Modelling CleanBC: 2021 Methodology Report

SUBMITTED TO

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SUBMITTED BY

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About Us

Navius Research Inc. ("Navius") is a private consulting firm in Vancouver. Our consultants specialize in analysing government and corporate policies designed to meet environmental goals, with a focus on energy and greenhouse gas emissions policy. They have been active in the energy and climate change field since 2004, and are recognized as some of Canada's leading experts in modelling the environmental and economic impacts of energy and climate policy initiatives. Navius is uniquely qualified to provide insightful and relevant analysis in this field because:

- We have a broad understanding of energy and environmental issues both within and outside of Canada.
- We use unique in-house models of the energy-economy system as principal analysis tools.
- We have a strong network of experts in related fields with whom we work to produce detailed and integrated climate and energy analyses.
- We have gained national and international credibility for producing sound, unbiased analyses for clients from every sector, including all levels of government, industry, labour, the non-profit sector, and academia.

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Executive Summary

British Columbia (BC) has legislated targets[1] for reducing provincial greenhouse gas (GHG) emissions by 40% below 2007 levels in 2030, 60% in 2040, and 80% in 2050[2]. Achieving these targets requires strong policies to shift BC towards low- and zero-carbon energy and processes. With this in mind, in December 2018, the Province released the initial CleanBC plan[3], a package of policies designed to significantly reduce BC's emissions. The initial plan was followed in October 2021 by a second phase of CleanBC initiatives, outlining the Province's Roadmap to 2030[4].

This report documents the methodology and assumptions of a comprehensive analysis of the impacts of both Phase 1 and 2 of CleanBC, performed by Navius Research under contract to the BC Government. The report is accompanied by the Provincial Forecast of GHG Emissions and Supporting Metrics[5], summarizing model results.

Each year, as new data becomes available, Navius updates the modelling of CleanBC and releases an edition of this report 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. Differences are noted as appropriate.

GHG emissions forecast

Modelling detailed in this report is used as the 2030 emissions estimates published in BC government documents such as the 2021 Climate Change Accountability Report[6] (CleanBC Phase 1) and the CleanBC Roadmap to 2030[7] (CleanBC Phase 2). Please

[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] The BC Government has since committed to 16% in 2025 and net-zero in 2050, but these have not yet been legislated.

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

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

[5] Government of British Columbia (2021). *Provincial Forecast of Greenhouse Gas Emissions and Supporting Metrics 2021*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/climate-reporting

[6] 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

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

note that results published in these documents include post-modelling adjustments summarized in Appendix A.

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, accounting for potential interaction or overlapping of individual policies.

Table 1 summarizes the CleanBC GHG emissions forecast. Provincial emissions in the reference scenario are projected to be 67.4 million tonnes of carbon dioxide equivalent ($MtCO_2e$) in 2030. CleanBC Phase 1 is projected to reduce emissions to 55.2 $MtCO_2e$ in 2030, while CleanBC Phase 2 (the Roadmap to 2030) is projected to further reduce emissions to 39.0 $MtCO_2e$ in 2030.[8]

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

	2007	Reference 2030	CleanBC 2030	Roadmap 2030
Emissions ($MtCO_2e$)	65.7	67.4	55.2	39.0
Change from 2007	-	+3%	-16%	-41%
Gap to target ($MtCO_2e$)	-	28.0	15.8	-

In combination, policies from Phase 1 and Phase 2 are projected to result in a 41% emissions reduction in 2030 relative to 2007 levels, achieving BC's legislated 2030 target.

Modelled policies

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

BC has formulated CleanBC Phase 1 and 2, policy packages designed to put the Province on track to meet its GHG targets. Phase 1 and 2 policies are summarized in Table 2 and

Table 3 respectively. Complete details about how these policies are modelled are provided in Sections 5 and 6.

[8] This value includes a post-modelling adjustment applied by the BC government. Please see Appendix A for more detail.

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 Phase 1 policies and their representation in the model

Policy	Description
Multi-sector	
Strengthened carbon tax	The analysis assumes a continued increase of the carbon tax by $5/t$CO_2$e annually, until it reaches $50/t$CO_2$e in 2022. The modelling follows the adjusted COVID-19 carbon price schedule, in which the rate remained constant at $40/t$CO_2$e in 2020, rather than increasing to $45/t$CO_2$e. Revenue collected from the tax increase is used to fund transfers to households and to achieve additional industrial emissions reductions under the CleanBC Program for Industry, described below.
Renewable gas mandate	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.
Industry	
CleanBC Industrial Incentive Program	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 $30/t$CO_2$e to facilities that reduce their emissions relative to a world-leading emissions intensity benchmark.
CleanBC Industry Fund	The analysis assumes that a portion of carbon tax paid above $30/t$CO_2$e by industrial large final emitters is invested in low-carbon technologies.
Small and medium business supports	The modelling assumes that future programming directs carbon tax paid above $30/t$CO_2$e by industrial small and medium final emitters toward low-carbon technologies.
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% by 2025.
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.
Carbon capture and storage regulations	This policy establishes 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.

Transport	
Light-duty zero-emissions vehicle mandate	The light-duty ZEV mandate establishes a target of 10% new zero-emissions light-duty vehicle sales by 2025, and 30% by 2030. The analysis assumes that vehicle suppliers earn credits in line with annual targets called compliance ratios. Modelling requires zero-emissions light-duty vehicle sales, including pure electric, hydrogen fuel-cell, and plug-in hybrid, to meet compliance ratios of 22% by 2025 and 71% by 2030. Additionally, pure electric vehicles and hydrogen fuel-cell vehicles must reach a separate compliance ratio of 16% in 2025 and 50% in 2030.
Heavy-duty zero-emissions vehicle mandate	The analysis assumes that a minimum share of heavy-duty and medium-duty vehicles sold in BC is zero-emissions by 2030: 10% of vehicles excluding buses are electric, 16% are LNG, and 94% of buses are electric.
Strengthened zero-emissions vehicle incentives	The analysis assumes financial 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. Values from 2022 onwards may be adjusted in future modelling as policies are confirmed.
Strengthened Low-Carbon Fuel Standard	The analysis assumes that fuel suppliers reduce the carbon intensity of transport fuel pools by 9.1% in 2020, 14.5% in 2025, and 20% in 2030 from 2010 levels. Coverage excludes domestic aviation and navigation fuels.
Strengthened light-duty vehicle emissions standards	The analysis assumes that tailpipe emissions standards for new light-duty vehicles sold after 2025 are strengthened such that the emissions intensity of new light-duty vehicles sold in BC declines to 119 grams per kilometer in 2030 and disallows compliance via zero-emissions vehicles.
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.
Buildings and communities	
Better Homes and Better Buildings incentives	The analysis assumes financial incentives to reduce emissions from buildings of $15 million in 2020, $28.5 million in 2021, $31.7 million in 2022, and $23.5 million annually beginning in 2023. Values from 2023 onwards may be adjusted in future modelling as policies are confirmed.
Organic waste diversion	The analysis assumes an increase of the organic waste diversion rate in municipal, agricultural, and industrial solid waste to 95% by 2025.
Landfill gas management regulations	The analysis assumes 75% capture of landfill gas by 2025 from all large sites accepting municipal solid waste.

Table 3: Summary of CleanBC Phase 2 policies and their representation in the model

Policy	Description
Multi-sector	
Further strengthened carbon tax	The analysis assumes that the carbon tax rises to $170/t$CO_2$e by 2030, in line with the increase signaled by the federal government. Revenue collected from the tax is used to fund transfers to households, industrial programs, and general revenue. The final carbon tax design for BC has not been confirmed beyond 2022/23.
Strengthened clean electricity mandate	The analysis assumes that by 2030, 100% of electricity produced in BC is required to be clean.
Natural gas GHG emissions cap	The analysis assumes that starting in 2030, GHG emissions from the combustion of natural gas are capped at an annual level of 6.1 MtCO_2e. This cap applies to GHG emissions from industry (excluding oil and gas) and buildings.
Industry	
Enhanced CleanBC Program for Industry	The analysis assumes that starting in 2022, the CleanBC Program for Industry will be enhanced to achieve increased GHG reductions as the carbon tax rises. The approach has not been determined and will be subject to stakeholder consultations.
Strengthened oil and gas sector methane requirements	The modelling assumes methane requirements in the oil and gas sector are strengthened such that emissions in 2030 are 75% lower than 2014 levels.
Transport	
Strengthened light-duty zero-emissions vehicle mandate	The modelling assumes that a fraction of new light-duty vehicles sold in BC are zero-emissions, requiring 30% zero-emissions vehicle sales by 2026, and 90% by 2030.
Strengthened heavy-duty zero-emissions vehicle mandate	The modelling assumes that by 2030, 32% of class 2B-3, 44% of class 4-8, and 23% of truck tractors sold will be required to be zero-emissions.
Strengthened zero-emissions bus mandate	The analysis requires 100% of new buses sold to be zero-emissions by 2029.
Heavy-duty zero-emissions vehicle stock mandate	The modelling assumes that by 2030, 19% of heavy-duty vehicles in use and 35% of drayage trucks and off-road vehicles in use will be required to be zero-emissions.
Further strengthened Low-Carbon Fuel Standard	The modelling assumes that the average emissions intensity of gasoline, diesel, and marine and aviation fuels in BC are required to decrease 30% from 2010 levels by 2030. Coverage includes domestic aviation and navigation fuels. Electricity is omitted as a compliance option after 2020.
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 emissions intensity reduction	The analysis requires the emissions intensity of new freight (in $tCO_2e/t{\cdot}km$) 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 2027, all new building shells are required to meet net zero emissions standards.
Heating equipment standards	The analysis assumes that starting in 2030, new space and water heating equipment must be a heat pump.

Key 2021 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.
- **Model Improvements.** Structural updates are made to the models to better represent energy systems and to expand functionality.

As a result of these updates, model results change in each iteration of the analysis. Table 4 lists the most significant model updates since the previous release of this report in 2020[9]. The effects of these updates on modelling results are discussed in Appendix C.

Table 4: Key updates in 2021 modelling

Model update	Description	2020 modelling	2021 modelling
Calibration assumptions			
Historic GHG emissions	Historic emissions are calibrated to the annual	Most sectors are calibrated to the 1990-	Most sectors are calibrated to the 1990-

[9] Navius Research (2020). *Supporting the Development of CleanBC 2020*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/climate-reporting

	BC Provincial Inventory of Greenhouse Gas Emissions[10]. The inventory releases new data each year including revisions to past reported emissions.	2018 Provincial Inventory, in which provincial emissions are reported to be 67.9 $MtCO_2e$ in 2018.	2019 Provincial Inventory, in which provincial emissions are reported to be 68.5 and 68.6 $MtCO_2e$ in 2018 and 2019, respectively.
Gross domestic product (GDP)	BC's economy is calibrated to external growth forecasts.	BC's GDP is calibrated to Budget 2020, declining by 6.8% in 2020 and increasing by 3.1% in 2021[11]. Future years are adjusted using IMF recovery values[12].	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 to grow at an annual rate of 2.1%
Electricity consumption	Electricity consumption for some sectors is informed by BC Hydro load forecasts. However, Navius allows the model to endogenously forecast electricity consumption in other sectors.	Electricity consumption is informed by BC Hydro's 2019 load forecast. Since the 2019 forecast excludes impacts from COVID-19, Navius adjusts electricity data to include COVID-19 impacts on GDP, fuel prices, the rate of recovery, and future economic growth.	Electricity consumption is informed by BC Hydro's 2020 load forecast.
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 is calibrated to a 2019 forecast, with adjustments made by Navius to account for the impacts of COVID-19. Production is forecast to be 7.7 BCF/day in 2030.	The model is calibrated to a new 2021 forecast, which accounts for the impacts of COVID-19. Production is forecast to be 7.4 BCF/day in 2030.
Policy assumptions			
Reference scenario	Abatement from Phase 1 and Phase 2 of CleanBC is measured relative to a reference scenario.	Abatement is measured relative to a reference scenario either including (1) policies existing as of July 2018 or (2) policies existing as of July 2017.	Abatement is measured relative to a reference scenario including policies existing as of July 2017.

