Supporting the development of CleanBC

2019 updated methodology report for assessing the impacts of CleanBC policies

SUBMITTED TO

BC Climate Action Secretariat
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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 emission 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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Summary

British Columbia has set a target of reducing provincial greenhouse gas emissions by 40% below 2007 levels in 2030[1]. Subsequent targets call for reductions of 60% in 2040 and 80% in 2050. Achieving these targets requires strong policies to shift BC's energy system towards low- and zero-carbon sources of energy and processes.

This report documents the methodology, assumptions and results of a comprehensive analysis into the impacts of CleanBC – a package of policies designed to help achieve BC's 2030 greenhouse gas target[2].

This report is intended to supplement the greenhouse gas 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.

[1] Bill 34 – 2018. Greenhouse Gas Reduction Targets Amendment Act, 2018.

[2] Government of British Columbia. CleanBC. Available from: www.cleanbc.gov.bc.ca

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

BC has formulated CleanBC, a package of policies, to help put the province on track to meeting its greenhouse gas targets. These policies are summarized in Table 1. Complete details about these policies and how they are modelled is provided in Chapter 5.

Table 1: Summary of how CleanBC policies are represented in the modelling

Sector	Policy	Description of how policies are modelled
Multi-sector		
	Carbon pricing	The analysis assumes a continued increase of the carbon tax by $5 per tonne of carbon dioxide equivalent annually, until it reaches $50 per tonne in 2021. Revenue collected from the tax is used to fund transfers to households and to achieve additional industrial emission reductions under the CleanBC Program for Industry, described below.
	Renewable gas standard	The analysis assumes that 15% of natural gas consumed by sectors outside upstream oil and gas (i.e., industry and buildings) is renewable by 2030.
Industry		
	CleanBC Industry Fund	The analysis assumes that a portion of carbon tax revenue above $30 per tonne is invested in low carbon technologies.
	CleanBC Industrial Incentive Program	The analysis assumes that an additional incentive is provided for industry to reduce greenhouse gas emissions by returning a portion of carbon tax revenue above $30 per tonne to facilities that reduce their emissions relative to a world leading emissions intensity benchmark.
	Reduce emissions from methane	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. Not all regulated best practices are currently available in gTech. We plan to parameterize these abatement options in future modelling. We expect this revision to reduce GHG emissions under CleanBC (for more details please see section 5.3.2)
	Industrial electrification	The analysis assumes increased electricity consumption in the upstream natural gas sector in keeping with BC Hydro's load forecast. By aligning to BC Hydro data, we implicitly align with their assumptions, including connecting to the DCAT and PRES transmissions lines. Electricity consumption in the upstream natural gas sector is slightly higher than what is forecast by BC Hydro. In future modelling, we plan to keep working with BC Hydro to ensure continued appropriate alignment.
	Carbon capture and storage	This policy establishes a regulatory framework for the geological sequestration of formation carbon dioxide separated from natural gas during processing. The policy specifications and modelling method are both currently under review.
Transport		

Sector	Policy	Description of how policies are modelled
	Zero-emission vehicle mandate	The analysis assumes that a minimum share of light-duty vehicles sold in BC is zero-emission. This mandate achieves 10% electric vehicles sales by 2025, 30% by 2030 and 100% by 2040. The analysis assumes that a minimum share of heavy-duty vehicles sold in BC is zero-emission by 2030: 10% of vehicles excluding buses are electric, 16% are LNG and 94% of buses are electric.
	Zero-emission vehicle rebates	The analysis assumes financial incentives of $14 million per year[3] through 2030 for the purchase of plug-in hybrid electric and battery electric light duty vehicles. The analysis assumes incentives for zero- and low-emissions heavy duty vehicles in the modelled amount of $3.33 million per year through 2030. These incentives target both electric and natural gas-fueled vehicles.
	Strengthened Renewable & Low Carbon Fuel Requirements	The analysis assumes that fuel suppliers reduce the carbon intensity of diesel and gasoline pools by 20% by 2030 from 2010 levels, while expanding coverage to domestic aviation and navigation fuels and omitting electricity as a compliance option by 2030.
	Tailpipe emissions standard	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 by over 10% to 105 grams per kilometre in 2030 and disallow compliance via zero-emission vehicles.
Buildings		
	Heat pump incentives	The analysis assumes financial incentives of $38 million (2015$) annually for the purchase of electric heat pumps for space and water heating between 2021 and 2030.
Waste		
	Strengthened organic waste diversion	The analysis assumes an increase of the organic waste diversion rate to 95% by 2025. Assumes adoption by all local governments.
	Landfill gas management	The analysis assumes 75% capture of landfill gas from all large municipal sites by 2025.

