduce their emissions. Similarly, if the natural gas sector chooses to electrify its operations instead of using natural gas, that decision will reduce its emissions.

gTech provides a detailed accounting of the types of energy-related technologies available to households and businesses. In total, gTech includes over 200 technologies across more than 50 end-uses (e.g., residential space heating, industrial process heat, management of agricultural manure).

Naturally, technological choice is influenced by many factors. Table 3 summarizes key factors that influence technological choice and the extent to which these factors are included in gTech.

Table 3: Technological choice dynamics captured by gTech

Criteria	Description
Purchasing (capital) costs	Purchasing costs are simply the upfront cost of purchasing a technology. Every technology in gTech has a unique capital cost that is based on research conducted by Navius. Everything else being equal (which is rarely the case), households and firms prefer technologies with a lower purchasing cost.
Energy costs	Energy costs are a function of two factors: (1) the price for energy (e.g., cents per litre of gasoline) and (2) the energy requirements of an individual technology (e.g., a vehicle's fuel economy, measured in litres per tonne kilometres). In gTech, the energy requirements for a given technology are fixed, but the price for energy is determined by the model. The method of "solving" for energy prices is discussed in more detail below.
Time preference of capital	Most technologies have both a purchasing cost as well as an energy cost. Households and businesses must generally incur a technology's purchasing cost before they incur the energy costs. In other words, an operator will buy a vehicle before it needs to be fueled. As such, there is a tradeoff between near-term capital costs and long-term energy costs. gTech represents this tradeoff using a "discount rate". Discount rates are analogous to the interest rate used for a loan. The question then becomes: is consumer willing to incur greater upfront costs to enable energy or emissions savings in the future? Many energy modelers use a "financial" discount rate (commonly between 5% and 10%). However, given the objective of forecasting how households and firms are likely to respond to climate policy, gTech employs "behaviourally" realistic discount rates of between 8% and 25% to simulate technological choice. Research consistently shows that households and firms do not make decisions using a financial discount rate, but rather use significantly higher rates.[15] The implication is that using a financial discount rate would overvalue future savings relative to revealed behavior and provide a poor forecast of household and firm decisions.

[15] For example, see: Rivers, N., & Jaccard, M. (2006). Useful models for simulating policies to induce technological change. *Energy policy*, *34*(15), 2038-2047; Axsen, J., Mountain, D.C., Jaccard, M., 2009. Combining stated and revealed choice research to simulate the neighbor effect: The case of hybrid-electric vehicles. *Resource and Energy Economics* 31, 221-238.

Criteria	Description
Technology specific preferences	In addition to preferences around near-term and long-term costs, households (and even firms) exhibit “preferences” towards certain types of technologies. These preferences are often so strong that they can overwhelm most other factors (including financial ones). For example, some households may worry about the risk of buying new technology such as an electric vehicle, while others may see such a vehicle as a “status symbol” that they or their company would value[16]. gTech quantifies these technology-specific preferences as “non-financial” costs and benefits, which are added to the technology choice algorithm. As detailed below, these non-financial preferences are also dynamic, where consumers generally increase their valuation of new technologies as they gain more prominence in the market.
The diverse nature of Canadians	Canadian households and firms are not homogenous groups. Individuals are unique and will weigh factors differently when choosing what type of technology to purchase. For example, one company may be conservative and prefer only established diesel drivetrains, while another company might seek out technological innovations, such as battery-electric or hydrogen-powered vehicles. gTech uses a “market share” equation in which technologies with the lowest net costs (including all the cost dynamics described above) achieve the greatest market share, but technologies with higher net costs may still capture some market share[17]. As a technology becomes increasingly costly relative to its alternatives, that technology earns less market share.
Changing costs over time	Costs for technologies are not fixed over time. For example, the cost of solar panels has come down significantly over the past decade, and costs are expected to continue declining in the future. Similarly, costs for many other energy efficient devices and emissions-reducing technologies are expected to continue declining. gTech accounts for whether and how costs for technologies are projected to decline over time and/or in response to cumulative production of that technology.
Policy	One of the most important drivers of technological choice is government policy. Current federal and provincial initiatives in Canada are already altering the technological choices households and firms make through various policies: (1) incentive programs, which pay for a portion of the purchasing cost of a given technology; (2) regulations, which either require a group of technologies to be purchased or prevent another group of technologies from being purchased; (3) carbon pricing, which increases fuel costs in proportion to their carbon content; (4) variations in other tax policy (e.g., whether or not to charge GST on a given technology); and (5) flexible regulations, like BC’s low-carbon fuel standard which creates a market for compliance credits. gTech simulates the combined effects of all these policies implemented together.

Understanding the macroeconomic impacts of policy

As a full macroeconomic model (specifically, a "general equilibrium model"), gTech provides insight about how policies affect the economy at large. The key macroeconomic dynamics captured by gTech are summarised in Table 4.

Table 4: Macroeconomic dynamics captured by gTech

Dynamic	Description
Comprehensive coverage of economic activity	gTech accounts for all economic activity in Canada as measured by Statistics Canada national accounts[18]. Specifically, it captures all sector activity, all gross domestic product, all trade of goods and services and a large number of transactions that occur between households, firms and government. As such, the model provides a forecast of how government policy affects many different economic indicators, including gross domestic product, investment, household income, etc.
Full equilibrium dynamics	gTech ensures that all markets in the model return to equilibrium (i.e., that the supply for a good or service is equal to its demand). This means that a decision made in one sector is likely to have ripple effects throughout the entire economy. For example, greater demand for electricity requires greater electricity production. In turn, greater production necessitates greater investment and demand for goods and services from the electricity sector, increasing demand for labor in construction services and finally leading to higher wages. The model also accounts for price effects. For example, if a policy increases the cost of trucking freight, that sector will pass on policy compliance costs to households and businesses who may alter their demand for trucking freight and other services. By accounting for these dyanmics, gTech can identify and measure indirect effects of policies.
Sector detail	gTech provides a detailed accounting of sectors in Canada. In total, gTech simulates how policies affect over 100 sectors of the economy. Each of these sectors produces a unique good or service (e.g., the natural gas sector produces natural gas, while the trucking sector produces transport services) and requires specific inputs into production.

[18] Statistics Canada. Supply and Use Tables. Available from: www150.statcan.gc.ca/n1/en/catalogue/15-602-X

Dynamic	Description
Labor and capital markets	Labor and capital markets must also achieve equilibrium in the model. The availability of labor can change with the "real" wage rate (i.e., the wage rate relative to the consumption level). If the real wage increases, the availability of labor increases. The model also accounts for "equilibrium unemployment". Capital markets are introduced in more detail below.
Interactions between regions	Economic activity in Canada is highly influenced by interactions among provinces and with the United States and countries outside of North America. Each province in the model interacts with other regions via (1) the trade of goods and services, (2) capital movements, (3) government taxation and (4) various types of "transfers" between regions (e.g., the federal government provides transfers to provincial governments). The version of gTech used for this model subscription accounts for 10 Canadian provinces, the three territories in an aggregated region and the United States. The model simulates each of the interactions described above, and how interactions may change in response to policy. In other words, the model can forecast how a policy may affect the trade of natural gas between Canada and the United States; or whether a policy would affect how corporations invest in Canada.
Households	On one hand, households earn income from the economy at large. On the other, households use this income to consume different goods and services. gTech accounts for each of these dynamics, and how either changes with policy.

