



Modelling CleanBC: 2022 Methodology Report



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SUBMITTED BY

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About Us

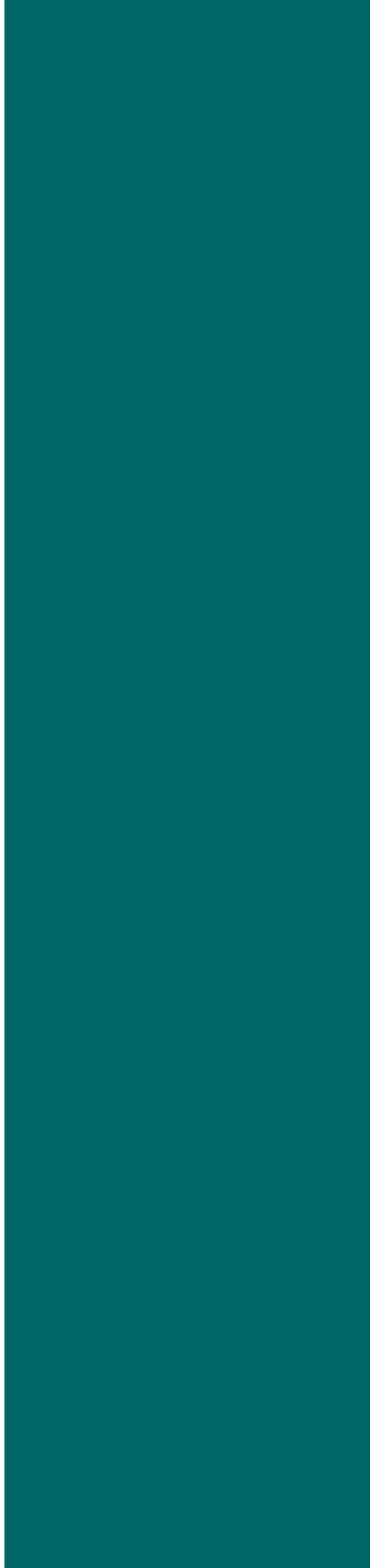
Navius Research Inc. is an independent and non-partisan consultancy based in Vancouver. We operate proprietary energy-economy modeling software designed to quantify the impacts of climate change mitigation policy on greenhouse gas emissions and the economy. We have been active in this field since 2008 and have become one of Canada's leading experts in modeling the impacts of energy and climate policy. Our analytical framework is used by clients across the country to inform energy and greenhouse gas abatement strategy.

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Executive summary

British Columbia (BC) has legislated targets¹ for reducing provincial greenhouse gas (GHG) emissions by 40% below 2007 levels in 2030, 60% in 2040, and 80% in 2050. Additionally, both the BC and Federal Government have committed to reaching net zero emissions by 2050^{2,3}. Achieving these targets requires strong policies to shift BC towards low- and zero-carbon energy, processes, behaviours, and technologies. With this in mind, in December 2018 the Province released the initial *CleanBC* plan⁴, a package of policies designed to significantly reduce BC's emissions. The initial plan was followed in October 2021 by a second phase of initiatives outlined in the Province's *CleanBC Roadmap to 2030*⁵.

This report documents the methodology and assumptions of a comprehensive analysis of the impacts of CleanBC, performed by Navius Research under contract to the BC Government. This report accompanies the *Provincial Forecast of Greenhouse Gas Emissions and Supporting Metrics*⁶, a document summarizing the resulting data of this analysis.

Each year, as new information becomes available, Navius updates the modelling of CleanBC and an edition of this report is published to document the updated methodology and assumptions. This report is intended to supplement the GHG forecasts that the Province has publicly released about CleanBC. Some policy options selected by government do not exactly align with those presented in this report.

¹ SBC 2007, Chapter 42. *Climate Change Accountability Act* (2007). Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/07042_01

² Government of British Columbia (2022). *Climate action and accountability*. Available from: <https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action>

³ SC 2021, Chapter 22. *Canadian Net-Zero Emissions Accountability Act*. (2021). Available from: <https://laws-lois.justice.gc.ca/eng/acts/C-19.3/FullText.html>

⁴ Government of British Columbia (2018). *CleanBC*. Available from: https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_2018-bc-climate-strategy.pdf

⁵ Government of British Columbia (2021). *CleanBC Roadmap to 2030*. Available from: www.cleanbc.gov.bc.ca

⁶ Government of British Columbia (2022). *Provincial Forecast of Greenhouse Gas Emissions and Supporting Metrics 2022*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-forecast

Differences are noted as appropriate, including adjustments made by the Province in its publication of the *2022 Climate Change Accountability Report*⁷.

GHG emissions forecast

Modelling detailed in this report is used as the 2030 emissions estimate published in BC’s *2022 Climate Change Accountability Report*. Please note that results published by the BC government include post-modelling adjustments and additions summarized in Section 6.

Emissions reductions and other policy impacts are calculated relative to a reference scenario representing business-as-usual with only policies announced as of July 2017. Policies are grouped and simulated as packages to quantify total reductions, while accounting for potential interaction of individual policies.

Table 1 summarizes the CleanBC GHG emissions forecast produced by Navius Research (including post-modelling adjustments and additions described in Section 6). Provincial emissions in the reference scenario are projected to be 66.2 million tonnes of carbon dioxide equivalent (MtCO₂e) in 2030. CleanBC is projected to reduce provincial emissions to 40.1 MtCO₂e in 2030.

Table 1: Summary of BC’s emissions projections relative to provincial targets

	2007	Reference	CleanBC
		2030	2030
Emissions (MtCO ₂ e)	65.5	66.2	40.1
Change from 2007	-	+1%	-39%
Gap to target (MtCO ₂ e)	-	29.2	0.8

CleanBC is projected to result in a 39% emissions reduction in 2030 relative to 2007 levels, short of the Province’s legislated 40% target⁸.

⁷ Government of British Columbia (2022) *2022 Climate Change Accountability Report*. Available from: www.cleanbc.gov.bc.ca

⁸ This estimate includes post-modelling adjustments and additions described in Section 6.

Modelled policies

What policies can help BC transition to a clean energy economy?

BC has formulated CleanBC policies designed to put the Province on track to meet its GHG targets. CleanBC policies are summarized in Table 2. Complete details about how these policies are modelled are provided in Section 5.

Modelling assumptions used to simulate these policies are not always identical to how the policies are implemented in the real world. Some simplifications are necessary as an inherent part of modelling, while some policies are still in development. Similarly, incentive levels assumed in this year's modelling may not be representative of approved programs. Incentive programs are frequently reviewed and funding levels are considered through annual processes. Funding may be adjusted in future modelling as policies are confirmed.

Table 2: Summary of CleanBC policies and their representation in the model

Policy	Description
Multi-sector	
Strengthened carbon tax	<p>The analysis assumes a continued increase of the carbon tax until it reaches \$50/tCO_{2e} in 2022 and \$170/tCO_{2e} in 2030. The modelling follows the adjusted COVID-19 carbon price schedule, in which the rate remained constant at \$40/tCO_{2e} in 2020, rather than increasing to \$45/tCO_{2e}.</p> <p>Revenue collected from the tax increase is recycled towards general revenue, as well as to fund transfers to households and to achieve additional industrial emissions reductions under the CleanBC Program for Industry, described below.</p>
Strengthened clean electricity mandate	The analysis assumes that by 2030, 100% of electricity produced in BC is required to be clean.
Household fuel PST exemption	From 2019, the modelling assumes that all residential fuels and electricity consumed by commercial and industrial users are exempt from the PST.
BC Hydro's electrification plan	<p>BC Hydro's 2021 electrification plan proposes new programs and incentives to advance the switch from fossil fuels to clean electricity in buildings, vehicles, businesses, and industry. The modelling includes nearly \$160 million to promote electrification in these sectors.</p> <p>Although the BC Hydro plan outlines additional resources for public education and plan implementation, no further funding is modelled because 1) impacts from funding public education are very uncertain, and 2) the BC Hydro plan does not give sufficient details to model the funding of plan implementation.</p>

Natural gas utility GHG reduction standard	From 2030, allowed annual emissions from the combustion of natural gas and propane by utility building and industry customers (excluding transportation, LNG and upstream oil and gas) is capped at 6.0 MtCO _{2e} .
Federal climate funding	The modelling includes funding for various federal climate initiatives announced in plans such as “A Healthy Environment and a Healthy Economy” and the “2030 Emissions Reduction Plan”.
Industry	
CleanBC Industrial Incentive Program (CIIP)	The analysis assumes that an additional incentive is provided for industrial large final emitters to reduce GHG emissions by returning an increasing portion of carbon tax revenue above \$30/tCO _{2e} to facilities that reduce their emissions relative to a world-leading emissions intensity benchmark.
CleanBC Industry Fund (CIF)	The CIF provides funding to support the adoption of low-carbon technologies by businesses covered by the CIIP. The modelling assumes a portion of carbon tax paid above \$30/tCO _{2e} by industrial large final emitters is invested in low-carbon technologies.
Industrial electrification	The analysis assumes increased electricity consumption in the upstream natural gas sector. The modelling implicitly includes the connection to the DCAT and PRES transmission lines.
Oil and gas sector methane regulations	The analysis assumes that all oil and gas facilities adopt technologies in keeping with regulated best practices for reducing methane venting and leaks by 45% in 2025 and 75% in 2030.
Oil and gas sectoral target	The modeling requires that the oil and gas sector reduces its emissions by 33% from 2007 by 2030.
Transport	
Light-duty ZEV sales mandate	The modelling assumes that a fraction of new light-duty vehicles sold in BC are low to zero-emissions, requiring 26% zero-emissions vehicle sales by 2026, and 90% by 2030.
Heavy-duty ZEV sales mandate	The analysis requires that by 2030 44% of on-road heavy-duty and 23% of medium-duty vehicles sold in BC are zero-emissions. The modelling assumes 60% of these vehicles are battery electric and 40% are hydrogen fuel cell.
Heavy-duty ZEV stock mandate	The modeling requires that from 2030 onwards, 19% of on-road heavy-duty vehicles in use are zero-emissions. The modelling assumes 60% of these vehicles are battery electric and 40% are hydrogen fuel-cell.
Zero-emissions bus mandate	The analysis requires 100% of new buses sold be zero-emissions by 2029, with 41% of buses in use zero-emissions by 2030. The modelling assumes 60% of these ZEVs are battery electric and 40% are hydrogen fuel cell.
Strengthened ZEV incentives	The analysis assumes provincial incentives for the purchase of low- to zero- emissions vehicles of \$52 million in 2019, \$25 million in 2020, and \$93 million per year beginning in 2021. Additionally, the modelling includes the Federal iZEV incentive program targeting low- to zero-emissions vehicles.
Strengthened Low-Carbon Fuel Standard (LCFS)	The analysis assumes that on average fuel suppliers reduce the life-cycle emissions intensity of transport fuel pools by 18.3% in 2025, and 30% in 2030 from 2010 levels. Aviation and marine fuels receive an additional separate requirement to reduce life-cycle emissions intensity by 0.5% by 2025 and 5.0% by 2030 from 2010 levels.

Strengthened light-duty vehicle emissions standards	The analysis assumes that tailpipe emissions standards for new light-duty vehicles sold are strengthened such that the emissions intensity of new light-duty vehicles sold in Canada declines to 119 grams per kilometer in 2025 and 107 grams per kilometer in 2030.
Strengthened heavy-duty vehicle emissions standards	The analysis assumes that new medium- and heavy-duty vehicles sold in Canada must meet seller fleet-wide GHG emissions standards. The standards are modelled as a reduction in the average emissions intensity of medium- and heavy-duty vehicles of 20% by 2025 and 24% by 2030, relative to 2015.
Light-duty vehicle travel reduction	The analysis requires total vehicle kilometers travelled to decline by 25% by 2030, relative to 2020 levels. Policies able to achieve this reduction are in development. The aim of these policies is to increase walking, cycling, and transit use.
Freight energy intensity reduction	The analysis requires the emissions intensity of freight (in tCO _{2e} /t-km) to be reduced 10% by 2030 relative to 2020 levels. Policies able to achieve this reduction are in development.
Buildings and communities	
Strengthened BC Building Code	The analysis assumes that starting in 2030, all new buildings are required to meet zero-emissions standards.
Heating equipment standards	The analysis assumes that starting in 2030, new space and water heating equipment must be supplied by heat pumps or electric resistance.
Building retrofit code	Requires the improvement of heat load demand when buildings are retrofit. This policy is currently under development by the BC government
Building incentives	The analysis includes the provincial Better Homes and Better Buildings incentives.
Organic waste diversion	The analysis assumes an increase of the organic waste diversion rate from municipal, agricultural, and industrial solid waste to 95% by 2025.

Key 2022 updates

Navius makes regular updates to improve their in-house models. These models include (1) gTech, which provides a comprehensive representation of economic activity, energy consumption, and most GHG emissions in BC, and (2) IESD, which focuses on the electricity sector (see details in Section 2.2). Updates are made to the following:

- **Calibration assumptions.** Core assumptions and data sources are revised via literature review and consultation with subject matter experts.
- **Policy assumptions.** Policies are updates as more information becomes available on the design of announced policies, existing policies are modified, or new policies are added.

As a result of these updates, model results change in each iteration of the analysis. Table 3 lists the most significant model updates since the previous release of this

report in 2021⁹. The effects of these updates on modelling results are discussed in Appendix B:

Table 3: Key updates in 2022 modelling

	Description	2021 modelling	2022 modelling
Calibration updates			
Historic GHG emissions	Historic GHG emissions are calibrated to the annual BC <i>Provincial Inventory of Greenhouse Gas Emissions</i> ¹⁰ .	The model is calibrated to the 1990-2019 Provincial Inventory, in which provincial 2019 emissions are 65.7 MtCO ₂ e (excluding land-use change GHGs).	The model is calibrated to the 1990-2020 Provincial Inventory, in which provincial 2020 emissions are 61.7 MtCO ₂ e (excluding land-use change GHGs).
Road transport GHG emissions	Navius calibrates historic road transportation GHG emissions using external data sources.	Road transportation GHGs are informed using data from the Ministry of Energy, Mines and Low Carbon Innovation fuel consumption reported under the <i>Renewable and Low Carbon Fuel Requirements Regulation</i> ¹¹ .	Road transportation GHGs are informed using data from the BC <i>Provincial Inventory of Greenhouse Gas Emissions</i> ¹² ,
Gross domestic product (GDP)	BC's economy is calibrated to external growth forecasts.	BC's GDP is calibrated to Budget 2021, declining by 5.3% in 2020 and increasing by 4.4% in 2021 ¹³ . After 2025, GDP is assumed	BC's economy is partially calibrated to align with the forecast published in Budget 2022 ¹⁵ reflecting an average annual growth rate of 2.4% from 2020 to 2025. After 2025, GDP is calibrated to

⁹ Navius Research (2021). *Supporting the Development of CleanBC 2021*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/climate-reporting

¹⁰ Government of British Columbia (annual). *Provincial Inventory of Greenhouse Gas Emissions*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

¹¹ Ministry of Energy, Mines and Low Carbon Innovation (2021). *Renewable and Low-Carbon Fuel Requirements Regulation Summary: 2010-2019*. Available from www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/transportation/renewable-low-carbon-fuels/rlcf007_2019_summary_2010-19.pdf

¹² Government of British Columbia (annual). *Provincial Inventory of Greenhouse Gas Emissions*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

¹³ Government of British Columbia (2021). *Budget 2021*. Available from: www.bcbudget.gov.bc.ca/default.htm

¹⁵ Government of British Columbia (2022). *Budget 2022*. Available from: www.bcbudget.gov.bc.ca/default.htm

		to grow at an annual rate of 2.1%. ¹⁴	economic forecasts from the Parliamentary Budget Officer ¹⁶ , growing at an annual rate of 1.3%.
Natural gas production	Natural gas production is calibrated to a forecast supplied to Navius by the BC Ministry of Energy, Mines, and Low-Carbon Innovation.	The model was calibrated to a forecast from 2021, in which production is forecast to be 7.6 BCF/day in 2030.	The model is informed by a new 2022 forecast, in which production is forecast to be 7.0 BCF/day in 2030. Navius adjusts this forecast to 6.8 BCF/day in 2030 to account for a defined level of LNG production.
Renewable gas prices	Commodity prices in gTech (including renewable gas) are either determined endogenously or exogenously.	The price of renewable gas is determined endogenously by the model.	The price for notional RNG is assumed to be fixed at \$27.35/GJ. This is assumed to be a weighted average of renewable gas contracts currently in negotiation.
Hydrogen prices	In the modelling, prices for hydrogen are determined endogenously. In terms of hydrogen produced via electrolysis, the price is largely affected by the price of electricity.	Green hydrogen producers are assumed to receive cheaper electricity rates for using surplus intermittent renewable electricity.	Green hydrogen producers are assumed to receive the standard industrial electricity rate without any economic benefit from consuming surplus intermittent renewable electricity.
Policy updates			
Carbon tax	The carbon tax applies to biofuels at the relevant gasoline or diesel rate. The current modelling is updated to reflect this dynamic.	The modelling did not apply the carbon tax to biofuels.	The modelling is updated to apply the carbon tax to biofuels.
Natural gas utility GHG reduction standard (GHGRS)	Policy makers are considering including notional renewable gas as a compliance pathway under the GHGRS. This action would allow BC utilities to comply with the	Notional renewable gas is not included as a compliance pathway towards the GHGRS	Notional renewable gas is included as a compliance pathway towards the GHGRS. Additionally, it is assumed there will be no physical import of renewable gas from

¹⁴ Government of British Columbia (2021). *Budget 2021*. Available from: www.bcbudget.gov.bc.ca/default.htm

¹⁶ Fiscal Sustainability Report 2021 - Parliamentary Budget Officer. Available from: <https://www.pbo-dpb.ca/en/publications/RP-2122-010-S-fiscal-sustainability-report-2021-rapport-viabilite-financiere-2021>

	GHGRS by notionally purchasing renewable gas from outside the province.		Alberta into British Columbia.
CleanBC Industrial Program (CIIP)	The portion of carbon tax applied to industry that falls under the CIIP program is different between the 2021 and 2022 analysis.	The analysis assumes that a portion of carbon tax paid from \$0 - 170/tCO _{2e} by industrial large final emitters is invested in low-carbon technologies.	The analysis assumes that a portion of carbon tax paid from \$30 - \$170/tCO _{2e} by industrial large final emitters is invested in low-carbon technologies.
Small and medium business (SME) fund	Previously, the SME Fund was a policy under consideration by policymakers	The modelling represents the SME Fund which assumes that future programming directs carbon tax paid above \$30/tCO _{2e} by industrial small and medium final emitters toward low-carbon technologies.	The SME Fund is no longer represented in the modelling.
Renewable gas mandate	This policy requires a minimum renewable content in the natural gas pool. This policy is no longer included in the 2022 modelling.	The analysis assumes that by 2030, 15% of natural gas demand by sectors outside upstream oil and gas is met by either renewable gas or hydrogen.	The renewable gas mandate is no longer represented in the modelling. This policy has been superseded by the GHGRS. However, to represent long-term Canadian renewable gas contracts, the modelling assumes a minimum of 30.5 PJ renewable gas consumed either domestically (i.e. within BC) or notionally attributed.
Carbon capture and storage (CCS) regulations	The 2022 modelling no longer explicitly simulates CCS regulations, which establish a regulatory framework for the geological sequestration of formation carbon dioxide separated from natural gas during processing.	The modelling assumes 25% of formation carbon dioxide is geologically sequestered by 2030.	The CCS regulations are no longer represented in the modelling, as they are assumed to be an enabling measure.

Federal <i>Clean Fuel Regulations</i>	The 2022 modelling includes the federal requirement that the national emissions intensity of gasoline and diesel blends be reduced on average by 12.5% by 2030, from 2016 levels.	The proposed <i>Clean Fuel Regulations</i> are not represented in the modelling.	The proposed <i>Clean Fuel Regulations</i> are included in the modelling.
Strengthened light-duty vehicle emissions standards	In the new 2022 modelling, requirements under the light-duty vehicle emissions standards are updated.	The modelling represents these standards prior to the 2022 amendment, reaching 119 gCO _{2e} /km in 2030.	The modelling includes the amended 2022 values, reaching an average standard of 107 gCO _{2e} /km in 2030.
Freight energy intensity reduction	The 2022 modelling, updates the <i>CleanBC</i> commitment to reduce the average energy intensity of freight transport by 10% relative to 2030.	In the modelling, these reduction targets apply only to new freight vehicles.	In the modelling, these reduction targets apply to the entire stock of freight vehicles.
Landfill gas management regulations	The 2022 modelling updates the representation of BC's <i>Landfill Gas Management Regulation</i> .	The reference scenario assumes the landfill gas capture rate reaches 35% in 2020. The <i>CleanBC</i> scenario increases the capture rate to 75% by 2025.	The reference scenario assumes the landfill gas capture rate reaches 40%. As no further measures to increase capture have been implemented, this value is assumed to be consistent in the <i>CleanBC</i> scenario.

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1. Introduction

British Columbia (BC) has legislated targets¹⁷ for reducing provincial greenhouse gas (GHG) emissions by 40% below 2007 levels in 2030, 60% in 2040, and 80% in 2050. Additionally, both the BC and Federal Government have committed to reaching net zero emissions by 2050^{18,19}. Achieving these targets requires strong policies to shift BC towards low- and zero-carbon energy, processes, behaviours, and technologies. With this in mind, in December 2018 the Province released the initial *CleanBC* plan²⁰, a package of policies designed to significantly reduce BC's emissions. The initial plan was followed in October 2021 by a second phase of initiatives outlined in the Province's *CleanBC Roadmap to 2030*²¹.

This report documents the methodology and assumptions of a comprehensive analysis of the impacts of both phases of CleanBC, performed by Navius Research under contract to the BC Government. This report accompanies the *Provincial Forecast of Greenhouse Gas Emissions and Supporting Metrics*²², a document summarizing the resulting data of this analysis. The supporting document includes a summary of emissions data for scenarios corresponding to individual CleanBC policies, as well as emissions, energy, and economic data for the reference scenario and CleanBC scenarios.