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 Government of British Columbia (2020). *Economic and Fiscal Scenario- Update 2020-2021*. Available from: www2.gov.bc.ca/assets/gov/british-columbians-our-governments/government-finances/quarterly-reports/2020-21-economic-fiscal-update-backgrounder.pdf

12 International Monetary Fund (2020). *World Economic Outlook Update, June 2020: A Crisis Like No Other, An Uncertain Recovery*. Available from: www.imf.org/en/Publications/WEO/Issues/2020/06/24/WEOUpdateJune2020

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

CleanBC Program for Industry	The CleanBC Program for Industry comprises the CleanBC Industrial Incentive Program, the CleanBC Industry Fund, and a potential program for small and medium sized businesses.	The three elements of the Program for Industry are modelled together as a single policy.	The three elements are modelled separately, allowing their individual impacts to be identified.
Strengthened LCFS	The LCFS as currently implemented allows fuel suppliers to generate compliance credits by supplying electricity for use in electric vehicles.	At the request of the BC Government, providing electricity for electric vehicles was not included as a compliance option in the modelling, despite the policy allowing it in reality.	Under CleanBC Phase 1, the modelling allows suppliers to provide electricity as a compliance option towards the LCFS. However, electricity is not included as a compliance option in the Phase 2 modelling, and is instead accounted for as a post-modelling adjustment (more details in Appendix A).
Better Homes and Better Buildings incentives	This program incentivizes abatement in buildings. Program funding is uncommitted for years not published in the most recent Budget[14] and is therefore assumed in the modelling.	Program funding is assumed to be $23 million in 2023 and $120 million annually from 2024 to 2030.	Program funding is assumed to be $23.5 million annually from 2023 to 2030. Values from 2023 onward may be adjusted in future modelling as policies are confirmed.
Waste policies	CleanBC includes two waste policies: an organic waste diversion target, and the landfill gas management regulations.	The two waste policies are modelled together as a single policy.	The two waste policies are modelled separately, allowing their individual impacts to be identified.
Structural updates			
Electric vehicle representation	Navius continues to update the representation of electric vehicles in the gTech model.	The 2020 version of the model introduces the ability for low- to zero-emissions vehicle costs to change in relation to the following: ▪ Battery capital costs decline relative to cumulative adoption of electric vehicles.	Relative to previous modelling, various new updates increase the adoption of electric vehicles. These include: ▪ Updated capital costs ▪ Capital costs of a greater number of vehicle components decline with

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

		■ Intangible costs change in response to the market share for different technologies.	increased cumulative adoption (e.g. batteries, electric components, and powertrains) ■ Batteries are assumed to get lighter. ■ Charging infrastructure costs are assumed to decline over time
Expanded hydrogen pathways	Navius continues to expand the representation of hydrogen by including more pathways for the utilization of hydrogen.	In addition to including hydrogen as a chemical feedstock, Navius introduced hydrogen fuel pathways into the gTech model for the following end-uses: (1) transport, and (2) blending in the natural gas stream.	Navius introduced new hydrogen consumption and production pathways, including (1) dedicated pipelines for hydrogen, (2) and technologies able to receive pure hydrogen in buildings and industry.
New methodology for estimating GDP for different sectors of the economy	Estimating GDP for emerging sectors is difficult because prices are unavailable in the base year of the model. The current model includes an updated method to improve accounting of such sectors.	GDP is estimated in constant $2015. While this is an established methodology for estimating GDP, it has some flaws in estimating economic contribution of new sectors that emerge in response to climate policy.	The method for GDP reporting is improved: (1) Navius calculates a chained Fisher price index for expenditure GDP, based on 2015$. (2) Navius then deflates both income- and expenditure-based GDP by this price index.
Improved representation of CO_2 pipelines	Navius improved the representation of carbon capture and storage by updating the representation of CO_2 pipeline infrastructure in the gTech model.	The gTech model includes fixed cost for transporting CO_2 from the point of capture to the point of disposal	Navius introduced a pipeline sector in the gTech model which includes (1) the energy consumption associated with transporting CO_2, and (2) an endogenous representation of costs (cost per throughput), which decline as pipeline usage increases.
Improved representation of electricity storage in IESD	IESD represents electricity storage options including battery and pumped storage. Several updates have been made over the past year.	Electricity storage is simulated over individual days. The model includes a single battery storage technology.	The model is now able to simulate the store of power over consecutive days. Battery options are expanded to include both lithium ion and flow

			batteries. Battery costs are updated.
Updated wind and solar representation in IESD	The representation of wind and solar continues to be updated.	Model capital costs for wind and solar generation declined over time. Capacity factors are static.	Model capital costs are updated and decline over time as in previous model. The model is updated to include capacity factors that increase over time.
Addition of green hydrogen in IESD	The new IESD model adds the ability to simulate the production of hydrogen using renewable power.	IESD does not represent green hydrogen.	IESD is now capable of simulating dispatchable green hydrogen production.
Expanded reserve requirements	IESD is now able to represent 3 types of electricity system reserves.	Model contains a simplified representation of system reserves.	Model represents spinning, regulation, and flexibility reserves. Each reserve is a function of total load and intermittent renewable capacity. The model explicitly simulates resources needed to meet reserve requirements.
Expanded dispatchable load capabilities	The IESD model is able to simulate how utilities could facilitate the adoption of renewables by deciding when certain technologies consume electricity.	Model simulates dispatchable load for light-duty electric vehicles only.	Model simulates dispatchable load for light-, medium-, and heavy-duty electric vehicles, as well as space heating and cooling.
Dynamic electricity distribution costs	The IESD model can simulate how electricity load affects electricity distribution costs.	Distribution costs are static.	Electricity distribution costs are now a function of the peak load on an hourly basis.

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1. Introduction

British Columbia (BC) has legislated targets[15] of reducing provincial greenhouse gas (GHG) emissions by 16% below 2007 levels in 2025, 40% in 2030, 60% in 2040, and 80% in 2050[16]. Achieving these targets requires strong policies to shift BC towards low- and zero-carbon energy and processes. With this in mind, in December 2018 the Province released the initial CleanBC plan[17], a package of policies designed to significantly reduce BC's emissions. The initial plan was followed in October 2021 by a second phase of CleanBC initiatives, outlining the Province's Roadmap to 2030[18].

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. Each year, Navius updates the modelling of CleanBC and releases an edition of this report to document the methodology. The report is accompanied by the Provincial Forecast of GHG Emissions and Supporting Metrics[19], which provides a summary of the model results. The Provincial Forecast includes a summary of emissions data for scenarios corresponding to each individual CleanBC Phase 1 policy, as well as emissions, energy, and economic data for the reference scenario, CleanBC Phase 1 scenario, and CleanBC Phase 2 scenario.

This report:

- Introduces the modelling tools used to analyze climate policy impacts (Section 2).
- Reviews key forecast assumptions (Section 3).
- 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 Phase 1 forecast and describes how they are modelled (Section 5).

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

[16] The BC Government has since committed to 100% in 2050, but this has not yet been legislated.

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

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

[19] Government of British Columbia (2021). *Provincial Forecast of Greenhouse Gas Emissions and Supporting Metrics 2021*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/climate-reporting

- Identifies policies that are included in the CleanBC Phase 2 (Roadmap to 2030) forecast and describes how they are modelled (Section 6).
- Discusses the addition of non-modelled emissions and post-modelling adjustments made to the model results by the BC Government (Appendix A).

Modelling detailed in this report is used as the 2030 emissions estimates published in BC government documents such as the 2021 Climate Change Accountability Report[20] (CleanBC Phase 1) and the CleanBC Roadmap to 2030[21] (CleanBC Phase 2). Please note that results published in these documents include post-modelling adjustments summarized in Appendix A.

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 5 summarizes the CleanBC GHG emissions forecast. Provincial emissions in the reference scenario are projected to be 67.4 million tonnes of carbon dioxide equivalent ($MtCO_2e$) in 2030. CleanBC Phase 1 is projected to reduce emissions to 55.2 $MtCO_2e$ in 2030, while CleanBC Phase 2 (the Roadmap to 2030) is projected to further reduce emissions to 39.0 $MtCO_2e$ in 2030.[22]

Table 5: Summary of BC's emissions projections relative to provincial targets

	2007	Reference 2030	CleanBC 2030	Roadmap 2030
Emissions ($MtCO_2e$)	65.7	67.4	55.2	39.0
Change from 2007	-	+3%	-16%	-41%
Gap to target ($MtCO_2e$)	-	28.0	15.8	-

In combination, policies from Phase 1 and Phase 2 are projected to result in a 41% emissions reduction in 2030 relative to 2007 levels, achieving BC's legislated 2030 target.

[20] 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

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

[22] This value includes a post-modelling adjustment applied by the BC government. Please see Section Appendix A for more detail.

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 within BC's economy, and often 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 tailpipe 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.

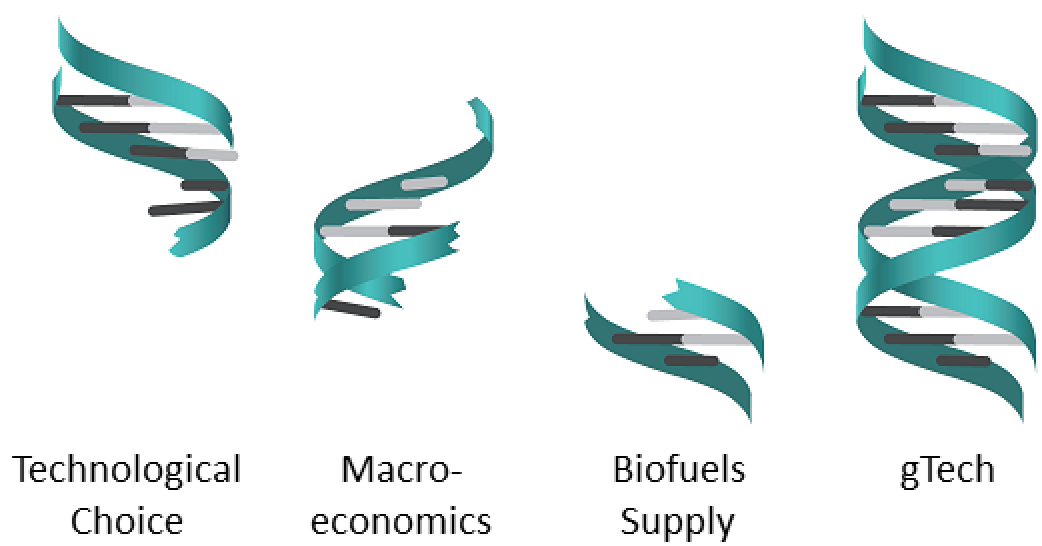
2.2.1. gTech

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 200 technologies across more than 50 end-uses (e.g. residential space heating, industrial process heat, management of agricultural manure).

Naturally, technological choice is influenced by many factors. Table 6 summarizes key factors that influence technological choice and the extent to which these factors are included in gTech.

Table 6: 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 solving for 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	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. 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 energy or emissions savings in the future once this discount rate is applied? 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 higher

	rates[23]. 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%[24] to simulate technological choice.
Technology-specific preferences	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 between[25]. gTech quantifies these technology-specific preferences as "non-financial" costs, which are added to the technology choice algorithm.
The diverse nature of British Columbians	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. gTech uses a market share equation in which technologies with the lowest net costs (including all the cost dynamics described above) achieve the greatest market share, but technologies with higher net costs may still capture some market share[26]. As a technology becomes increasingly costly relative to its alternatives, that technology earns less market share.
Changing costs over time	Costs for technologies are not fixed over time. For example, the cost of electric vehicles has come down significantly over recent years, and it is expected to continue its decline into the future[27]. Similarly, costs for many other energy-efficient devices and emissions-reducing technologies have declined and are expected to continue declining. 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.
Policy	One of the most important drivers of technological choice is government policy, and CleanBC will alter the technological choices households and businesses

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

[24] 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.

[25] 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.

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

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

	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 LCFS which creates a market for compliance credits. 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 Sections 5 and 6.

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 7.

Table 7: 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[28]. 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 B “Covered sectors, fuels, end-uses”.

[28] 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	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). 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.
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, the model 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).

gTech: The 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. The implication is that 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[29]. 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 load.

[29] For brevity, we've skipped many factors that influence generation from intermittent renewables.

- **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 time[30].

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

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

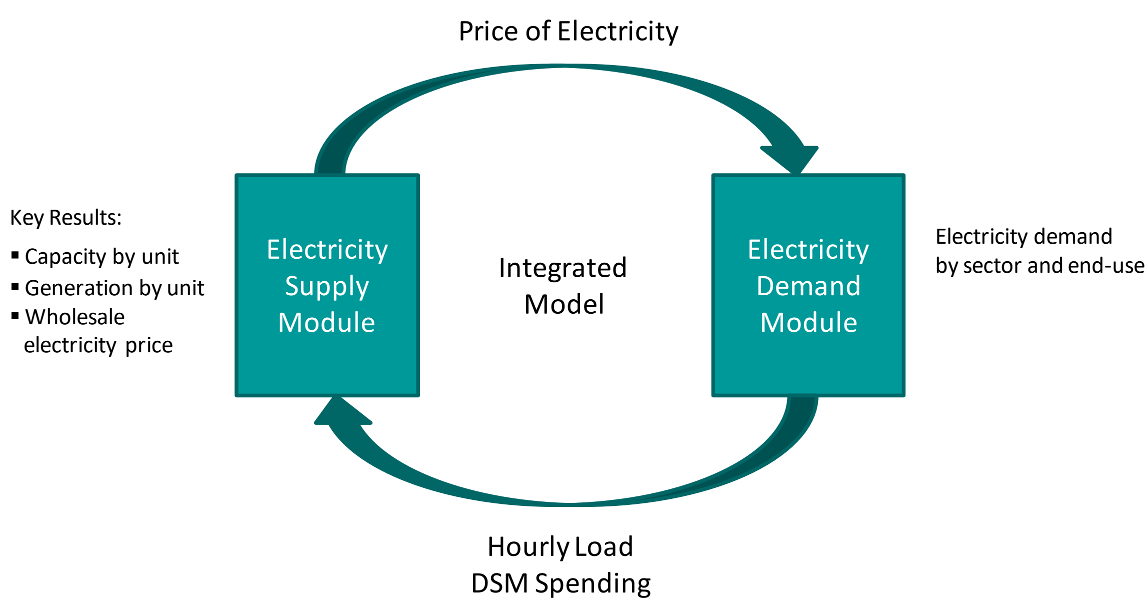
How IESD works

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.