Understanding energy supply markets

gTech accounts for all major energy supply markets, such as electricity, refined petroleum products and natural gas. Each market is characterized by resource availability and production costs by province, as well as costs and constraints (e.g. pipeline capacity) of transporting energy between regions.

Low carbon energy sources can be introduced within each fuel stream in response to policy, including renewable electricity, bioenergy and hydrogen. The model accounts for the availability and cost of bioenergy feedstocks, allowing it to provide insight about the economic effects of emission reduction policy, biofuels policy and the approval of pipelines.

Research questions

By merging the three features described above (technological detail, macroeconomic dynamics, and energy supply dynamics), gTech can provide extensive insight into the effect of climate and energy policy.

First, gTech can provide insights that would typically be provided by a technologically explicit model. These include answering questions such as:

- How do policies affect technological adoption (e.g. how many electric MDVs and HDVs are likely to be on the road in 2030)?
- How does technological adoption affect greenhouse gas emissions and energy consumption?

Second, gTech can further provide insights associated with macroeconomic models (in this case "computable general equilibrium" models) by answering questions such as:

- How do policies affect provincial gross domestic product?
- How do policies affect individual sectors of the economy?
- Are households affected by the policy?
- Does the policy affect energy prices?

Third, gTech answers questions related to its energy supply modules:

- Will a policy generate more supply of renewable fuels?
- Does policy affect the cost of transporting liquid fuels, and therefore the price for gasoline or diesel in Canada?

Finally, gTech expands our insights into areas where there is overlap between its various features:

- What is the effect of investing carbon revenue into low- and zero-carbon technologies? This answer can only be answered with a model such as gTech.
- What are the macroeconomic impacts of technology-focused policies (e.g. how might a zero-emissions vehicle standard for MDVs/HDVs impact GDP)?
- Do biofuels focused policies affect (1) technological choice and (2) the macroeconomy?

This modeling toolkit allows for a comprehensive examination of the greenhouse gas and economic impact of policies in Canada.

Key technical assumptions and data sources

Calibration sources

To characterize New Brunswick's energy-economy, and that of the rest of North America, gTech is calibrated to a large variety of historical data sources. Key calibration data sources are listed below, in order of priority:

- Environment and Climate Change Canada's National Inventory Report[19].
- Statistics Canada's Supply-Use Tables[20].
- Natural Resources Canada's Comprehensive Energy Use Database[21].
- Statistics Canada's Annual Industrial Consumption of Energy Survey[22].
- Statistics Canada's Report on Energy Supply and Demand[23].
- Navius' technology database.

Each of these data sources is generated using different methods and are therefore not necessarily consistent with one another. For example, expenditures on gasoline by households in Statistics Canada's Supply-Use tables may not be consistent with natural gas consumption reported by Natural Resources Canada's Comprehensive Energy Use Database. Further, energy expenditures are a function of consumption and prices, so if prices vary over the course of the year, it is difficult to perfectly align consumption and expenditures.

---

19 Environment and Climate Change Canada. National Inventory Report. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

20 Statistics Canada. Supply and Use Tables. Available from: www150.statcan.gc.ca/n1/en/catalogue/15-602-X

21 Natural Resources Canada. Comprehensive Energy Use Database. Available from: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

22 Statistics Canada. Annual Industrial Consumption of Energy Survey. Available from: www.statcan.gc.ca

23 Statistics Canada. Report on Energy Supply and Demand in Canada. Available from: https://www150.statcan.gc.ca/n1/en/catalogue/57-003-X

gTech's calibration routine places greater emphasis on some data sources relative to others. This approach means that gTech achieves near perfect alignment with data sources receiving the highest priority weight, but alignment starts to diverge from data sources that receive a lower weight.

For this project, the datasets that receive the highest weight are:

- Environment and Climate Change Canada's National Inventory Report.
- Natural Resources Canada's Comprehensive Energy Use Database.
- Navius' technology database.

Please note that gTech is intended to capture medium and long-term trends rather than short-term dynamics like business cycles and pandemics. As such, it smooths out certain trends relative to historical data and is intentionally not fully aligned to actual energy use, economic activity and greenhouse gas emissions in 2020. For example, 2020 witnessed a substantial (and temporary) decline in light-duty vehicle activity which is irrelevant to projecting future emissions and which we have not attempted to capture.

Economic activity

New Brunswick's economy is calibrated to grow at an average annual growth rate of 2.5% between 2020 and 2025 and 1% between 2026 and 2050. This assumption is based on data shared by the New Brunswick Climate Change Secretariat for the 2022 Consultation Case (22.7.21).

GDP by sector is largely determined by this rate of growth and the relative capital and labour productivity of each sector (i.e., the value of goods and services produced for a given amount of capital and labour inputs). In other words, the overall economic growth is "allocated" amongst sectors based on historical data regarding the structure of North America's economy and changes brought on by policy and other factors.

Energy prices

Global oil and natural gas prices are calibrated to the 2021 Canada Energy Regulator's *Canada's Energy Future* report[24]. Global oil prices are calibrated to CER WTI prices and natural gas prices to the CER Henry Hub price forecast.

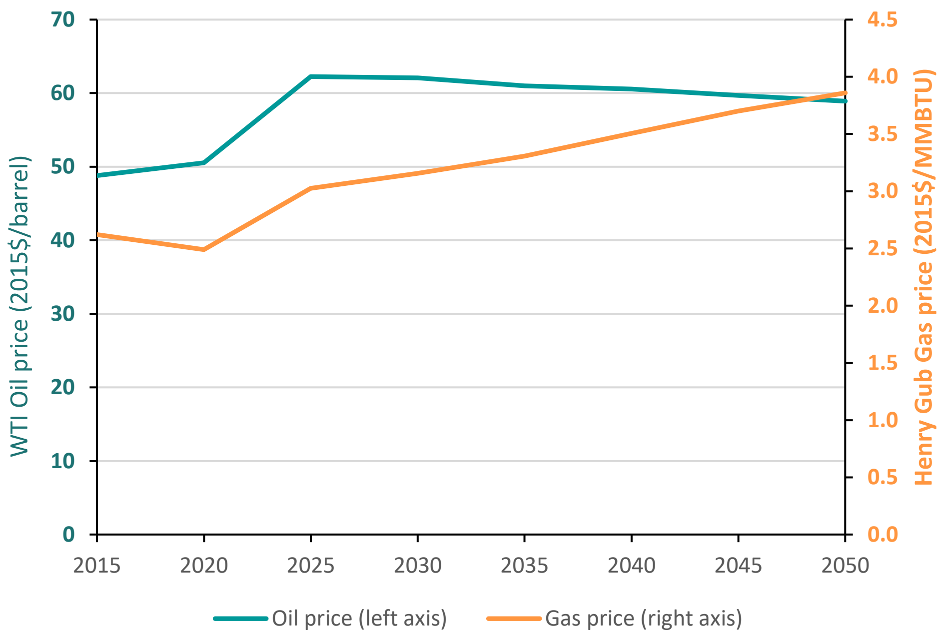
---

[24] Canada Energy Regulator (2021). *Canada's Energy Future 2021: Energy Supply and Demand Projections to 2050*. Available from: https://apps.cer-rec.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA .

The baseline price forecasts for global oil and gas are shown in Figure 16.

- Crude oil (WTI) prices are calibrated to rise from $49/barrel (2015 $USD) in 2015 to $62/barrel by 2030 and then decline to $59/barrel by 2050.
- Natural gas (Henry Hub) prices are calibrated to rise from $2.6/MMBTU (2015 $USD) in 2015 to $3.2/MMBTU by 2030 and $3.9/MMBTU by 2050.

Figure 16: Oil and natural gas price forecast



The price for other energy commodities is determined by the model based on demand and the cost of production. For example, the price of electricity in New Brunswick depends on a variety of factors that are accounted for by the modeling, such as:

- The cost of generating electricity while meeting policy constraints.
- The cost of maintaining the transmission and distribution network.
- The value of electricity exports and cost of imports.
- Any taxes on or subsidies to the sector.

Abatement options

gTech includes a large number of technologies, fuels and actions that can reduce greenhouse gas emissions. Table 5 lists key commercialized or near-commercialized abatement opportunities that are included in this analysis and the sources used to parameterize them.

Table 5: Summary of key abatement opportunities included in gTech

Greenhouse gas source	Key abatement opportunities	Data sources
Industry		
Stationary Combustion		
Electricity generation	Renewables, nuclear, bioenergy, storage	IESD (please see Appendix B: "IESD")
	Electricity efficiency	EIA (2017)
Process heat (high-grade heat)	Fuel switching	Park et al (2017), CIMS
	Carbon capture and storage	CIMS
	Renewables (Biomass and RNG)	DENA (2016)
	Electric resistance	Park et al (2017), CIMS
Process heat (low-grade heat)	Fuel switching	Park et al (2017), CIMS
	Renewables (biomass and RNG)	DENA (2016)
	Industrial heat pumps	Onmen et al (2015)
Compression	Electrification	Greenblatt (2015)
Industrial Processes		
Hydrogen production	Carbon capture and storage	US DOE (2014)
	Electrolysis	US DOE (2014)

Greenhouse gas source	Key abatement opportunities	Data sources
Agriculture		
Enteric fermentation	No abatement available	
Manure management	Anaerobic digestion to produce RNG	IEA ETSAP (2013)
Agricultural soils	No abatement available	
Waste		
Waste	Capture of methane for flaring, generating electricity	Navius waste model
	Organic waste diversion	Navius waste model
Transport		
Energy – Transport		
Light, medium and heavy-duty vehicles	Efficiency improvements	DOE (2003), Transport Canada (2011), NRCan (2007)
	Electrification	Nykvist et al (2019), Bloomberg (2017), Moawad et al (2016), Argonne (2018), Curry (2017), US DOE (2013), Bloomberg (2018), ICCT (2017)
	Renewable fuels	IRENA (2013), APEC (2010), AAFC (2017), Kludze et al (2013), Yemshanov et al (2014), Petrolia (2008), (S&T)[2] Consultants, (2012), Chavez-Gherig et al (2017), G4 Insights (2018), IEA ETSAP (2013)
	Transport demand change, mode shifting to transit and smaller vehicles	Endogenously determined by gTech

Greenhouse gas source	Key abatement opportunities	Data sources
Domestic navigation	Renewable fuels	See list above
Domestic aviation	Renewable fuels	See list above
Railways	Renewable fuels	See list above
Industrial Processes and Product Use		
Light, medium and heavy-duty vehicles	Abatement is fixed to align with the federal policy to reduce HFCs	
Buildings		
Stationary Combustion		
Space heating	Thermal improvements to building shells	RDH (2018)
	More energy efficient fossil fuel furnaces and boilers	EIA (2016), NREL (2018)
	Electric space heating (resistance and heat pump)	EIA (2016), NREL (2018)
	Biomass space heating	CIMS
Water heating	More energy efficient fossil fuel water heaters and boilers	EIA (2016), NREL (2018)
	Electric water heaters (resistance and heat pump)	EIA (2016), NREL (2018)
	Biomass water heating	CIMS
Cooking	Electric ranges	EIA (2016), NREL (2018)
Industrial Processes		
Air conditioning	Thermal improvements to building shells	RDH (2018)
	Abatement is fixed to align with the federal policy to reduce HFCs	
Auxiliary equipment	Efficiency	CIMS

References

(S&T)² Consultants Inc. (2012). Update of Advanced Biofuel Pathways in GHGenius.

Argonne. (2018). U.S. DOE Benefits & Scenario Analysis.

Bloomberg New Energy Finance. (2017). Electric Vehicle Outlook 2017.

Bloomberg New Energy Finance. (2018). Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2. Available from: www.about.bnef.com

Chavez-Gherig, A., Ducru, P., & Sandford, M. (2017). The New Jersey Pinelands and the Green Hospital, NRG Energy Case Study.

CIMS. Technology database. Maintained by Navius Research, Inc.

Curry, C. (2017). Lithium-ion Battery Costs and Market, Bloomberg New Energy Finance.

Energy Information Administration (EIA). (2016). Analysis & Projections: Updated Buildings Sector Appliance and Equipment Costs and Efficiency. Available from: https://www.eia.gov/analysis/studies/buildings/equipcosts/

Energy Information Administration (EIA). (2017). Assumptions to the Annual Energy Outlook 2016: Electricity Market Module. Available from: https://www.eia.gov/outlooks/archive/aeo16/

G4 Insights Inc. (2018). Our Technology. Available from: http://www.g4insights.com/about.html

German Energy Agency (DENA). (2016). Process Heat in Industry and Commerce: Technology Solutions for Waste Heat Utilisation and Renewable Provision.

International Council on Clean Transportation (ICCT). (2017). Transitioning to zero-emission heavy-duty freight vehicles. Available from: https://theicct.org/

International Energy Agency Energy Technology System Analysis Programme (IEA ETSAP). (2013). Biogas and bio-syngas production.

Integrated Energy Supply and Demand model (IESD). Maintained by Navius Research, Inc.