This report includes the following:

- Introduces the modelling tools used to analyze climate policy impacts (Section 2).
- Reviews key forecast assumptions (Section 3).

¹⁷ SBC 2007, Chapter 42. *Climate Change Accountability Act* (2007). Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/07042_01

¹⁸ Government of British Columbia (2022). Climate action and accountability. Available from: <https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action>

¹⁹ SC 2021, Chapter 22. *Canadian Net-Zero Emissions Accountability Act*. (2021). Available from: <https://laws-lois.justice.gc.ca/eng/acts/C-19.3/FullText.html>

²⁰ Government of British Columbia (2018). *CleanBC*. Available from: https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_2018-bc-climate-strategy.pdf

²¹ Government of British Columbia (2021). *CleanBC Roadmap to 2030*. Available from: www.cleanbc.gov.bc.ca

²² Government of British Columbia (2022). *Provincial Forecast of Greenhouse Gas Emissions and Supporting Metrics* 2022. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-forecast

- Identifies policies that are included in the reference scenario forecast and describes how they are modelled (Section 4).
- Identifies policies that are included in the CleanBC forecast and describes how they are modelled (Section 5).
- Discusses the addition of non-modelled emissions and post-modelling adjustments made to the model results by the BC Government (Section 6).

Modelling detailed in this report is used as the 2030 emissions estimates published in BC government documents such as the *2022 Climate Change Accountability Report*²³. Please note that results published in these documents include post-modelling adjustments and additions summarized in Section 6.

Emission reductions and other policy impacts are calculated relative to a reference scenario representing business-as-usual with only policies announced as of July 2017. Policies are grouped and simulated as packages to quantify total reductions, accounting for potential interaction or overlapping of individual policies.

Table 4 summarizes the CleanBC GHG emissions forecast (including post-modelling adjustments and additions described in Section 6). Provincial emissions in the reference scenario are projected to be 68.5 million tonnes of carbon dioxide equivalent (MtCO_{2e}) in 2030, while CleanBC is projected to reduce emissions to 40.1 MtCO_{2e} in 2030.

Table 4: Summary of BC's emissions projections relative to provincial targets

	2007	Reference	CleanBC
		2030	2030
Emissions (MtCO _{2e})	65.5	68.5	40.1
Change from 2007	-	+5%	-39%
Gap to target (MtCO _{2e})	-	29.2	0.8

CleanBC is projected to result in a 39% emissions reduction in 2030 relative to 2007 levels, short of the Province's legislated 40% target²⁴.

The model results are produced in 5-year intervals and are based on the parameters, assumptions, and policy designs described in this document, and thus are likely to

²³ Government of British Columbia (2022). *2022 Climate Change Accountability Report*. Available from: www.cleanbc.gov.bc.ca/

²⁴ This estimate includes post-modelling adjustments and additions (described in Section 6).

deviate from observations. These forecasts should be interpreted within this context and should be used for reference only.

2. Method

This section provides an overview of the methods and assumptions employed to forecast BC's GHG emissions. It introduces energy-economy modelling and how it can inform policymaking (Section 2.1), and then reviews Navius' modelling toolkit (Section 2.2).

2.1. Introduction to energy-economy modelling

BC's energy economy is complex, with the Province's energy consumption and GHG emissions ultimately resulting from millions of British Columbians making millions of decisions. To name just a few, households must choose what type of vehicles they will buy and how they heat their homes; industry must decide whether to install technologies that might cost more but produce lower emissions; local governments must manage their organic waste; and investors must decide whether to invest their money in BC or somewhere else.

In addition, many of the policies envisioned in CleanBC are likely to have effects throughout the economy, affect niche sectors, and interact with other policies. For example, CleanBC calls for a strengthening of the carbon tax rate, which applies to fuels used in all sectors and has knock-on effects on the prices of diverse goods and services. Additionally, many policies directly or indirectly target the same sources of emissions as each other. For example, the carbon tax, zero-emissions vehicle (ZEV) mandate, low-carbon fuel standard (LCFS), and light-duty vehicle emissions standards all seek to reduce GHG emissions from passenger vehicles.

To estimate how CleanBC will affect the Province's economy and GHG emissions, a suitable modelling framework must be able to capture the complexity of the energy-economic system and the range of policies envisioned in the plan.

2.2. Navius' modelling toolkit

Navius used two models to analyze the impacts of CleanBC, each with unique strengths:

- The **gTech** model, which provides a comprehensive representation of all economic activity, energy consumption, and most GHG emissions in BC, and is itself an amalgamation of several different types of models; and

- The **Integrated Electricity Supply and Demand (IESD)** model, which focuses on the electricity sector.

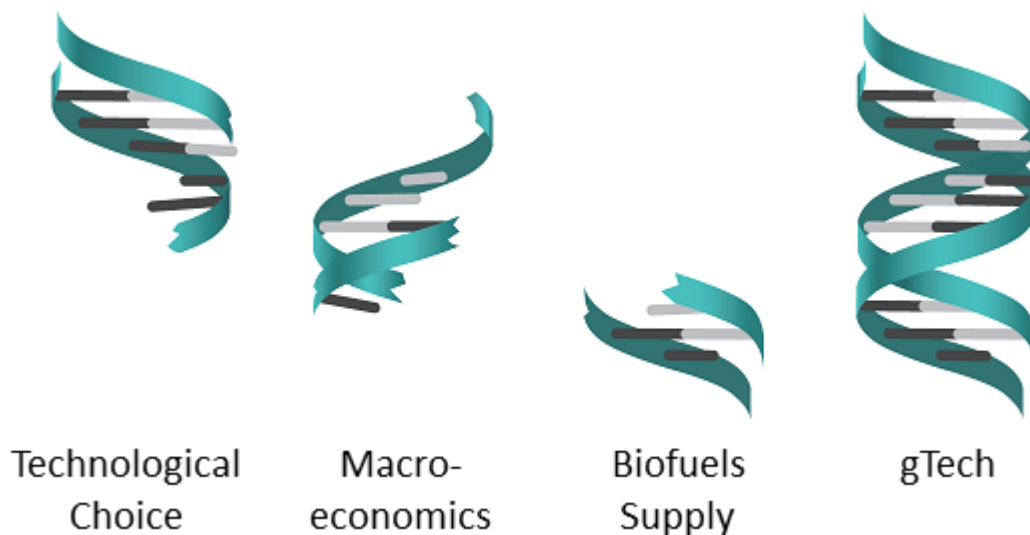
2.2.1. gTech

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 BC interacts with other provinces and the rest of the world.
- A detailed representation of liquid fuel (crude oil and biofuel) and gaseous fuel (natural gas and renewable gas) supply chains.

As illustrated in Figure 1, gTech builds on three of Navius' previous models (CIMS, GEEM and OILTRANS), combining their best elements into a comprehensive integrated framework.

Figure 1: The gTech model



Simulating technological choice

Technological choice is one of the most critical decisions that influence GHG emissions in BC'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 300 technologies across more than 70 end-uses (e.g., residential space heating, industrial process heat, management of agricultural manure).

Naturally, technological choice is influenced by many factors. Table 5 summarizes key factors that influence technological choice and the extent to which these factors are included in gTech.

Table 5: 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. Data sources for the cost of key low-carbon technologies are identified in Section 3.
Energy costs	Energy costs are a function of two factors: (1) the price of 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 100 km). In gTech, the energy requirements of a given technology are fixed, but the price of energy is determined by the model. The method of determining energy prices is discussed in more detail below. Data sources for the performance requirements of key low-carbon technologies are identified in Section 3.
Time preference of capital	<p>Most technologies have both a purchasing cost and energy cost. Households and businesses must generally incur a technology's purchasing cost before they incur the energy costs. For example, a household will buy a vehicle before it needs to be fueled. As such, there is a trade-off between near-term capital costs and long-term energy costs.</p> <p>gTech represents the higher priority placed by households and businesses on near-term costs using a "discount rate". Discount rates are analogous to the interest rate used for a loan. The question then becomes: is a household willing to incur greater upfront costs to enable savings in the future once this discount rate is applied?</p> <p>Many energy modelers use a "financial" discount rate (commonly between 5% and 10%). However, research consistently shows that households and firms do not make decisions using a financial discount rate, but rather use significantly</p>

higher rates²⁵. This implies that using a financial discount rate would overvalue future savings relative to revealed behavior and provide a poor forecast of household and firm decisions. Given the objective of forecasting how households and firms are likely to respond to climate policy, gTech therefore employs behaviorally realistic discount rates of between 8% and 25%²⁶ to simulate technological choice.

Technology-specific preferences	<p>Households and businesses also exhibit preferences for certain types of technologies. These preferences are often so strong that they can overwhelm most other factors (including financial ones). For example, research on electric vehicles indicates that British Columbians often have very strong preferences (positive or negative) towards electric vehicles. One segment of the population prefers electric vehicles to such an extent that capital and energy costs are almost irrelevant. Another segment dislikes electric vehicles to such an extent that there are relatively few circumstances in which they would be willing to purchase such a vehicle. And then there are many other groups in between²⁷.</p> <p>gTech quantifies these technology-specific preferences as “non-financial” costs, which are added to the technology choice algorithm.</p>
The diverse nature of British Columbians	<p>British Columbians are not a homogenous group. Individuals are unique and will weigh factors differently when choosing what type of technology to purchase. For example, one household may purchase a Toyota Prius while another purchases an SUV and another takes transit.</p> <p>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 share²⁸. As a technology becomes increasingly costly relative to its alternatives, that technology earns less market share.</p>
Changing costs over time	<p>Costs for technologies are not fixed over time. For example, the cost of electric vehicles has come down significantly over recent years, and it is expected to continue its decline into the future²⁹. Similarly, costs for many other energy-efficient devices and emissions-reducing technologies have declined and are expected to continue declining.</p> <p>gTech accounts for whether and how costs for technologies are projected to decline over time. The most important technology with expected declining costs in this study is the electric battery. Data sources used to inform this declining capital cost function are identified in Section 3.</p>

²⁵ Rivers, N., & Jaccard, M. (2006). “Useful Models for Simulating Policies to Induce Technological Change”. *Energy Policy*, 34 (15), 2038-2047.

²⁶ 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.

²⁷ Axsen, J., Cairns, J., Dusyk, N., & Goldberg, S. (2018). “What Drives the Pioneers? Applying Lifestyle Theory to Early Electric Vehicle Buyers in Canada”. *Energy Research & Social Science*, 44, 17-30.

²⁸ Rivers, N., & Jaccard, M. (2006). “Useful Models for Simulating Policies to Induce Technological Change”. *Energy Policy*, 34 (15), 2038-2047.

²⁹ Nykvist, B., Sprei, F., & Nilsson, M. (2019). “Assessing the Progress Toward Lower Priced Long-Range Battery-Electric Vehicles”. *Energy Policy*, 124, 144-155.

Policy	<p>One of the most important drivers of technological choice is government policy, and CleanBC will alter the technological choices households and businesses make. The plan includes: (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 taxation, which increases fuel costs in proportion to their carbon content; (4) variations in other tax policy (e.g. whether or not to charge PST on a given technology); and (5) flexible regulations, like the low-carbon fuel standard which creates a market for compliance credits.</p> <p>gTech simulates the combined effects of all these policies implemented together. Policies included in the reference scenario (i.e. business as usual) forecast are described in Section 4. Policies included in the CleanBC forecast are described in Section 4.1.</p>
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Understanding the macroeconomic impacts of policy

As a full macroeconomic model (specifically, a CGE model), gTech provides insight about how policies affect the economy at large. The key macroeconomic dynamics captured by gTech are summarised in Table 6.

Table 6: Macroeconomic dynamics captured by gTech

Dynamic	Description
Comprehensive coverage of economic activity	gTech accounts for all economic activity in BC as measured by Statistics Canada national accounts ³⁰ . Specifically, it captures all sector activity, all GDP, all trade of goods and services and a large number of transactions that occur between households, firms, government, and people/firms outside of BC. As such, the model provides a forecast of how government policy affects many different economic indicators, including GDP, 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 in BC requires greater electricity production in BC. In turn, greater production necessitates greater investment and demand for goods and services from the electricity sector, increasing demand for labour in construction services and finally leading to higher wages.
Sector detail	gTech provides a detailed accounting of sectors in BC. In total, gTech simulates how policies affect over 80 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 services sector produces services) and requires specific inputs into production. Of these inputs, some are not directly related to energy consumption or GHG emissions (e.g. the demand by the natural gas sector for services or labour requirements) but other inputs are classified as “energy end-uses”. Covered energy end-uses (along with sectors and fuels) are listed in Appendix A: “Covered sectors, fuels, end-uses”.

³⁰ Statistics Canada (annual). *Supply and Use Tables*. Available from: www150.statcan.gc.ca/n1/en/catalogue/15-602-X

Labour and capital markets	Labour and capital markets must also achieve equilibrium in the model. The availability of labour can change with the real wage rate (i.e. the wage rate relative to the price for consumption). If the real wage increases, the availability of labour increases. The model also accounts for “equilibrium unemployment”. Capital markets are introduced in more detail below.
Interactions between BC and other regions	<p>Economic activity in BC is highly influenced by interactions with other provinces, the United States, and countries outside of North America. BC 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).</p> <p>The version of gTech used for this project accounts for 8 other regions in Canada and the United States, covering the whole of both countries through combined regions as appropriate. Each of these regions is simulated with the same level of detail as BC. The model simulates each of the interactions described above, and how interactions may change in response to policy. For example, the model can forecast how a policy may affect the trade of natural gas between BC and the United States; or whether a policy would affect how corporations invest in BC.</p>
Households	On one hand, households earn income from the economy at large. On the other, households use this income to consume various goods and services. gTech accounts for each of these dynamics, and how they change with policy.

Understanding petroleum, natural gas, hydrogen, and biofuels markets

gTech offers two additional features that are critical to understanding BC’s future energy economy.

First, it accounts for nascent sectors that may develop in the future, including liquefied natural gas (LNG) production, hydrogen production, and biofuels manufacturing.

Second, it accounts for the transport costs of liquid and gaseous fuels between regions. BC’s natural gas sector is somewhat unique in that it is “at the end of the pipeline”. BC is situated about as far away as possible from the key areas of natural gas demand in North America (i.e. the Northeastern United States). As such, natural gas producers in BC receive the lowest price for their product of all producers in North America (producers indirectly pay the cost of transporting natural gas to the key areas of demand via lower prices).

Benefits of merging macroeconomics with technological detail

By merging the three features described above (technological detail, macroeconomic dynamics, and energy supply dynamics), gTech can provide extensive insight into the effects 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. what proportion of total household heating and cooling is met by heat pumps)?
- How does technological adoption affect GHG emissions and energy consumption?

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

- How do policies affect provincial gross domestic product (GDP)?
- How do policies affect individual sectors of the economy?
- How are households affected by policies?
- Do policies affect energy prices or any other price in the model (e.g. food prices)?

Third, gTech answers questions related to its biofuels and natural gas module:

- Will policies generate more supply of renewable fuels?
- Do policies affect the cost of transporting natural gas, and therefore the price for natural gas in BC?

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

- What are the effects of investing carbon tax revenue into low- and zero-carbon technologies? This question can only be answered with a model such as gTech.
- What are the macroeconomic impacts of technology-focused policies (e.g. how might a ZEV standard impact provincial GDP)?
- Do hydrogen or biofuels-focused policies affect (1) technological choice and (2) the macroeconomy?

This modelling toolkit allows for a comprehensive examination of the impacts of policies outlined in CleanBC.

2.2.2. IESD

While gTech provides extensive insight into the effects of climate policy, it has a limitation with respect to the electricity sector. To account for this, the analysis is supplemented by the Integrated Electricity Supply and Demand model (IESD). IESD specializes in dynamics unique to the electricity sector, including:

- **Hourly electricity consumption.** Electricity markets are distinct from perhaps any other market in that 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 electricity consumption is not consistent throughout the day or year. For example, electricity demand is highest in BC during cold winter evenings, when people go home after work and turn on their lights, appliances, and heat. Unfortunately, electricity is less easily stored than other commodities such as food or natural gas, so BC Hydro must be able to supply enough electricity to balance demand at all times.
- **Hourly generation profiles.** Some generation units can be made available upon demand, but some cannot. For example, generation from wind resources is available when the wind is blowing and generation from solar photovoltaics is available when the sun is up, amongst other factors. This means that these sources of power may or may not be available to meet demand in any given moment.
- **Technology capital costs.** Just as with gTech, each technological option for generating electricity has a specific upfront capital cost.
- **Technology energy profiles.** Also similar to gTech, thermal electricity generation technology units have energy requirements (e.g. GJ of natural gas per MWh of electricity generated). When combined with the energy price, which is informed by gTech, each resource has a unique energy cost.
- **Electricity trade.** IESD explicitly simulates the hourly trade of electricity between BC and Alberta and between BC and the United States.
- **Electricity storage options.** Electricity storage is a promising option for integrating intermittent renewables into the electricity system (i.e. ensuring that electricity supply can match electricity demand at all times of the day). gTech simulates two options for storage (battery and pumped storage), but both systems operate by generating electricity when it is not needed for use during peak.
- **Utility controlled charging.** An alternative to storage is to allow utilities to shift load off peak hours. gTech simulates that utility-controlled charging for electric vehicles is gradually phased in over time³¹.

IESD is used to provide insight about the effects of CleanBC on:

³¹ Wolinetz, M., Aksen, J., Peters, J., & Crawford, C. (2018). "Simulating the Value of Electric-Vehicle-Grid Integration Using a Behaviourally Realistic Model". *Nature Energy*, 3 (2), 132.

- Electricity generation and generation capacity by source (e.g. hydro, wind, natural gas, etc.).
- Electricity sector GHG emissions.
- Wholesale and end-use electricity prices.

How IESD works

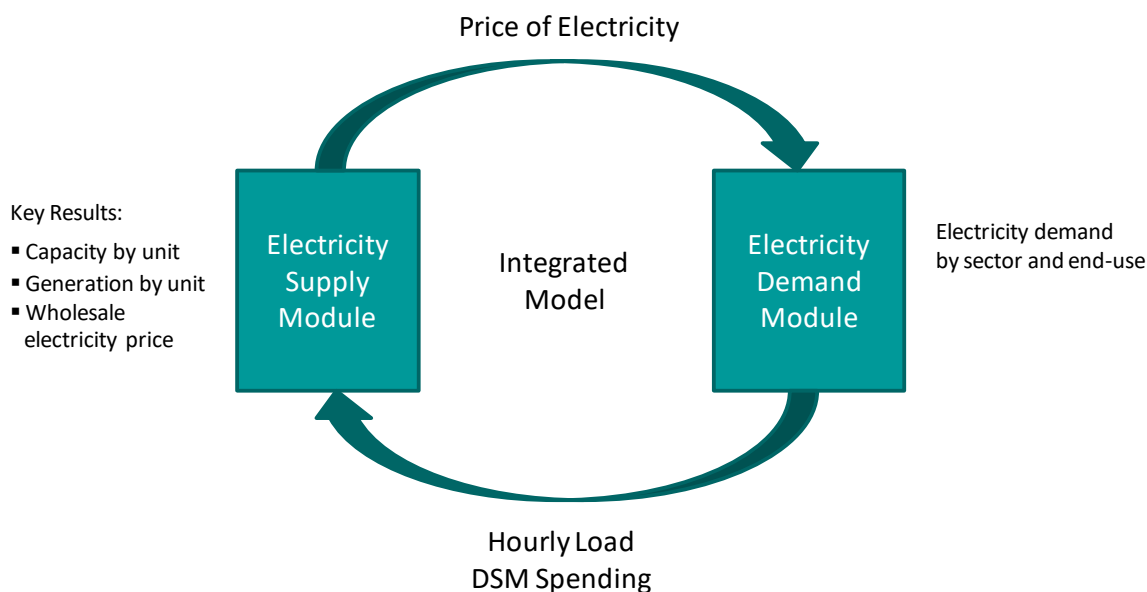
The IESD model simulates:

- How utilities meet electric load by adding new capacity and by dispatching new and existing units on an hourly basis; and
- How each sector alters its electricity consumption in response to the price for electricity.

Figure 2 depicts the key components of IESD's simulation process. The simulation begins with the Electricity Supply Module, which includes a detailed representation of the different units available to generate electricity in each region, including their unique costs and generation constraints. The electricity supply simulation determines new capacity additions, hourly dispatch of each unit to meet electric load over the course of the year, GHG emissions from the electricity sector, and the wholesale price for electricity.

The price for electricity is then sent to the Electricity Demand Module, which simulates how households and firms change their electricity consumption. The resulting electricity consumption by end-use is used to adjust the magnitude and shape of the hourly load profile. Total load and total demand side management spending are then sent back to the Electricity Supply Module.

Figure 2: Conceptualization of IESD model simulation



Electricity supply module

The electricity supply module of IESD is a linear programming model that simulates how the electricity sector makes capacity and dispatch decisions based on the hourly load profile, energy prices, and the cost of installing and operating different units. The electricity supply module endogenously adds and dispatches electricity units such that the total costs of the electricity system are minimized, system revenues are maximized, and load in each hour is met.

Representative days

The IESD model represents 43 representative days throughout the year that vary by (1) season, (2) load, and (3) wind capacity utilization (i.e. how much wind power is available in each hour of the day). These 43 representative days were selected to provide an accurate representation of the variation observed in load profiles and wind capacity utilization over all 365 days in a year (2010 data was used to provide the benchmark for electric load). To calculate total annual load, each representative day is assigned a weight such that the load profiles over the 43 days matches the load profile and wind capacity utilization over all 365 days in the year.

Capacity additions

The electricity supply module endogenously adds electricity generation units to supply energy (i.e. consumption over the year) and capacity (i.e. consumption at a given moment) such that the costs of the electricity system are minimized. Each type of electricity generation resource is characterized by its cost profile (i.e. capital costs,

fixed operating costs, and variable operating costs), heat rate (i.e. energy efficiency), and maximum capacity utilization. The model can simulate specific policy decisions that may promote or constrain the use of a given technology (e.g. a performance standard that constrains coal power, or a portfolio standard that requires renewable energy).