Figure 2: Conceptualization of IESD model simulation



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

IESD's simulation process 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.

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 Database[31], the Energy Information Agency[32], and the Alberta Electricity System Operator[33].

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

[31] BC Hydro (2013). *Resource Option Update Report, Appendix 3, Resource Options Database Summary Sheets*
[32] USA Energy Information Agency (2013). *Updated Capital Cost Estimates for Utility Scale Electricity Generation Plants*
[33] Alberta Electricity System Operator (2013). *Long-Term Transmission Plan*

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 energy economy 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 literature[34]. Further, Navius undertakes significant efforts to calibrate and to back-cast the model (see the discussion starting on page 24).

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

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

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. The delineation for gTech is presented in Table 8 and

Table 9.

Table 8: 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	gTech accounts for actions to reduce emissions in virtually every end-use characterized in the model, as discussed in Section 3.2. The actions available to reduce emissions include: ▪ 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: ➢ Changes in income. gTech explicitly simulates how policies	gTech does not include all available actions to reduce GHG emissions. Of those not included, the most important are likely: ▪ 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 (see Appendix A for more details). ▪ Urban planning or land use planning. gTech does not account for how changes in urban planning would affect GHG emissions. Changes in

	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.	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	gTech captures the following attributes of technologies in the model: ■ 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	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.

	confirms that this dynamic is important[35]. ■ 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 important[36]. ■ 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.

Table 9: 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 B "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 being able to	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 alignment with

[35] Löschel, A. (2002). "Technological Change in Economic Models of Environmental Policy: A Survey". *Ecological Economics*, 43 (2-3), 105-126.

[36] 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.

	simulate competitiveness dynamics. More information about this trade-off is provided starting on page 29.	external data sources. More information about this trade-off is provided starting on page 29.
Interactions with regions outside of BC	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: ▪ 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.	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: ▪ 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.	gTech is not able to represent all possible household demographics (e.g. the difference between a single-parent household and a two-parent household).
Solve periods	The version of gTech used in this study solves in 5-year increments. While Navius has developed versions that	By solving in five-year increments, gTech:

	solve in smaller time increments, Navius uses 5-year increments for two reasons: ■ 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).	■ 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	gTech captures two important labour dynamics: ■ 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.	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.

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 10).

Table 10: 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	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.	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.
Regional boundaries	The version of IESD used for this analysis accounts for the electricity system in BC, Alberta, and the United States portion of the Western Electricity Coordinating Council (WECC).	This version of IESD cannot provide insight into how/whether policy outside these regions affects BC (these impacts are likely to be small). 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	The two models are linked via two separate processes: ■ 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[37].
- Environment and Climate Change Canada's (ECCC) National Inventory Report[38].
- Statistics Canada's Supply-Use Tables[39].
- Natural Resources Canada's Comprehensive Energy Use Database[40].
- Statistics Canada's Annual Industrial Consumption of Energy Survey[41].
- Navius' technology database (see Table 31 "List of technologies in gTech").

[37] 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

[38] 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

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

[40] 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

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

- BC's Ministry of Energy, Mines, and Low-Carbon Innovation's 2021 natural gas production forecast.
- BC's Ministry of Energy, Mines, and Low-Carbon Innovation's LCFS supply data.
- BC Hydro's 2020 load forecast (electricity consumption for some sectors is informed by BC Hydro data, but we have allowed the model to endogenously forecast 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-Use Tables may not be consistent with natural gas consumption in Natural Resources Canada's Comprehensive Energy Use Database. Further, energy expenditures are a function of consumption and prices, so if prices vary over the course of the year, it is difficult to perfectly align consumption and expenditures.

Navius' calibration routine places greater emphasis on some data sources than others. This approach means that gTech achieves near-perfect alignment 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.

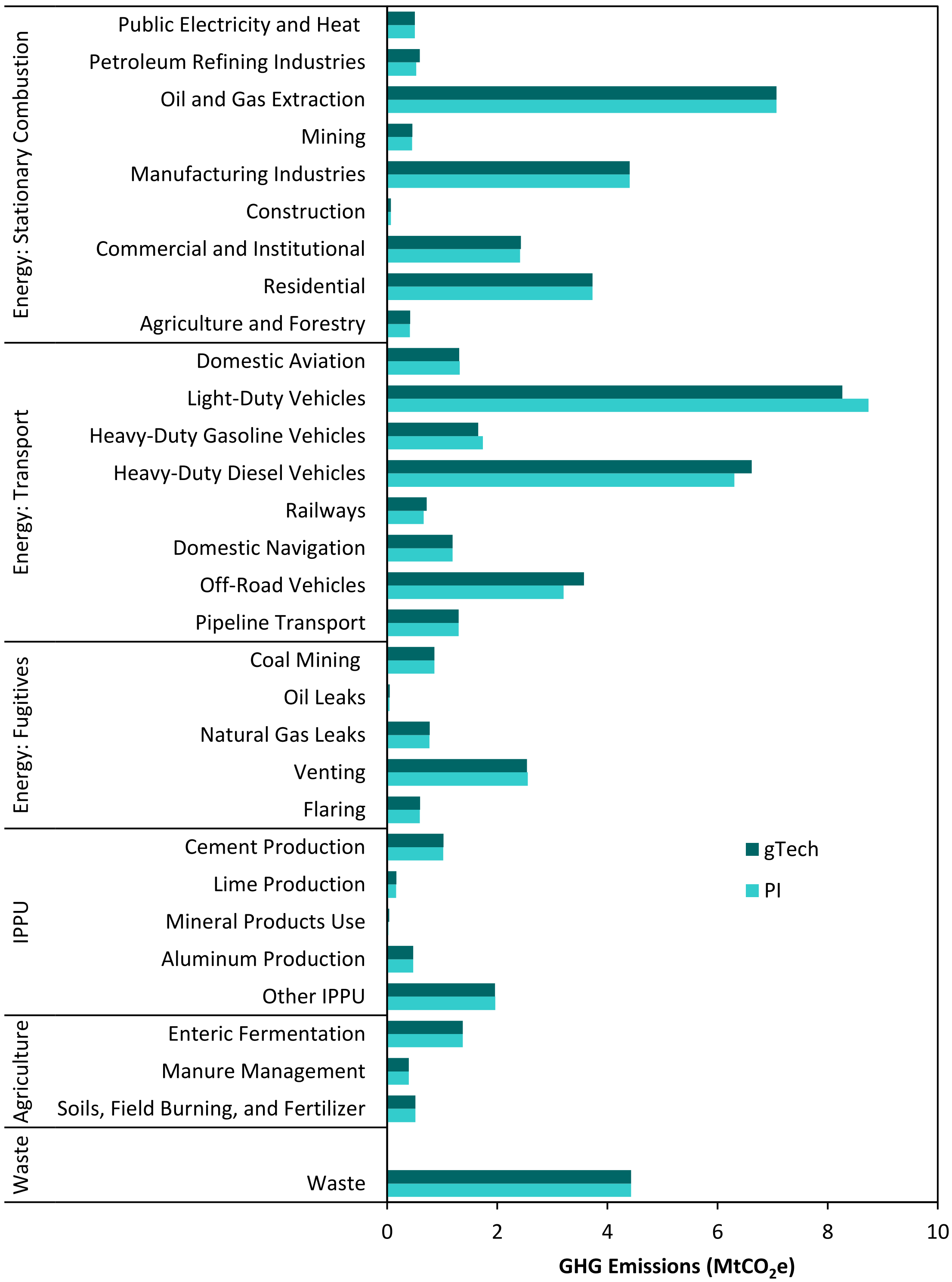
Navius allows the model to diverge more significantly from other datasets in order to ensure near-perfect alignment with these data sources.

Figure 3 and Figure 4 show how modelled GHG emissions align with BC's Provincial Inventory of Greenhouse Gas Emissions 1990-2019, both by sector and over time. As shown in Figure 3, emissions in the 2015 base year align well with the Provincial Inventory for all sectors apart from road transport. The increase in emissions from 2015 to 2019 reported in the Provincial Inventory is not reflected in the modelling (as seen in Figure 4) because

- the model only outputs in timesteps of five years;
- due to the impacts of COVID-19, 2020 emissions are expected to be lower than the 2015-2019 trend would suggest; and

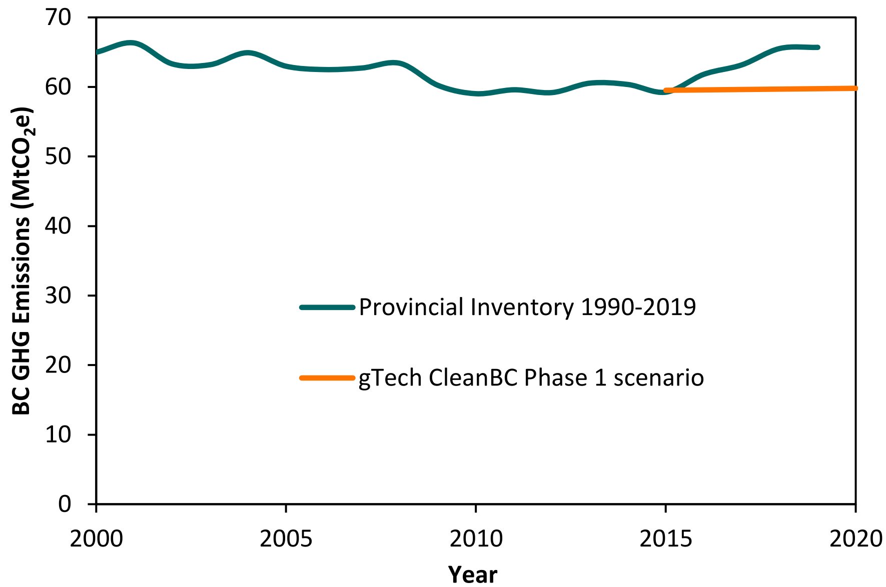
- road transport GHG emissions are not calibrated to the Provincial Inventory; rather these emissions are informed by fuel consumption data reported under the *Renewable and Low Carbon Fuel Requirements Regulation*.

Figure 3: Calibration of GHG emissions by category in 2015



Source for historical data: 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. Note: land-use change emissions, which are not included in gTech, amount to 2.9 $MtCO_2e$ in 2019. 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, excluding land-use change, 2015-2020



Source for historical data: 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. Note: land-use change emissions, which are not included in gTech, amount to 2.9 $MtCO_2e$ in 2019. 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-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, if they do.

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-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. Navius calibrates these assumptions to a model forecast that includes policies announced as of July 2018 (referred to as the calibration scenario in this report). Over the past three 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.

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 calibrated to align with the forecast published in Budget 2021[42] reflecting a real GDP change of -5.3% in 2020 and +4.4% in 2021 and averaging an annual growth rate of 2.7% from 2022 to 2025. After 2025, GDP is assumed to grow at an annual rate of 2.1%.

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 3.2.

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

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

the relevant year) to account for inflation in order to compare costs across years in terms of purchasing power. Navius assumes a constant annual inflation rate of 2.0% to make this adjustment.

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 2021[43] 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. Energy prices

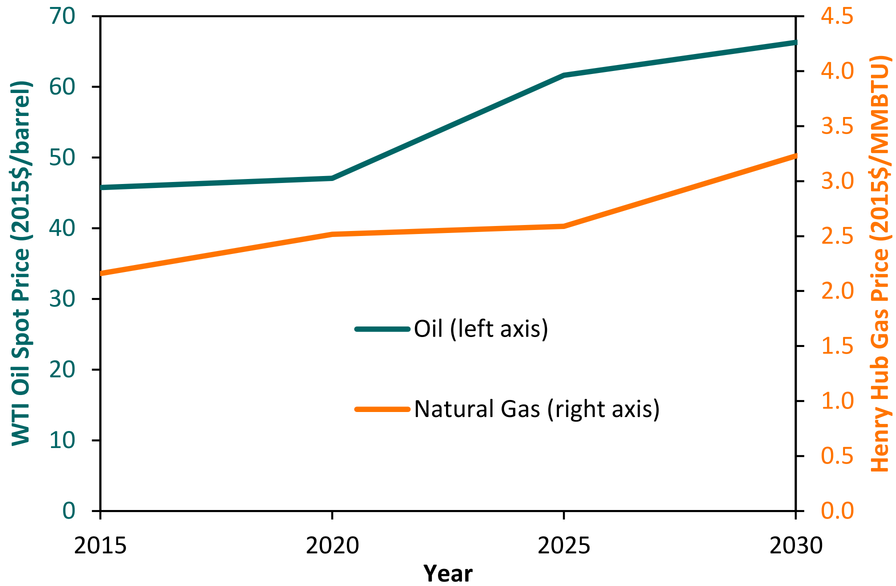
Oil and gas prices are calibrated to the 2020 Canada Energy Regulator's *Canada's Energy Future* report[44]. The price of oil is an exogenous input to the model (i.e. based on an assumed global price). After the model has been calibrated to the external forecast, the price for natural gas is determined endogenously in the model based on supply of and demand for natural gas in North America. The resulting price forecast is shown in Figure 5:

- Natural gas (Henry Hub) prices rise from $2.5/MMBTU (2015 $USD) in 2020 to $3.2/MMBTU by 2030.
- Crude oil (WTI) prices rise from $47.1/barrel (2015 $USD) in 2020 to $66.3/barrel by 2030.