International Renewable Energy Association (IRENA). (2013). Road transport: the cost of renewable solutions.

Jones, S., Meyer, P., Snowden-Swan, L., Padmaperuma, A., Tan, E., Dutta, A., Jacobson, J., & Cafferty, K. (2013). Process design and economics for the conversion of lignocellulosic biomass to hydrocarbon fuels: fast pyrolysis and hydrotreating bio-oil pathway (No. PNNL-23053; NREL/TP-5100-61178). Pacific Northwest National Lab. (PNNL), Richland, WA (United States).

Kludze, H., Deen, B., Weersink, A., van Acker, R., Janovicek, K., De Laport, A., & McDonald, I. (2013). Estimating sustainable crop residue removal rates and costs based on soil organic matter dynamics and rotational complexity. Biomass and Bioenergy, 56, 607-618.Moawad, A., Kim, N., Shidore, N., & Rousseau, A. (2016). Assessment of vehicle sizing, energy consumption and cost through large scale simulation of advanced vehicle technologies (No. ANL/ESD-15/28). Argonne National Lab. (ANL), Argonne, IL (United States).

National Renewable Energy Laboratory (NREL). (2018). National Residential Efficiency Measures Database. Available from: https://remdb.nrel.gov/

Natural Resources Canada (NRCan). (2007). Canadian Vehicle Survey 2007 Summary Report. Available from: http://oee.nrcan.gc.ca/Publications/statistics/cvs07/index.cfm?attr=0

Nykvist, B., Sprei, F., & Nilsson, M. (2019). Assessing the progress toward lower priced long range battery electric vehicles. Energy Policy, 124, 144-155.

Ommen, T., Jensen, J., Markussen, W., Reinhold, L., & Elmegaard, B. (2015). Technical and Economic Working Domains of Industrial Heat Pumps: Part 1 - Single Stage Vapour Compression Heat Pump, International Journal of Refrigeration, 55, 168-182.

Park, N., Park, S., Kim, J., Choi, D., Yun, B., & Hong, J. (2017). Technical and economic potential of highly efficient boiler technologies in the Korean industrial sector. Energy, 121, 884-891.

Petrolia, R. (2008). The economics of harvesting and transporting corn stover for conversion to fuel ethanol: A case study for Minnesota. Biomass and Bioenergy, 32, 603-612.

RDH Building Science. (2018). Building shell performance and cost data. Prepared for Navius Research.

Transport Canada. (2011). Operating Costs of Trucking and Surface Intermodal Transportation in Canada.

UBS Evidence Lab, Global Research. (2017). UBS Evidence Lab Electric Car Teardown – Disruption Ahead? Available from: https://neo.ubs.com/shared/d1wkuDIEbYPjF/

US Department of Energy (US DOE). (2003). The Potential Effect of Future Energy-Efficiency and Emissions-Improving Technologies on Fuel Consumption of Heavy Trucks. Available from: http://www.osti.gov/bridge/product.biblio.jsp?osti_id=810465

US Department of Energy (US DOE). (2013). EV Everywhere Grand Challenge Blueprint.

US Department of Energy (US DOE). (2014). H2A Hydrogen Production Analysis Models: Current Central Hydrogen Production from Coal with CO2 Sequestration version 3.101 (https://www.nrel.gov/hydrogen/h2a-production-models.html)

Yemshanov D., McKenney, D.W., Fraleigh, S., McConkey, B., Huffman, T., & Smith, S. (2014). Cost estimates of post harvest forest biomass supply for Canada. Biomass and Bioenergy, 69, 80-94.

Appendix B: IESD

The Integrated Electricity Supply and Demand model (IESD) simulates the impact of government policies and economic conditions on electricity demand, supply, and prices. IESD is effectively two separate models: one that simulates the addition to electricity generation capacity and hourly dispatch (generation) decisions in the electricity sector and another that simulates decisions by end-users that affect electricity demand (e.g., technology and fuel choice).

IESD can explore multiple policy and economic scenarios in any region or set of regions[25], and provides detailed insight into their impact on:

- The market for specific generation or supply technologies, in terms of installed capacity and electricity generation by unit, fuel type, technology type etc.
- GHG emissions from the electricity sector
- Electricity trade between regions
- Electricity consumption by sector and end-use
- Wholesale and end-use electricity prices

Electricity demand

Demand for electricity is derived from gTech. IESD then uses gTech's projections to "shape" the load curve for electricity demand/generation.

Hourly load curves

We obtained hourly load data for all jurisdictions in North America (over 200 utilities), including New Brunswick. These data provide a starting point for understanding how load varies over the course of 2015, the model's base year.

The electricity demand module disaggregates the hourly load curves into seven end-uses based on data derived from Natural Resource Canada's Comprehensive Energy End-Use Database. The end-uses for residential and commercial buildings include:

[25] The version of IESD used for this study includes 10 Canadian provinces and 10 regions in the US.

- Space heating
- Lighting
- Other multi-fuel end-uses (water heating, cooking, clothes dryers)
- Other electric-only end-uses (refrigerators, freezers, dishwashers, clothes washers, computers, televisions, etc.)

The model also represents industrial electric loads. However, they are represented in less detail. Industrial load is not broken down by end use (e.g., compression, pumping etc.) and we assume a flat load profile that is relatively constant over every hour of the year.

Electricity load forecast

gTech determines total electricity consumption and the “shape” of electricity consumption in IESD. After a model simulation in gTech is complete, the resulting electricity consumption by end-use is compiled and used to “shape” an electricity consumption load curve. For example, if a policy increases the adoption of electric heat pumps, it will affect electricity consumption at specific times and days of the year.

Electricity supply

Cost of generation technologies

To meet the electricity demand (from Navius’ gTech model), IESD may choose to generate via a range of technologies, depending on their costs. Table 6 shows the assumed costs of generation resources. These costs are based on the following sources:

- For conventional nuclear: the US Energy Information Administration’s Capital Cost and Performance Characteristic Estimates for Utility Scale Electric Power Generating Technologies[26]
- For hydro projects: averaged costs from a variety of specific projects across different Canadian provinces
- For cogeneration: Navius’ technology database

[26] See: https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capital_cost_AEO2020.pdf

- For all other generation technologies, including nuclear small modular reactors (SMRs): the US-based National Renewable Energy Laboratory's Annual Technology Baseline[27]

Table 6 Capital costs, operating costs and heat rates for electricity generation technologies

Technology	Capital cost ($/kW)				Operating cost		Fuel consumption
	2020	2030	2040	2050	$/kW	$/MWh	GJ/MWhe
Coal	3,126	3,126	3,126	3,126	33	0	9.3
Combined-cycle Nat. Gas	1,268	1,268	1,268	1,268	23	5	7.4
Single-cycle Nat. Gas	1,122	1,122	1,122	1,122	8	16	11.4
Oil	1,037	1,037	1,037	1,037	8	17	11.4
Biomass	5,690	5,690	5,690	5,690	122	13	13.5
Solar	1,427	733	642	551	30	0	0.0
Onshore wind	1,851	1,048	927	788	51	0	0.0
Offshore wind	5,294	2,999	2,652	2,255	150	0	0.0
Nuclear (conventional)	8,200	8,200	8,200	8,200	152	1	11.1
Nuclear SMR	7,728	7,728	7,728	7,728	134	6	11.1
Run-of-the-river hydro	5,621	5,621	5,621	5,621	98	0	0.0
Geothermal	6,839	5,782	5,499	5,230	106	14	0.0
Cogeneration	1,352	1,352	1,352	1,352	14	6	6.8

Notes: All costs in 2020 CAD. Where applicable, we used a fixed USD-CAD exchange rate of 1.3 to convert our assumed values in USD to CAD inputs.