The attributes of new and existing electricity generation capacity are informed by the BC Hydro Resource Options Database³², the Energy Information Agency³³, and the Alberta Electricity System Operator³⁴.

Dispatch and capacity utilization

Thermal electricity generation (i.e. fossil fuel or biomass combustion) can be dispatched at any time when it will minimize total system costs subject to any existing policy constraints. However, IESD assumes cogenerated electricity is not dispatchable and is produced when heat is required by the thermal host.

Hydroelectric resources with reservoirs are unique because they can store energy (i.e. water) in order to generate electricity at a later date such that revenue from the electricity system is maximized. In BC, this allows electricity to be purchased from the regional market with the expectation of selling it later at a higher price. Therefore, hydroelectricity results in some opportunistic electricity trading between BC and other regions.

Electricity from intermittent resources must be used when it is available: either consumed, exported, or stored. As stated above, hourly wind energy generation is based on the installed capacity and the hourly capacity utilization in each hour of the representative day being simulated. Run-of-river hydroelectric capacity availability varies for each month of the year (lowest in winter and highest in spring) and IESD assumes it is constant during each hour of a given month. Solar capacity availability varies for each month of the year (lowest in winter and highest in summer) but changes each hour according to the movement of the sun through the sky (e.g. zero at night, low the morning, and highest at noon). For both run-of-river and solar capacity, the hourly capacity utilization adds up to the annual capacity utilization specified for

³² BC Hydro (2013). *Resource Option Update Report, Appendix 3, Resource Options Database Summary Sheets*

³³ USA Energy Information Agency (2013). *Updated Capital Cost Estimates for Utility Scale Electricity Generation Plants*

³⁴ Alberta Electricity System Operator (2013). *Long-Term Transmission Plan*

each resource (e.g. run-of-river on Vancouver Island vs. interior BC, and solar in BC vs. the USA).

Detailed BC model inputs

The IESD model has a detailed representation of technologies available to generate electricity in BC. In total, the model includes 48 resource options, which are based on the resource options provided by BC Hydro as well as other sources.

Electricity demand module

For this project, the demand for electricity is derived from gTech. The IESD model uses gTech's projections to shape the load curve for electricity demand and generation.

Sectors and end-uses in the electricity demand module

The electricity demand module aggregates end-uses from gTech for each major sector of the economy. The end-uses for residential and commercial buildings are:

- Space heating;
- Air conditioning;
- Lighting;
- Other multi-fuel end-uses (water heating, cooking, clothes dryers, etc.); and
- 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 IESD assumes it is a base load that is relatively constant over every hour of the year.

Summary of linkage between gTech and IESD

IESD interacts with gTech in two main ways:

- **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 electric load in space heating, it will affect electricity consumption at specific times and days of the year.

- **gTech determines the price for natural gas.** The price for natural gas is determined in gTech and is then supplied to IESD.

2.2.3. Limits to forecasting

Forecasting BC's future GHG emissions is inherently uncertain, and any method selected has inherent limitations. Limitations generally fall into three categories:

- Uncertainty about the future energy economy.
- Boundaries of the model. It is important to delineate what the model is and is not designed to do.
- Calibration challenges. The challenges of model calibration are not unique to gTech or IESD, but the level of complexity of gTech magnifies some challenges.

The remainder of this section discusses each of these types of uncertainty and limitations.

Uncertainty about the future energy economy

Despite using the best available forecasting methods and assumptions, the evolution of our energy economy is uncertain. In particular, forecasting GHG emissions is subject to two main types of uncertainty.

First, all models are simplified representations of reality. Navius' models are, effectively, a series of mathematical equations that are intended to forecast the future. This raises key questions, such as "are the equations selected a good representation of reality?" and "do the equations selected miss any important factors that may influence the future?"

The use of CGE models and technology choice models (gTech) and linear optimization programming (IESD) is well founded in the academic literature³⁵. Further, Navius undertakes significant efforts to calibrate and to back-cast the model (see the discussion starting on page 25).

However, Navius' tools do not account for every factor that will influence the future. For example, household and firm decisions are influenced by many factors, which cannot be fully captured by even the most sophisticated model. The inherent limitation

³⁵ Rivers, N., & Jaccard, M. (2006). "Useful Models for Simulating Policies to Induce Technological Change". *Energy Policy*, 34 (15), 2038-2047.

of energy forecasting is that virtually all projections of the future will differ, to some extent, from what ultimately transpires.

Second, the assumptions used to parameterize the models are uncertain. These assumptions include, but are not limited to, oil prices, improvements in labour productivity, and the level of LNG development in BC. If any of the assumptions used prove incorrect, the resulting forecast could be affected.

The uncertainties in modelling mean that all models will err in their forecasts of the future. However, some models are more correct than others. The analysis of CleanBC employs highly sophisticated models that provide powerful insights into the effects of the plan. Further, at a future date, the uncertainties inherent in the forecast could be examined in much greater detail.

“All models are wrong, but some are useful.”
George Box

Model boundaries

It is important to delineate the objectives of gTech and IESD, and to distinguish them from what the models are not intended to do. This delineation and distinction is presented for gTech in Table 7 and Table 8.

Table 7: What gTech is intended and not intended to do (technological choice)

Model dynamic	What gTech is intended to do	What gTech is not intended to do
Actions to reduce GHG emissions	<p>gTech accounts for actions to reduce emissions in virtually every end-use characterized in the model, as discussed in Section 3.2.</p> <p>The actions available to reduce emissions include:</p> <ul style="list-style-type: none"> ■ Technological change. Different technologies are available to alter the energy or emissions profile of every end-use characterized in the model. More information on the technological explicitness of the model is available in Section 2.2.1. ■ Changes in output. In addition to technological choice, GHG emissions can change if the demand for a particular end-use increases or declines. This can occur due to one of three reasons: 	<p>gTech does not include all available actions to reduce GHG emissions. Of those not included, the most important are likely:</p> <ul style="list-style-type: none"> ■ Afforestation and forest management. gTech does not currently account for carbon cycles in forests or agriculture. Therefore, the model cannot show how changes in forestry or agricultural practices may affect land use, land-use change, and forestry (LULUCF) emissions. The BC Government therefore adds a separate forecast of land-use change emissions, including afforestation and deforestation, to the gTech forecast of other provincial emissions (see Section 6.1 for more details). ■ Urban planning or land use planning. gTech does not account

- Changes in income. gTech explicitly simulates how policies affect provincial income, household income, and income generated by each industry. Everything else equal, less/more income leads to lower/higher emissions.
 - Changes in household preferences. gTech has some ability to simulate how households change preferences in response to a policy. If the cost of one end-use (e.g. personal transport) rises relative to another (e.g. going to restaurants), the model can simulate how the demand for the end-use with the higher relative cost declines. Nevertheless, gTech does not capture all possible dynamics.
 - Changes in industrial competitiveness. gTech explicitly simulates trade between BC and other jurisdictions. As such, an increase or decline in industrial costs can affect competitiveness and trade.
- for how changes in urban planning would affect GHG emissions. Changes in land use planning, for example, that support increased job density, amenity density, or unit density, could lead to reduced vehicle kilometers travelled (VKT), increase viability of active transport, and support more energy efficient buildings. gTech could incorporate this information from an external source, but this step has not been taken in this forecasting exercise.
- Changes in the demand for end-uses by industry. In gTech, the demand for various end-uses is typically (but not always) fixed. For example, the natural gas sector requires a fixed amount of compression per unit of natural gas production. GHG reductions can then be simulated via the choice of technology to meet the demand for compression. The model does not simulate how the sector may improve efficiency in order to reduce the demand for compression.

Technological dynamics	<p>gTech captures the following attributes of technologies in the model:</p> <ul style="list-style-type: none"> ■ Capital costs. ■ Fuel requirements (e.g. GJ of electricity per electric vehicle). ■ Non-financial factors, which are converted to a monetary value in order to simulate people's preferences. ■ Discount rates. gTech uses a "revealed" discount rate as opposed to a "financial" discount rate. More information on the distinction is available in Section 2.2.1. ■ The extent to which capital costs of some technologies may decline as a function of cumulative experience with a technology. The literature 	<p>gTech excludes undefined technologies, such as backstop technologies, i.e. discrete and undefined new technologies often used to limit abatement costs and to represent technology learning in a more abstract way than by including discrete emerging technologies.</p>
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confirms that this dynamic is important³⁶.

- How non-financial costs for some technologies may change in response to the market share of different technologies. The literature indicates that this dynamic is important³⁷.
- Various other parameters as described in Section 2.2.1.

Policy representation	As discussed in Section 2.2.1, gTech has the ability to simulate many types of policies and to account for how they are likely to interact with each other.	Policies that target dynamics outside the scope of gTech cannot be modelled. For example, planning and land-use cannot be explicitly modelled.
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Table 8: What gTech is intended and not intended to do (macroeconomics)

Model dynamic	What gTech is intended to do	What gTech is not intended to do
Full equilibrium dynamics	gTech ensures that every market simulated in the model returns to equilibrium.	While the equilibrium abilities of the model are generally viewed as an asset, it should be recognized that in reality some markets could remain out of equilibrium for a period of time. For example, labour markets can experience non-equilibrium unemployment, which would not be captured by gTech.
Sector detail	gTech includes 80 sectors of the economy. A list of these sectors is provided in Appendix A: “Covered sectors, fuels, end-uses, and technologies”.	gTech provides a greater level of disaggregation of energy- and emissions-intensive sectors of the economy, while aggregating non-energy- or emissions-intensive sectors (e.g. services). An implication of this approach is that the version of gTech used for this analysis cannot provide insight into how different services sectors (e.g. restaurant versus financial services) are affected by CleanBC.
Sector characterization	A trade-off exists between (1) simulating competitiveness dynamics and (2) achieving alignment with external data sources. gTech’s calibration routine places a priority on	As shown below, gTech is well calibrated to provincial emissions. Nevertheless, placing a priority on the ability to simulate competitiveness dynamics may at times sacrifice

³⁶ Löschel, A. (2002). “Technological Change in Economic Models of Environmental Policy: A Survey”. *Ecological Economics*, 43 (2-3), 105-126.

³⁷ 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 (3), 221-238.

	being able to simulate competitiveness dynamics. More information about this trade-off is provided starting on page 30.	alignment with external data sources. More information about this trade-off is provided starting on page 30.
Interactions with regions outside of BC	<p>gTech provides an explicit representation of other regions in North America. As such, any policy or sector that is modelled in the BC module of gTech can likewise be modelled in the rest of North America. For example, the model explicitly includes policies implemented in other jurisdictions such as carbon pricing (e.g. Québec’s cap-and-trade system and the federal carbon pricing backstop in jurisdictions with no carbon pricing policy), Alberta’s accelerated coal phase-out, and Québec’s ZEV mandate. Including policies in other jurisdictions is important because they may have several types of impacts on BC:</p> <ul style="list-style-type: none"> ■ Policy interaction effects. The implementation of provincial policies outside BC can affect the stringency of federal policies in BC. For example, the ZEV mandate in Québec will improve the fleet average fuel economy of vehicles in that province, allowing auto manufacturers to sell less efficient vehicles in other provinces while still complying with the federal vehicle emissions standard. ■ Income and substitution effects. Policies in other jurisdictions can change the types of goods or services exported from BC and/or the cost of imports from other jurisdictions. ■ Competitiveness effects. Policies in other jurisdictions can influence competitiveness pressures on firms in BC. 	<p>gTech does not explicitly model regions outside of North America. Nevertheless, the model captures trade between North America and the rest of the world. Implications of this approach include:</p> <ul style="list-style-type: none"> ■ gTech cannot explicitly simulate policy in regions outside of North America. For example, the model could not simulate how the closure of coal plants in China affects the demand or price for LNG. ■ In general, the global price for commodities is treated as fixed.
Households	Households supply labour and capital and receive income. Households are disaggregated into 5 different income groups to provide greater insight into how CleanBC might affect different households. Additionally, in the last year, gTech has been updated to be able to inform impacts on household demographics other than income (e.g.	gTech is not able to represent all possible household demographics.

the difference between a single-parent household and a two-parent household).

Solve periods	<p>The version of gTech used in this study solves in 5-year increments. While Navius has developed versions that solve in smaller time increments, Navius uses 5-year increments for two reasons:</p> <ul style="list-style-type: none"> ■ gTech simulates full equilibrium in all markets and is intended to capture long-term trends. ■ Solving the model in 5-year increments reduces the amount of time required to complete analyses (relative to annual or biannual increments). 	<p>By solving in five-year increments, gTech:</p> <ul style="list-style-type: none"> ■ Is not intended to examine the short-term effects of business-cycles in which markets may be out of equilibrium (or any other dynamics that occur over a short time period). ■ Cannot perfectly capture the impacts of policies that change within a five-year period. For example, the carbon tax is scheduled to change on an annual basis. Simulating this policy in gTech requires averaging the price over each five-year period.
Labour Supply	<p>gTech captures two important labour dynamics:</p> <ul style="list-style-type: none"> ■ The extent to which labour supply will change in response to real wages. ■ How the equilibrium level of unemployment changes in response to real wage rates. 	<p>gTech does not capture labour business cycles as it excludes a non-equilibrium unemployment function. gTech also does not explicitly include how policies might affect migration between BC and other regions.</p>

The IESD model is used to provide insight into how CleanBC affects the electricity system and electricity prices. Similar to gTech, it is important to delineate the objectives of the model for the purposes of this analysis (see Table 9).

Table 9: What IESD is intended and not intended to do

Model dynamic	What IESD is intended to do	What IESD is not intended to do
Resource availability	<p>The version of IESD used for this analysis includes 48 resources available to generate electricity. The characterization of these resources is based on data provided by BC Hydro and a more expansive discussion of these resources is provided in Section 2.2.2.</p>	<p>IESD performs very well in terms of simulating the economics of producing electricity from different types of resources. Any challenges are related to uncertainty, as opposed to whether IESD provides a good characterization of resources in BC. The modelling is not intended to identify the future least-cost generating resources for BC.</p>
Regional boundaries	<p>The version of IESD used for this analysis accounts for the electricity system in BC, Alberta, and the USA portion of the Western Electricity Coordinating Council (WECC).</p>	<p>This version of IESD cannot provide insight into how/whether policy outside these regions affects BC (these impacts are likely to be small).</p>

		More importantly, IESD does not provide regional disaggregation of BC.
Temporal resolution	IESD simulates hourly variability in electricity demand and supply (e.g. how demand for lighting increases between 6 am and 7 am during winter when people wake up).	IESD does not simulate intra-hourly variability in demand and supply.
Linkages between IESD and gTech	<p>The two models are linked via two separate processes:</p> <ul style="list-style-type: none"> ■ The electricity sector in gTech has been calibrated to provide similar (but not identical) results as IESD. ■ After each simulation in gTech, the resulting electricity consumption is used to shape hourly electricity load in IESD. 	The two models do not iterate to equilibrium, as would be ideal.

Model preparation challenges

Calibrating to several inconsistent data sources

A central challenge with all energy-economy models is their calibration to external datasets (e.g. BC's *Provincial Inventory of Greenhouse Gas Emissions*) or other forecasts (e.g. BC's GDP forecast). This challenge is magnified for gTech. gTech must start with a completely internally consistent dataset, but this dataset is based on external data sources that are not internally consistent.

A more comprehensive list of data sources is available in the following sections, but at a high level gTech relies on:

- BC's *Provincial Inventory of Greenhouse Gas Emissions*³⁸.
- Environment and Climate Change Canada's (ECCC) *National Inventory Report: Greenhouse Gas Sources and Sinks in Canada*³⁹.
- Statistics Canada's *Supply and Use Tables*⁴⁰.

³⁸ Government of British Columbia (annual). *Provincial Inventory of Greenhouse Gas Emissions*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

³⁹ Environment and Climate Change Canada (annual). *National Inventory Report: Greenhouse Gas Sources and Sinks in Canada*. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

⁴⁰ Statistics Canada (annual). *Supply and Use Tables*. Available from: www150.statcan.gc.ca/n1/en/catalogue/15-602-X

- Natural Resources Canada's *Comprehensive Energy Use Database*⁴¹.
- Statistics Canada's *Annual Industrial Consumption of Energy Survey*⁴².
- Navius' technology database (see Table 32 "List of technologies in gTech").
- BC's Ministry of Energy, Mines, and Low-Carbon Innovation's 2022 natural gas production forecast⁴³.
- BC's Ministry of Energy, Mines, and Low-Carbon Innovation's LCFS supply data⁴⁴.
- BC Hydro's load forecast (electricity consumption for some sectors is informed by BC Hydro data, but the model endogenously forecasts electricity consumption in others).

Each of these data sources is generated using different methods, so they are not necessarily consistent. For example, expenditures on natural gas by households in Statistics Canada's *Supply and Use Tables* may not be consistent with natural gas consumption in Natural Resources Canada's *Comprehensive Energy Use Database*. Further, 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.

Navius' calibration routine places greater emphasis on some data sources than others. This approach means that gTech achieves near-perfect alignment (in the calibration scenario) with data sources receiving the highest priority, but alignment starts to diverge from data sources that receive a lower priority. For this project, the datasets that receive the highest priority are:

- BC's *Provincial Inventory of Greenhouse Gas Emissions*.
- Natural Resources Canada's *Comprehensive Energy Use Database*.
- Navius' technology database.

⁴¹ Natural Resources Canada (annual). *Comprehensive Energy Use Database*. Available from: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

⁴² Statistics Canada (annual). *Annual Industrial Consumption of Energy Survey*. Available from: www.statcan.gc.ca

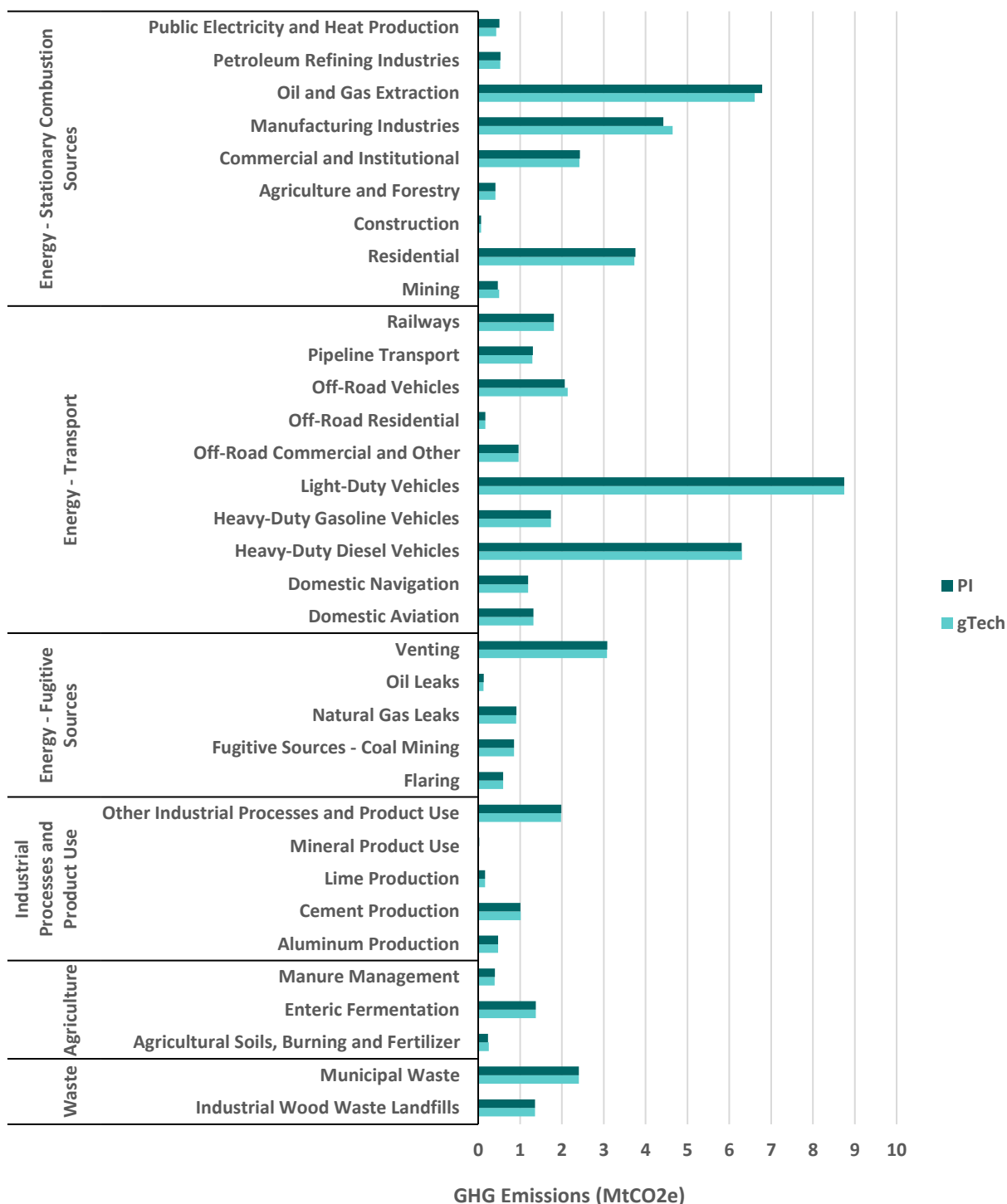
⁴³ Navius receives this forecast directly from the BC government.

⁴⁴ Government of British Columbia (annual). *Renewable and Low Carbon Fuel Requirements Regulation Summary*. Available from: www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/transportation/renewable-low-carbon-fuels/rlcf007-2020_-_summary_2010-20.pdf

Navius allows the model to diverge more significantly from other datasets in order to ensure alignment with these data sources.