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

[44] Canada Energy Regulator (2020). *Canada's Energy Future 2020: Energy Supply and Demand Projections to 2050*. Available from: www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2020/index.html

Figure 5: Oil and natural gas price forecast



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

- The cost of generating electricity while meeting any policy constraints (e.g. the requirements of the *Clean Energy Act*).
- The cost of maintaining the transmission and distribution network.
- The value of electricity exports and cost of imports.
- Any taxes on or subsidies to the sector.

3.2. Sector-specific assumptions

This section reviews assumptions specific to each sector in gTech:

- 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 B "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 has been calibrated to ensure activity for these sectors aligns with the external forecast in a scenario that includes policies announced as of July 2018 (referred to as the calibration scenario in this report). Any deviations from this scenario (e.g. with CleanBC) can change the sector activity from the external assumption.

For all other sectors, gTech determines or simulates sector activity. In the case of industrial sectors (as seen in Table 11) activity usually refers to output. 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.

Table 11 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 11: Industry sector activity in selected years under the calibration scenario

Sector	Unit	2015	2020	2025	2030	Source
Fossil fuel industry						
Coal mining	Index 2015 = 1	1.0	1.2	1.2	1.2	gTech

Natural gas production	BCF per day	4.1	5.3	7.9	7.4	BC's Ministry of Energy, Mines, and Low-Carbon Innovation[45]
Conventional	BCF per day	0.6	0.4	0.3	0.1	
Montney	BCF per day	3.1	4.8	7.5	7.2	
Horn River	BCF per day	0.4	0.1	0.1	0.0	
Conventional light oil production	Thousand barrels per day	21.2	14.4	18.4	29.0	CER[46]
Petroleum refining	Index 2015 = 1	1.0	1.0	1.0	1.0	gTech
Natural gas distribution	Index 2015 = 1	1.0	1.2	1.2	1.2	gTech
LNG	MTPA	0.0	0.0	14.0	14.0	Published final investment decisions
Electricity						
Electricity generation	TWh	66.5	73.3	74.7	70.6	gTech & IESD
Electricity distribution	Index 2015 = 1	1.0	1.0	1.0	1.0	gTech
Heavy industry						
Mining	Index 2015 = 1	1.0	1.4	1.4	1.4	gTech
Metals	Index 2015 = 1	1.0	1.5	1.5	1.6	gTech
Pulp and paper	Index 2015 = 1	1.0	1.2	1.1	1.1	gTech
Non-metallic minerals	Index 2015 = 1	1.0	1.0	1.0	1.0	gTech
Chemicals	Index 2015 = 1	1.0	1.0	1.1	1.4	gTech
Services						
Services	Index 2015 = 1	1.0	1.1	1.2	1.4	gTech
Agriculture						
Agriculture	Index 2015 = 1	1.0	1.0	1.1	1.3	gTech
Light industry						
Other manufacturing	Index 2015 = 1	1.0	1.0	1.1	1.3	gTech
Construction	Index 2015 = 1	1.0	1.1	1.3	1.3	gTech
Forestry	Index 2015 = 1	1.0	1.2	1.3	1.4	gTech

Key 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,

45 BC Ministry of Energy, Mines, and Low-Carbon Innovation (2021, Unpublished). *Long-Term Natural Gas Production Forecast*.

46 Canada Energy Regulator (2020). *Canada's Energy Future 2020: Energy Supply and Demand Projections to 2050*. Available from: www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2020/index.html

each source of emissions tends to be concentrated in a small group of sectors. Table 12 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 12: GHG crosswalk for the industry sector in 2015 ($MtCO_2e$)

Sector	Stationary Combustion	Transport	Fugitive Sources	Industrial Processes	Agriculture	Total (excluding transport)
Total industry (excluding transport)	**14.8**	**-**	**4.8**	**1.8**	**2.3**	**23.7**
Agriculture and Forestry	0.4	0.8	-	-	2.3	2.7
Oil and gas extraction	7.2	0.3	3.6	-	-	10.8
Mining	0.5	0.9	0.9	-	-	1.3
Electricity	0.4	-	-	-	-	0.4
Construction	0.1	0.4	-	-	-	0.1
Pulp and paper manufacturing	1.6	-	-	-	-	1.6
Petroleum refining	0.6	-	0.0	-	-	0.6
Cement manufacturing	0.6	-	-	1.0	-	1.7
Lime manufacturing	0.1	-	-	0.2	-	0.3
Aluminum smelting	0.0	-	-	0.5	-	0.5
Other manufacturing	2.0	-	-	0.2	-	2.2
Pipelines	1.3	-	0.3	-	-	1.6

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

Oil and 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, direct drive compression, and process heat. In 2015, these emissions accounted for 7.2 $MtCO_2e$.

- 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 it 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 CO_2 accounted for about 1.5 $MtCO_2e$. However, different natural gas resources in British Columbia have widely different compositions, with the Montney having very low concentrations of formation CO_2, the Horn River having very high concentrations of formation CO_2, and conventional in between.

  As 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. As such, formation CO_2 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 1.2 $MtCO_2e$.
- Surfacing 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 0.6 $MtCO_2e$ 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 Engineering[47], (2) Ministry of Energy, Mines and Low-Carbon Innovation internal data[48], and then (3) adjusted in order to ensure near alignment with BC's Provincial Inventory of Greenhouse Gas Emissions[49].

Figure 6 shows the emissions intensity of natural gas production for each resource in the 2015 model base year. Table 13 provides details for each resource.

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[47] Clearstone Engineering (2014). *Canadian Upstream Oil and Gas Emissions Inventory*.

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

[49] Government of British Columbia (2020). *Provincial Inventory of Greenhouse Gas Emissions 1990-2019*. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

Forecast assumptions

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

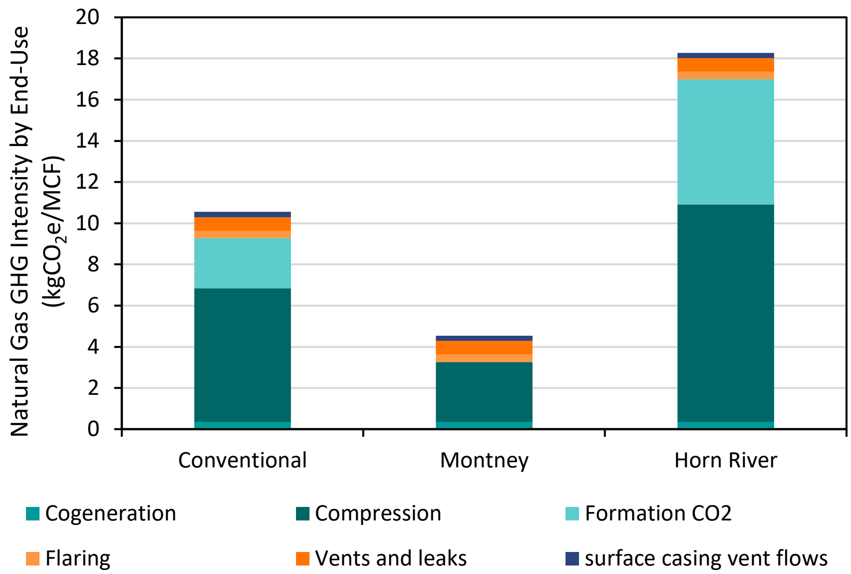


Table 13: Natural gas production and processing sector emissions in 2015 ($MtCO_2e$)

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	0.2	0.0	0.0	0.0	0.2	0.0	0.5
Conventional natural gas	1.5	0.0	0.1	0.1	0.6	0.2	0.1	2.5
Montney natural gas	3.3	0.0	0.4	0.4	0.0	0.7	0.3	5.1
Horn River natural gas	1.6	0.0	0.1	0.1	0.9	0.1	0.0	2.7
Total (excluding transport)	**6.5**	**0.2**	**0.5**	**0.6**	**1.5**	**1.2**	**0.4**	**10.8**

Petroleum refining

Petroleum refining emits GHGs mostly from combustion for producing process heat and other processes (estimated at 0.6 $MtCO_2e$ in 2015). Additionally, the refining process uses hydrogen which requires venting when it is produced on-site (estimated at 0.03 $MtCO_2e$ 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 29).

Table 14: Petroleum refining sector emissions in 2015 ($MtCO_2e$)

IPCC category	Stationary combustion	Fugitive sources	Total
End-use	Process heat (high-grade heat)	Vents	Total (excluding transport)
Petroleum refining	0.6	0.0	0.6

LNG production

Liquefied natural gas (LNG) production as represented in the model produces both combustion emissions and process emissions from three main sources (not including any emissions upstream of the liquefaction facility):

- Most combustion emissions at LNG facilities come from natural gas combustion in turbines which drive the liquefaction process (i.e. a cooling cycle resulting from the compression and expansion of refrigerants). Electric LNG facilities use electric motors to drive the cooling cycle and would not produce these combustion emissions.
- Further combustion emissions may come from on-site electricity generation to meet the LNG facilities' ancillary electricity loads (i.e. for end-uses other than the liquefaction process). Alternatively, this electricity may be supplied by the electricity grid, or cogenerated with the energy used for the cooling cycle, in which case there are no combustion GHG emissions from electricity generation.
- Process emissions come from further removal and venting of formation carbon dioxide. Raw natural gas often includes carbon dioxide along with natural gas and other constituents. Most of this carbon dioxide is removed when the gas is processed, but pipeline grade gas still contains some. This carbon dioxide must be removed completely before liquefaction, after which it is vented.

The combustion GHG emissions intensity of LNG production depends on how the cooling cycle is powered at each LNG facility and how the electricity is supplied to each LNG facility (Table 15). The archetypes in the model are based on the range of LNG facilities proposed for British Columbia, as described in environmental assessments and project descriptions. The quantity of formation carbon dioxide vented from each facility depends on the quantity of carbon dioxide present in the natural gas supplied to each facility. Navius assumes non-combustion emissions are 0.028 $tCO_2/tLNG$, assuming 1% carbon dioxide in the natural gas by volume, equivalent to 2.7% by mass[50]. Navius also assumes LNG combustion emissions average 0.134 $tCO_2/tLNG$ starting in 2025.

Table 15: LNG archetype direct GHG emissions intensity ($tCO_2e/tLNG$)

Archetype	Combustion GHG intensity	Non-combustion GHG intensity	Total
Direct-drive, single-cycle gas turbines	0.1615	0.028	0.1895
Direct-drive, high-efficiency, single-cycle gas turbines	0.128	0.028	0.156
Direct-drive, with combined-cycle gas turbine cogeneration	0.091	0.028	0.119
Electric-drive LNG	0.000	0.028	0.028

The analysis for CleanBC assumes that 60% of natural gas used by the terminal comes from new resource development in British Columbia and the remaining 40% from existing pipeline supply.

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 0.4 $MtCO_2e$, while emissions from industrial cogeneration are estimated at 0.1 $MtCO_2e$.

Mining

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

- Stationary sources (0.5 $MtCO_2e$ in 2015), which are assumed to be from producing process heat.
- Transport emissions (0.8 $MtCO_2e$ in 2015). These emissions are discussed in greater detail in Section 3.2.2.
- Fugitive emissions from coal beds (0.9 $MtCO_2e$ in 2015).

Table 16 shows the key sources of emissions for the mining sector.

[50] Union Gas. Chemical Composition of Natural Gas. Available from: www.uniongas.com/about-us/about-natural-gas/chemical-composition-of-natural-gas

Table 16: Mining sector emissions in 2015 ($MtCO_2e$)

IPCC category	Stationary combustion	Transport	Fugitive sources	Total (excluding transport)
End-use	Process heat (high-grade heat)	Transport	Coalbed methane	
Coal mining	0.3	0.7	0.9	1.2
Metal ore mining	0.2	0.2	0.0	0.2
Mineral mining	0.0	0.0	0.0	0.0
Mining services	0.0	0.0	0.0	0.0
Total (excluding transport)	**0.5**	**0.0**	**0.9**	**1.3**

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 (0.4 $MtCO_2e$ in 2015). The aluminum sector uses carbon anodes to smelt aluminum. These anodes decompose during the smelting process, emitting carbon dioxide.
- Perfluorocarbons (0.1 $MtCO_2e$ in 2015). These emissions originate from reactions between the carbon anode and the fluorine bath as a consequence of the aluminum manufacturing process.

Emissions for the sector are set to align with (1) the Provincial Inventory of Greenhouse Gas Emissions[51], (2) the National Inventory Report[52], and (3) national industrial fuel consumption by industry[53]. Table 17 shows estimated emissions from the aluminum sector in 2015.

Table 17: Aluminum sector emissions in 2015 ($MtCO_2e$)

IPCC category	Stationary combustion	Industrial processes		Total
End-use	Natural gas combustion	Aluminum CO_2	Aluminum PFCs	
Aluminum smelting	0.0	0.4	0.1	0.5

[51] 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

[52] Environment and Climate Change Canada (2021). *National Inventory Report 1990-2019: Greenhouse Gas Sources and Sinks in Canada*. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

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

Cement and lime manufacturing

Cement and lime manufacturing include two main sources of emissions: (1) combustion emissions from producing process heat (0.8 $MtCO_2e$ in 2015) and (2) industrial process emissions associated with the calcination of limestone (1.2 $MtCO_2e$).