Availability of intermittent renewables

Navius' model has a built-in representation of the hourly availability of intermittent renewable energy sources (wind and solar). Specifically, the model input is the hourly capacity availability from a specific type of renewable generator (i.e., % of installed power available in a given hour). This availability is defined using publicly available meteorological data. Data on the wind speeds are obtained from the Pan-Canadian Wind Integration Study, published by Environment and Climate Change Canada[28], while the

[27] See: https://atb.nrel.gov/

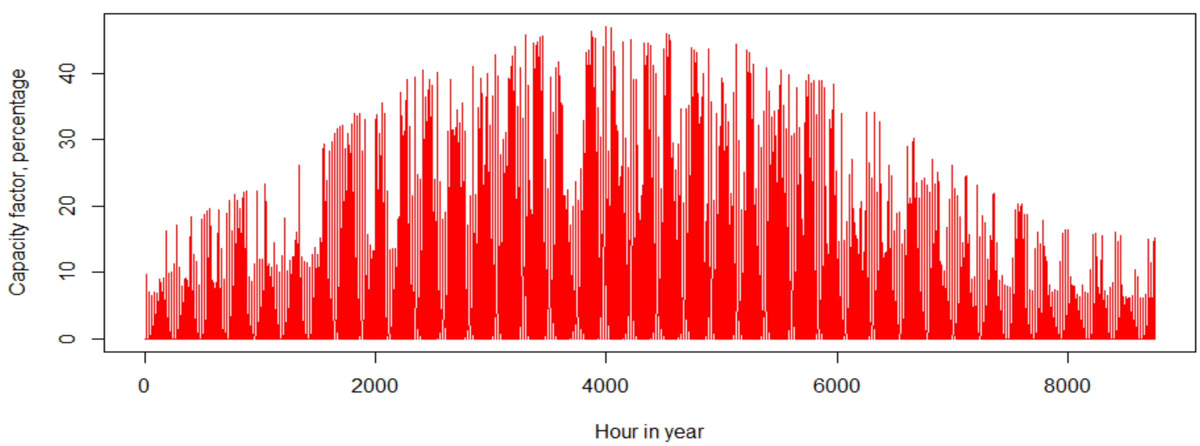
[28] See https://www.nrcan.gc.ca/energy/funding/current-funding-programs/eii/16634

solar insolation data comes from a publicly available database released by the US' National Renewable Energy Lab[29].

Consequently, IESD ensures that the availability of renewable electricity within the model is aligned with physical reality, e.g., our model will not suppose a substantial amount of solar electricity at a time of day and year when it is likely to be cloudy in New Brunswick.

Below, we present a practical example of what these variations in hourly capacity factor means in terms of the IESD model. If we were to plot the hourly capacity values (or, alternatively, "capacity factor"[30]) from potential solar PV installations within New Brunswick for the entire year, we obtain Figure 17. In other words, it shows when electricity from PV panels in New Brunswick would feed into the grid within an IESD simulation.

Figure 17: Hourly capacity factor for solar in New Brunswick over the course of a year

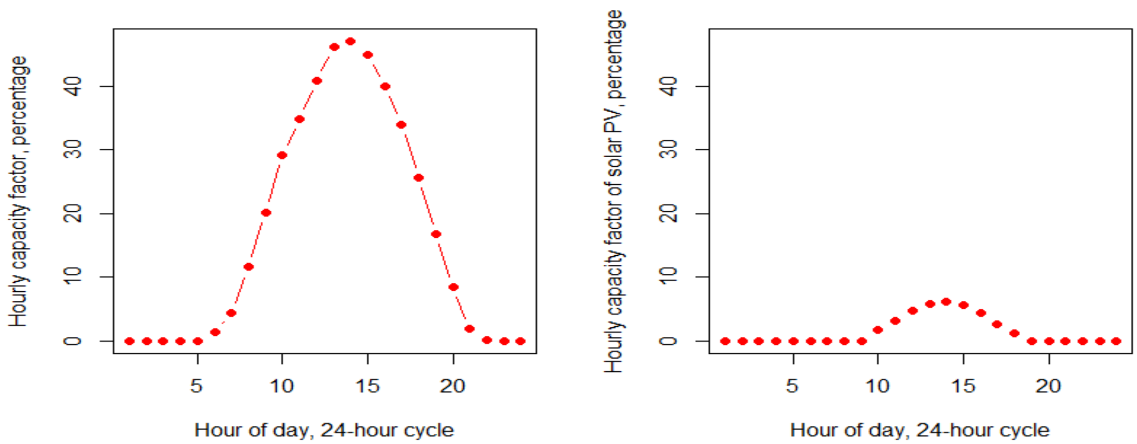


Taking a closer look, it is possible also to focus on individual days, specifically at the days with the highest (16 June) and lowest (27 December) averages for solar PV capacity factor in New Brunswick (Figure 18).

[29] See US-based National Solar Radiation Database: https://nsrdb.nrel.gov/

[30] Please note that the term "capacity factor" to refer to the hourly (projected) ratio of energy generated to the capacity of the generator. It should not be confused with the wider usage of an annual capacity factor.

Figure 18: Days with best (left) and worst (right) levels of solar PV capacity factors



Likewise, we also calculate hourly values for the availability of wind turbines within specific jurisdictions in the IESD model. Just as the solar PV data are based on solar insolation values from the area in question, our projections of the capacity factor for wind power are based on wind speed data.

In total, IESD represents the average hourly capacity factor for New Brunswick using:

- 17 different wind locations, both onshore and offshore
- Five different solar PV locations

Electricity storage

We represent two types of electricity storage options in the New Brunswick: lithium-ion batteries and flow batteries. Table 7 and Table 8 present costs for these two options as well as how they may decline over time, which are based on the National Renewable Energy Laboratory[31].