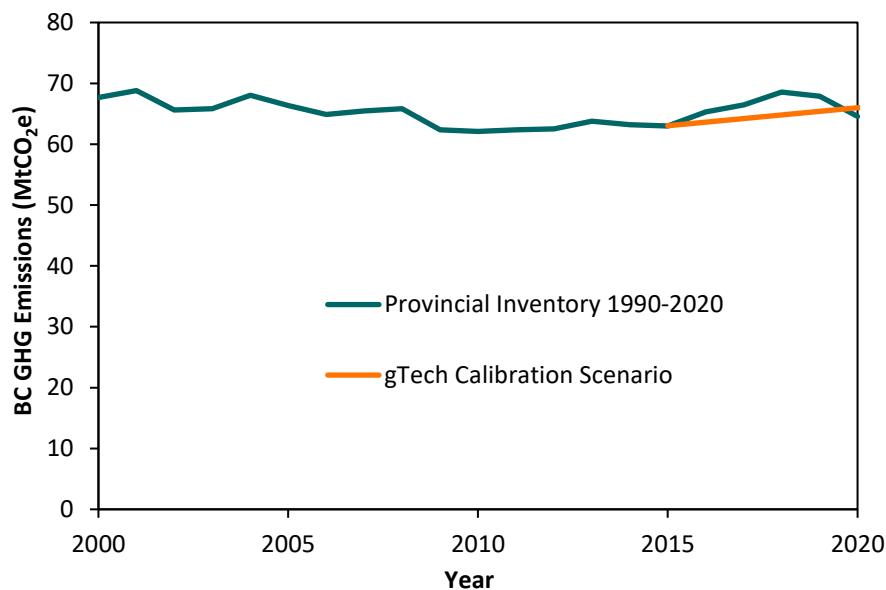
Figure 3 and Figure 4 show how modelled GHG emissions align with BC's *Provincial Inventory of Greenhouse Gas Emissions 1990-2020*. As shown in Figure 3, emissions in the 2015 base year align well with the Provincial Inventory for all sectors. However, Figure 4 shows that by 2020, gTech's GHG emissions are higher than those reported under the Provincial Inventory Report. Modelled emissions are higher in 2020 because gTech smooths out some impacts from covid-19. Since gTech is intended to show medium to long term trends, rather than short term economic impacts, the full impact on GHG emissions from covid-19 is softened during the calibration of the model.

Figure 3: Calibration of GHG emissions by category in 2015



Source for historical data: Government of British Columbia (2022). *Provincial Inventory of Greenhouse Gas Emissions 1990-2020*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory. Note: land-use change emissions, which are not included in gTech, amount to 3.0 MtCO_{2e} in 2015. Other land use emissions, also not included in gTech, do not contribute to BC's total emissions in the Provincial Inventory.

Figure 4: Calibration of provincial emissions 2015-2020



Source for historical data: Government of British Columbia (2022). *Provincial Inventory of Greenhouse Gas Emissions 1990-2020*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory. Note: land-use change emissions, which are not included in gTech, amount to 2.8 MtCO_{2e} in 2020. Other land use emissions, also not included in gTech, do not contribute to BC's total emissions in the Provincial Inventory.

Disaggregating key sectors in the data

An additional challenge during the calibration process is that some sectors are aggregated together in certain datasets. Key examples include:

- 'Conventional oil and gas extraction' from Statistics Canada's *Supply and Use Tables* comprises the following sectors, which are central to the analysis:
 - Natural gas from conventional resources
 - Natural gas from the Montney region
 - Natural gas from the Horn River region
 - Light oil extraction
- 'Other basic organic chemicals manufacturing' comprises:
 - 7 individual sectors representing different pathways for biofuels production
 - The rest of 'other basic organic chemicals manufacturing'
- 'Electric power generation, transmission, and distribution' comprises:
 - Electric generation from fossil fuels

- Electric generation from hydroelectric or other renewable resources
- Electric power transmission and distribution

Each of the above subsectors is expected to play an important role in BC's future energy economy and respond differently to CleanBC. As such, it is essential to disaggregate these sectors in the model. The process for disaggregating each sector is different, but typically starts with “what we know” before moving into “what we are less confident about”. Taking electricity generation, transmission, and distribution as an example:

- The allocation of electricity generation between the two generation sectors is based on data from Statistics Canada.
- All fossil fuel consumption is allocated to ‘electric generation from fossil fuels’.
- The capital requirements for each sector are based on Navius’ technology database.
- The GDP from ‘electric power transmission and distribution’ is estimated from the difference between total expenditures on electricity and the cost of electricity generation.

Constructing representations of sectors that do not yet exist

Some sectors that will impact the emissions reduction pathway of CleanBC do not yet exist. Of these, the following are most important:

- LNG production
- Several pathways for liquid and gaseous renewable fuels production

While these sectors are characterized based on the best available data (see Section 3.2), the exact characterization is uncertain until these sectors begin operation.

Competitiveness dynamics versus alignment with external data sources

The method for calibration to external data sources has important implications for gTech’s ability to (1) simulate competitiveness dynamics and (2) achieve alignment with external data sources. In general, the model performs reasonably well in both tasks, but the calibration routine is weighted towards being better at simulating competitiveness dynamics.

This trade-off is best illustrated with an example. Statistics Canada's *Supply and Use Tables* provide data on an aggregated sector for cement and concrete manufacturing. However, these two sectors are vastly different. Cement manufacturing is highly emissions-intensive and trade-exposed. Concrete manufacturing requires cement and is generally not emissions-intensive or trade-exposed (in part because transporting concrete is costly).

This aggregation of sectors would pose a significant problem for simulating trade between Saskatchewan (which has both cement and concrete manufacturing) and Manitoba (which only has concrete manufacturing). If these sectors were not disaggregated in gTech (they are), the model could show that Manitoba could export cement and concrete products to Saskatchewan in order to reduce emissions in Saskatchewan. Such a result would naturally be unrealistic.

The best solution is therefore to disaggregate sectors in order to explicitly represent those that are both emissions-intensive and trade-exposed. However, this solution has limits. For some sectors, the data to fully disaggregate sectors is simply not available. This issue is most acute in some chemicals sectors (e.g. petrochemical manufacturing), but also emerges in some other sectors to a lesser extent (e.g. pulp and paper manufacturing). If insufficient information is available to fully disaggregate an emissions-intensive and trade-exposed sector, gTech (intentionally and incorrectly) characterizes that sector in the same way across all regions. This ensures that the model will perform well at simulating competitiveness dynamics, but at the expense of alignment to external data sources.

In the context of BC, this trade-off is less of an issue than for other provinces (particularly those with large basic chemicals sectors). In addition, even though gTech places greater weight on competitiveness dynamics, the model generally aligns reasonably well with external sources.

On a final note, resources sectors (e.g. natural gas production) can have differentiated emissions profiles between regions. As these sectors are anchored in a resource, they do not exhibit the same challenge as manufacturing sectors.

3. Forecast assumptions

Given the scope of the forecasting undertaken for this project (covering all energy consumption, GHG emissions, and economic activity in BC as well as the rest of North America), many assumptions are required. Over the past four years, these assumptions have been subject to thorough review by both Navius staff and the BC Government and will continue to be updated as a process of continued improvement.

Navius uses assumptions related to economic activity, sector-specific factors, and technological choice to calibrate a model forecast. This calibration scenario is used as a starting point from which CleanBC policies are modelled. The calibration forecast includes policies implemented in 2020 but diverges from CleanBC policies in future years.⁴⁵

This section summarizes key assumptions that underpin the following factors:

- Economic assumptions (Section 3.1)
- Sector-specific assumptions (Section 3.2)
- Technological choice (Section 3.3)

3.1. Economic assumptions

3.1.1. Gross domestic product

BC's economy is partially calibrated to align with the forecast published in Budget 2022⁴⁶ and smoothed to even out the economic fluctuations from the pandemic, leading to an average annual growth rate of 2.4% from 2020 to 2025. In gTech, the GDP impact from the pandemic is smoothed out as the model is more suited to represent medium to long term trends rather than short term economic impacts. After

⁴⁵ The calibration scenario described in this section is not used to measure impacts from CleanBC policies, rather it is used to generate a forecast that includes policies implemented in 2020 which are likely in alignment with the endogenous forecasts used to inform the modelling. The scenario used to measure CleanBC impacts only includes policies announced as of 2017 and is described in Section 4.

⁴⁶ Government of British Columbia (2022). *Budget 2022*. Available from: www.bcbudget.gov.bc.ca/default.htm

2025, GDP is calibrated to economic forecasts from the Parliamentary Budget Officer⁴⁷, growing at an annual rate of 1.3%.

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). The activity of some sectors is calibrated to specific exogenous forecasts and assumptions, as discussed in Section 3.1.

3.1.2. Inflation

The assumed rate of inflation impacts the modelled effectiveness of pricing-based policies like the carbon tax. All monetary values are handled by gTech in constant 2015 dollars, adjusted from their “current” values (i.e. the actual, unadjusted value in the relevant year) to account for inflation in order to compare costs across years in terms of purchasing power.

3.1.3. Population

Population is tied to labor growth assumptions in gTech and is implicitly included by aligning GDP to an external forecast (Budget 2022⁴⁸ for years to 2025; see Section 3.1.1). Although population growth usually aligns closely to labor growth, in actuality this is not always the case, as was experienced during COVID-19.

3.1.4. Oil and gas prices

Oil and gas prices are informed by the current-policies scenario from the Canada Energy Regulator’s *Canada’s Energy Future 2021* report⁴⁹. To account for significant unforeseen price rises since the *Canada’s Energy Future* forecast was produced, data for 2021-2023 has been replaced by the US Energy Information Administration’s *July 2022 Short-Term Energy Outlook*⁵⁰, and values for following years are assumed to exponentially decline back to the *Canada’s Energy Future* forecast by 2030. Moreover,

⁴⁷ Fiscal Sustainability Report 2021 - Parliamentary Budget Officer. Available from: <https://www.pbo-dpb.ca/en/publications/RP-2122-010-S-fiscal-sustainability-report-2021--rapport-viabilite-financiere-2021>

⁴⁸ Government of British Columbia (2022). *Budget 2022*. Available from: www.bcbudget.gov.bc.ca/default.htm

⁴⁹ Canada Energy Regulator (2021). *Canada’s Energy Future 2021: Energy Supply and Demand Projections to 2050*. Available from: <https://open.canada.ca/data/en/dataset/5a6abd9d-d343-41ef-a525-7a1efb686300>

⁵⁰ US Energy Information Administration (2022). *July 2022 Short-Term Energy Outlook*. Available from: www.eia.gov/outlooks/steo/outlook.php

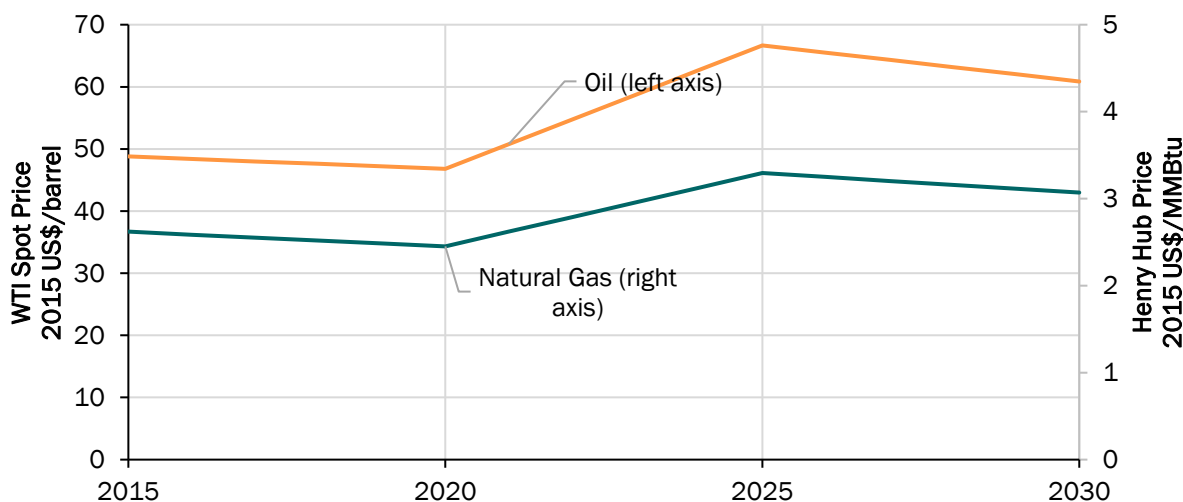
the drastic price drop in 2020 due to the pandemic is smoothed using the 2016-2020 average price since the model is best suited for medium to long term forecasts instead of short-term economic impacts.

The price of oil is an exogenous input to the model (i.e. based on an assumed global price). After the model is calibrated to the external forecast, the price for natural gas is determined endogenously based on supply and demand of natural gas in North America:

- Natural gas (Henry Hub) prices rise from \$2.5/MMBTU (2015 \$USD) in 2020 to \$3.1/MMBTU by 2030.
- Crude oil (WTI) prices rise from \$46.8/barrel (2015 \$USD) in 2020 to \$60.9/barrel by 2030.

Please see Figure 5 for the 2015-2030 oil and gas price trajectory. Since gTech solves in 5-year increments, price trajectories are smoothed out linearly.

Figure 5: Oil and natural gas price forecast



The price for most other energy commodities is determined by the model based on demand and the cost of production. For example, the price of natural gas in BC depends on a variety of factors that are accounted for by the modelling, such as:

- The cost of producing natural gas while meeting policy constraints.
- The cost of maintaining the pipeline and distribution network.
- The value of natural gas exports and cost of imports.

- Any taxes on or subsidies to the sector.

3.2. Sector-specific assumptions

This section reviews assumptions specific to each sector in gTech under the calibration scenario:

- Sector activity (whether it is calibrated to an exogenous forecast or determined by the model).
- Key sources of emissions. This discussion focuses on emissions in 2015, the model's base year. Starting the model simulation in 2015 allows for results to be checked against known historical data, helping to ensure that results are reasonable. Tables in this section are derived from gTech, which is calibrated against the Provincial Inventory and other data sources. For example, emissions in some industrial sectors (such as lime and cement) are informed by national fuel consumption, and then (approximately) disaggregated by each province's share of production. Calibrating to multiple datasets ensures that gTech represents national industry while still aligning to provincial emissions.
- Modelled opportunities to reduce emissions.

Sectors are organized into three categories: industry, transport, and buildings and communities.

3.2.1. Industry

The industry sector in gTech comprises over 70 individual sectors, which produce a wide variety of products throughout the province. A comprehensive list of all sectors is available in Appendix A: "Covered sectors, fuels, end-uses, and technologies".

Sector activity

Sector activity in gTech is a combination of external assumptions and a modelled result. For sectors that use external assumptions to generate the forecast, the model's calibration scenario is aligned with exogenous activity. For other sectors, gTech determines or simulates sector activity.

As a full economic model, gTech determines sector activity by ensuring that markets clear. If a given sector produces excess supply of a good or service, gTech responds in two ways: (1) the price for the good or service declines; and (2) given the lower

profitability of a sector that produces that good or service, sector activity declines until all markets return to equilibrium.

In the case of industrial sectors (as seen in Table 10) activity usually refers to output. Table 10 shows (1) which sectors are calibrated to external assumptions; (2) the source for each assumption; (3) which sectors are purely determined by gTech; and (4) which sectors are determined by a combination of IESD and gTech.

Table 10: Industry sector activity in selected years under the calibration scenario

Sector	Unit	2015	2020	2025	2030	Source
Fossil fuel industry						
Coal production	Index 2015 = 1	1.0	1.4	1.4	1.4	gTech
Natural gas production	BCF per day	4.1	5.4	6.4	6.8	BC's Ministry of Energy, Mines, and Low-Carbon Innovation ^{51,52}
Conventional and Horn River	BCF per day	1.1	0.5	0.4	0.2	
Montney	BCF per day	3.0	4.9	6.0	6.6	
Conventional light oil production	Thousand barrels per day	21.2	13.6	8.8	5.9	CER ⁵³ (current policies scenario)
Oil and natural gas transmission	Index 2015 = 1	1.0	1.2	1.3	1.3	gTech
Petroleum refining	Index 2015 = 1	1.0	1.0	1.0	1.0	gTech
Natural gas distribution	Index 2015 = 1	1.0	1.2	1.3	1.2	gTech
LNG	MTPA	0.0	0.0	10.5	14.0	Published final investment decisions
Electricity						
Electricity generation	TWh	71.5	71.0	73.4	74.6	gTech & IESD
Electricity distribution	Index 2015 = 1	1.0	1.1	1.1	1.2	gTech
Heavy industry						
Mining	Index 2015 = 1	1.0	1.4	1.4	1.4	gTech
Metals	Index 2015 = 1	1.0	1.4	1.5	1.6	gTech
Pulp and paper	Index 2015 = 1	1.0	1.0	1.0	1.0	gTech
Non-metallic minerals	Index 2015 = 1	1.0	1.0	1.0	1.0	gTech
Chemicals and fertilizers	Index 2015 = 1	1.0	1.1	1.2	1.4	gTech
Services						
Services	Index 2015 = 1	1.0	1.1	1.2	1.3	gTech
Agriculture						
Agriculture	Index 2015 = 1	1.0	1.0	1.1	1.2	gTech

⁵¹ BC Ministry of Energy, Mines, and Low-Carbon Innovation (2022, Unpublished). *Long-Term Natural Gas Production Forecast*.

⁵² The model is informed by a forecast provided by EMLI to Navius, in which production is forecast to be 7.0 BCF/day in 2030. Navius adjusts this forecast to 6.8 BCF/day in 2030 to account for a defined level of LNG production.

⁵³ Canada Energy Regulator (2021). *Canada's Energy Future 2021: Energy Supply and Demand Projections to 2050*. Available from: <https://open.canada.ca/data/en/dataset/5a6abd9d-d343-41ef-a525-7a1efb686300>

Waste						
Industrial wood waste	Index 2015 = 1	1.0	0.9	0.7	0.5	Navius
Light industry						
Light manufacturing	Index 2015 = 1	1.0	1.2	1.3	1.4	gTech
Construction	Index 2015 = 1	1.0	1.2	1.3	1.2	gTech
Forest resources	Index 2015 = 1	1.0	1.2	1.3	1.4	gTech

Sources of emissions

Unlike the transport and buildings and communities sectors, which are discussed in greater detail below, GHG emissions originate from many sources in industry. Further, each source of emissions tends to be concentrated in a small group of sectors. Table 11 summarizes the relationship between sectors (rows) and sources of GHG emissions in the model's base year, 2015 (columns). The estimates in 2015 are direct assumptions that go into the model.

Table 11: GHG crosswalk for industry in 2015 under the calibration scenario (MtCO_{2e})

Sector	Stationary combustion	Transport	Fugitive sources	Industrial processes	Agriculture	Total
Total industry	13.2	3.0	5.6	2.3	2.0	26.1
Fossil fuel industry	7.7	1.8	5.6	0.1	-	15.2
Coal production	0.4	0.3	0.9	0.0	-	1.6
Natural gas production and processing	6.5	0.2	4.0	0.0	-	10.6
Conventional oil production	0.3	0.0	0.3	0.0	-	0.6
Oil and natural gas transmission	-	1.2	0.3	-	-	1.5
Petroleum refining	0.5	-	0.1	0.0	-	0.7
Natural gas distribution	-	0.1	0.1	-	-	0.1
LNG	-	-	-	-	-	-
Electricity	0.3	-	-	-	-	0.3
Electricity	0.3	-	-	-	-	0.3
Heavy industry	3.4	0.2	-	2.3	-	5.9
Mining	0.1	0.2	-	0.0	-	0.3
Smelting and refining	0.4	-	-	0.9	-	1.3
Pulp and paper	1.8	-	-	-	-	1.8
Iron and steel	0.0	-	-	-	-	0.0
Cement	0.6	-	-	1.0	-	1.7
Lime and gypsum	0.1	-	-	0.2	-	0.3
Chemicals and fertilizers	0.3	-	-	0.2	-	0.5
Agriculture	0.4	0.1	-	0.0	2.0	2.6
On-farm fuel use	0.4	0.1	-	0.0	-	0.6
Crop production	-	-	-	-	0.2	0.2
Animal production	-	-	-	-	1.9	1.9

Light industry	1.4	0.8	-	0.0	-	2.2
Light manufacturing	1.3	-	-	-	-	1.3
Construction	0.1	0.3	-	0.0	-	0.4
Forest resources	-	0.5	-	0.0	-	0.5

The following discussion describes key assumptions for each industrial sector. Emissions are calibrated to a number of sources as identified in Section 2.2.3. Additional sources specific to industrial sectors are highlighted below.

Natural gas production

BC's natural gas sector emits GHGs from the following sources (as captured by the model):

- Stationary combustion. The natural gas industry consumes natural gas for several purposes: industrial cogeneration, and direct drive compression. In 2015, these emissions accounted for 6.5 MtCO_{2e}.
- Removal of formation carbon dioxide. Raw natural gas withdrawn from the ground can include carbon dioxide along with natural gas and other constituents. As carbon dioxide is a natural retardant, it must be removed below a specific level before the gas meets the requirements established by natural gas shippers. In the absence of abatement, this carbon dioxide is then emitted into the atmosphere.

In 2015, formation carbon dioxide accounted for about 1.5 MtCO_{2e}. However, different natural gas resources in BC have widely different compositions, with the Montney having very low concentrations of formation carbon dioxide, the Horn River having very high concentrations, and conventional in between.

Each of these resources is expected to experience different rates of growth over time, with Montney generally expanding, and conventional and the Horn River declining, meaning that formation carbon dioxide emissions are likewise expected to decline over time.

- Venting and leaks. Methane is released via both venting and unintentional leaks. In 2015, these emissions accounted for about 1.5 MtCO_{2e}.
- Surface casing vent flows. Gas or fluid can flow from the surface casing vent system of wells. In 2015, these emissions are estimated at 0.4 MtCO_{2e}.
- Flaring. Some methane is flared during natural gas production and processing. Flaring is estimated at 0.5 MtCO_{2e} in 2015.