Emissions are informed by fuel consumption at a national level, and then by (approximately) prorating these fuel shares based on BC's share of production.[54] Emissions are then aligned to the Provincial Inventory of Greenhouse Gas Emissions[55].

Table 18 shows the emissions from the cement and lime sectors assumed in 2015.

Table 18: 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	0.7	1.0	1.7
Lime manufacturing	0.1	0.2	0.3
Total	**0.8**	**1.2**	**2.0**

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 (0.8 $MtCO_2e$ 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.

[54] Environment and Climate Change Canada (2021). *National Inventory Report 1990-2019: Greenhouse Gas Sources and Sinks in Canada*. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html
Statistics Canada (annual). *Annual Industrial Consumption of Energy Survey*. Available from: www.statcan.gc.ca
[55] 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

- 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 (0.5 $MtCO_2e$ in 2015). The application of synthetic fertilizers causes the emission of nitrous oxide, which is a potent GHG.

Table 19 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 19: 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	0.0	0.0	0.2	0.4	1.4	2.0
Crop production	0.0	0.0	0.3	0.0	0.0	0.3
On-farm fuel use	0.4	0.2	0.0	0.0	0.0	0.4
Forest resources	0.0	0.7	0.0	0.0	0.0	0.0
Total (excluding transport)	**0.4**	**0.0**	**0.5**	**0.4**	**1.4**	**2.7**

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 20. 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 20: Light manufacturing sector emissions in 2015 ($MtCO_2e$)

IPCC category	Stationary combustion			Industrial processes		Total
End-use	Process heat (high-grade heat)	Process heat (low-grade heat)	Industrial cogeneration	Hydrogen production	Limestone calcination	Total (excluding transport)
Food	0.1	0.1	0.0	0.0	0.0	0.3
Beverage	0.0	0.0	0.0	0.0	0.0	0.0
Clothes and textiles	0.0	0.0	0.0	0.0	0.0	0.0
Wood products	0.1	0.5	0.0	0.0	0.0	0.6
Pulp and paper	1.4	0.3	0.0	0.0	0.0	1.6
Coal products	0.0	0.0	0.0	0.0	0.0	0.0
Chemicals	0.2	0.0	0.0	0.1	0.0	0.4
Plastics	0.0	0.0	0.0	0.0	0.0	0.0
Other non-metallic minerals	0.1	0.0	0.0	0.0	0.0	0.1
Steel	0.0	0.0	0.0	0.0	0.0	0.0
Other smelting	0.4	0.0	0.0	0.0	0.1	0.4
Foundries	0.1	0.0	0.0	0.0	0.0	0.1
Fabricated metals	0.1	0.0	0.0	0.0	0.0	0.1
Machinery	0.0	0.0	0.0	0.0	0.0	0.1
Electronics	0.0	0.0	0.0	0.0	0.0	0.0
Vehicles	0.0	0.0	0.0	0.0	0.0	0.0
Other	0.0	0.0	0.0	0.0	0.0	0.0
Total	**2.7**	**1.0**	**0.0**	**0.1**	**0.1**	**3.8**

Construction

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

- 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). Please note that these emissions are discussed in the section on transport (see Section 3.2.2) and are not discussed in detail here.

Emissions abatement opportunities

The discussion above identified many different sources of emissions. The majority of these are modelled to have abatement opportunities. Please note that abatement opportunities associated with the transport emissions in mining, agriculture, and construction are discussed in Section 3.2.2.

Table 21 summarizes the key abatement opportunities and the sources for the data.

Table 21: Abatement opportunities in the industry sector and the data sources used to characterize them

Economic sector	2015 GHG emissions ($MtCO_2e$)	Key GHG abatement opportunities	Data sources (see reference list in Section 3.2.4)
Stationary combustion			
Electric generation	0.4	Renewables	See Section 2.2.2
		Electricity efficiency	gTech
Process heat (high-grade heat)	5.1	Fuel switching	Park et al (2017), CIMS
		Carbon capture and storage	CIMS
		Renewables (Biomass and RNG)	DENA (2016)
		Electric resistance	Park et al (2017), CIMS
Process heat (low-grade heat)	1.0	Fuel switching	Park et al (2017), CIMS
		Carbon capture and storage	CIMS
		Renewables (biomass and RNG)	DENA (2016)
		Electric heat pumps	Onmen et al (2015)
Compression	7.8	Electrification	Greenblatt (2015)
		Electrification of LNG	ABB (2010)
Industrial cogeneration	0.5	No cogeneration	gTech
Fugitive sources			
Coalbed methane	0.9	No abatement available	
Vents and leaks	1.5	Various leak detection and reduction measures	ICF International (2015), Clearstone Engineering (2014)
Formation CO_2	1.5	Carbon capture and storage	CIMS
Flaring	0.6	For oil facilities: Natural gas production	Johnson & Coderre (2012)

		For natural gas facilities: no abatement	
Industrial processes			
Hydrogen production	0.1	Carbon capture and storage	US DOE (2014)
		Electrolysis	US DOE (2014)
Limestone calcination	1.3	No abatement available	
Aluminum CO_2	0.4	No abatement available	
Aluminum PFCs	0.1	Computer controls to reduce PFCs	CIMS
Other process	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	0.5	No abatement available	

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.

The forecasted transport sector activity is shown for a variety of modes in Table 22. 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 22: Transport sector activity in selected years under the calibration scenario

Sector	Unit	2015	2020	2025	2030	Source
Truck	Index (2015 = 1)	1.00	1.03	1.25	1.36	gTech
Passenger vehicles	Index (2015 = 1)	1.00	1.07	1.25	1.33	gTech
Transit	Index (2015 = 1)	1.00	1.13	1.29	1.44	gTech
Air	Index (2015 = 1)	1.00	1.29	1.47	1.66	gTech
Rail	Index (2015 = 1)	1.00	1.10	1.22	1.49	gTech

Other transport	Index (2015 = 1)	1.00	0.99	1.20	1.31	gTech

Sources of emissions

Table 23 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 in the following way: road transport is informed by the Ministry of Energy, Mines, and Low-Carbon Innovation fuel consumption data[56] reported under the *Renewable and Low Carbon Fuel Requirements Regulation*, and the remaining transport emissions are calibrated to the BC Provincial Inventory of Greenhouse Gas Emissions[57].

Most emissions in the sector (23.3 $MtCO_2e$, 97%, 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 (0.8 $MtCO_2e$, 3%) is categorized under "industrial processes and product use"; these emissions are hydrofluorocarbons (HFCs) associated with air conditioning in vehicles. To identify the share of these emissions attributable to transport, Navius estimated the amount of hydrofluorocarbons in the rest of the economy (primarily in the commercial and residential sectors), and allocated the residual to light-duty, medium and heavy-duty vehicles, as well as buses in proportion to their fuel consumption.

The largest sources of combustion emissions are light-duty, medium-duty, and heavy-duty vehicles, which together (both passenger and freight) account for 18.5 $MtCO_2e$, or 79% of total transport combustion emissions in 2015. Navigation (i.e. marine activity), aviation, railways and other transport 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).

[56] Government of British Columbia (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

[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

Table 23: GHG crosswalk for the transport sector in 2015 ($MtCO_2e$)[58]

Sector	Transport	Industrial processes and product use	Total
Total transport	**23.3**	**0.8**	**24.1**
Light-duty vehicles	8.3	0.2	8.4
Heavy-duty vehicles	5.8	0.4	6.2
Medium-duty vehicles	4.4	0.1	4.5
Buses	0.6	0.1	0.7
Domestic navigation	1.2	0.0	1.2
Domestic aviation	1.3	0.0	1.3
Railways	0.7	0.0	0.7
Other transport	1.1	0.0	1.1

Several of the end-uses shown in Table 23 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 24 summarizes sources used to parameterize transport abatement opportunities in the model.

[58] Numbers in this table and elsewhere in the document may not add up to the totals due to rounding.

Table 24: Abatement opportunities in the transport 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)
Transport			
Light-, medium-, and heavy-duty vehicles	18.5	Efficiency improvements	DOE (2003), Transport Canada (2011), NRCan (2007)
		Natural gas and renewable 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), US DOE (2013), Bloomberg (2018), ICCT (2017)
		Renewable fuels	IRENA (2013), APEC (2010), AAFC (2017), Kludze et al (2013), Yemshanov et al (2014), Petrolia (2008), (S&T)[2] Consultants, (2012), Chavez-Gherig et al (2017), G4 Insights (2018), IEA ETSAP (2013), Hallbar Consulting (2016)
		Hydrogen	NREL (2018), Strategic Analysis Consultants (2016; 2017), IEA (2019)
Domestic navigation	0.9	Efficiency improvements	CIMS
Domestic aviation	0.6	No abatement options are available	CIMS
Railways	0.7	Renewable fuels	See list for renewable fuels above

Forecast assumptions

Industrial processes and product use			
Light-, medium-, and heavy-duty vehicles	0.7	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 waste in Table 25. Building floor space increases based on the historical relationship between floor space and GDP or household income. 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, office, retail, schools, warehouses, and other. 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 (i.e. without CleanBC policies), while the share of floor space from attached homes and apartments rises. This shift is simulated by the model, but also aligns well with historical trends.

Table 25: Buildings and communities sector activity in selected years under the calibration scenario

Sector	Unit	2015	2020	2025	2030	Source
Commercial and institutional	Million m^2	102	120	137	154	gTech
Residential	Million m^2	280	331	359	384	gTech
Waste	Index (2015 = 1)	1.00	1.00	0.99	0.99	gTech

Sources of emissions

Table 26 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 End-Use Database.

Emissions come from several key sources:

- The combustion of natural gas for space heating in both residential and commercial buildings (4.2 $MtCO_2e$ in 2015).
- The combustion of natural gas for water heating (1.9 $MtCO_2e$ in 2015).
- The release of HFCs from air conditioning and auxiliary equipment (1.0 $MtCO_2e$ in 2015).
- The release of methane from landfills as organic matter decomposes or is incinerated (4.4$MtCO_2e$ in 2015). This is disaggregated into emissions from municipal solid waste and from industrial wood waste as in the Provincial Inventory of Greenhouse Gas Emissions.

Table 26: GHG crosswalk for the buildings and communities sector in 2015 ($MtCO_2e$)

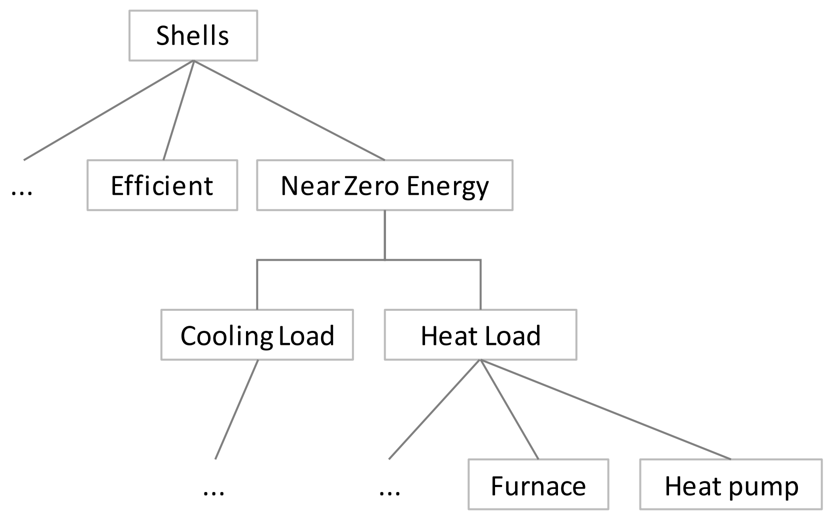
Sector	Stationary combustion	Industrial processes and product use	Waste	Total
Total buildings and communities	**6.2**	**1.0**	**4.4**	**11.6**
Residential buildings	**3.7**	**0.1**	**-**	**3.9**
Space heating	2.2	-	-	2.2
Water heating	1.5	-	-	1.5
Air conditioning	0.0	0.1	-	0.1
Cooking	0.1	-	-	0.1
Clothes drying	0.0	-	-	0.0
Commercial and institutional buildings	**2.4**	**0.8**	**0.0**	**3.3**
Space heating	2.0	-	-	2.0
Water heating	0.4	-	-	0.4
Air conditioning	-	0.2	-	0.2
Auxiliary equipment	-	0.7	-	0.7
Waste	**-**	**-**	**4.4**	**4.4**
Waste	-	-	4.4	4.4

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.