Table 7: Cost of storage technologies

Storage Type	Power CAPEX ($2020/kW)	Storage CAPEX ($2020/kWh)
Lithium-ion battery	277	662
Flow battery	2,223	552

[31] National Renewable Energy Laboratory. 2022. *Annual Technology Baseline..* https://atb.nrel.gov/electricity/2022/data

Table 8: Cost of lithium-ion batteries over time

CAPEX type		2030	2050
Storage ($2020/kW)	CAPEX	75	65
Power ($2020/kWh)	CAPEX	180	156

Table 9: Cost of flow batteries over time

CAPEX type		2030	2050
Storage ($2020/kW)	CAPEX	548	471
Power ($2020/kWh)	CAPEX	136	117

Roundtrip efficiency is assumed to be 85% for lithium-ion batteries and 80% for flow batteries.

Resource adequacy

NB Power is the delegated Regional Entity for planning compliance with grid reliability standards. In the long-term, a key standard for how resource adequacy is assessed, is compliance with the resource planning objective of limiting expected loss of load to less than 1 day in 10 years, as required in NPCC Reliability Reference Directory #1:

> ***R4*** *Each Planning Coordinator or Resource Planner shall probabilistically evaluate resource adequacy of its Planning Coordinator Area portion of the bulk power system to demonstrate that the loss of load expectation (LOLE) of disconnecting firm load due to resource deficiencies is, on average, no more than 0.1 days per year.*
>
> > ***R4.1*** *Make due allowances for demand uncertainty, scheduled outages and deratings, forced outages and deratings, assistance over interconnections with*

neighboring Planning Coordinator Areas, transmission transfer capabilities, and capacity and/or load relief from available operating procedures. [32]

To achieve the regulated requirement of the LOLE value, NB Power has historically used a target capacity reserve of 20% above non-interruptible load, yielding a LOLE value of 0.05 days per year[33]. The 20% capacity reserve is not a firm standard, but a planning objective which previous modeling has demonstrated achieves the resource adequacy standard with NB Power's portfolio of generating resources. This planning objective was applied as a constraint in this analysis.

Assessed capacity of intermittent resources

In a net-zero emissions electricity system, an increasing reliance on intermittent sources of generation and the integration of battery storage makes the calculation of a clearly defined reserve of capacity more challenging. To quantify the "capacity" of these resources, NB Power worked with a consultant (E3) to assess the Effective Load Carrying Capacity of wind, solar, and storage at increasing levels of penetration.

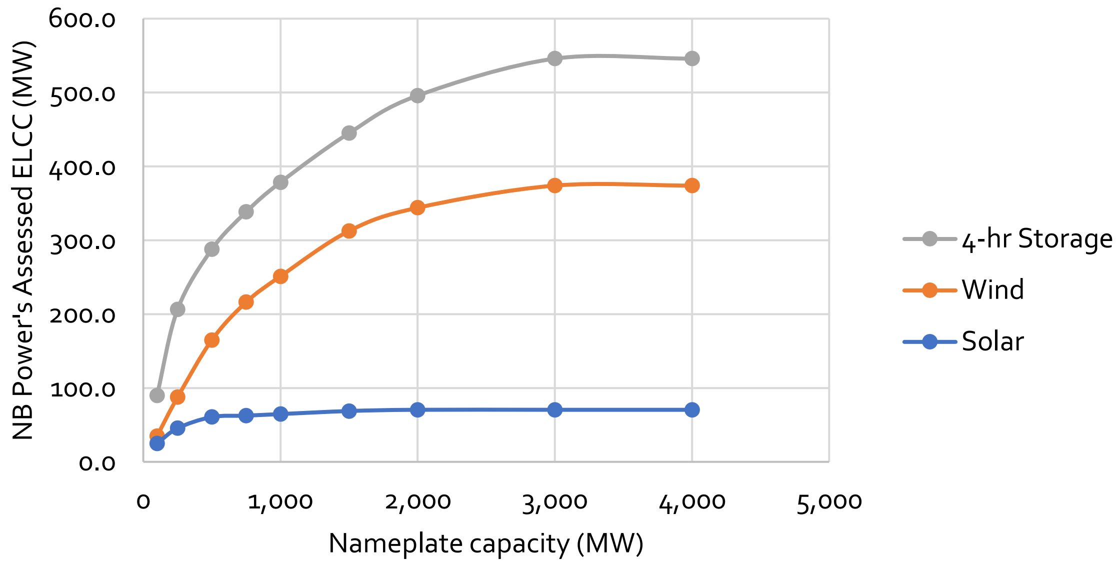
Effective Load Carrying Capacity is defined as the MW value of firm capacity of a reference technology that yields an equivalent reduction in expected loss of load as a quantity of the assessed technology. For example, if adding 100 MW of wind reduce the expectation of lost load by 0.1 hours per year, and this same increase in reliability would be achieved by an additional 25 MW of thermal generation, the ELCC of the 100 MW of wind is 25 MW.

NB Power's estimates for ELCC of intermittent resources are shown in Figure 19, below.

[32] NPCC. 2015. Regional Reliability Reference Directory #1, Design and Operation of the Bulk Power System. Available at: https://www.npcc.org/content/docs/public/program-areas/standards-and-criteria/regional-criteria/directories/directory-01-design-and-operation-of-the-bulk-power-system.pdf

[33] New Brunswick Power Corp. 2019. NPCC 2019 Maritimes Area Comprehensive Review of Resource Adequacy. Available at: https://www.npcc.org/content/docs/public/library/resource-adequacy/2019/2019-maritimes-area-crra-rcc-approved-december-3-2019.pdf

Figure 19: NB Power's estimates of ELCC for intermittent resources



Source: NB Power, provided via e-mail correspondence with Darren Clark, March 8, 2023.

Additional sources of load

In addition to New Brunswick's internal load, NB Power also incorporates load from PEI and a portion of Northern Maine which is largely islanded from the rest of New England into its resource adequacy requirements. The parameters in Table 10 were used for determining the resource adequacy requirement.

Table 10: Capacity requirement in IESD to align with NB Power's Resource Adequacy standards

Resource adequacy requirement equals 1.2 times:	
Domestic NB peak load in IESD	
Minus	130 MW interruptible load
Plus	375 MW for PEI and Northern Maine

Discussion of uncertainty

An increasing reliance on intermittent resources and storage renders the calculation of a level of equivalent "capacity", as a heuristic for achieving NPCC's loss-of-load standards, an increasingly challenging exercise.

The current approach to resource adequacy (a 20% reserve margin) rewards maintaining thermal resources, regardless of their utilization, rather than pairing intermittent renewables with storage to create “firm” low carbon resources. For example, the net-zero scenario presented in this report has about 1,300 MW of oil-fired capacity in 2050, nearly solely to comply with the configuration of the resource adequacy requirements, but a capacity utilization of 0.1%.

Overall, the quantity of reserve thermal capacity that is necessary in a net-zero electricity system is a key uncertainty that warrants further analysis. We note that the structure of how resource adequacy requirements credit the contributions of low carbon resources is likely to have an impact on system cost, but a much smaller potential impact on the generation mix and associated GHG emissions.