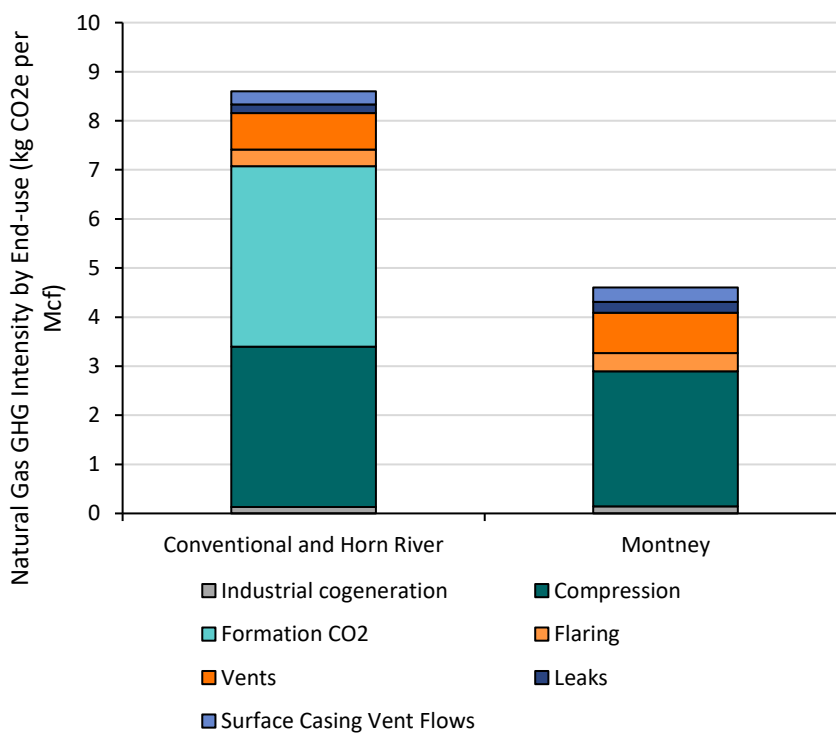
In addition to the data sources described above, GHG emissions from the different sources and resources have been calibrated to (1) a study by Clearstone

Engineering⁵⁴, (2) Ministry of Energy, Mines, and Low-Carbon Innovation internal data⁵⁵, and then (3) adjusted in order to ensure near alignment with BC’s *Provincial Inventory of Greenhouse Gas Emissions*⁵⁶.

Figure 6 shows the emissions intensity of natural gas production for each resource in the 2015 model base year.

Table 12 provides details for each resource.

Figure 6: GHG emissions intensity of natural gas production for each resource in BC



⁵⁴ Clearstone Engineering (2014). *Canadian Upstream Oil and Gas Emissions Inventory*.

⁵⁵ Bergerson Consulting (2019, Unpublished). *Upstream Emissions of Current and Potential Global LNG Projects*.

⁵⁶ Government of British Columbia (2021). *Provincial Inventory of Greenhouse Gas Emissions 1990-2019*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

Table 12: Natural gas production and processing sector emissions in 2015 (MtCO_{2e})

IPCC category	Stationary combustion				Fugitive sources			Total
End-use	Compression	Process heat (high-grade heat)	Industrial cogeneration	Flaring	Formation CO ₂	Vents and leaks	Surface casing vent flows	Total (excluding transport)
Conventional light oil	0.1	-	-	-	-	-	0.0	0.1
Conventional and Horn River natural gas	1.3	0.5	0.1	0.1	1.5	0.4	0.1	4.0
Montney natural gas	3.0	1.4	0.2	0.4	-	1.1	0.3	6.4
Total (excluding transport)	4.4	1.8	0.2	0.5	1.5	1.5	0.4	10.5

Petroleum refining

Petroleum refining emits GHGs mostly from combustion for producing process heat (estimated at 0.5 MtCO_{2e} in 2015). Additionally, refining generates emissions from industrial processes and product uses such as the use of hydrogen (estimated at 0.1 MtCO_{2e} in 2015). Lastly the refining process involves fugitive emissions in the form of leaks and flaring (estimated at 0.1 MtCO_{2e} in 2015).

The petroleum refining sector is emissions-intensive and trade-exposed. Therefore, please refer to the discussion on trade-offs between simulating competitiveness impacts and perfect alignment with external sources (see discussion starting on page 30).

Table 13: Petroleum refining sector emissions in 2015 in the calibration scenario (MtCO_{2e})

IPCC category	Stationary combustion	Industrial Processes and Product Use	Fugitive sources		Total
End-use	Process heat (high-grade heat)	Hydrogen production and other	Leaks	Flaring	Total (excluding transport)
Petroleum refining	0.5	0.1	0.1	0.0	0.7

Electricity generation

GHG emissions from electricity generation occur from two main sources: thermal generation by electric utilities and industrial electricity cogeneration. In 2015, emissions from utilities are estimated at 0.25 MtCO_{2e}, while emissions from industrial cogeneration are estimated at 0.18 MtCO_{2e}

Mining

BC's mining sector consists of four sub-sectors: coal mining, metal ore mining, non-metallic ore mining, and mining services. Emissions from these sectors fall into two sources:

- Stationary combustion (0.5 MtCO_{2e} in 2015), which is assumed to be for producing process heat.
- Transport (0.6 MtCO_{2e} in 2015). These emissions are from off-road vehicles. Freight transport is not included here and is covered in Section 3.2.2.
- Fugitive emissions from coal beds (0.9 MtCO_{2e} in 2015).

Table 14 shows the key sources of emissions for the mining sector.

Table 14: Mining sector emissions in 2015 in the calibration scenario (MtCO_{2e})

IPCC category	Stationary combustion	Transport	Fugitive sources	Total (excluding transport)
End-use	Process heat (high-grade heat)	Transport	Coalbed methane	
Coal mining	0.4	0.3	0.9	1.3
Metal ore mining	0.0	0.1	-	0.2
Mineral mining	0.0	0.0	-	0.0
Mining services	0.0	0.1	-	0.1
Total (excluding transport)	0.5	0.6	0.9	1.4

Aluminum smelting

Aluminum smelting in the province produces emissions from three main sources:

- Combustion emissions, although these emissions are relatively small in comparison to other sources from the sector (0.01 MtCO_{2e} in 2015).

- Carbon dioxide from anode decomposition (0.2 MtCO₂e in 2015). The aluminum sector uses carbon anodes to smelt aluminum. These anodes decompose during the smelting process, emitting carbon dioxide.
- Perfluorocarbons (0.3 MtCO₂e in 2015). These emissions originate from reactions between the carbon anode and the fluorine bath as a consequence of the aluminum manufacturing process.

Emissions from the sector are set to align with (1) the *Provincial Inventory of Greenhouse Gas Emissions*⁵⁷, (2) the National Inventory Report⁵⁸, and (3) national industrial fuel consumption by industry⁵⁹. Table 15 shows estimated emissions from the aluminum sector in 2015.

Table 15: Aluminum sector emissions in 2015 (MtCO₂e)

IPCC category	Stationary combustion	Industrial processes		Total
End-use	Natural gas combustion	Aluminum CO ₂	Aluminum PFCs	
Aluminum smelting	0.0	0.2	0.3	0.5

Cement and lime manufacturing

Cement and lime manufacturing include two main sources of emissions: (1) combustion emissions from producing process heat (0.7 MtCO₂e in 2015) and (2) industrial process emissions associated with the calcination of limestone (1.2 MtCO₂e).

Emissions are informed by fuel consumption at a national level, and then by (approximately) prorating these fuel shares based on BC’s share of production⁶⁸. Emissions are then aligned to the Provincial Inventory of Greenhouse Gas Emissions⁶⁷.

Table 16 shows the emissions from the cement and lime sectors assumed in 2015.

⁵⁷ Government of British Columbia (2021). *Provincial Inventory of Greenhouse Gas Emissions 1990-2019*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

⁵⁸ Environment and Climate Change Canada (annual). *National Inventory Report: Greenhouse Gas Sources and Sinks in Canada*. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

⁵⁹ Statistics Canada (annual). *Annual Industrial Consumption of Energy Survey*. Available from: www.statcan.gc.ca

Table 16: Cement and lime manufacturing emissions in 2015 (MtCO_{2e})

IPCC category	Stationary combustion	Industrial processes	Total
End-use	Process heat (high-grade heat)	Limestone calcination	
Cement manufacturing	0.6	1.0	1.7
Lime manufacturing	0.1	0.2	0.3
Total	0.7	1.2	1.9

Agriculture and forestry

Emissions from BC's agriculture and forestry sector are disaggregated into the following sources (please note that emissions associated with afforestation and deforestation as well as other land use are not included in the modelling):

- Stationary combustion (0.4 MtCO_{2e} in 2015). These emissions are primarily assumed to be for process heat.
- Transport (0.6 MtCO_{2e} in 2015). Transport emissions associated with agriculture and forestry are discussed in greater detail in Section 3.2.2. However, emissions associated with farm tractors and forestry equipment are allocated to agriculture and forestry as an end-use.
- Enteric fermentation (1.4 MtCO_{2e} in 2015). Enteric fermentation refers to methane emissions from the digestive process in livestock.
- Manure management (0.4 MtCO_{2e} in 2015). This refers to managing manure from livestock.
- Agricultural soils (0.3 MtCO_{2e} in 2015). The application of synthetic fertilizers causes the emission of nitrous oxide, which is a potent GHG.

Table 17 summarizes the sources of emissions for each agriculture and forestry sector. Please note Navius has aggregated some of the agriculture sectors together in the table.

Table 17: Agriculture sector emissions in 2015 (MtCO_{2e})

IPCC category	Stationary combustion	Transport	Agriculture			Total (excluding transport)
End-use	Process heat (high-grade heat)	Transport	Agricultural soils	Manure management	Enteric fermentation	
Animal production	-	-	0.1	0.4	1.4	1.9
Crop production	-	-	0.2	-	-	0.2

On-farm fuel use	0.4	0.1	-	-	-	0.4
Forest resources	-	0.5	-	-	-	-
Total (excluding transport)	0.4		0.3	0.4	1.4	2.4

Other manufacturing industries

Emissions from most other sectors (e.g. pulp and paper, food and beverage manufacturing) are assumed to be exclusively from fuel combustion used for producing process heat. These assumptions are shown in Table 18. As a reminder, the modelling includes other end-uses that provide energy-related services but don't result in direct emissions (e.g. black liquor in the pulp and paper sector, and electric only end uses such as lighting).

Table 18: Other manufacturing sector emissions in 2015 (MtCO_{2e})

IPCC category	Stationary combustion		Industrial processes			Total
	Process heat (high-grade heat)	Process heat (low-grade heat)	Industrial cogeneration	Hydrogen production	Limestone calcination	
Food	0.1	0.1	-	-	-	0.3
Beverage	0.0	0.0	-	-	-	0.0
Clothes and textiles	0.0	0.0	-	-	-	0.0
Wood products	0.1	0.5	-	-	-	0.6
Pulp and paper	1.5	0.3	-	-	-	1.8
Coal products	-	-	-	-	-	-
Chemicals	0.3	0.0	-	0.1	0.0	0.5
Plastics	0.0	0.0	-	-	-	0.0
Other non-metallic minerals	0.1	-	-	-	-	0.1
Steel	0.0	0.0	-	-	-	0.0
Other smelting	0.4	0.0	-	-	0.4	0.8
Foundries	0.1	-	-	-	-	0.1
Fabricated metals	0.1	0.0	-	-	-	0.1
Machinery	0.0	0.0	-	-	-	0.1
Electronics	0.0	0.0	-	-	-	0.0
Vehicles	0.0	0.0	-	-	-	0.0
Other	0.0	0.0	-	-	-	0.0
Total	2.9	1.0	-	0.1	0.4	4.5

Construction

BC's construction industry is assumed to emit GHGs from two sources:

- Stationary combustion (0.1 MtCO_{2e} in 2015). The exact origin of combustion emissions is not available from public data, but Navius has treated all these emissions as originating from process heat, in part because stationary combustion emissions outside of process heat are relatively small. In reality, however, some of these emissions are likely to originate from operating electricity generators, compressors, etc.
- Transport (0.4 MtCO_{2e} in 2015). These emissions are from off-road vehicles. Freight transport is not included here and is covered in Section 3.2.2.

Table 19 shows estimated emissions from the construction sector in 2015.

Table 19: Construction sector emissions in 2015 (MtCO_{2e})

IPCC category	Stationary combustion	Industrial processes	Total (excluding transport)
End-use	Process heat	Transport	
Construction	0.1	0.3	0.1

Emissions abatement opportunities

The discussion above identified many different sources of emissions. The majority of these are modelled to have abatement opportunities, which are summarized along with their data sources in Table 20. Abatement opportunities associated with the transport emissions in mining, agriculture, and construction are discussed in Section 3.2.2.

Table 20: Abatement opportunities in the industry sector and the data sources used to characterize them

Activity	2015 GHG emissions (MtCO _{2e})	Key GHG abatement opportunities	Data sources (see reference list in section 3.2.4)
Stationary combustion			
Electricity generation	0.3	Renewables	See Section 2.2.2
		Electricity efficiency	gTech
High-grade process heat	7.3	Fuel switching	Park et al (2017), CIMS
		CCS	CIMS
		Biomass and RNG	DENA (2016)
		Electric resistance	Park et al (2017), CIMS
Low-grade process heat	1.0	Fuel switching	Park et al (2017), CIMS
		CCS	CIMS
		Biomass and RNG	DENA (2016)
		Electric heat pumps	Onmen et al (2015)

Compression	5.7	Electrification	Greenblatt (2015)
		Electrification of LNG	ABB (2010)
Industrial cogeneration	0.2	No cogeneration	gTech
Fugitive sources			
Coalbed methane	0.9	No abatement available	-
Vents and leaks	2.1	Various leak detection and reduction measures	ICF International (2015), Clearstone Engineering (2014)
Formation CO ₂	1.5	CCS	CIMS
Flaring	0.6	For oil facilities: Natural gas production	Johnson & Coderre (2012)
		For natural gas facilities: no abatement	-
Industrial processes			
Hydrogen production	0.2	CCS	USA DOE (2014a)
		Electrolysis	USA DOE (2014a)
Limestone calcination	1.7	No abatement available	-
Aluminum CO ₂	0.2	No abatement available	-
Aluminum PFCs	0.3	Computer controls to reduce PFCs	CIMS
Other processes	0.0	No abatement available	-
Agriculture			
Enteric fermentation	1.4	No abatement available	-
Manure management	0.4	Anaerobic digestion to produce RNG	IEA ETSAP (2013)
Agricultural soils	0.3	No abatement available	-
Waste			
Industrial wood waste	1.4	Biocover oxidation	-

3.2.2. Transport

Sector activity

In gTech, transport activity is not an external assumption, but purely a result of the model. Transport activity is determined by the model based on the demand for transport from each sector (including households). For example, the mining sector requires a certain amount of freight to transport its mined material. If mining activity were to double, it would demand twice the amount of freight activity. Likewise, a growing number of households will demand more passenger travel by car, transit, air, etc. This also applies to the off-road transport identified in Section 3.2.1.

The forecasted transport sector activity is shown for a variety of modes in Table 21. Activity in each mode may depend on demand from multiple sectors. For example,

agriculture, mining, and construction all require freight transport. Likewise, households, courier services, and taxis all require the use of passenger vehicles.

Table 21: Transport sector activity in selected years in the calibration scenario

Sector	Unit	2015	2020	2025	2030	Source
Truck	Index (2015 = 1)	1.00	1.06	1.19	1.19	gTech
Passenger vehicles	Index (2015 = 1)	1.00	1.08	1.23	1.33	gTech
Transit	Index (2015 = 1)	1.00	1.08	1.23	1.34	gTech
Air	Index (2015 = 1)	1.00	1.08	1.25	1.34	gTech
Rail	Index (2015 = 1)	1.00	1.16	1.31	1.52	gTech
Other transport	Index (2015 = 1)	1.00	1.16	1.23	1.20	gTech

Sources of emissions

Table 22 identifies key sources of transport GHG emissions in 2015, the model's start year. These emissions are those reported by gTech, which have been calibrated to the *BC Provincial Inventory of Greenhouse Gas Emissions*⁶⁰.

Most emissions in the sector (24.4 MtCO₂e in 2015) result from the combustion of fossil fuels (e.g. gasoline, diesel, aviation fuels, etc.) to provide motive power across various transport modes. A smaller amount (0.3 MtCO₂e) is categorized under "industrial processes and product use"; these emissions are hydrofluorocarbons (HFCs) associated with air conditioning in vehicles.

The largest sources of combustion emissions are light-duty, medium-duty, and heavy-duty road vehicles, which together (both passenger and freight) account for 18.5 MtCO₂e of total transport sector combustion emissions in 2015. Marine navigation, aviation, and railways account for most remaining emissions.

The various transport modes are largely independent from one another in gTech (i.e. the activity in one doesn't directly affect the activity in another). One exception is the choice between light-duty vehicle travel and transit, which is captured by gTech. Therefore, an increase in the price of light-duty vehicle travel will (all else being equal) result in less travel via light-duty vehicles and more travel via transit (which includes buses and light-rail transit).

⁶⁰ Government of British Columbia (2021). *Provincial Inventory of Greenhouse Gas Emissions 1990-2019*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

Table 22: GHG crosswalk for the transport sector in 2015 (MtCO₂e)

Sector	Transport	Industrial processes and product use	Total
Total	24.4	0.3	24.7
Light-duty vehicles	8.7	0.1	8.9
Heavy-duty vehicles	5.0	0.1	5.2
Medium-duty vehicles	4.7	0.0	4.8
Buses	0.4	0.0	0.4
Domestic navigation	1.2	0.0	1.2
Domestic aviation	1.3	0.0	1.3
Railways	1.8	0.0	1.8
Other transport	1.1	0.0	1.1

Several of the transport end-uses include “nested” end-uses that provide gasoline and diesel services. For example, light-duty vehicles do not consume gasoline directly in the model but consume a gasoline service which can be met with fossil-based gasoline or various types of renewable gasoline substitutes (e.g. ethanol or renewable gasoline). Likewise, heavy-duty vehicles, buses, and railways consume a diesel service that allows fuel switching to be simulated. Medium-duty vehicles demand either gasoline or diesel services.

Emissions abatement opportunities

gTech models several ways for reducing transport emissions:

- The adoption of more energy-efficient vehicles that use less gasoline or diesel.
- The adoption of natural-gas-powered vehicles.
- The adoption of plug-in electric light-, medium-, and heavy-duty vehicles.
- The adoption of hydrogen fuel-cell vehicles.
- The blending of renewable fuels into the gasoline, diesel, and other fossil-fuel pools.
- Switching from light-duty passenger vehicles to transit.

Table 23 summarizes sources used to parameterize transport abatement opportunities in the model.

Table 23: Abatement opportunities in the transport sector and the data sources used to characterize them

Activity	2015 GHG emissions (MtCO ₂ e)	Key GHG abatement opportunities	Data sources (see reference list in Section 3.2.4)
Transport			
Light-, medium-, and heavy-duty vehicles	18.5	Efficiency improvements	DOE (2003), Transport Canada (2011), NRCan (2007)
		Natural gas	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), Hallbar Consulting (2016)
		Electrification	Nykvist et al (2019), Bloomberg (2017), Moawad et al (2016), Argonne (2018), Curry (2017), USA 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), Hallbar Consulting (2016)
		Hydrogen	NREL (2018), Strategic Analysis Consultants (2016; 2017), IEA (2019a)
Domestic marine	1.2	Efficiency improvements	CIMS
Domestic aviation	1.3	No abatement options are available	CIMS
Railways	1.8	Renewable fuels	See list for renewable fuels above
Industrial processes and product use			
Light-, medium-, and heavy-duty vehicles	0.3	Abatement is fixed to align with the federal policy to reduce HFCs	-

3.2.3. Buildings and communities

Sector activity

As with transport, activity in the buildings and communities sector is not an assumption, but a result of the model. The forecasted activity is shown for the service industry (commercial and institutional buildings), residential buildings, and municipal waste in Table 24.

Table 24: Buildings and communities sector activity in selected years in the calibration scenario

Sector	Unit	2015	2020	2025	2030	Source
Buildings						
Service industry	Million m ²	102	114	128	137	gTech
Residential	Million m ²	280	318	347	364	gTech
Single-family detached	Million m ²	189	210	225	233	gTech
Single-family attached	Million m ²	33	39	44	48	gTech
Apartments	Million m ²	59	69	78	84	gTech
Waste						
Municipal waste	Index 2015 = 1	1.0	1.01	0.91	0.87	gTech

Building floor space increases based on the historical relationship between floor space and GDP or household income, with historic floorspace informed by NRCAN's Comprehensive Energy Use Database. Waste activity is aligned to historical trends and is forecasted based on policies targeting landfill emissions.

Building floor space is further disaggregated into different types of buildings. Commercial and institutional buildings are split into six categories: food (7% of floorspace), office (38%), retail (17%), schools (13%), warehouses (4%), and other (21%). The share of these different building types remains constant over time.

Residential buildings are split into three categories: single-family detached, single-family attached, and apartments. The share of floor space attributable to single-family detached homes decreases from 67% in 2015 to 64% in 2030 in the calibration scenario, while the share of floor space from attached homes rises from 12% to 13% in 2030 and apartments rises. This shift is simulated by the model, but also aligns well with historical trends.

Each of these nine categories of building in the model (six commercial/institutional and three residential) are disaggregated into six vintages with representative building shell archetypes (three for new buildings, which are aligned with different levels of the BC Energy Step Code, and three for existing buildings): new near-zero emissions, new efficient, new basic, pre-2015 & post-2000, pre-2000 & post-1980, and pre-1980

Sources of emissions

Table 25 identifies the key sources of GHG emissions from the buildings and communities sector in 2015, the model's start year. These emissions are those reported by gTech and reflect (1) the *Provincial Inventory of Greenhouse Gas Emissions* and (2) additional calibration effort to attribute these emissions to specific end-uses based on Natural Resources Canada's *Comprehensive Energy Use Database*.