[3] Program funding values in Table 1 for years beyond the 3-year forecast in *Budget 2019* are modelling assumptions only and do not represent actual funding commitment levels.

Key 2019 Model Updates

Navius makes regular updates to improve the accuracy of the gTech model. Core assumptions and data sources are revised via literature review and consultation with subject matter experts. The CleanBC policy package that is modelled will also change over time as more information becomes available on the design of announced individual policies and new policies are added. As a result of policy and core updates, model results will change in each iteration of the modelling.

Since the release of CleanBC in December 2018, the gTech model has undergone substantial core updates. These updated core assumptions are detailed in Table 2. There have also been some modelling changes applied to specific CleanBC Phase 1 policies; these are detailed in Section 5. Policy designs and modelling assumptions will continue to change as policies are implemented, and as they begin to produce results.

Table 2: Key updates in 2019 modelling

Model update:	Description:	Fall 2018:	Fall 2019:
Economic data	Updated to 2015 Statistics Canada Supply and Use tables. GDP and all prices reported in 2015$, as opposed to 2010$. Any recent changes in the structure of the BC economy between 2010 and 2015 are explicitly accounted for in the model.	Used 2010 Statistics Canada Supply and Use tables	Uses 2015 Statistics Canada Supply and Use tables
Provincial Inventory (PI)	Calibrated to the 2017 BC PI which includes updates to all past emission years as is standard practice.[4]	Model calibrated to 2016 BC PI	Model calibrated to 2017 BC PI
Natural gas production forecast	Calibrated to a more accurate 2030 BC natural gas production forecast that is 18% higher than 2018 modelling in the reference case.	Calibrated to NEB 2017 natural gas production forecast. 2030 forecast is 6.6 bcf/d and includes all natural gas produced in BC including supply expected to service the liquefied natural gas sector.	Calibrated to BC's current natural gas production forecast from the Ministry of Energy, Mines and Petroleum Resources which contains more accurate BC production data. 2030 forecast is 7.8 bcf/d and includes all natural gas produced in BC including

[4] Government of British Columbia. Provincial Greenhouse Gas Emissions Inventory. Available from: https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

Model update:	Description:	Fall 2018:	Fall 2019:
			supply expected to service the liquefied natural gas sector.
Natural gas carbon intensity	Compared to 2018 modelling, 2019 modelling: 1) assumes lower electrification in the upstream natural gas sector based on estimates received from BC Hydro); 2) assumes a lower emissions intensity (EI) value for the Montney based on estimates received from the Ministry of Energy, Mines, and Petroleum Resources; and 3) applies an autonomous energy efficiency improvement index (AEEI) to better align with historic decline in combustion emission intensities.	2015 Montney EI: 5.1 kg CO_2e per Mcf 2030 Montney EI under CleanBC: 3.0 kg CO_2e per Mcf	2015 Montney EI: 5.0 kg CO_2e per Mcf 2030 Montney EI under CleanBC: 2.3 kg CO_2e per Mcf
Industrial electrification	Aligns electricity consumption forecast for upstream natural gas sector with data provided by BC Hydro.	Dawson Creek/Chetwynd Area Transmission (DCAT) line capacity: 185 MW Peace Region Electricity Supply (PRES) line capacity: 800 MW Capacity utilization (subscription rates): DCAT: 100%, PRES: 75% DCAT and PRES meet electricity demand solely in the upstream natural gas sector.	By aligning to BC Hydro's load forecast in the upstream natural gas sector, we implicitly align with their assumptions. These assumptions include: Interconnecting upstream gas customers to the BC Hydro transmission system, primarily the capacity resulting from the DCAT and PRES projects. A small portion of the transmission capacity resulting from DCAT and PRES is also used to serve loads from sectors other than natural gas.
Renewable gas	Updated renewable content of natural gas for downstream sectors.	Renewable gas content modelled at 10% in 2030. This requirement was scaled up to 15% based on the results of prior model runs at 10% and 30% as a post-modelling adjustment by the BC government.	Assumes a Renewable Portfolio Standard for natural gas utilities that starts at 2% in 2020 and increases linearly to reach 15% by 2030. Allows for contractual arrangements outside of BC.