Appendix C: Current and announced policies

This Appendix summarizes current and announced provincial and federal policies that are included in the projections.

Current provincial policies

Policy	Description
Carbon tax[34]	The tax applies a charge on fossil fuel use that rises to $170/t CO_2e by 2030.
Output-Based Pricing System[35]	This policy is a tradable performance standard that applies to facilities emitting more than 50 kt CO_2e annually. Each regulated entity is assigned an emissions-intensity based standard. Firms have several options for complying with the standard, including (1) reducing their GHGs, (2) purchasing credits from firms that have exceeded the standard and (3) making payments to the government at a set price that rises to $170/t (nominal) in 2022.
Renewable Portfolio Standard[36]	The renewable portfolio standard requires NB Power to ensure that 40% of in-province electricity sales are from renewable energy by 2020. Imports of renewable energy from other jurisdictions qualify for compliance, as do energy efficiency improvements.
Nuclear replacement capacity	Replacement of Point Lepreau's capacity (660 MW) in the 2040s, in line with current provincial plans.

[34] Government of New Brunswick. Chapter G-3. Gasoline and Motive Fuel Tax Act. Available from: https://laws.gnb.ca/fr/ShowPdf/cs/G-3.pdf & Government of New Brunswick. (2022). Tax on carbon-emitting products to increase April 1. Available from: https://www2.gnb.ca/content/gnb/en/news/news_release.2022.03.0168.html

[35] Government of New Brunswick. New Brunswick Regulation 2021-43 under the Climate Change Act (O.C. 2021-152). 2021-43.pdf (gnb.ca)

[36] Government of New Brunswick. (2015). New Brunswick Regulation 2015-60 under the Electricity Act (O.C. 2016-263). Available from: www.gnb.ca/0062/acts/BBR-2015/2015-60.pdf

Policy	Description
Belledune biomass conversion	By the end of 2029, the Belledune coal plant is planned to be converted to biomass, with a capacity of 375 MW. The plant is scheduled be retired in 2040.
Landfill gas capture[37]	All six landfills in New Brunswick capture methane, with five of them combusting methane to produce electricity.
Energy Efficiency Programs[38]	New Brunswick offers a variety of energy efficiency programs (e.g. for home insulation, efficient appliances, etc.). These programs are simulated by aligning modeled energy use trends with historical data.

Announced provincial policies

Policy	Description
SMR deployment	Deployment of 400 MW of small modular reactor (SMR) capacity by 2035.

[37] Government of New Brunswick. New Brunswick's Climate Change Action Plan: Progress Report 2020. https://www2.gnb.ca/content/dam/gnb/Departments/env/pdf/Climate-Climatiques/nb-climate-change-action-plan-progress-report-2020.pdf

[38] Government of New Brunswick. New Brunswick's Climate Change Action Plan: Progress Report 2020. https://www2.gnb.ca/content/dam/gnb/Departments/env/pdf/Climate-Climatiques/nb-climate-change-action-plan-progress-report-2020.pdf

Current federal policies

Policy	Description
Multi-sectoral	
Federal Hydrofluorocarbon Controls[39]	The Canadian government was one of the signatories of the 2016 Montreal Protocol-amending Kigali Agreement on ozone-depleting substances. Canada has pledged to reduce its HFC consumption by 10% in 2019, increasing in stringency until an 85% HFC reduction is achieved by 2036.
Investment tax credit for Carbon Capture, Utilization, and Storage[40]	This policy is an investment tax credit for 50% of upfront costs for carbon capture, utilization, and storage, 60% for Direct Air Capture, and 37.5% for related transportation infrastructure capital investments. The government expects this policy to cost about $2.6 billion dollars between 2022 and 2026, and $1.5 billion annually from 2027 to 2030.
Canada Infrastructure Bank Spending[41]	The Healthy Environment and Healthy Economy federal climate plan states that the Canada Infrastructure Bank (CIB) has a long-term investment target of $5 billion for clean power projects. It further outlines that the CIB has committed $1.5 billion for zero emission buses, $2.5 billion for low-carbon power projects, including storage, transmission and renewables, over 3 years, and $2 billion for commercial building retrofit upfront costs. The ERP mentions that CIB will receive a total of $35 billion with priorities to invest in green infrastructure ($5 billion), public transit ($5 billion) and clean power ($5 billion).

[39] Government of Canada. (2022). Regulatory amendments on hydrofluorocarbons: frequently asked questions. https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/ozone-regulations-amendments-questions.html

[40] Government of Canada. (2022). Budget 2022. Chapter 3: Clean Air and Strong Economy. Available from: https://budget.gc.ca/2022/report-rapport/chap3-en.html#wb-cont.

[41] Government of Canada. (2020). A Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf & Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf.

Policy	Description
Buildings	
Energy efficiency regulations[42]	Federal standards exist for space conditioning equipment, water heaters, household appliances, and lighting products. Major standards include a minimum annual fuel utilization efficiency of 95% for natural gas furnaces, a minimum energy factor of 0.61 for gas water heaters and ban of incandescent light bulbs.
Greener Homes Grant[43]	$2.6 billion for residential energy efficiency improvements over seven years. 700,000 grants of up to $5,000 to help homeowners make energy efficient retrofits to their homes.
Greener Homes Loan Program[44]	Budget 2021 also allocated $4.4 billion on a cash basis ($778.7 million on an accrual basis over five years, starting in 2021-22, with $414.1 million in future years), to the Canada Mortgage and Housing Corporation to provide interest-free loans up to $40,000 to low-income homeowners for home retrofits. Budget 2022 allocates an additional investment of $458.5 million into the low-income loan program.
Increase energy efficiency in community buildings[45]	The A Healthy Environment and a Healthy Economy plan proposed to invest $1.5 billion over three years for repairs and efficiency upgrades in community buildings and for building new energy efficient community buildings.

[42] Natural Resources Canada. (n.d.). Canada's Energy Efficiency Act and Energy Efficiency Regulations. Available from: www.nrcan.gc.ca/energy/regulations-codes-standards/6861

[43] Government of Canada. (2020). Fall Economic Statement. Supporting Canadians and Fighting Covid-19. Available from: https://www.budget.gc.ca/fes-eea/2020/report-rapport/toc-tdm-en.html

[44] Government of Canada. (2021). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html & Government of Canada. (2022). Budget 2022. Available from: https://budget.gc.ca/2022/report-rapport/chap1-en.html#2022-1

[45]Government of Canada. (2020). A Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf

Policy	Description
Transportation	
Clean Fuel Regulation[46]	The Clean Fuel Regulation is a performance-based fuel supply standard with annual reduction requirements that will come into force in 2023. The regulations will require liquid fossil fuel suppliers to reduce the lifecycle greenhouse gas intensity (CI) of their fuels, starting with 3.5 gCO2e/MJ in 2023 and increasing annually until reaching 14 g CO2e/MJ in 2030.
Regulations Amending the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations[47]	The national government has proposed amending the Heavy-Duty Vehicle Emissions Standard to increase the vehicle emission stringency for vehicles manufactured in model years 2018 to 2027.
Regulations Amending the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations[48]	New passenger vehicles and light-commercial vehicles/light trucks sold in Canada must meet fleet-wide GHG emission standards between 2012 and 2016, and between 2017 and 2025. Fleet targets for passenger cars are aligned with US regulation.
Renewable Fuels Regulation[49]	Specifies a minimum renewable content of 5% for gasoline and 2% for diesel, by volume. This will become part of the Clean Fuel Regulation (CFR) once the CFR comes into force in 2023.