Emissions come from several key sources:

- The combustion of natural gas for space heating in both residential and commercial buildings (4.3 MtCO_{2e} in 2015).
- The combustion of natural gas for water heating (1.8 MtCO_{2e} in 2015).
- The release of HFCs from air conditioning and auxiliary equipment (1.1 MtCO_{2e} in 2015).
- The release of methane from landfills as organic matter in municipal waste decomposes or is incinerated (2.4 MtCO_{2e} in 2015).

Table 25: GHG crosswalk for the buildings and communities sector in 2015 in the calibration scenario (MtCO_{2e})

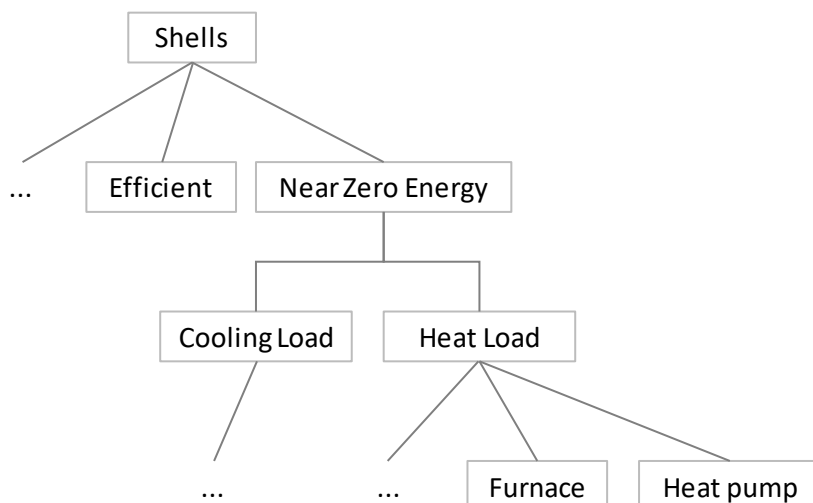
Sector	Stationary combustion	Industrial processes and product use	Waste	Total
Total buildings and communities	6.2	1.1	2.6	9.7
Buildings	6.2	1.1	-	7.3
Service industry	2.4	0.9	-	3.4
Space heating	2.0	-	-	2.0
Water heating	0.4	-	-	0.4
Air conditioning	-	0.2	-	0.2
Auxiliary equipment	-	0.7	-	0.7
Residential buildings	3.7	0.2	-	3.9
Space heating	2.3	-	-	2.3
Water heating	1.4	-	-	1.4
Air conditioning	-	0.2	-	0.2
Cooking	0.1	-	-	0.1
Clothes drying	0.0	-	-	0.0
Waste	-	-	2.4	2.4
Municipal waste	-	-	2.4	2.4

Interactions between end-uses

More so than in other sectors, the model captures relationships between end-uses in the buildings sector. gTech simulates the interactions between (1) the efficiency of residential/commercial building shells and the requirement for heat load; and (2) hot water requirements from clothes washers and dishwashers and the requirement for hot water.

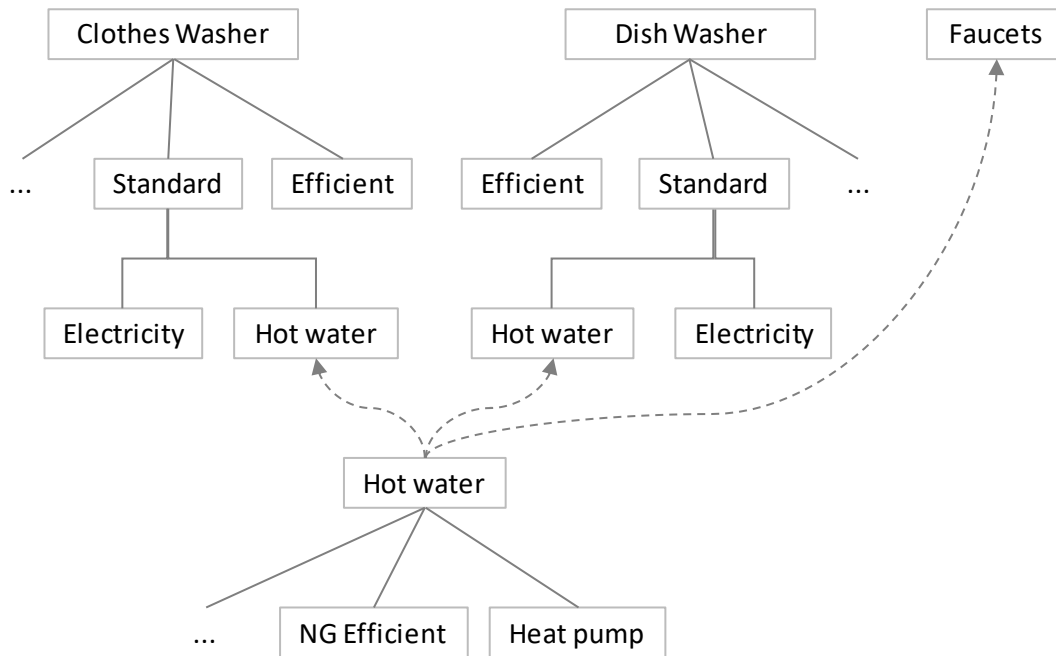
Figure 7 shows the relationship between various end-uses in the commercial building sector (the relationships for residential buildings are similar, but slightly more complicated). gTech simulates three decisions that affect building efficiency and GHG emissions. At the top level, gTech simulates the choice between shells of different levels of efficiency. The efficiency ranges from shells that were built prior to 1980 to a “near-zero-energy” building. Each building shell has a specific requirement for cooling and heat load. In general (but not always) more efficient buildings have lower cooling and heating requirements. At the bottom level, gTech simulates the choice of heating system. For example, space heating can be met with a heat pump or a natural gas furnace, among other options.

Figure 7: Commercial space conditioning end-uses



In the residential sector, hot water is not demanded directly by households, but it is demanded by three end-uses that consume hot water: (1) clothes washers, (2) dish washers, and (3) faucets. For clothes and dish washers, gTech simulates the choice between different types of technologies that have different hot water requirements. So, one option for reducing emissions from hot water production is to adopt clothes or dish washers with lower hot water requirements. See Figure 8 for a schematic of the demand for hot water.

Figure 8: Residential demand for hot water



Emissions abatement opportunities

gTech models the following ways to reduce GHG emissions in the buildings and communities sector:

- The adoption of more thermally efficient building shells.
- Improvements to the energy efficiency of natural gas furnaces and boilers.
- Blending renewable natural gas (RNG) and hydrogen into the natural gas distribution network.
- The adoption of electric space and water heating (resistance and heat pump).
- The adoption of more efficient appliances (e.g. clothes washers and refrigerators).
- The capture of methane from landfills for flaring, generating electricity, or supply into the natural gas distribution network.
- The diversion of organic waste from landfills.

These technologies do not always lead to GHG reductions, a dynamic which is captured by gTech. For example, improving the thermal efficiency of a building shell won't reduce space heating emissions if that building uses electric heating. While it would reduce demand for electricity, the impact on electricity emissions is small given the low GHG intensity of electricity generation in BC.

Table 26 summarizes sources used to parameterize abatement opportunities in the buildings and communities sector in the model.

Table 26: Abatement opportunities in the buildings and communities sector and the data sources used to characterize them

Activity	2015 GHG emissions (MtCO ₂ e)	Key GHG abatement opportunities	Data sources (see reference list in Section 3.2.4)
Stationary combustion			
Space heating	4.3	Thermal improvements to building shells	RDH (2018)
		More energy efficient natural gas furnaces and boilers	EIA (2016), NREL (2018)
		RNG	IRENA (2013), APEC (2010), AAFC (2017), Kludze et al (2013), Yemshanov et al (2014), (S&T) ² Consultants, (2012), Chavez-Gherig et al (2017), G4 Insights (2018), IEA ETSAP (2013), Hallbar Consulting (2016)
		Hydrogen	NREL (2018), IEA (2019a)
		Electric space and water heating (resistance and heat pump)	EIA (2016), NREL (2018)
Water heating	1.8	More energy efficient natural gas water heaters and boilers	EIA (2016), NREL (2018)
		RNG	See list for renewable gas above
		Electric water heaters (resistance and heat pump)	EIA (2016), NREL (2018)
Cooking	0.1	Electric ranges or renewable gas	EIA (2016), NREL (2018)
Industrial processes and product use			
Air conditioning	0.4	Thermal improvements to building shells	RDH (2018)
		Abatement is fixed to align with the federal policy to reduce HFCs	
Auxiliary equipment	0.7	Efficiency	CIMS
Waste			
Municipal waste	2.4	Capture of methane for flaring, generating electricity, or supply into the natural gas distribution network	BC (2017)
		Organic waste diversion	BC (2017)

3.2.4. Reference list for sector assumptions

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3.3. Technology choice

The previous section identified various pathways for reducing GHG emissions that are included in the model. These pathways are represented as technologies, which households and firms can select in order to alter their GHG profile.

gTech is unique among CGE models in that it is technologically explicit. Technological choice in gTech is represented using a "constant elasticity of substitution" (CES) production function, which models the ability of demand for a given end-use to be met by several distinct technologies. The production function is specified as:

$$Y = \gamma \left(\sum_t \alpha_t T_t^\rho \right)^{\frac{1}{\rho}}$$

where Y is the physical consumption of an end-use in units specific to that end-use, γ is a unitless constant production adjustment factor; α_t is a unitless distribution parameter specific to each technology t available for the end-use in question; T_t is the physical consumption of each technology t in the same units as Y ; ρ is a unitless parameter representing the substitutability between the different technologies t where

$\rho = 1 - 1/\sigma$; and σ is the elasticity of substitution between the different technologies t .

Skipping several steps, and assuming that a firm minimizes its costs or that a household maximizes its utility, the conditional demand for a specific technology can be estimated as:

$$T_t = \left[\sum_{tt} \alpha_{tt} \left(\frac{P_{tt}}{\alpha_{tt}} \right)^{\frac{\rho}{\rho-1}} \right]^{-\frac{1}{\rho}} \left(\frac{P_t}{\alpha_t} \right)^{\frac{1}{\rho-1}} \left(\frac{Y}{\gamma} \right)$$

where P_t is the price or life-cycle cost for technology t and all other parameters and variables are defined above (t indicates a specific value corresponding to the specific technology of T_t and tt indicates a value for each technology available for the end-use in question).

From the conditional demand function, the market share for each technology can be estimated as:

$$M_t = \frac{T_t}{\sum_{tt} T_{tt}} = \frac{\left(\frac{P_t}{\alpha_t} \right)^{-\sigma}}{\sum_{tt} \left(\frac{P_{tt}}{\alpha_{tt}} \right)^{-\sigma}}$$

where M_t is the market share of technology t as a unitless fraction, and all other parameters and variables are defined above. This function aligns with the market share equation from the CIMS technology simulation model in which the distribution parameter (α_t) is equally allocated to all technologies (i.e. $\alpha_t = 1/\sum_t(1)$). Making this adjustment, the market share equation can be rewritten as:

$$M_t = \frac{P_t^{-\sigma}}{\sum_{tt} P_{tt}^{-\sigma}}$$

The price for each technology in year y ($P_{t,y}$) is a function of its annualized capital costs, fuel costs, and various policy-induced costs/benefits. These latter costs can be anything: carbon pricing, the constraints imposed by various regulations, etc.

$$P_{t,y} = c_{t,y} \times \frac{r}{1 - (1+r)^{-l_t}} + \sum_f (F_{t,f} \times p_f) + \sum_p (M_{t,m} \times s_p)$$

where $C_{t,y}$ is technology t 's capital cost in year y , r is the unitless discount rate used to amortize capital costs, l_t is the lifespan of technology t in years, $F_{t,f}$ is the amount

of each fuel f required by technology t , p_f is the price (cost per amount) of fuel f (which is determined by gTech), $M_{t,m}$ is the requirement for technology t imposed by policy measure m , and s_m is the explicit or implicit (shadow) price of policy measure m (which is determined by gTech, for example extra production costs incurred by complying with emissions standards).

Technological and behavioral dynamics are introduced into the technological choice decision in the following ways:

- Household and firm implicit time preference (see Section 2.2.1) is incorporated through the discount rate (r).
- Market heterogeneity is incorporated through the elasticity of substitution between technologies (σ).
- Intangible costs and preferences are incorporated via the distribution parameters (α_t).
- Declining capital costs are introduced via altering a technology's capital cost over time ($c_{t,y}$).

4. Reference scenario policies

The impact of CleanBC is measured relative to a reference scenario including only policies announced as of July 2017. This section provides a summary of how these policies are modelled. These policies include those implemented provincially (such as the *Clean Energy Act*) as well as those implemented federally that apply to BC (e.g. the *Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations*).

The forecast also includes policies implemented in other jurisdictions, such as carbon pricing (e.g. Québec’s cap-and-trade system and the federal carbon pricing backstop in jurisdictions with no carbon pricing policy), Alberta’s accelerated coal phase-out, and Québec’s ZEV mandate.

Including policies in other jurisdictions is important because they may have several types of impacts on BC:

- **Policy interaction effects.** The implementation of provincial policies can affect the stringency of federal policies in BC. For example, the ZEV mandate in Québec will improve the fleet average fuel economy of vehicles in that province, allowing auto manufacturers to sell less efficient vehicles in other provinces while still complying with the federal vehicle emissions standard.
- **Income and substitution effects.** Policies in other jurisdictions can change the types of goods or services exported from BC and/or the cost of imports from other jurisdictions.
- **Competitiveness effects.** Policies in other jurisdictions can influence competitiveness pressures on firms in BC.

4.1. Multi-sector

4.1.1. Carbon tax

BC’s carbon tax was implemented in the *Carbon Tax Act*⁶¹, in 2008. The tax applies to the purchase and use of fossil fuels, with some exemptions. The tax was first

⁶¹ SBC 2008, Chapter 40. *Carbon Tax Act*, 2008. Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/08040_01

implemented, at a rate of \$10/tCO_{2e}, increasing by \$5/tCO_{2e} per year, until reaching \$30/tCO_{2e} in 2012. The modelling of the reference scenario begins in 2015 and assumes that the carbon tax is set at \$30/tCO_{2e}. The analysis also assumes revenue raised by the tax is used to lower personal and corporate income taxes and transferred directly to households through rebates. Fuels exempt in the analysis include fuels not combusted but rather used as raw materials in chemical process as well as fuels purchased by agricultural sectors.

4.1.2. Clean electricity mandate

The clean electricity mandate was implemented in 2010 in the *Clean Energy Act*⁶². It requires that a minimum of 93% of provincial electricity generation be provided by clean or renewable sources. BC has generally exceeded this legal requirement in recent years with current levels reaching 98%⁶³. The modelling assumes the current level of 98% is maintained to 2030 and includes the requirement that BC be electricity self-sufficient.

4.1.3. Hydrofluorocarbon regulations

The modelling requires that HFCs are reduced relative to 2015 by 10% in 2020, 40% by 2025, and 70% by 2030.

4.2. Industry

4.2.1. Cement Low-Carbon Fuel Program

The Cement Low-Carbon Fuel Program provided support for the cement industry to reduce its emissions using funding provided in Budget 2015⁶⁴. The modelling assumes a total of \$27 million of investments enabling increased use of low-carbon

⁶² SBC 2010, Chapter 22. *Clean Energy Act*, 2010. Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/10022_01

⁶³ BC Hydro (2022), *2021/22 Annual Service Plan Report*. Available from: www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/accountability-reports/financial-reports/annual-reports/21-22-bc-hydro-annual-service-plan-report-final.pdf

⁶⁴ Government of British Columbia (2015). *Budget 2015*. Available from: www.bcbudget.gov.bc.ca/default.htm

fuels; and payments for achievement of annually decreasing emissions intensity benchmarks.

4.3. Transport

4.3.1. Clean vehicle incentives

The Clean Energy Vehicle Program provides funding for zero- and low-emissions vehicles⁶⁵. The modelling assumes incentives of \$40 million in total spread over 2016-2020.

4.3.2. Low-Carbon Fuel Standard

The LCFS was enacted in the *Greenhouse Gas Reduction (Renewable & Low Carbon Fuel Requirements) Act*⁶⁶ and the *Renewable and Low Carbon Fuel Requirements Regulation*⁶⁷ in 2008, and amended several times up to 2017.

The modelling includes two components from this policy:

- a minimum renewable fuel content for gasoline (5% by volume) and diesel (4% by volume); and
- a decrease in the average life-cycle emissions intensity of transport fuels by 9.1% by 2020 relative to 2010, growing to 10% in 2030.

The second component of the LCFS is unique among existing BC policies in that it is a “flexible regulation”. Rather than require a group of fuels to be purchased, the policy establishes a “market” for compliance, and allows market participants to trade their compliance obligations among each other. As such, this type of policy can only be accurately simulated in a modelling environment such as gTech that can simulate how markets arrive at an equilibrium.

⁶⁵ www.gov.bc.ca/zeroemissionvehicles

⁶⁶ SBC 2008, Chapter 16. *Greenhouse Gas Reduction (Renewable & Low Carbon Fuel Requirements) Act*, 2008. Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/08016_01

⁶⁷ BC Reg. 394/2008. *Renewable and Low Carbon Fuel Requirements Regulation*. Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/394_2008

4.3.3. Light-duty vehicle emissions standards

New light-duty passenger vehicles sold in Canada must meet retailer fleet-wide GHG emissions standards aligned to those in the USA. Cars and light trucks face different standards. These standards were implemented in the federal *Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations*⁶⁸ in 2010 for vehicle model years 2012 to 2016 and in an amendment in 2014 for vehicle model years 2017 onwards. The federal regulations refer directly to the *USA Code of Federal Regulations*⁶⁹ for the standards for the 2017 vehicle model year onwards.

The modelling assumes a weighted average requirement (i.e. accounting for the current share of cars and light trucks) declining from 200 g/km in 2015, to 167 g/km in 2020, to 133 g/km in 2030.

4.3.4. Heavy-duty vehicle emissions standards

The *Heavy-Duty Vehicle and Engine Greenhouse Gas Emissions Regulation* requires new heavy-duty vehicles sold in Canada meet fleet-wide GHG emissions standards from 2014⁷⁰. The modelling assumes that GHG emissions from 2018 model-year vehicles are reduced by an average of 10%.

4.4. Buildings and Communities

4.4.1. Electricity provincial sales tax exemption

The BC provincial sales tax (PST) is a retail sales tax that applies when taxable goods or services are purchased, acquired, or brought into BC. The modelling assumes that purchases of electricity for all end-users is excluded from the PST. This policy will be revised for future modelling as this exemption was not announced prior to July 2017, the cut-off date for policies included in the reference scenario (see paragraph at beginning of this chapter for a description of the reference scenario).

⁶⁸ SOR/2010-201. *Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations*. Available from: www.laws-lois.justice.gc.ca/eng/regulations/sor-2010-201/index.html

⁶⁹ *Code of Federal Regulations. Title 40: Protection of Environment, Part 86—Control of Emissions from New and In-Use Highway Vehicles and Engines. Subpart S*. Available from: www.ecfr.gov/cgi-bin/text-idx?SID=1cb63f280ad4797d2d330f189a2f114f&mc=true&node=se40.21.86_11818_612

⁷⁰ SOR/2013-24. *Heavy-Duty Vehicle and Engine Greenhouse Gas Emission Regulations*. Available from: www.laws-lois.justice.gc.ca/eng/regulations/sor-2013-24/index.html

4.4.2. Energy efficiency regulations

Federal standards exist for new space conditioning equipment, water heaters, household appliances, and lighting products. The standards were implemented in the federal *Energy Efficiency Regulations*⁷¹ in 2016. The modelling accounts for these standards by including a minimum annual fuel utilization efficiency of 90% for natural gas furnaces, a minimum energy factor of 0.61 for gas water heaters, and a ban on incandescent light bulbs.

4.4.3. BC Building Code

The BC Building Code is a provincial regulation containing standards for new construction, building alterations, repairs, and demolitions. Energy efficiency was first introduced as a BC Building Code objective in 2008. The version of the Code included in the reference scenario is the BC Building Code 2012⁷², first adopted in December 2012 and amended several times up to April 2017. This policy is modelled by requiring that new residential buildings demand 43% less space heating load than the average residential building in 2010, and new commercial buildings demand 32% less space heating load.

4.4.4. Organic waste diversion

Organic waste diversion is implemented at the local government level with large variation in diversion rates.

In the reference scenario, the modelling assumes that 30% of organic municipal, agricultural, and industrial waste (excluding industrial wood waste) is diverted from landfills by 2025, and that this rate is maintained indefinitely.

4.4.5. Landfill gas management regulations

Landfills that generate at least 1,000 kt of methane a year are required to install landfill gas management facilities and implement management practices to collect the gas in accordance with a design plan approved by the BC Government, and ensure it is either flared or used. These requirements were implemented in the *Landfill Gas*

⁷¹ SOR/2016-311. *Energy Efficiency Regulations*. Available from: www.laws-lois.justice.gc.ca/eng/regulations/SOR-2016-311

⁷² Government of British Columbia (2012). *British Columbia Building Code 2012*. Available from: www.bccodes.ca/building-code.html

*Management Regulation*⁷³ in 2008. The modelling assumes that 40% of landfill gas (excluding from industrial wood waste landfills) is captured by 2020, and that this capture rate is maintained indefinitely.

⁷³ BC Reg. 391/2008. *Landfill Gas Management Regulation*. Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/391_2008

5. CleanBC policies

This section describes CleanBC policies, expanding on details summarized in Table 2 at the beginning of the report. As several policies are still in development, their final design may differ from the assumptions used to model them at this time. Additionally, some policy options selected by government are adjusted to account for other factors not represented in gTech. Differences are noted as appropriate throughout and summarized in Section 6.

Multi-sector

5.1.1. Strengthened carbon tax

In 2018, BC's price on carbon increased for the first time since 2012 to \$35/tCO_{2e}. The government further committed to raise the price to \$170/tCO_{2e} by 2030 (see Table 27 for tax rate schedule).