Model update:	Description:	Fall 2018:	Fall 2019:
Vehicle population	Higher number of electric vehicles (EVs) in the reference case of the 2019 model relative to the 2018 model.	Vehicle population is a function of a variety of external inputs in the model, including prices, and federal and provincial vehicle policies.	Updated oil prices result in electrification becoming a more cost-effective way of meeting the federal vehicle emissions standards. This leads to a greater number of EVs in the 2019 reference case, especially in provinces with relatively low electricity prices like BC.
Carbon pricing	The analysis assumes a continued increase of the carbon tax by $5 per tonne of carbon dioxide equivalent annually, until it reaches $50 per tonne in 2021.	No difference in the modelling of carbon pricing between 2018 and 2019. However, there are greater reductions in the 2018 modelling, in part due to a greater amount of GHG emissions (and more carbon-taxed emissions) in the reference case.	There are fewer reductions in response to carbon pricing in the 2019 model. The most significant difference is localized in the natural gas sector. Electricity consumption in the natural gas sector is aligned to BC Hydro's forecast. This alignment limits incremental electricity consumption as a response to increased carbon pricing, resulting in fewer GHG reductions in the natural gas sector.

2019 modelling of CleanBC policies

The modelling updates described above result in changes to the expected 2030 emission reductions of the CleanBC policy package. Emission reductions are calculated for each CleanBC policy by comparing expected emissions in 2030 under a reference case scenario (business as usual with no new policies after July 2017) to a scenario with the policy in place. A scenario with all the CleanBC Phase 1 policies in place is used to quantify the total reductions, to account for potential interaction or overlapping of the individual policies.

In the updated modelling (2019), reference case emissions are lower than in the 2018 modelling, meaning that more decarbonization is now expected to occur in the absence of policy than was previously. As a result, there are fewer emissions for CleanBC policies to target resulting in fewer reductions needed to achieve a similar 2030 emissions level. This is largely due to updates to the modelling of the upstream natural gas sector described previously. A comparison of how additional modelling updates have affected individual CleanBC policies is presented in Appendix D.

The 2030 emissions estimates included in the 2019 Climate Change Accountability Report are a product of the modelling detailed in this report with some post-modelling adjustments applied, as noted in Appendix C. In the updated modelling, the 2030 emissions totals are estimated to be 44.3 Mt under CleanBC and 60.7 Mt under the reference case. In the 2018 modelling, the 2030 emissions totals were estimated to be 44.3 Mt under CleanBC and 63.2 Mt under the reference case.

Table of Contents

1. Introduction

British Columbia has set a target of reducing provincial greenhouse gas emissions by 40% below 2007 levels in 2030[5]. Subsequent targets call for reductions of 60% in 2040 and 80% in 2050. Achieving these targets requires strong policies to shift BC's energy system towards low- and zero-carbon sources of energy and processes.

Navius Research Inc. provides a suite of analytical models to forecast the effect of government policy. This report documents the methodology, assumptions and results of a comprehensive analysis into the impacts of CleanBC – a package of policies designed to help achieve BC's 2030 greenhouse gas targets[6].

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 case forecast and describes how they are modelled (Section 4).
- Identifies policies that are included in the CleanBC forecast and describes how they are modelled (Section 5).

The appendices provide additional information about the modelling, including results of the reference case and CleanBC forecasts.

Some policy options selected by government do not exactly align with those presented in this report. Differences are noted as appropriate throughout and summarized in Appendix C: "Post modelling modifications by the BC Government".

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[5] Bill 34 – 2018. Greenhouse Gas Reduction Targets Amendment Act, 2018.

[6] Government of British Columbia. CleanBC. Available from: www.cleanbc.gov.bc.ca

2. Method

This Section provides an overview of the methods and assumptions employed to forecast BC's greenhouse gas emissions. It introduces energy-economy modelling and how it can inform policymaking (Section 2.1), and then reviews our 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 greenhouse gas 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 fewer emissions; local governments must manage their organic waste; and investors need to 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 times interact with other policies. For example, CleanBC calls for a strengthening of the low carbon fuel standard on transportation fuels. This policy is not a conventional regulation because it creates a new market where market participants (fuel suppliers) can trade their obligations towards the policy. The plan also calls for new transmission lines to be built that would directly target and enable greenhouse gas reductions in the natural gas sector. And many policies directly or indirectly target the same sources of emissions. The carbon tax, zero-emission vehicle standard, low-carbon fuel standard and revisions to the tailpipe standard all seek to reduce greenhouse gas emissions from passenger vehicles.