[46] Government of Canada. (2019). Clean Fuel Standard: proposed regulatory approach. Available from: https://www.canada.ca/en/environment-climate-change/services/managing-pollution/energy-production/fuel-regulations/clean-fuel-standard/regulatory-approach.html

[47] Government of Canada. (2018). Regulations Amending the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations and Other Regulations Made Under the Canadian Environmental Protection Act, 1999: SOR/2018-98. http://gazette.gc.ca/rp-pr/p2/2018/2018-05-30/html/sor-dors98-eng.html

[48] Government of Canada. (2018). Regulations Amending the Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations. http://www.gazette.gc.ca/rp-pr/p2/2014/2014-10-08/html/sor-dors207-eng.html

[49] Government of Canada. (2013). Renewable Fuels Regulations: SOR/2010-189. Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2010-189/index.html

Policy	Description
Light-Duty ZEV Subsidy[50]	Light-duty vehicle subsidies are available at $2,500 for short-range plug-in hybrids and $5,000 for long-range plug-in hybrids, hydrogen vehicles, and battery electric vehicles. The government committed an additional $1.7 billion over five years, starting in 2022-23, with $0.8 million in remaining amortization, to Transport Canada to extend the Incentives for Zero-Emission Vehicles (iZEV) program until March 2025.
Heavy-Duty Zev Subsidy[51]	Funding of $547.5 million over four years, starting in 2022/23, will be available to Transport Canada to launch a new purchase inventive program for medium- and heavy-duty zero-emission vehicles.
Tax Write-Off[52]	Businesses can receive a 100% tax write-off when purchasing a zero-emission vehicle before 2024. The tax write-off rate declines to 75% in 2024, 25% in 2025, and 0% in 2028. Vehicles that qualify for the federal Incentive for Zero-Emission Vehicles Program are ineligible for the tax write-off.
ZEV Charging Infrastructure Subsidy[53]	Federal funding of $400 million over five years, starting in 2022/23, is committed to funding the deployment of zero-emission vehicle (ZEV) charging infrastructure in sub-urban and remote communities through the Zero-Emissions Vehicle Infrastructure Program (ZEVIP).

[50] Government of Canada. (2022). Eligible vehicles. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/light-duty-zero-emission-vehicles/eligible-vehicles.

[51] Government of Canada. (2022). Medium and heavy-duty zero-emission vehicles. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/medium-heavy-duty-zero-emission-vehicles .

[52] Government of Canada. (2020). Zero Emission Vehicles. Tax Write-Off. Available from: https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles

[53] Government of Canada. (2022). Budget 2022. Available from: https://budget.gc.ca/2022/report-rapport/chap1-en.html#2022-1

Policy	Description
Electricity Generation	
Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations[54]	This policy requires coal-fired power plants to be closed by 2030 unless they emit less than 420 tonnes CO_2e/GWh.
Regulations Limiting Carbon Dioxide Emissions from Natural Gas-fired Generation of Electricity[55]	This policy limits the emissions intensity of natural-gas fired electricity generation to 420 tonnes CO_2e/GWh.
Renewable Electricity Investments[56]	Budget 2021 allocated $964 million over four years for renewable electricity generation. An additional $600 million will be invested in renewable electricity and grid modernization and $250 million to support large clean electricity projects.
Industry	
Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds[57]	Oil and gas facilities must adopt methane control technologies and practices.

[54] Government of Canada. (2018). Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations: SOR/2018-263. Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2012-167/page-2.html#h-4

[55] Government of Canada. (2018). Regulations Limiting Carbon Dioxide Emissions from Natural Gas-fired Generation of Electricity: SOR/2018-261. Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2018-261/index.html

[56] Government of Canada. (2021). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html & Government of Canada. (2020). A Healthy Environment and a Healthy Economy. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf

[57] Government of Canada. (2020). Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector): SOR/2018-66. Available from: https://laws-lois.justice.gc.ca/eng/regulations/SOR-2018-66/index.htm

Policy	Description
Net Zero Accelerator[58]	The Net Zero Accelerator is simulated as an $8 billion subsidy over seven years for industrial low-carbon technologies, including carbon capture and storage technologies, electrification of industrial heat production and compression, fuel switching to wood waste and hydrogen for industrial heat production, efficient electric motors, and direct air capture.

Announced federal policies

Policy	Description
Oil and Gas	
GHG emissions cap on the oil and gas sector[59]	The federal government has announced its intention to cap greenhouse gas emissions from the oil and gas extraction sector. The Emissions Reduction Plan (ERP) does not provide detail on the policy mechanism that will be used to implement an emissions cap on oil and gas extraction. It also does not specify the level at which emissions will be capped but references federal analysis which projects that oil and gas sector emissions would decline to 110 Mt in 2030 under the most economically efficient pathway to achieving Canada's 2030 target. For the purposes of this project, refining is assumed to be included though coverage is uncertain.

[58] Government of Canada. (2021). Budget 2021. Available from: https://www.budget.gc.ca/2021/home-accueil-en.html.

[59] Government of Canada. (2022). 2030 Emissions Reduction Plan. Available from: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf.

Policy	Description
Electricity	
Clean Electricity Standard[59]	The federal government has stated its intention to implement a Clean Electricity Standard (CES), which will achieve net-zero emissions from electricity generation by 2035. At the time of writing, the ERP doesn't specify the policy mechanisms that will be used to achieve this target. The CES will cover electricity generation sold to the electricity grid. The ERP does not specify whether the CES will cover cogeneration providing electricity to the grid.
Transportation	
Light-duty Emissions Standard[59]	The ERP states that the federal government plans to implement a light-duty zero emissions vehicle (ZEV) sales mandate. The ZEV mandate will require at least 20% of all new light-duty vehicle sales to be ZEVs by 2026, 60% by 2030, and 100% by 2035.
Medium- and Heavy-duty Emissions Standard[59]	The ERP announced plans to develop a medium- and heavy-duty ZEV sales mandate with the goal of achieving 35% ZEV sales by 2030 and 100% by 2040 in selected medium- and heavy-duty categories, based on feasibility. Furthermore, interim targets for pre-2030 years will be explored.