In the modelling, the carbon price signal is represented as an incentive for firms and consumers to reduce their GHG emissions by investing in lower-carbon technologies, switching to lower-carbon fuels or otherwise making choices that reduce their carbon tax payments.

In the modelling, revenue from the carbon tax is divided into three streams:

- **Carbon revenue raised from the carbon tax at \$30/tCO_{2e}.** Under CleanBC, revenue earned from the carbon tax below \$30/tCO_{2e} goes to general revenue. However, government has not reversed the personal income tax cuts that had been associated with the previous carbon tax design, and so Navius has kept the portion of revenue used to cut personal income taxes and provide the climate action tax credit in the model.
- **Carbon revenue raised from the carbon tax above \$30/tCO_{2e} on households.** Revenue above \$30/tCO_{2e} is transferred to households via lump-sum transfers. This change reflects the BC government's intention to provide carbon tax relief for low- and moderate-income families.
- **Carbon revenue raised from the carbon tax above \$30/tCO_{2e} on businesses** is used to fund several initiatives to reduce GHG emissions in industry and businesses (discussed below in Section 5.2.1).

Table 27: Carbon tax rates by year under CleanBC

Financial year	Model year	Carbon tax rate (\$/tCO _{2e})
2015/16	2015	30
2016/17		30
2017/18		30
2018/19		35
2019/20		40
2020/21	2020	40
2021/22		45
2022/23		50
2023/24		65
2024/25		80
2025/26	2025	95
2026/27		110
2027/28		125
2028/29		140
2029/30		155
2030/31 onward	2030 onward	170

5.1.2. Strengthened clean electricity mandate

The analysis assumes that by 2030, 100% of electricity produced in BC is required to be clean. This is an increase from the 93% legally required and 98% assumed in the modelling of the reference scenario (see Section 4.1.2 for standards under the reference scenario). Additionally, the analysis includes federal electricity requirements announced in the *2030 Emissions Reduction Plan*⁷⁴. The modelling assumes that on average by 2030 90% of electricity generation in Canada is produced using non-emitting sources.

5.1.3. Household fuel provincial sales tax exemption

The BC provincial sales tax (PST) is a retail sales tax that applies when taxable goods or services are purchased, acquired, or brought into BC. From 2019, the modelling assumes the exemption of all residential fuels and all electricity consumed by commercial and industrial users from the PST.

⁷⁴ Government of Canada (2022). *2030 Emissions Reduction Plan*. Available from: www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

5.1.4. BC Hydro's electrification plan

BC Hydro released an electrification plan⁷⁵ in September 2021, outlining new programs and incentives to advance the switch from fossil fuels to electricity in buildings, transportation and industry, and to attract new electricity customers to BC. The modelling assumes the following funding spread over 5 years starting in 2022:

- \$18 million towards buildings,
- \$30 million towards transportation,
- \$90 million towards industry, and
- \$20 million towards supporting the production of hydrogen.

Although the BC Hydro plan outlines additional resources for public education and plan implementation, no further funding is currently modelled because 1) impacts from funding public education are very uncertain, and 2) the BC Hydro plan does not currently give sufficient details on how plan implementation will be funded.

5.1.5. Natural gas utility greenhouse gas reduction standard

The analysis represents the natural gas greenhouse gas reduction standard (GHGRS), by assuming that in 2030, GHG emissions from the combustion of natural gas and propane are capped at an annual level of 6.0 MtCO₂e. This cap applies to GHG emissions from industry (excluding LNG and upstream oil and gas) and buildings. Navius models the GHGRS as an emissions cap, such that ratepayers experience an additional price signal to reduce consumption of natural gas until modelled emissions reach the specified target. The modelling requires revenue from the cap be recycled towards general government revenue.

Policy makers are considering including notional renewable gas as a compliance pathway under the GHGRS. This action would allow BC utilities to notionally purchase renewable gas outside of BC. Navius models this action by allowing BC to purchase renewable gas at an assumed price of \$27.35 per GJ. The price assumed is based on

⁷⁵ BC Hydro (2021). *BC Hydro's Electrification Plan: A Clean Future Powered by Water*. Available from: www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/electrification/Electrification-Plan.pdf

the weighted average pricing expectations from renewable gas contracts in negotiation as of summer 2022⁷⁶.

In summary, the modelling applies the GHGRS cap to the sum of:

- (1) GHG emissions within BC from the combustion of natural gas and propane (excluding emissions from oil and gas sectors).
- (2) GHG emissions abated as a result of notionally purchased renewable gas.

To represent long-term Canadian renewable gas contracts, the modelling assumes compliance with the GHGRS from the following annual levels of renewable gas for 2025 to 2030:

- A minimum of 30.5 PJ renewable gas consumed either domestically (i.e. within BC) or notionally attributed.
- A minimum of 6.1 PJ renewable gas consumed domestically (i.e. within BC).
- A maximum of 24.4 PJ renewable gas notionally attributed.

5.1.6. Federal climate funding

The modelling includes federal funding for various GHG emission abatement initiatives as announced in the December 2020 release of *A Healthy Environment and A Healthy Economy*⁷⁷, and the March 2022 release of *2030 Emissions Reduction Plan*⁷⁸. Funding programs target various sectors, including transportation, buildings, power generation, CCS, and Direct Air Capture. Examples of some of the federal initiatives modelled by Navis are described below:

- **Canada Infrastructure Bank Spending**⁷⁹: require invests in green infrastructure, public transit, and clean power.

⁷⁶ Navis received the weighted average price for renewable gas contracts in Canada directly from the BC government.

⁷⁷ Government of Canada (2020). *A Healthy Environment and a Healthy Economy*. Available from: www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/healthy-environment-healthy-economy.html

⁷⁸ Government of Canada (2022). *2030 Emissions Reduction Plan*. Available from: www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

⁷⁹ 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*.

- **Investment tax credit for Carbon Capture, Utilization, and Storage**⁸⁰: covers a portion of upfront costs for carbon capture, utilization, and storage, and Direct Air Capture.
- **Greener Homes Grant**⁸¹: \$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.
- **ZEV Charging Infrastructure Subsidy**⁸²: commits funding towards the deployment of zero-emission vehicle (ZEV) charging infrastructure.
- **Renewable Electricity Investments**⁸³: starting in 2021 commits funding over four years for renewable electricity generation.
- **Net Zero Accelerator**⁸⁴: 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.

5.2. Industry

5.2.1. CleanBC program for industry

The Program for Industry comprises the CleanBC Industrial Incentive Program (CIIP) and the CleanBC Industry Fund. The analysis assumes carbon revenue spent on the Program for Industry is used for several government priorities. In the modelling, all

Available from: <https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf>.

⁸⁰ 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>.

⁸¹ 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>

⁸² Government of Canada. (2022). Budget 2022. Available from: <https://budget.gc.ca/2022/report-rapport/chap1-en.html#2022-1>

⁸³ 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

⁸⁴ Government of Canada. (2021). Budget 2021. Available from: <https://www.budget.gc.ca/2021/home-accueil-en.html>.

carbon tax revenue collected from industry that is above \$30/tCO₂e is divided into the following categories:

- **Revenue from businesses that emit less than 10 ktCO₂e annually** are recycled back to the government as general revenue.
- **Revenue from businesses that emit at least 10 ktCO₂e annually (i.e. “large final emitters”)** is used in the following fashion:
 - **CleanBC Industrial Incentive Program.** This program provides an additional incentive for large emitters to reduce their emissions by providing increasing tax rebates as facilities lower their emissions intensity from an eligibility threshold to a performance benchmark. Already, the carbon tax provides an incentive for firms to reduce their GHG emissions, because as they do so they pay less tax. The CIIP provides an additional incentive by returning an increasing portion of carbon tax revenue for facilities as they reduce their emissions relative to a global best-in-class benchmark. The program is modelled as (1) a higher explicit carbon price based on facilities’ GHG intensity and (2) an output rebate to offset the higher carbon price. These values were set to align with current program benchmarks and thresholds⁸⁵.
 - **CleanBC Industry Fund.** Any remaining funds received by the program are used to invest in low-carbon technologies within large final emitters.

The choice of low-carbon technologies eligible for investment under the CleanBC Industry Fund was determined in consultation with the BC Government.

5.2.2. Industrial electrification

This policy represents the construction of new electricity transmission lines to supply the upstream natural gas sector with electricity. These projects include the Dawson Creek-Chetwynd Area Transmission (DCAT) project and the Peace Region Electricity Supply (PRES) project.

The modelling represents this policy as increased electricity consumption in the upstream natural gas sector. In the reference scenario, electricity demand is assumed to remain fairly constant from 2015 onwards. Under the CleanBC scenario, electrification in upstream natural gas from 2020 onwards is increased to represent expanded transmission.

⁸⁵ Government of British Columbia. (2022). CleanBC Industrial Incentive Program. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/industry/cleanbc-industrial-incentive-program

5.2.3. Oil and gas sector methane regulations

Starting in 2020, all new oil and gas facilities are required to implement a range of best practices and technologies for reducing methane leaks and venting (including surface casing vent flows). These requirements were implemented in an amendment to the *Drilling and Production Regulation*⁸⁶ in 2018. Additionally, by 2030, the modelling caps national methane emissions from the oil and gas sector to achieve a 75% reduction relative to 2014, in alignment with the federally announced policy in the 2030 Emissions Reduction Plan⁸⁷.

5.2.4. Oil and gas sectoral target

The Province has committed to implementing programs and policies such that oil and gas emissions are reduced in line with sectoral targets⁸⁸. By 2030, the analysis assumes a reduction in oil and gas sector GHG emissions by 33% relative to 2007 levels. The modelling requires the following sectors to be capped at a combined total of 8.9 MtCO₂e in 2030:

- Petroleum refining industries
- Oil and gas extraction (including LNG production up to 14 MTPA)
- Pipeline transport
- Oil leaks
- Natural gas leaks
- Venting
- Flaring

⁸⁶ BC Reg. 282/2010. *Drilling and Production Regulation*. Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/282_2010

⁸⁷ Government of Canada (2022). *2030 Emissions Reduction Plan*. Available from: www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

⁸⁸ Government of British Columbia (2021). *CleanBC Roadmap to 2030*. Available from: www.cleanbc.gov.bc.ca

5.3. Transport

5.3.1. Light-duty zero-emission vehicle sales mandate

The light-duty ZEV mandate was implemented in the *Zero-Emission Vehicles Act*⁸⁹ in 2019, followed by the supporting *Zero-Emission Vehicles Regulation*⁹⁰ in 2020. In the past year, the BC government has announced its intention to raise previously established light-duty ZEV targets even further⁹¹. The modelling follows the most stringent announced targets. For new light-duty vehicles sold in BC, the analysis requires 26% zero-emission vehicle sales by 2026, and 90% by 2030.

5.3.2. Heavy-duty zero-emission vehicle sales mandate

By 2030, the analysis requires 44% of on-road heavy-duty and 23% of medium-duty vehicles sold in BC be zero-emission. The modelling assumes 60% of these vehicles are battery electric and 40% hydrogen fuel cell. Additionally, the modelling follows the federal commitment in the *2030 Emissions Reduction Plan*⁹² to reach 35% ZEV sales nationally for medium- and heavy-duty vehicle sales by 2030.

⁸⁹ SBC 2019, Chapter 29. *Zero-Emission Vehicles Act*, 2019. Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/19029

⁹⁰ BC Reg 196/2020. *Zero-Emission Vehicles Regulation*. Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/196_2020

⁹¹ Government of British Columbia (2022). *BC Zero-Emission Vehicles Act and Regulation: 2022 Formal Review Intentions Paper*. Available from: www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/energy-efficiency/zeva_formal_review_intentions_paper_28july2022.pdf

⁹² Government of Canada (2022). *2030 Emissions Reduction Plan*. Available from: www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf

5.3.3. Heavy-duty zero-emission vehicle stock mandate

The modelling requires that from 2030 onwards, 19% of on-road heavy-duty vehicles in use are zero-emission. The modelling assumes 60% of these vehicles are battery electric and 40% are hydrogen fuel cell.

5.3.4. Zero-emission bus mandate

The analysis requires 100% of new buses sold be zero-emissions by 2029, with 41% of buses in use zero-emission by 2030. The modelling assumes 60% of these ZEVs are battery electric and 40% are hydrogen fuel cell.

5.3.5. Strengthened zero-emission vehicle incentives

In 2019, the Clean Energy Vehicle Program was renamed the Go Electric Program and continued to offer financial incentives for zero- and low-emissions vehicles. Details of the Program are available online⁹³.

The analysis assumes financial incentives for the purchase of low- and zero-emission vehicles of \$52 million in 2019, \$25 million in 2020, and \$93 million per year beginning in 2021.

Additionally, the modelling includes federal incentives for Zero-Emission Vehicles (iZEV) Program targeting low- to zero- emission vehicles. These incentives are up to \$5,000 for pure-electric, hydrogen fuel-cell, and longer-range (at least 50 km) plug-in hybrid vehicles, and up to \$2,500 for shorter-range plug-in hybrid vehicles.

5.3.6. Strengthened Low-Carbon Fuel Standard

The LCFS is currently being re-legislated, with a new *Low-Carbon Fuels Act*⁹⁴ passed in 2022, and new accompanying regulations planned to be approved in 2023 to come

⁹³ Government of British Columbia (2022). *Clean Transportation Policies and Programs*. Available from: www.gov.bc.ca/zeroemissionvehicles

⁹⁴ SBC 2022, Chapter 21. *Low-Carbon Fuels Act, 2022*. Available from www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/22021 (as the Act is not yet in force, see the third-reading Bill for its text: www.leg.bc.ca/Pages/BCLASS-Legacy.aspx#%2Fcontent%2Fdata%2520-%2520ldp%2Fpages%2F42nd3rd%2F3rd_read%2Fgov15-3.htm)

into force in January 2024. This new LCFS legislation will maintain the strengthened requirements for the gasoline and diesel fuel pools. Emissions intensity requirements for aviation and marine fuels are under consideration.

The analysis aligns with these strengthened targets, requiring that on average fuel suppliers reduce the life-cycle emissions intensity of transport fuel pools by 18.3% in 2025, and 30% in 2030 from 2010 levels. Aviation and marine fuels receive an additional separate requirement to reduce life-cycle emissions intensity by 0.5% by 2025 and 5.0% by 2030 from 2010 levels.

5.3.7. Strengthened light-duty vehicle emissions standards

New light-duty passenger vehicles sold in Canada must meet retailer fleet-average GHG emissions standards.

Cars and light trucks face different standards, which are further differentiated within the two categories by vehicle size. The lowest standard (for the smallest vehicles) and highest standard (for the largest vehicles) are given for each vehicle model year for both cars and light trucks in Table 28. gTech represents the different light-duty vehicle emissions standards as a single weighted-average standard, accounting for the share of cars and light trucks of each size. The average standard is given in Table 28 for each year that gTech resolves declining from 200 gCO₂e/km in 2015 to 107 gCO₂e/km in 2030.

Table 28: Light-duty vehicle GHG emissions standards (gCO₂e/km)

Vehicle model year	CleanBC				
	Cars		Light trucks		gTech average
	Lowest	Highest	Lowest	Highest	
2012	152	196	183	245	-
2013	147	191	176	239	-
2014	142	186	171	234	-
2015	135	179	162	225	200
2016	128	172	153	216	-
2017	121	163	148	216	-
2018	115	155	141	213	-
2019	109	148	137	211	-
2020	103	140	132	209	167
2021	101	137	128	205	-
2022	99	135	126	201	-
2023	90	124	113	194	-

2024	86	118	107	184	-
2025	81	111	99	172	119
2026	71	100	88	158	-
2027	71	100	88	158	-
2028	71	100	88	158	-
2029	71	100	88	158	-
2030	71	100	88	158	107

5.3.8. Strengthened heavy-duty vehicle emissions standards

New heavy-duty vehicles sold in Canada must meet retailer fleet-average emissions standards for carbon dioxide, methane, and nitrous oxide, starting with the 2014 vehicle model year. The standards were first implemented in the federal *Heavy-Duty Vehicle and Engine Greenhouse Gas Emission Regulations*⁹⁵ in 2013. More stringent standards for 2021 onwards were implemented in an amendment⁹⁶ in 2018.

The standards are modelled in gTech as a reduction in the average emissions intensity of medium- and heavy-duty vehicles of 20% by 2025 and 24% by 2030, relative to 2015.

5.3.9. Light-duty vehicle travel reduction

The analysis requires total vehicle kilometers travelled to decline by 25% by 2030, relative to 2020 levels. Policies able to achieve this reduction are in development. The aim of these policies is to increase walking, cycling, and transit use.

5.3.10. Freight energy intensity reduction

The analysis requires the energy intensity of freight (in tCO₂e/t·km) to be reduced 10% by 2030 relative to 2020 levels. Policies able to achieve this reduction are in development.

⁹⁵ SOR/2013-24. *Heavy-Duty Vehicle and Engine Greenhouse Gas Emission Regulations*. Available from: www.laws-lois.justice.gc.ca/eng/regulations/sor-2013-24/FullText.html

⁹⁶ SOR/2018-98. *Regulations Amending the Heavy-Duty Vehicle and Engine Greenhouse Gas Emission Regulations and Other Regulations Made Under the Canadian Environmental Protection Act, 1999*. Available from: www.gazette.gc.ca/rp-pr/p2/2018/2018-05-30/html/sor-dors98-eng.html

5.4. Buildings and communities

5.4.1. Strengthened BC Building Code

The analysis assumes that starting in 2030, all new buildings (both residential and commercial) are required to meet zero-emissions standards. The model simulates this requirement by only allowing sales of heat pumps and electric resistance equipment for ranges, hot water heating, and space heating.

5.4.2. Heating equipment standards

The analysis assumes that starting in 2030, new space and water heating equipment must be supplied by heat pumps (including electric, natural gas, and hybrid) or electric resistance.

5.4.3. Building retrofit code

Requires the improvement of heat load demand when buildings are retrofit. This policy is currently under development by the BC government.

5.4.4. Building incentives

The analysis includes the provincial Better Homes and Better Buildings incentives. The modelling represents these incentives as lump sums spread over multi-year periods to lower costs for clean technologies in buildings, including:

- Heat pump incentives: \$90.0 million over 2021-2025, and \$100.0 million over 2026-2030.
- Efficient building shells: \$30.6 million over 2021-2025, and \$17.5 million over 2026-2030.

5.4.5. Organic waste diversion

The modelling follows the provincial government's target⁹⁷ to divert 95% of organic waste (municipal, agricultural, and industrial waste excluding industrial wood waste)

⁹⁷ Government of British Columbia (2018). *CleanBC*. Available from: www.cleanbc.gov.bc.ca

starting in 2025. Policies that support the achievement of this target are currently under development.

6. Additions and adjustments by the BC Government

The BC Government uses Navius' modelling results to inform the ongoing development of CleanBC and to report on projected emissions. After Navius generates results, a number of post-modelling adjustments and additions are made by the BC Government for publication in the *2022 Climate Change Accountability Report*⁹⁸ and elsewhere.

The following sections describe these additions and adjustments, starting with the addition of GHG emissions not covered by the modelling (Section 6.1), followed by adjustments made to CleanBC modelling results (Section 6.2) and lastly the addition of abatement related to BC policy but occurring outside the province (Section 6.3).

6.1. GHG emissions not covered by modelling

gTech currently does not represent GHG emissions associated with (1) land-use change (primarily deforestation), as well as (2) land use management. Therefore, the BC Government adds GHG emissions associated with land-use change after receiving modelling results from Navius. These emissions are assumed to remain constant at present levels; specifically, the average of the five-most recent years for which data is available: 2016-2020⁹⁹. This amounts to 2.9 MtCO₂e, almost entirely from deforestation.

6.2. Post-modelling adjustments

6.2.1. CleanBC Industry Fund

An additional 2.8 MtCO₂e of emissions reduction is assumed in response to the CleanBC Industry Fund (CIF) in 2030. Twenty-five percent of this additional reduction is also assumed in 2025. Several different methodologies were considered in producing

⁹⁸ Government of British Columbia (2021) *2021 Climate Change Accountability Report*. Available from www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/climate-reporting

⁹⁹ Government of British Columbia (2021). *Provincial Inventory of Greenhouse Gas Emissions 1990-2020*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

this estimate, including Navius forecasts using gTech, analysis of marginal abatement cost curves for technology options, and the analysis of reductions achieved from industrial sectors at different proxy carbon prices. Results of these methodologies were analyzed in combination to overcome potential modelling limitations in projecting impacts of complex incentive programs, such as the CleanBC Program for Industry. Some of the factors contributing to the program's complexity include (a) coverage of multiple industrial sectors where relative sector intensities are different; and (b) potential for multiple funding sources and inter-sectoral projects.

6.2.2. Agriculture policies

A further 0.1 MtCO₂e of emissions reduction is assumed in the agriculture sector in 2030. In 2025, 25% of this additional reduction is assumed. This estimate was developed by the Ministry of Agriculture in collaboration with an independent contractor to account for planned initiatives targeting greenhouse retrofits, manure composting, feed additives, electric tractors, and anaerobic digesters for biogas production.

6.2.3. Deforestation policies

A further 0.2 MtCO₂e of reduction in deforestation emissions is assumed for 2030. Similarly, in 2025, 25% of this additional reduction is assumed. Policies able to achieve this abatement are still in development. As discussed in Section 6.1, deforestation emissions are not modelled in gTech; in the Provincial Forecast¹⁰⁰ the BC government assumes these emissions continue at current levels.