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

2.2. Our modelling toolkit

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

1. The **gTech** model, which provides a comprehensive representation of all economic activity, energy consumption and greenhouse gas emissions in BC and is itself an amalgamation of several different types of models; and
2. The **Integrated Electricity Supply and Demand (IESD)** model, which focuses on the electricity sector.

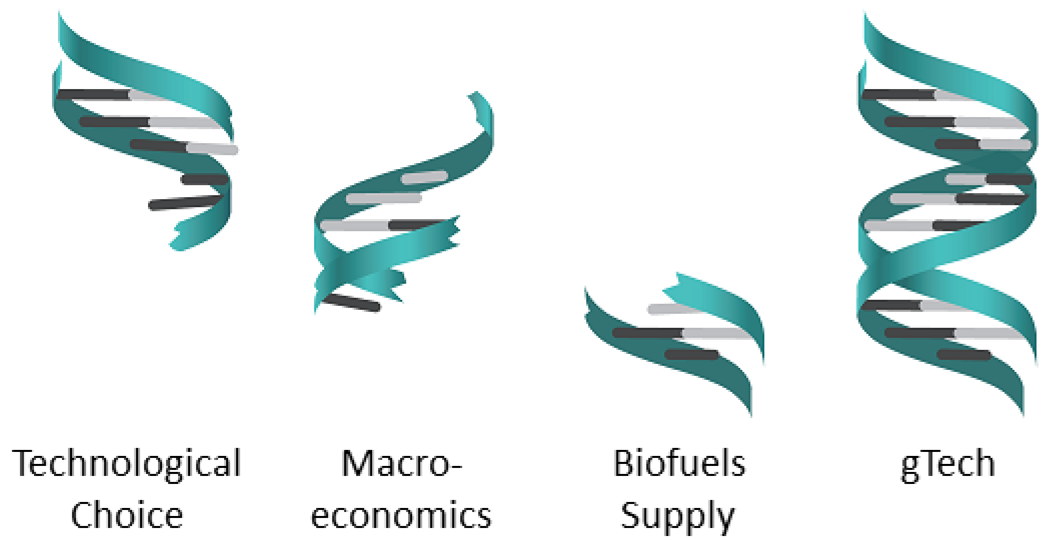
These models are introduced below.

2.2.1. gTech

gTech 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 greenhouse gas 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.

Figure 1: The gTech model



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

Simulating technological choice

Technological choice is one of the most critical decisions that influence greenhouse gas emissions in BC's economy. For example, if a household chooses to purchase an electric vehicle over a gasoline car, that decision will reduce their emissions. Similarly, if the natural gas sector chooses to electrify their operations, as opposed to using natural gas, that decision reduces their 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 3 summarizes key factors that influence technological choice and the extent to which these factors are included in gTech.

Table 3: Technological choice dynamics captured by gTech

Criteria	Description
Purchasing (capital) costs	Purchasing costs are simply the upfront cost of purchasing a technology. Every technology in gTech has a unique capital cost that is based on research conducted by Navius. Everything else being equal (which is rarely the case), households and firms prefer technologies with a lower purchasing cost. 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 for energy (e.g., cents per litre of gasoline) and (2) the energy requirements of an individual technology (e.g., a vehicle's fuel economy, measured in litres per 100 km). In gTech, the energy requirements for a given technology are fixed, but the price for energy is determined by the model. The method of "solving" for energy prices is discussed in more detail below. 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 as well as an energy cost. Households and businesses must generally incur a technology's purchasing cost before they incur the energy costs. In other words, a household will buy a vehicle before it needs to be fueled. As such, there is a tradeoff between near-term capital costs and long-term energy costs. gTech represents this tradeoff using a "discount rate". Discount rates are analogous to the interest rate used for a loan. The question then becomes: is a household willing to incur greater upfront costs to enable energy or emissions savings in the future? Many energy modelers use a "financial" discount rate (commonly between 5% and 10%). However, given the objective of forecasting how households and firms are likely to respond to climate policy, gTech employs "behaviourally" realistic discount rates of between 8% and 25% to simulate technological choice. Research consistently shows that households and firms do not make decisions using a financial discount rate, but rather use significantly higher rates.[7] The implication is that using a financial discount rate would overvalue future savings relative to revealed behavior and provide a poor forecast of household and firm decisions.