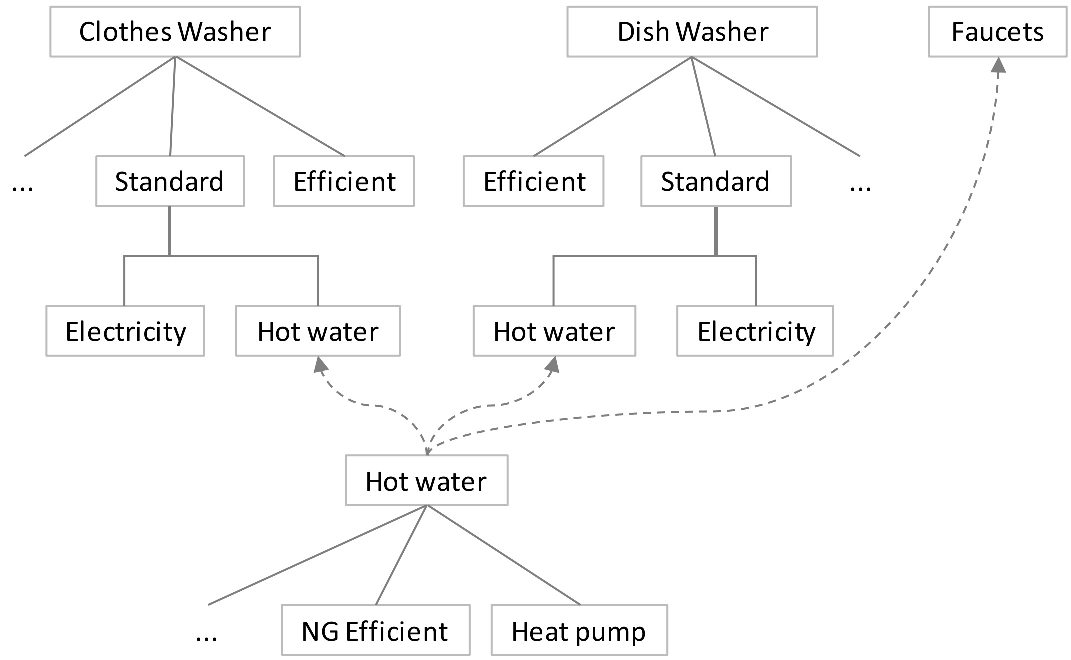
Figure 7 shows the relationship between various end-uses in the commercial building sector (the relationships for residential buildings are similar, but slightly more complicated). gTech simulates three decisions that affect building efficiency and GHG emissions. At the top level, gTech simulates the 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 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 27 summarizes sources used to parameterize abatement opportunities in the buildings and communities sector in the model.

Table 27: Abatement opportunities in the buildings and communities 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			
Space heating	4.2	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 (2019)
		Electric space and water heating (resistance and heat pump)	EIA (2016), NREL (2018)
Water heating	1.9	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	0.3	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			
Waste	4.4	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

- (S&T)[2] Consultants Inc. (2012). *Update of Advanced Biofuel Pathways in GHGenius*.
- ABB (2010). *All-Electric LNG Plants: Better, Safer, More Reliable – and Profitable*. Available from: https://library.e.abb.com/public/9e770a172afc8d7ec125779e004b9974/Paper%20LNG_Rev%20A_lowres.pdf
- Agriculture and Agri-Food Canada (AAFC) (2017). *Biomass Agriculture Inventory Median Values*. Available from: www.open.canada.ca
- Argonne (2018). *USA DOE Benefits and Scenario Analysis*.
- Asia-Pacific Economic Cooperation (APEC) (2010). *Biofuel Costs, Technologies, and Economics in APEC Economies*.
- Bergerson Consulting (2019, Unpublished). *Upstream Emissions Intensities of Current and Potential Global LNG Projects*.
- Bloomberg New Energy Finance (2017). *Electric Vehicle Outlook 2017*.
- Bloomberg New Energy Finance (2018). *Electric Buses in Cities: Driving Towards Cleaner Air and Lower* CO_2. Available from: www.about.bnef.com
- Government of British Columbia (BC) (2017). *Technical Methods and Guidance Document 2007 - 2012 Reports, Community Energy and Emissions Inventory (CEEI) Initiative*.
- Chavez-Gherig, A., Ducru, P., & Sandford, M. (2017). *The New Jersey Pinelands and the Green Hospital, NRG Energy Case Study*.
- Navius Research Inc. (CIMS). *CIMS Technology Database*.
- Clearstone Engineering (2014). *Canadian Upstream Oil and Gas Emissions Inventory*.

Forecast assumptions

- Curry, C. (2017). *Lithium-Ion Battery Costs and Market, Bloomberg New Energy Finance*.
- Energy Information Administration (EIA) (2016). *Analysis and Projections: Updated Buildings Sector Appliance and Equipment Costs and Efficiency*. Available from: www.eia.gov/analysis/studies/buildings/equipcosts
- G4 Insights Inc. (2018). *Our Technology*. Available from: www.g4insights.com/about.html
- German Energy Agency (DENA) (2016). *Process Heat in Industry and Commerce: Technology Solutions for Waste Heat Utilisation and Renewable Provision*.
- GHGenius 4.03. (2018). *GHGenius: A Model for Lifecycle Analysis of Transportation Fuels*. Available from: www.ghgenius.ca
- Greenblatt, J. (2015). *Opportunities for Efficiency Improvements in the US Natural Gas Transmission, Storage, and Distribution System*.
- Hallbar Consulting (2016). *Resource Supply Potential for Renewable Natural Gas in BC*.
- ICF International (2015). *Economic Analysis of Methane Emission Reduction Opportunities in the Canadian Oil and Natural Gas Industries*.
- International Council on Clean Transportation (ICCT) (2017). *Transitioning to Zero-Emission Heavy-Duty Freight Vehicles*. Available from: https://theicct.org
- International Energy Agency Energy Technology System Analysis Programme (IEA ETSAP) (2013). *Biogas and Bio-syngas Production*.
- International Energy Agency (IEA) (2019). *The Future of Hydrogen*.
- International Renewable Energy Association (IRENA) (2013). *Road Transport: The Cost of Renewable Solutions*.
- Johnson, M., & Coderre, A. (2012). “Opportunities for CO_2 Equivalent Emissions Reductions via Flare and Vent Mitigation: A Case Study for Alberta, Canada”. *International Journal of Greenhouse Gas Control*, 8, 121-131.
- Jones, S., Meyer, P., Snowden-Swan, L., Padmaperuma, A., Tan, E., Dutta, A., Jacobson, J., & Cafferty, K. (2013). *Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels: Fast Pyrolysis and*

Hydrotreating Bio-Oil Pathway (No. PNNL-23053; NREL/TP-5100-61178). Pacific Northwest National Laboratory (PNNL), Richland, WA (USA).

- Kludze, H., Deen, B., Weersink, A., van Acker, R., Janovicek, K., De Laport, A., & McDonald, I. (2013). "Estimating Sustainable Crop Residue Removal Rates and Costs Based on Soil Organic Matter Dynamics and Rotational Complexity". *Biomass and Bioenergy*, 56, 607-618

- Moawad, A., Kim, N., Shidore, N., & Rousseau, A. (2016). *Assessment of Vehicle Sizing, Energy Consumption, and Cost Through Large-Scale Simulation of Advanced Vehicle Technologies* (No. ANL/ESD-15/28). Argonne National Laboratory (ANL), Argonne, IL (USA).

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

- National Renewable Energy Laboratory (NREL) (2018). *H2A: Hydrogen Analysis Production Case Studies*.

- Natural Resources Canada (NRCan) (2007). *Canadian Vehicle Survey 2007 Summary Report*. Available from: https://oee.nrcan.gc.ca/Publications/statistics/cvs07/index.cfm

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

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

- Park, N., Park, S., Kim, J., Choi, D., Yun, B., & Hong, J. (2017). "Technical and Economic Potential of Highly Efficient Boiler Technologies in the Korean Industrial Sector". *Energy*, 121, 884-891.

- Petrolia, R. (2008). "The Economics of Harvesting and Transporting Corn Stover for Conversion to Fuel Ethanol: A Case Study for Minnesota". *Biomass and Bioenergy*, 32, 603-612.

- RDH Building Science (2018). *Building Shell Performance and Cost Data*. Prepared for Navius Research.

- Strategic Analysis Consultants (2016). *Final report: Hydrogen Storage System Cost Analysis.*

Forecast assumptions

- Strategic Analysis Consultants (2017). *Mass Production Cost Estimation of Direct H_2 PEM Fuel Cell Systems for Transportation Applications.*
- Transport Canada (2011). *Operating Costs of Trucking and Surface Intermodal Transportation in Canada*.
- UBS Evidence Lab, Global Research (2017). *UBS Evidence Lab Electric Car Teardown – Disruption Ahead?*. Available from: https://neo.ubs.com/shared/d1wkuDlEbYPjF
- USA Department of Energy (US DOE) (2003). *The Potential Effect of Future Energy-Efficiency and Emissions-Improving Technologies on Fuel Consumption of Heavy Trucks*. Available from: www.osti.gov/bridge/product.biblio.jsp?osti_id=810465
- USA Department of Energy (US DOE) (2013). *EV Everywhere Grand Challenge Blueprint*.
- USA Department of Energy (US DOE) (2014). H2A *Hydrogen Production Analysis Models: Current Central Hydrogen Production from Coal with CO_2 Sequestration Version 3.101*. Available from: www.nrel.gov/hydrogen/h2a-production-models.html
- Yemshanov D., McKenney, D.W., Fraleigh, S., McConkey, B., Huffman, T., & Smith, S. (2014). "Cost Estimates of Post Harvest Forest Biomass Supply for Canada". *Biomass and Bioenergy*, 69, 80-94.

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.

Forecast assumptions

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

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 or "business as usual" forecast. This forecast only includes policies existing as of July, 2017[59]. 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.

[59] Some policies have been implemented since July 2017 (e.g. strengthening of the federal heavy-duty vehicle regulations). Although these policies are not included in the reference case described in this report, they are included in the CleanBC scenarios.

4.1. Multi-sector

4.1.1. Carbon tax

BC's carbon tax was implemented in 2008 in the *Carbon Tax Act*[60]. Carbon tax rates can be found within the Act. The reference scenario modelling assumes the carbon tax is set at $30/t$CO_2$e. Revenue raised by the tax is used to lower personal and corporate income taxes and transferred directly to households through rebates. The modelling also excludes biofuels (such as ethanol and renewable diesel) from the carbon tax.

4.1.2. Clean electricity mandate

The clean electricity mandate is outlined within the *Clean Energy Act*[61]. 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%[62]. The modelling assumes the current level of 98% is maintained to 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 announced in Budget 2015[63] The modelling assumes a total of $27 million of investments enabling increased use of low-carbon fuels; and payments for achievement of annually decreasing emissions intensity benchmarks.

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

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

[62] BC Hydro (2021), *2020/21 Annul Service Plan Report*. Available from: www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/accountability-reports/financial-reports/annual-reports/bchydro-annual-service-plan-report-2020-2021.pdf

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

4.3. Transport

4.3.1. Clean vehicle incentives

The Clean Energy Vehicle Program provides funding for zero- and low-emissions vehicles[64]. The modelling assumes incentives of $40 million in total spread over 2020-2016.

4.3.2. Low-carbon fuel standard

The LCFS was enacted in the *Greenhouse Gas Reduction (Renewable & Low Carbon Fuel Requirements) Act*[65] and the *Renewable and Low Carbon Fuel Requirements Regulation*[66] 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 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.

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*

64 www.cevforbc.ca

65 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

66 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

and Light Truck Greenhouse Gas Emission Regulations[67] 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*[68] 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 2014[69]. 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. Provincial sales tax exemption

Provincial sales tax exemptions were enacted in 2013 via the *Provincial Sales Tax Exemption and Refund Regulation*[70]. More information is available in a Provincial Sales Tax Bulletin[71]. The modelling includes this policy by exempting the use of electricity in residential and industrial buildings from the provincial sales tax.

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

[67] 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

[68] *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

[69] 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

[70] BC Reg. 97/2013. *Provincial Sales Tax Exemption and Refund Regulation*. Available from www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/1414726040

[71] Government of British Columbia (2017). *Provincial Sales Tax (PST) Bulletin: Energy, Energy Conservation, and the ICE Fund Tax*. Available from: www2.gov.bc.ca/assets/gov/taxes/sales-taxes/publications/pst-203-energy-conservation-ice-fund-tax.pdf

federal *Energy Efficiency Regulations*[72] in 2016. More information is available online[73]. 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 2012[74] (first adopted in December 2012) as amended several times up to April 2017. This policy is modelled as requiring that new residential buildings demand 43% less space heating load than the average residential building in 2010. 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 capture rate is maintained indefinitely.

4.4.5. Landfill gas management regulations

Landfills are required to implement landfill gas management measures to collect methane in accordance with requirements enacted in the 2008 *Landfill Gas Management Regulation*[75].

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

[73] Natural Resources Canada (2017). *Guide to Canada's Energy Efficiency Regulations*. Available from: www.nrcan.gc.ca/energy-efficiency/energy-efficiency-regulations/guide-canadas-energy-efficiency-regulations/6861

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

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

Reference scenario policies

The modelling assumes that 35% of landfill gas (excluding from industrial wood waste landfills) is captured by 2020, and that this capture rate is maintained indefinitely.

5. CleanBC Phase 1 policies

This section describes CleanBC Phase 1 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 were adjusted to account for other factors not represented in gTech. Differences are noted as appropriate throughout and summarized in Appendix A.

5.1. Multi-sector

5.1.1. Strengthened carbon tax

In 2018, BC's price on carbon increased for the first time since 2012 to $35/t$CO_2$e. The price is assumed to increase to $50/t$CO_2$e in 2022. This price signal is modelled 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.

Revenue from the carbon tax is divided into three streams in the modelling:

- **Carbon revenue raised from the carbon tax at $30/t$CO_2$e.** Under CleanBC, revenue earned from the carbon tax below $30/t$CO_2$e 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 $30/t$CO_2$e on households**. Revenue above $30/t$CO_2$e 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 $30/t$CO_2$e on businesses** is used to fund several initiatives to reduce GHG emissions in industry and businesses (discussed below in Section 5.2.1).