6.3. Abatement outside BC

The modelling assumes that under the GHGRS, utilities in BC can notionally purchase renewable gas from outside of the province (see more details in Section 5.1.5). Abatement from out of Province renewable natural gas is modelled in gTech, but as this abatement occurs out of Province it does not appear in the standard territorially based GHG outputs by activity. In this report, the accompanying *Supporting Metrics*¹⁰¹,

¹⁰⁰ Government of British Columbia (2022). *Provincial Forecast of Greenhouse Gas Emissions and Supporting Metrics 2022*. Available from: <https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/climate-reporting>

¹⁰¹ Government of British Columbia (2022). *Provincial Forecast of Greenhouse Gas Emissions and Supporting Metrics 2022*. Available from: <https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/climate-reporting>

and in the *2022 Climate Change Accountability Report*¹⁰², the BC Government subtracts an additional 1.2 MtCO₂e in 2025 and 2030 to account for compliance with the GHGRS outside of BC.

¹⁰² Government of British Columbia (2022) *2022 Climate Change Accountability Report*. Available from www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/climate-reporting

Appendix A: Covered sectors, fuels, end-uses, and technologies

Table 29: List of sectors in gTech

Sector	NAICS code
Soybean farming	11111
Oilseed (except soybean) farming	11112
Wheat farming	11114
Corn farming	11115
Other farming	Rest of 1111
Animal production and aquaculture	112
Forestry and logging	113
Fishing, hunting, and trapping	114
Agriculture services	115
Natural gas extraction (conventional)	211113
Natural gas extraction (tight)	
Natural gas extraction (shale)	
Light oil extraction	
Heavy oil extraction	
Oil sands in-situ	211114
Oil sands mining	
Bitumen upgrading (integrated)	
Bitumen upgrading (merchant)	
Coal mining	2121
Metal mining	2122
Non-metallic mineral mining and quarrying	2123
Oil and gas services	213111 to 213118
Mining services	213119
Fossil-fuel electric power generation	221111
Renewable electric power generation	221112 and 221119
Nuclear electric power generation	221113
Electric power transmission, control and distribution	22112
Natural gas distribution	222
Construction	23
Food manufacturing	311
Beverage and tobacco manufacturing	312
Textile and product mills, clothing manufacturing, and leather and allied product manufacturing	313-316
Wood product manufacturing	321
Paper manufacturing	322
Petroleum refining	32411
Coal products manufacturing	Rest of 324
Petrochemical manufacturing	32511
Industrial gas manufacturing	32512
Other basic inorganic chemicals manufacturing	32518
Other basic organic chemicals manufacturing	32519

technologies

Biodiesel production from canola seed feedstock	
Biodiesel production from soybean feedstock	
Ethanol production from corn feedstock	
Ethanol production from wheat feedstock	
Hydrogenation-derived renewable diesel (HDRD) production from canola seed feedstock	
Renewable gasoline and diesel production	
Cellulosic ethanol production	
Resin and synthetic rubber manufacturing	3252
Fertilizer manufacturing	32531
Other chemicals manufacturing	Rest of 325
Plastics manufacturing	326
Cement manufacturing	32731
Lime and gypsum manufacturing	3274
Other non-metallic mineral products manufacturing	Rest of 327
Iron and steel mills and ferro-alloy manufacturing	3311
Electric-arc steel manufacturing	
Steel product manufacturing from purchased steel	3312
Alumina and aluminum production and processing	3313
Other primary metals manufacturing	3314
Foundries	3315
Fabricated metal product manufacturing	332
Machinery manufacturing	333
Computer and electronic product, equipment, appliance, and component manufacturing	334 and 335
Transport equipment manufacturing	336
Other manufacturing	Rest of 31-33
Wholesale and retail trade	41 to 45
Air transport	481
Rail transport	482
Water transport	483
Truck transport	484
Transit and ground passenger transport	485
Pipeline transport of crude oil	4861 and 4869
Pipeline transport of natural gas	4862
Other transport, excluding warehousing and storage	4867 to 492
Landfills	Part of 562
Services	Rest of 51-91
LNG	N/A
RNG	N/A

Table 30: List of fuels in gTech

Fuel
Fossil fuels
Coal
Coke oven gas
Coke
Natural gas
Natural gas liquids
Gasoline and diesel

Heavy fuel oil
Still gas
Electricity
Electricity
Renewable fuels (non-transport)
Spent pulping liquor
Wood
Wood waste (in industry)
RNG
Renewable fuels (transport)
Ethanol produced from corn
Ethanol produced from wheat
Cellulosic ethanol
Biodiesel produced from canola
Biodiesel produced from soy
Hydrogenation-derived renewable diesel (HDRD)
Renewable gasoline and diesel from pyrolysis of biomass
Hydrogen

Table 31: List of end-uses in gTech

End-use
Stationary industrial energy/emissions sources
Fossil-fuel electricity generation
Process heat for industry
Process heat for cement and lime manufacturing
Heat in remote areas without access to natural gas
Electricity and heat cogeneration
Compression for natural gas production and pipelines
Large compression for LNG production
Electric motors (in industry)
Other electricity consumption
Transport
Air transport
Buses
Rail transport
Light rail for personal transport
Marine transport
Light-duty vehicles
Medium-duty gasoline vehicles
Medium-duty diesel vehicles
Trucking freight
Diesel services (for simulating biodiesel and other renewable diesel options)
Gasoline services (for simulating ethanol options)
Oil and gas fugitives
Formation CO ₂ removal from natural gas processing
Flaring in areas close to natural gas pipelines
Flaring in areas far from natural gas pipelines
Venting and leaks of methane (oil and gas sector)
Industrial processes
Mineral product production
Aluminum electrolysis

technologies

Metallurgical coke consumption in steel production
Hydrogen production for petroleum refining and chemicals manufacturing
Non-fuel consumption of energy in chemicals manufacturing
Nitric acid production
Agriculture
Enteric fermentation
Manure management
Agricultural soils
Waste
Landfill gas management
Residential buildings
Single-family detached shells
Single-family attached shells
Apartment shells
Heat load
Furnaces
Air conditioning
Lighting
Dishwashers
Clothes washers
Clothes dryers
Ranges
Faucet use of hot water
Refrigerators
Freezers
Hot water
Other appliances
Commercial buildings
Food retail shells
Office building shells
Non-food retail shells
Educational shells
Warehouse shells
Other commercial shells
Heat load
Hot water
Lighting
Air conditioning
Auxiliary equipment
Auxiliary motors

Table 32. List of technologies in gTech

End-use	Technology
Agricultural soils	Existing
Air travel	Existing New
Aluminum electrolysis	Existing Inert anodes Low PFC emitting technology New
Apartment building shells	Near-zero emissions

	New New efficient Post-2000 Post-1980 pre-2000 Pre-1980
Auxiliary equipment	Existing New New efficient
Auxiliary motors (in commercial buildings)	Existing New New efficient
Buses	Compressed natural gas Diesel Existing Hybrid Hydrogen fuel-cell Pure-electric
Cement CO ₂	CCS Existing
Cement heat	Baseline coal Baseline coal with CCS Baseline coke Baseline heavy fuel oil Baseline natural gas Baseline natural gas with CCS Baseline wood
Clothes dryers	Existing Existing natural gas New New efficient
Clothes washers	Existing New New efficient
Cogeneration	Baseline natural gas No cogeneration
Commercial air conditioning	Existing New New efficient New highly efficient
Commercial heating	Air-source heat pump Electric Existing Gas Gas efficient Gas highly efficient Ground-source heat pump Oil Oil efficient
Commercial hot water	Electric Existing Gas Gas efficient Heat pump Oil
Commercial lighting	Existing New

technologies

	New efficient
Compression	Electric Existing
Diesel services	Canola-based biodiesel Diesel Hydrogenation-derived renewable diesel (HDRD) Renewable gasoline or diesel Soy-based biodiesel
Direct air capture (DAC) of carbon	CCS
Dishwashers	Existing New New efficient
Electric motors (in industry)	Existing New New efficient
Electricity generation	Baseline coal Baseline coke Baseline heavy fuel oil Baseline natural gas Coal Coal with CCS Coke Natural gas combined cycle Natural gas combined cycle with CCS Natural gas combustion turbine Wood stove
Elementary or secondary school building shells	Near-zero emissions New New efficient Post-2000 Post-1980 pre-2000 Pre-1980
Faucets	Existing
Flaring in areas close to natural gas pipelines	Existing
Flaring in areas far from natural gas pipelines	Existing Reduction in methane flaring from oil wells
Formation CO ₂ from natural gas processing	CCS Existing
Freezers	Existing New New efficient
Furnaces	Air-source heat pump Existing Gas air-source heat pump Gas Gas efficient Oil Oil efficient Wood stove
Gasoline services	Cellulosic ethanol Corn-based ethanol Gasoline Renewable gasoline or diesel Wheat-based ethanol
Heat	Baseline coal

	<ul style="list-style-type: none"> Baseline coal with CCS Baseline coke Baseline coke oven gas Baseline heavy fuel oil Baseline natural gas Baseline natural gas liquids Baseline natural gas with CCS Baseline refinery catalyst coke Baseline spent pulping liquor Baseline still gas Baseline wood Baseline wood waste Electric Heavy fuel oil Natural gas Natural gas efficient
Heat in remote areas	<ul style="list-style-type: none"> Baseline coal Baseline diesel Baseline heavy fuel oil Baseline natural gas Baseline natural gas liquids
Heavy-duty vehicles that consume gasoline	<ul style="list-style-type: none"> Diesel Diesel efficient Diesel highly efficient Existing LNG efficient Electric Hydrogen fuel-cell
Household air conditioning	<ul style="list-style-type: none"> Existing New New efficient New highly efficient
Household heating load	<ul style="list-style-type: none"> Electric baseboard Furnaces Ground-source heat pump
Household hot water	<ul style="list-style-type: none"> Electric tank 92 Electric tank 95 Existing Gas tank 59 Gas tank 67 Gas tankless 82 Gas tankless 96 Heat pump 200 Oil tank 68
Household lighting	<ul style="list-style-type: none"> Compact florescent Existing Halogen incandescent Incandescent Light-emitting diode (LED)
Hydrogen	<ul style="list-style-type: none"> CCS Existing Hydrogen production from still gas
Integrated steel production	<ul style="list-style-type: none"> Existing
Landfills	<ul style="list-style-type: none"> Existing Landfill gas flaring Landfill gas utilization as fuel

technologies

	Landfill gas utilization for electricity generation
Large compression for LNG production	AC induction motors for LNG compression Combined-cycle gas turbine Single-cycle gas turbine Single-cycle gas turbine efficient
Leaks	Existing Low-leak and vented methane measures Lowest-leak and vented methane measures
Light-duty vehicle motor	Existing Gasoline Gasoline efficient Hydrogen fuel-cell Hybrid Plug-in hybrid Pure-electric
Light-duty vehicle size	Car Passenger truck
Light rail for personal transport	Existing
Low-temperature industrial heat	Baseline coal Baseline coal with CCS Baseline coke Baseline coke oven gas Baseline heavy fuel oil Baseline natural gas Baseline natural gas liquids Baseline natural gas with CCS Baseline spent pulping liquor Baseline still gas Baseline wood Baseline wood waste Electric Heavy fuel oil Industrial heat pump Natural gas Natural gas efficient
Manure management	Anaerobic digestion small Existing
Marine transport	Diesel Existing Heavy fuel oil Hydrogen fuel-cell LNG efficient
Medium-duty diesel vehicles	Compressed natural gas Diesel Diesel efficient Diesel highly efficient Existing Hybrid Hydrogen fuel-cell Plug-in hybrid Pure-electric
Natural gas services	Natural gas RNG
Nitric acid production	Existing
Non-fuel consumption of energy	Existing

Office building shells	Near-zero emissions New New efficient Post-2000 Post-1980 pre-2000 Pre-1980
Off-road vehicles	Diesel Existing Electric
Other appliances	Existing New New efficient
Other building shells	Near-zero emissions New New efficient Post-2000 Post-1980 pre-2000 Pre-1980
Other electric	Existing
Process methane	Existing
Rail freight	Diesel Existing Hydrogen fuel-cell
Ranges	Electric Electric efficient Existing electric Existing natural gas Natural gas
Refrigerators	Existing New New efficient New highly efficient
Retail building shells	Near-zero emissions New New efficient Post-2000 Post-1980 pre-2000 Pre-1980
Retail food building shells	Near-zero emissions New New efficient Post-2000 Post-1980 pre-2000 Pre-1980
Single-family attached building shells	Near-zero emissions New New efficient Post-2000 Post-1980 pre-2000 Pre-1980
Single-family detached building shells	Near-zero emissions New New efficient Post-2000 Post-1980 pre-2000 Pre-1980

technologies

Surface casing vent flows	Existing
Trucking freight	Diesel Diesel efficient Diesel highly efficient Existing Hydrogen fuel-cell LNG efficient Electric
Venting	Existing Low-leak and vented methane measures Lowest-leak and vented methane measures
Warehouse building shells	Near-zero emissions New New efficient Post-2000 Post-1980 pre-2000 Pre-1980

Appendix B: CleanBC impacts in the 2021 and 2022 modelling

Table 33 compares the emissions reductions forecast for each CleanBC policy in the 2021 and 2022 modelling. Values in this table do not include post-modelling adjustments applied by the BC Government (see Section 6.2 for a description of these adjustments). However, emissions from land-use change (see section 6.1) are included in the totals for 2021 and 2022, and emissions from abatement outside of B.C. (see section 6.3) are included in the 2022 total.

In the 2022 modelling, it appears that abatement from several policies has changed from the previous year's analysis. However, many of these differences can be attributed to the annual model updates and to the way abatement is measured in 2021 and 2022. First, as detailed in this report, the 2022 modelling is updated to incorporate the latest available data for calibration: policy details are updated to include the latest information on design and implementation, some post-modelling adjustments made in 2021 are now incorporated directly into the model, and several structural updates improve the representation of technologies and decarbonization pathways. Second, the 2022 modelling compares individual policies relative to a reference scenario that only includes policies announced as of 2017. Whereas, in some cases, the 2021 modelling compares policies relative to a scenario that includes earlier CleanBC policies. The result of these different approaches is that although the overall abatement between analyses has stayed relatively similar (23.6 and 25.3 MtCO_{2e} in the 2021 and 2022 modelling respectively), abatement has shifted between policies. Policies often have interactive effects that when modelled together are difficult to tease apart. Standardizing the approach used to measure abatement in future analyses will allow for better estimates of how abatement is changing in response to updated policy design.

modelling

Table 33: CleanBC emissions reductions in 2021 and 2022 modelling¹⁰³

Policy	Description	2030 impact (MtCO _{2e})		Comment
		2021 modelling	2022 modelling	
Total¹⁰⁴		-23.6	-25.3	
Multi-sector		-9.0	-11.8	
Strengthened carbon tax	Continue the successful carbon pricing framework, with rebates for low- and middle-income British Columbians and support for clean investments	-3.3	-5.5	Much of the difference in abatement can be attributed to a change in the way the 2021 and 2022 modelling are measuring abatement. Please see paragraphs at the beginning of this chapter for further details.
Strengthened clean electricity mandate	Mandates that 100% of electricity produced in BC is clean	-0.2	-0.2	The 2022 modelling forecasts a similar emissions reduction to the 2021 modelling.
Strengthened fuel PST exemption	Exempts all residential fuels and all electricity consumed by commercial and industrial users from the PST	-	+0.0	
BC Hydro's electrification plan	Funding targeting electrification in various sectors	-	-0.1	Only the 2022 modelling includes this policy. In the 2021 modelling, abatement from this policy was accounted for in a post-modelling adjustment.
Natural gas utility GHGRS	Limits annual emissions from the combustion of natural gas and propane	-5.5	-5.9	Much of the difference in abatement can be attributed to a change in the way the 2021 and 2022 modelling are measuring abatement. Please see paragraphs at the beginning of this chapter for further details. Additionally, unlike the 2021 modelling, in 2022 the analysis allows for compliance towards the GHGRS to also be

¹⁰³ While policies presented in this table have been grouped together under sectoral headings, emissions reduction estimates represent the difference between reference scenario and policy scenario emissions across the entire economy.

¹⁰⁴ The total combined impact of all policies is not the same as the sum of their individual impacts. This is because of interaction effects between policies. For example, policies acting in the same area may target the same emissions, meaning their impacts would not be incremental. Additionally, emissions from deforestation (see section 6.1) are included in the totals for 2021 and 2022, and emissions from abatement outside of B.C. (see section 6.3) are included in the 2022 total.

				met via notional purchases of renewable gas.
Federal climate funding	Federal funding towards various GHG emissions abatement initiatives	-	-0.1	Only the 2022 modelling includes this policy. In the 2021 modelling, abatement from this policy was accounted for in a post-modelling adjustment.
Industry		-2.6	-7.8	
CIIP	Return a portion of carbon tax paid by high-emitting industrial facilities as rebates, which increase as facilities lower their emissions intensity	+0.6	+1.5	Much of the difference in abatement can be attributed to a change in the way the 2021 and 2022 modelling are measuring abatement. Please see paragraphs at the beginning of this chapter for further details. Additionally, the 2022 modelling updates benchmarks used under the CIIP with more current data. This update leads to further differences between analyses.
CIF	Directly fund emissions reductions in eligible sectors	-0.2	-0.0	The 2022 modelling forecasts a similar emissions reduction to the 2021 modelling.
SME Fund	Directly fund emissions reductions in sectors not eligible for the CIF	-0.2	-	Unlike the 2021 modelling, the 2022 modelling removes the SME Fund.
Industrial electrification	Provide clean electricity to planned natural gas production in the Peace River region with new transmission lines and interconnectivity to existing lines	-1.1	-0.9	The 2022 modelling forecasts a similar emissions reduction to the 2021 modelling.
Oil and gas sector methane regulations	Reduce methane emissions from upstream oil and gas operations by 45% from 2014 levels	-1.5	-1.5	The 2022 modelling forecasts a similar emissions reduction to the 2021 modelling.
Oil and gas sectoral target	Requires the reduction of emissions in the oil and gas sector	-	-6.8	This policy was not included in the 2021 modelling. Instead, it was accounted for with a post-modelling adjustment.
CCS regulations	Ensure a regulatory framework for safe and effective underground CO ₂ storage	-0.2	-	In the 2022 modelling, the CCS regulation is removed from the analysis.

modelling

Transport		-12.0	-15.9	
Light-duty ZEV sales mandate	By 2030, 90% of new light-duty vehicles sold in BC must be low to zero-emissions.	-1.8	-0.5	Much of the difference in abatement can be attributed to a change in the way the 2021 and 2022 modelling are measuring abatement. See paragraphs at the beginning of this chapter for further details.
Heavy-duty ZEV sales mandate	By 2030, 44% of new on-road heavy-duty vehicles and 23% of medium-duty vehicles sold in BC must be low to zero-emissions.	-0.2	-1.0	Much of the difference in abatement can be attributed to a change in the way the 2021 and 2022 modelling are measuring abatement. Please see paragraphs at the beginning of this chapter for further details.
Heavy-duty ZEV stock mandate	By 2030, 19% of on-road heavy-duty vehicles in use are zero-emissions	-0.0	-0.2	The 2022 modelling forecasts a similar emissions reduction to the 2021 modelling.
Zero-emissions bus mandate	The analysis requires 100% of new buses sold to be zero-emissions by 2029.	-0.0	-0.0	The 2022 modelling forecasts a similar emissions reduction to the 2021 modelling.
Strengthened ZEV incentives	The analysis assumes provincial incentives for the purchase of low- to zero- emissions vehicles	-0.2	-1.5	The updated modelling includes greater funding under the federal iZev program by representing funds committed out to 2025.
Strengthened LCFS	Make our fuel cleaner by increasing the LCFS to 30% by 2030	-4.7	-5.7	Much of the difference in abatement can be attributed to a change in the way the 2021 and 2022 modelling are measuring abatement. Please see paragraphs at the beginning of this chapter for further details.
Strengthened light-duty vehicle emissions standards	Make light-duty vehicles run cleaner by increasing tailpipe emissions standards	-1.1	-0.7	The 2022 analysis requires more stringent standards in line with recent amendments. However, less abatement is observed under the 2022 modelling because more electric vehicles are forecast in the 2022 reference scenario, leading to fewer fossil-fuel vehicles targeted by this policy.
Strengthened heavy-duty vehicle	Make heavy-duty vehicles run cleaner by	-0.4	-0.7	In the 2022 modelling reference scenario, the emissions intensity of heavy-

emissions standards	increasing tailpipe emissions standards			duty vehicles was increased to better align with emissions reported in the Provincial Inventory Report. This change in assumptions led to a greater amount of abatement from the updated analysis.
Light-duty vehicle travel reduction	Policy intended to increase walking, cycling, and transit use	-3.5	-5.6	Much of the difference in abatement can be attributed to a change in the way the 2021 and 2022 modelling are measuring abatement. Please see paragraphs at the beginning of this chapter for further details.
Freight energy intensity reduction	Policy intended to reduce emissions intensity of freight	-0.0	+0.0	The 2022 modelling forecasts a similar emissions reduction to the 2021 modelling.
Buildings and communities		-2.1	-1.0	
Strengthened BC Building Code	Zero-emissions standards for new buildings	-1.2	-0.2	Much of the difference in abatement can be attributed to a change in the way the 2021 and 2022 modelling are measuring abatement. Please see paragraphs at the beginning of this chapter for further details. Additionally, the 2022 modelling, assumes fewer new purchases of heating equipment between 2025 and 2030 resulting in less equipment targeted by this policy.
Heating equipment standards	Requires new heating equipment to be either a heat pump or electric	-0.1	-0.1	The 2022 modelling forecasts a similar emissions reduction to the 2021 modelling.
Building retrofit code	Shell efficiency requirements for homes undergoing retrofits.	0.0	0.0	The 2022 modelling forecasts a similar emissions reduction to the 2021 modelling.
Building incentives	Incentives to make homes more energy-efficient and heat pumps more affordable	-0.1	-0.1	The 2022 modelling forecasts a similar emissions reduction to the 2021 modelling.
Organic waste diversion	Decreases waste in landfills	-0.1	-0.6	Much of the difference in abatement can be attributed to a change in the way the 2021 and 2022 modelling are measuring abatement. Please see paragraphs at the

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				beginning of this chapter for further details.
Landfill gas management regulations	Regulates the capture of landfill gas	-0.6	-	The 2022 modelling excludes this policy.

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