[7] Rivers, N., & Jaccard, M. (2006). Useful models for simulating policies to induce technological change. *Energy policy*, *34*(15), 2038-2047.

Criteria	Description
Technology specific preferences	In addition to preferences around near-term and long-term costs, households (and even firms) exhibit “preferences” towards certain types of technologies. These preferences are often so strong that they can overwhelm most other factors (including financial ones). For example, 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 will be willing to purchase such a vehicle. And then there are many other groups in between.[8] 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 one neighbour 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[9]. 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 the past couple of years, and they are expected to continue their decline into the future[10]. 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.

[8] 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.

[9] Rivers, N., & Jaccard, M. (2006). Useful models for simulating policies to induce technological change. *Energy policy*, *34*(15), 2038-2047.

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

Criteria	Description
Policy	One of the most important drivers of technological choice is government policy, and CleanBC will alter the technological choices households and firms make. The plan includes: (1) incentive programs, which pay for a portion of the purchasing cost of a given technology; (2) regulations, which either require a group of technologies to be purchased or prevent another group of technologies from being purchased; (3) carbon taxation, which increases fuel costs in proportion to their carbon content; (4) variations in other tax policy (e.g., whether or not to charge PST on a given technology); and (5) flexible regulations, like the low-carbon fuel standard which creates a market for compliance credits. gTech simulates the combined effects of all these policies implemented together. Policies included in the reference case (i.e., business as usual) forecast are described in Section4. Policies included in the CleanBC forecast are described in Section5.

Understanding the macroeconomic impacts of policy

As a full macroeconomic model (specifically, a “general equilibrium model”), gTech provides insight about how policies affect the economy at large. It can also answer each of the questions identified above. The key macroeconomic dynamics captured by gTech are summarised in Table 4.

Table 4: Macroeconomic dynamics captured by gTech

Dynamic	Description
Comprehensive coverage of economic activity	gTech accounts for all economic activity in British Columbia as measured by Statistics Canada national accounts[11]. Specifically, it captures all sector activity, all gross domestic product, all trade of goods and services and a large number of transactions that occur between households, firms, government and people/firms outside of British Columbia. As such, the model provides a forecast of how government policy affects many different economic indicators, including gross domestic product, investment, household income, etc.
Full equilibrium dynamics	gTech ensures that all markets in the model return to equilibrium (i.e., that the supply for a good or service is equal to its demand). This means that a decision made in one sector is likely to have ripple effects throughout the entire economy. For example, greater demand for electricity in British Columbia 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.

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

Dynamic	Description
Sector detail	gTech provides a detailed accounting of sectors in British Columbia. 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 greenhouse gas emissions (e.g., the demand by the natural gas sector for services or labour requirements). But other inputs are classified as “energy end-uses”. Covered energy end-uses (along with sectors and fuels) are listed in Appendix A: “Covered sectors, fuels, end-uses”.
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 British Columbia 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 British Columbia. The model simulates each of the interactions described above, and how interactions may change in response to policy. In other words, the model can forecast how a policy may affect the trade of natural gas between 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 different goods and services. gTech accounts for each of these dynamics, and how either changes with policy.

Understanding petroleum, natural gas and biofuels markets

gTech offers two additional features that are critical to understand BC’s future energy-economy. First, it accounts for “nascent” sectors that may develop in the future, including Liquified Natural Gas (LNG) production and biofuels manufacturing.

Second, the model accounts for the transportation costs of liquid and gaseous fuels between regions. British Columbia’s natural gas sector is somewhat unique in that it is “at the end of the pipeline”. The province is situated about as far away as possible from the key areas of natural gas demand in North America (i.e., the North Eastern 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 captures such dynamics.

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 effect of climate and energy policy.

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

- How do policies affect technological adoption (e.g. what proportion of total household heating and cooling is met by heat pumps)?
- How does technological adoption affect greenhouse gas emissions and energy consumption?

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

- How do policies affect provincial gross domestic product?
- How do policies affect individual sectors of the economy?
- How are households affected by the policy?
- Does the policy 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 a policy generate more supply of renewable fuels?
- Does policy affect the cost of transporting natural gas, and therefore the price for natural gas in BC?