CleanBC Phase 1 policies

5.1.2. Renewable gas mandate

This policy is modelled as a minimum renewable content in natural gas for downstream sectors (i.e. excluding natural gas consumption by the oil and gas sector) that starts at 2% in 2020 and increases linearly to reach 15% by 2030, allowing for contractual agreements outside of BC. Compliance options include the blending of either renewable gas or hydrogen. However, the modelling assumes a hydrogen blend constraint of 5% by volume due to limitations associated with upgrading natural gas equipment and safety sensors for the use of hydrogen[76].

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 modelling also assumes support for small and medium sized businesses.

The analysis assumes carbon revenue spent on the Program for Industry is used for several government priorities depending on who pays the tax. All carbon tax revenue collected from industry that is above $30/t$CO_2$e is divided into two categories in the modelling:

- **Revenue from businesses that emit less than 10 ktCO_2e annually** is assumed to support small and medium sized businesses to adopt low-carbon technologies. No such program currently exists. This assumption is designed to mimic the **CleanBC Industry Fund**.
- **Revenue from businesses that emit at least 10 ktCO_2e 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

[76] Yoo Y. et al. (2017). *Review of hydrogen tolerance of key Power-to-Gas (P2G) components and systems in Canada: final report*.

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 the program benchmarks and thresholds published in 2020[77].

- **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 and for small and medium sized businesses was determined in consultation with the BC Government. These technologies were selected such that their abatement costs exceed $50/t$CO_2$e, and only technologies with a GHG impact are eligible (i.e. no electrical efficiency technologies).

5.2.2. Oil and gas sector methane regulations

Starting in 2020, all new oil and gas facilities are required to implement a range of 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*[78] in 2018. The modelling represents this policy by requiring the adoption of such technologies in the oil and gas sector.

5.2.3. Industrial electrification

Information about BC's industrial electrification projects is available online[79].The analysis assumes increased electricity consumption in the upstream natural gas sector. Data from BC Hydro's 2020 load forecast is used to inform the level of electricity consumption in the upstream natural gas sector. This data includes the connection to (1) the completed Dawson Creek/Chetwynd Area Transmission (DCAT) project and (2) the Peace Region Electricity Supply (PRES) project. In future modelling, Navius plans to keep working with BC Hydro to ensure continued appropriate alignment.

[77] www2.gov.bc.ca/gov/content/environment/climate-change/industry/cleanbc-industrial-incentive-program

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

[79] www.bchydro.com/news/press_centre/news_releases/2011/dcat.html, www.bchydro.com/energy-in-bc/projects/pres.html

CleanBC Phase 1 policies

5.2.4. Carbon capture and storage regulations

BC's carbon capture and storage requirements have been implemented in *Carbon Dioxide Storage Application Guide – Oil and Gas Industry Emissions*, published by the BC Oil and Gas Commission in July 2021[80]. Projects for carbon capture and storage will be considered for approval as a Section 75 Special Project under the *Oil and Gas Activity Act*[81].

This policy establishes 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.

5.3. Transport

5.3.1. Light-duty zero-emissions vehicle mandate

The light-duty ZEV mandate establishes a target of 10% new zero-emissions light duty vehicle sales by 2025, and 30% by 2030. It requires that vehicle suppliers earn credits in line with an annual target called a compliance ratio, scheduled in the *Zero-Emission Vehicles Regulation*[82]. The number of credits required is calculated as the compliance ratio multiplied by the number of new light-duty vehicle sales. Modelling requires zero-emissions light-duty vehicle sales (including pure electric, hydrogen fuel-cell, and plug-in hybrids) to meet compliance ratios of 22% by 2025 and 71% by 2030. Additionally, pure electric vehicles and hydrogen fuel-cell vehicles must reach a separate compliance ratio of 16% in 2025 and 50% in 2030.

The modelling awards credits to zero-emissions vehicles using a per-vehicle formula that gives more credit to pure electric and hydrogen fuel-cell vehicles than plug-in hybrid vehicles. Vehicles are awarded credits based on their range (in kilometres) and class as follows:

$$c = r \times 0.006214 + \mathrm{a}$$

[80] British Columbia Oil and Gas Commission (2021). *Carbon Dioxide Storage Application Guide – Oil and Gas Industry Emissions*. Available from: www.bcogc.ca/files/operations-documentation/Reservoir-Management/Subsurface-Disposal/Carbon-Dioxide-Storage-Application-Guideline.pdf

[81] SBC 2008, Chapter 36. *Oil and Gas Activity Act*, 2008. Available from: www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/08036_01

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

where c is the number of credits, r in the range of the vehicle in km, and a is 0.5 for pure electric and hydrogen fuel-cell vehicles and 0.3 for plug-in hybrid vehicles.

5.3.2. Heavy-duty zero-emissions vehicle mandate

The analysis assumes the following minimum ZEV and LNG sales requirements apply, ramping up linearly from 2019 to the following levels in 2030:

- 10% of new medium- and heavy-duty vehicles sold (excluding buses) must be electric.
- 16% of new heavy-duty vehicles sold (excluding buses) must be powered by LNG.
- 94% of new buses sold must be electric.

5.3.3. Strengthened zero-emissions 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 online[83].

The analysis assumes financial incentives for the purchase of low- and zero-emissions vehicles of $52 million in 2019, $25 million in 2020, and $93 million per year beginning in 2021. Values from 2022 onwards are strictly assumed and may be adjusted in future modelling as policies are confirmed.

5.3.4. Strengthened low-carbon fuel standard

Increases to the stringency of the LCFS starting in 2021 were enacted in an amendment[84] to the *Renewable and Low Carbon Fuel Requirements Regulation*[85] in 2020.

BC's LCFS requires transport fuel suppliers to reduce the average emissions intensity of transport fuels by 9.1% by 2020, from 2010 levels. Phase 1 of CleanBC increases

[83] www.gov.bc.ca/zeroemissionvehicles

[84] BC Reg 178/2020. Available from: www.bclaws.gov.bc.ca/civix/document/id/lc/bcgaz2/v63n13_178-2020

[85] 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

the stringency to 20% by 2030. The strengthened policy continues to exclude domestic aviation and marine fuels.

To comply with the policy, fuel providers can:

- Blend a low-carbon fuel into the gasoline or diesel pool (e.g. ethanol, biodiesel, renewable gasoline).
- Purchase credits from suppliers of other low-carbon energy used for transport (e.g. electricity or renewable gas).
- Obtain credits via Part 3 Agreements.

5.3.5. Strengthened light-duty vehicle emissions standards

Currently Canada has federal fleet-wide GHG emissions standards for sales of new light-duty passenger vehicles[86]. The modelling assumes this federal standard is strengthened and adds a provincial standard:

- The modelling strengthens the Canadian emissions standard to align with the most stringent standards in the USA as intended by the federal government[87]. The most stringent standards are assumed to be those in California[88].
- Additionally, the modelling assumes a provincial GHG emissions standard for new light-duty vehicles. This policy requires that BC meet an average fleet-wide GHG emissions standard across the province in addition to contributing to the national requirement.

Both the federal and provincial policies are modelled as a weighted average requirement (i.e. accounting for the current share of cars and light trucks) declining from 200 gCO_2e/km in 2015 to 119 gCO_2e/km by 2030. Both the provincial and federal policies are assumed to disallow battery-electric and plug-in hybrid electric vehicles as a compliance option, preventing automakers from offsetting zero-

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86 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

87 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

88 *California Code of Regulations. Title 13: Motor Vehicles, Division 3 – Air Resources Board. The California Low-Emission Vehicle Regulations*. Available from: ww2.arb.ca.gov/sites/default/files/2019-07/cleancomplete%20lev-ghg%20regs%2010-19.pdf

emissions vehicle sales (which are required by the zero-emissions vehicle mandate) with less efficient conventional vehicles.

5.3.6. Strengthened heavy-duty vehicle emissions standards

New heavy-duty vehicles sold in Canada must meet retailer fleet-average emissions standards listed in the federal *Heavy-Duty Vehicle and Engine Greenhouse Gas Emission Regulations*[89].

This policy applies additional efficiency standards from 2021 onwards in line with the EPA's standards for on-road heavy-duty vehicles and engines[90]. The analysis assumes: (1) a 20% reduction in emissions intensity in 2025 relative to 2015 and (2) a 24% reduction in emissions intensity in 2030 relative to 2015.

5.4. Buildings and communities

5.4.1. Better homes and better buildings incentives

Information about Better Homes and Better Buildings Incentives is available online[91].

The modelled policy assumes incentives provided annually for the reduction of GHG emissions in both residential and commercial/institutional buildings.

- Incentives target the purchase of heat pumps in buildings between 2019 and 2030 ($2.1 million in 2019, $4.7 million in 2020, $16.6 million in 2021, $13.4 million in 2022, and $20 million annually from 2023 through 2030). Values from 2022 onwards are strictly assumed and may be adjusted in future modelling as policies are confirmed.

- Incentives target more efficient shells in buildings between 2019 and 2030 ($7.2 million in 2019, $10.7 million in 2020, $11.9 million in 2021, $18.3 million in 2022, and $3.5 million annually from 2023 through 2030). Values from 2023

[89] 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

[90] 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

[91] www.betterhomesbc.ca, www.betterbuildingsbc.ca

CleanBC Phase 1 policies

onwards are strictly assumed and may be adjusted in future modelling as policies are confirmed.

5.4.2. Organic waste diversion

BC's organic waste policy is available online[92].The modelling assumes that 95% of organic municipal, agricultural, and industrial waste (excluding industrial wood waste) is diverted from landfills by 2025, and that this capture rate is maintained indefinitely.

5.4.3. Landfill gas management regulations

BC's landfill gas management regulations are listed in the *Landfill Gas Management Regulation*[93].

The modelling assumes that 75% of landfill gas (excluding from industrial wood waste landfills) is captured by 2025 and that this capture rate is maintained indefinitely.

92 www2.gov.bc.ca/gov/content/environment/waste-management/food-and-organic-waste/organic-waste-diversion

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

6. CleanBC Phase 2 (Roadmap to 2030) policies

In addition to CleanBC Phase 1 policies, the BC government is developing a second phase of policies. This section describes how CleanBC Phase 2 policies (announced in the CleanBC Roadmap to 2030[94]) are modelled. This section also expands on Phase 2 policy details provided in Table 3. As several policies are still in development, their final design may differ from the assumptions used to model them at this time. In addition, some policy options selected by the government were adjusted to account for other factors not represented in the modelling. These adjustments are summarized in Appendix A.

Impacts from Phase 2 policies are measured relative to a scenario that includes all CleanBC Phase 1 policies. However, this version of Phase 1 differs from what is described in both Section 5 and the 2021 Climate Change Accountability Report. The Phase 1 scenario used to measure impacts of policies described in this section excludes electricity as a compliance option under the LCFS. Electricity as a compliance option was accounted for as a post-modelling adjustment (see Appendix A).

6.1. Multi-sector

6.1.1. Further strengthened carbon tax

Under CleanBC Phase 1 the carbon tax is assumed to rise to \$50/tCO_2e by 2022. Phase 2 modelling strengthens the carbon tax by \$15/tCO_2e each year until it reaches \$170/tCO_2e in 2030. The final carbon tax design for BC has not been confirmed beyond 2022/23.

The modelling assumes revenue generated under Phase 2 is recycled much like in Phase 1. See Section 5.2.1 for a detailed description of the streams of revenue assumed in the modelling. However, Phase 2 modelling differs in the treatment of industrial revenue. Revenue recycling from businesses that emit less than 10 ktCO_2e annually is described below. Revenue recycling from large final emitters (at least 10 ktCO_2e annually) is summarized in Section 6.2.1.

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

Revenue from businesses that emit less than 10 ktCO_2e annually is recycled as follows in the modelling:

- Revenue generated from the carbon tax between \$0-\$30/tCO_2e is used to lower labor income taxes and as general government revenue.
- Revenue generated from the carbon tax between \$30-\$50/tCO_2e is used to invest in low-carbon technologies and programs. This policy modelling is designed to mimic the CleanBC Industry Fund.
- Revenue generated from the carbon tax between \$50-\$170/tCO_2e is allocated as general government revenue. This carbon revenue may be used for other government priorities which are yet to be specified.

6.1.1. 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 in the reference and CleanBC Phase 1 scenarios.

6.1.1. Natural gas GHG emissions cap

The analysis assumes that starting in 2030, GHG emissions from the combustion of natural gas are capped at an annual level of 6.1 MtCO_2e. This cap applies to GHG emissions from industry (excluding oil and gas) and buildings.

6.2. Industry

6.2.1. Enhanced CleanBC program for industry

As described in Phase 1 of CleanBC (see Section 5.2.1), the CleanBC Program for Industry provides an additional incentive for facilities to reduce their GHG emissions, However, unlike Phase 1, Phase 2 modelling assumes that as the carbon tax rises an increased amount of carbon tax paid by large emitters is made available for the CIIP. Additionally, the modelling assumes the carbon tax on industry rises to \$170/tCO_2e by 2030.

Revenue from businesses that emit at least 10 ktCO_2e annually (i.e. “large final emitters”) is recycled as follows in the modelling:

- **CleanBC Industrial Incentive Program**. Already, the carbon tax provides an incentive for firms to reduce their GHG emissions, because as they do so firms 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 CIIP 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 the program benchmarks and thresholds published in 2020[95].

- **CleanBC Industry Fund**. Any carbon tax revenue between \$0-\$50/tCO_2e not used for the CIIP is 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.

- Revenue generated from the carbon tax between \$50-\$170/tCO_2e not used for the CIIP is recycled as general government revenue. This carbon tax revenue may be used for other government priorities which are yet to be specified. The final carbon tax design for BC has not been confirmed beyond 2022/23.

6.2.2. Strengthened oil and gas sector methane requirements

The modelling assumes methane requirements in the oil and gas sector are strengthened such that emissions in 2030 are 75% lower than 2014 levels.

6.3. Transport

6.3.1. Strengthened light-duty zero-emissions vehicle mandate

Phase 2 strengthens the light-duty ZEV mandate modelled in Phase 1 (described in Section 5.3.1). The modelling requires light-duty vehicles to reach 30% ZEV sales by 2026, and 90% by 2030. Unlike Phase 1, the modelling of this policy does not assume different credits between pure electric, hydrogen fuel-cell, and plug-in hybrid vehicles. Instead, all three types receive an equal number of credits.

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95 www2.gov.bc.ca/gov/content/environment/climate-change/industry/cleanbc-industrial-incentive-program

6.3.2. Strengthened heavy-duty zero-emissions vehicle mandate

Phase 2 of the analysis builds on Phase 1 by strengthening the heavy-duty ZEV mandate. The modelling assumes that by 2030, 32% of class 2B-3 vehicles, 44% of class 4-8 vehicles, and 23% of truck tractors sold are required to be zero-emissions.

The modelling assumes 60% of the requirement is met by pure electric vehicles and 40% by hydrogen fuel-cell vehicles.

6.3.3. Strengthened zero-emissions bus mandate

The analysis assumes that Phase 2 requires 100% of bus sales to be zero-emissions by 2029. It is assumed that the bus fleet will be split between 60% pure electric vehicles and 40% hydrogen fuel-cell vehicles.

6.3.4. Heavy-duty zero-emissions vehicle stock mandate

The analysis assumes that by 2030, 19% of heavy-duty vehicle stock and 35% of drayage truck and off-road vehicle stock is required to be zero-emissions.

The modelling assumes 60% of these ZEVs are pure electric and 40% are hydrogen fuel-cell vehicles.

6.3.5. Further strengthened low-carbon fuel standard

Under Phase 1, the modelling requires transport fuel suppliers to reduce the average emissions intensity of transport fuels 20% by 2030 under the LCFS. The Phase 2 modelling builds on the LCFS by increasing the stringency to 30% by 2030.

Additionally, the Phase 2 analysis expands the coverage of the LCFS to include fuels consumed in marine and aviation, which were previously omitted in Phase 1. Phase 2 modelling excludes electricity as a compliance option under the LCFS. However, electricity is included as a compliance option in the post-modelling adjustment made by the BC Government as described in Appendix A.

6.3.6. Light-duty vehicle travel reduction

The analysis requires total vehicle kilometres 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.

6.3.7. Freight emissions intensity reduction

The analysis requires the emissions intensity of freight (in $tCO_2e/t{\cdot}km$) to be reduced 10% by 2030, relative to 2020 levels. Policies able to achieve this reduction are in development.

6.4. Buildings and Communities

6.4.1. Strengthened BC building code

The analysis assumes that starting in 2027, all new buildings are required to meet zero-emissions standards. After the Phase 2 modelling was completed, this policy was revised to start in 2030, as stated in the CleanBC Roadmap to 2030.

6.4.2. Heating equipment standards

The analysis assumes that starting in 2030, only heat pumps (including electric, natural gas, and hybrid) can be purchased for space and water heating.

CleanBC Phase 2 (Roadmap to 2030) policies

Appendix A. 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 generated results, a number of post-modelling adjustments were made by the BC Government for publication in the 2021 Climate Change Accountability Report[96] and the CleanBC Roadmap to 2030[97].

The following sections describe these additions and adjustments, starting with the addition of GHG emissions not covered by the modelling, followed by adjustments made to CleanBC Phase 1 modelling results, and lastly adjustments made to CleanBC Phase 2 modelling results.

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: 2015-2019[98]. This amounts to 2.9 $MtCO_2e$, almost entirely from deforestation. Alternative approaches that can account for future changes and mitigation actions are being considered for future forecasts.

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[96] 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

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

[98] 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

CleanBC Phase 1 post-modelling adjustments

After CleanBC Phase 1 is modelled, adjustments are made by the BC Government for publication in the 2021 Climate Change Accountability Report[99] and elsewhere.

CleanBC program for industry

CleanBC Program for Industry emissions reductions were increased to a total of 2.5 $MtCO_2e$ in 2030. Several different methodologies were considered in producing 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. These factors are expected to influence a new type of enhanced signal to reduce GHGs.

CleanBC Phase 2 post-modelling adjustments

Similar to CleanBC Phase 1, modelling results are adjusted by the BC Government for publication in the CleanBC Roadmap to 2030[100] and elsewhere. These adjustments are made to account for policies not modelled due to time constraints or because they have yet to be designed.

Federal climate funding

In consultation with Navius, a further 0.3 $MtCO_2e$ of emissions reduction is assumed for 2030, to account for anticipated federal funding of climate action initiatives. These

[99] 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

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

funding amounts are listed in the federal A Healthy Environment and a Healthy Economy document[101].

CleanBC industry fund

An additional 0.5 $MtCO_2e$ of emissions reduction is assumed from the CIF in 2030, to recognize the effect of added resources from a heightened carbon tax.

Additional oil and gas sector policies

A further 1.1 $MtCO_2e$ of emissions reduction within the oil and gas sector is assumed in 2030 to account for policies to be implemented to achieve the sectoral target commitment made in the Roadmap to 2030[102]. Similarly, in 2025, 25% of this additional reduction is assumed. The policies that will achieve these reductions are yet to be developed.

BC Hydro's electrification plan

A further 0.1 $MtCO_2e$ of emissions reduction is assumed for 2030, to account for actions in the electrification plan[103] BC Hydro released in September 2021. Similarly, in 2025, 25% of this additional reduction is assumed.

Agriculture policies

A further 0.2 $MtCO_2e$ 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.

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[101] 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

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

[103] 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

Low-carbon fuel standard

While the LCFS modelled in CleanBC Phase 2 excludes supplying electricity as a compliance option, the LCFS as currently implemented does include supplying electricity. To account for this difference, the CleanBC Phase 2 emissions forecast is increased by 1.3 MtCO_2e in 2030. Abatement from the LCFS is expected to decrease with the inclusion of electricity because other policies (e.g. the ZEV mandate) also incentivize the adoption of electric vehicles, leading to policy overlap.

Municipal policies

A further 0.1 MtCO_2e of emissions reduction is assumed for 2030, to account for intended municipal climate actions. Examples of these include the City of Vancouver's Climate Emergency Action Plan[104].

Industrial wood waste policies

A further 1.3 MtCO_2e of emissions reduction is assumed for 2030 to account for an intended policy to increase the oxidation of industrial wood waste methane. This policy is still in development.

Deforestation policies

A further 0.2 MtCO_2e 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 "GHG emissions not covered by modelling" in Appendix A, deforestation emissions are not modelled in gTech; in the Provincial Forecast they are assumed by the BC Government to continue at current levels.

[104] City of Vancouver (2020). *Climate Emergency Acton Plan Summary 2020-2025*. Available from: www.vancouver.ca/green-vancouver/vancouvers-climate-emergency.aspx

Appendix B. Covered sectors, fuels, end-uses, and technologies

Table 28: 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
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 29: 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 30: 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
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

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 31. 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

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

	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 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 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	Baseline coal Baseline diesel Baseline heavy fuel oil Baseline natural gas Baseline natural gas liquids

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

Heavy-duty vehicles that consume gasoline	Diesel Diesel efficient Diesel highly efficient Existing LNG efficient Electric Hydrogen fuel cell
Household air conditioning	Existing New New efficient New highly efficient
Household heating load	Electric baseboard Furnaces Ground-source heat pump
Household hot water	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	Compact florescent Existing Halogen incandescent Incandescent Light-emitting diode (LED)
Hydrogen	CCS Existing Hydrogen production from still gas
Integrated steel production	Existing
Landfills	Existing Landfill gas flaring Landfill gas utilization as fuel 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
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 C. CleanBC Phase 1 impacts in 2020 and 2021 modelling

Table 32 compares the emissions reductions forecast for each CleanBC Phase 1 policy in the 2020 and 2021 modelling (not including the post-modelling adjustments applied by the BC Government).

Table 32: CleanBC Phase 1 emissions reductions in 2020 and 2021 modelling[105]

Policy	Description	2030 impact ($MtCO_2e$) 2020 modelling	2030 impact ($MtCO_2e$) 2021 modelling	Comment
Total[106]		**-14.8**	**-9.9**	
Multi-sector		**-0.9**	**-0.9**	
Strengthened carbon tax	Continue the successful carbon pricing framework, with rebates for low- and middle-income British Columbians and support for clean investments	-0.9	-0.9	The 2021 modelling forecasts very similar emissions reductions to the 2020 modelling.
Renewable gas mandate	Make natural gas consumption cleaner with a minimum 15% to come from renewable gas	-2.6	-3.2	In the 2021 modelling, abatement associated with the renewable gas mandate is greater by 0.5 $MtCO_2e$ relative to 2020 modelling. Total reductions increased because the 2021 modelling assumes higher natural gas consumption in the reference scenario.
Industry		**-5.8**	**-4.1**	
CIIP	Return a portion of carbon tax paid by high-emitting industrial	-0.8	+0.2	The CIIP, CIF, and small and medium enterprise support, were modelled as a single policy

105 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.

106 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.

	facilities as rebates, which increase as facilities lower their emissions intensity			in 2020, but have been disaggregated in 2021 to identify their individual impacts. The combined impact in the 2021 modelling is lower than in the 2020 modelling. BC is currently reviewing the model representation of these policies.
CIF	Directly fund emissions reductions in eligible sectors		-0.2	
Small and medium enterprise support	Directly fund emissions reductions in sectors not eligible for the CIF		-0.2	
Oil and gas sector methane regulations	Reduce methane emissions from upstream oil and gas operations by 45% from 2014 levels	-1.5	-1.4	The 2021 modelling forecasts very similar emissions reductions to the 2020 modelling.
Industrial electrification	Provide clean electricity to planned natural gas production in the Peace River region with new transmission lines and interconnectivity to existing lines	-1.8	-1.1	In the 2021 modelling, GHG reductions are 0.7 $MtCO_2e$ lower than in the 2020 modelling. Abatement is lower because of updates made to (1) the natural gas production forecast and (2) electricity load forecast.
CCS regulations	Ensure a regulatory framework for safe and effective underground CO_2 storage	-0.2	-0.2	The 2021 modelling forecasts very similar emissions reductions to the 2020 modelling.
Transport		**-6.0**	**-4.5**	
Light-duty ZEV mandate	By 2040, every new car will be a ZEV, with phased-in increases in intervening years	-0.5	-0.4	The 2021 modelling forecasts a smaller emissions reduction than the 2020 modelling because the reference scenario assumes greater ZEV adoption than the 2020 modelling.
Heavy-duty ZEV mandate	By 2030, 10% of new heavy-duty vehicles will be ZEVs and 94% of buses will be electric	-0.2	-0.2	The 2021 modelling forecasts very similar emissions reductions to the 2020 modelling.
Strengthened ZEV incentives	Help people to afford cleaner cars with ZEV incentives	-0.1	-0.2	The 2021 modelling forecasts very similar emissions reductions to the 2020 modelling.
Strengthened LCFS	Make our fuel cleaner by increasing the LCFS to 20% by 2030	-4.3	-2.2	Abatement is lower in the updated modelling because the 2021 modelling includes electricity as a compliance

				option under the LCFS while the 2020 modelling did not. This update decreases abatement from the LCFS because other policies (such as the ZEV mandate) also incentivize electrification in transport (i.e. policy overlap increases).
Strengthened light-duty vehicle emissions standards	Make light-duty vehicles run cleaner by increasing tailpipe emissions standards	-0.8	-1.1	The 2021 modelling forecasts similar emissions reductions to the 2020 modelling.
Strengthened heavy-duty vehicle emissions standards	Make heavy-duty vehicles run cleaner by increasing tailpipe emissions standards	-	-0.4	The impact of the heavy-duty vehicle standards was not reported separately in 2020, although it was included in the CleanBC total.
Buildings and communities		**-1.5**	**-2.0**	
Building retrofit code		0.0	0.0	The retrofit code takes effect in 2030
Better Homes and Better Buildings incentives	Incentives to make homes more energy-efficient and heat pumps more affordable	-0.3	-0.1	The 2021 modelling forecasts a smaller emissions reduction relative to the 2020 modelling because less funding was assumed.
Organic waste diversion	Achieve 95% organic waste diversion for municipal waste	-0.7	-0.1	The two waste policies were modelled as a single policy in 2020,but have been disaggregated in 2021 to identify their individual impacts.
Landfill gas management regulations	Capture 75% of landfill gas for use or flaring		-0.6	The 2021 modelling forecasts very similar emissions reductions to the 2020 modelling.

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