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

- What is the effect of investing carbon revenue into low- and zero-carbon technologies? This answer can only be answered with a model such as gTech.

- What are the macroeconomic impacts of technology-focused policies (e.g. how might a zero-emissions vehicle standard impact provincial GDP)?
- Do 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. As such, 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 unique 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 relative to 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. Likewise, generation from solar photovoltaics is available when the sun is up.[12] The implication is 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 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.

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

- **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 electric 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.
- **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.[13]

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

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

How IESD works

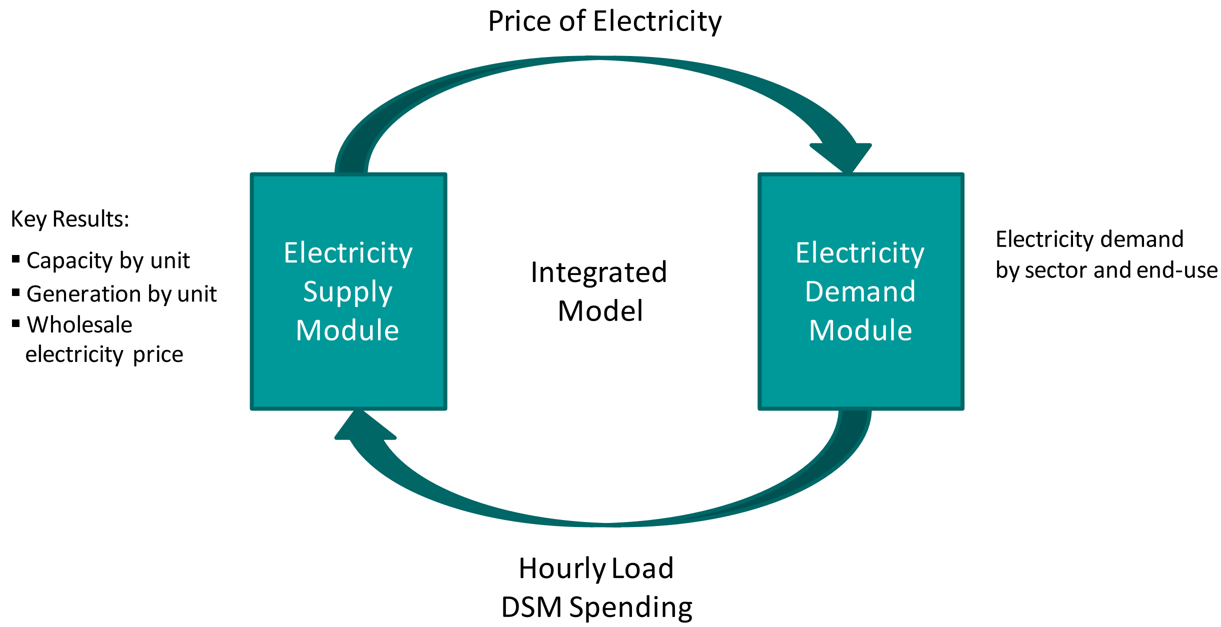
The IESD model simulates:

- 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.

[13] 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.

Figure 2: Conceptualization of IESD model simulation



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, greenhouse gas 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 were 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, 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, 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,[14] the Energy Information Agency[15] and the Alberta Electricity System Operator.[16]

Dispatch and capacity utilization

Thermal 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,

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[14] BC Hydro, 2013 Resource Option Update Report, Appendix 3, Resource Options Database Summary Sheets

[15] US Energy Information Agency, 2013, Updated Capital Cost Estimates for Utility Scale Electricity Generation Plants

[16] Alberta Electricity System Operator (AESO), 2013, Long Term Transmission Plan

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, the hourly wind energy 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 (e.g. lowest in winter, highest in spring) and IESD has assumed it is constant during each hour of a given month. Solar capacity availability varies for each month of the year (e.g. lowest in winter, 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, 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, solar in BC vs. the US).

Detailed BC Model Inputs

The IESD model has a detailed representation of technologies available to generate electricity in British Columbia. In total, the model includes 48 resource options, which are based on the resource options provided from 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/generation.

Sectors and end-uses in the electricity demand module

The electricity demand module aggregates end-uses from gTech into seven end-uses in 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);
- 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, which 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 was designed to do from what it is not intended 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 greenhouse 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: "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.[17] Further, Navius undertakes significant efforts to calibrate and to back-cast the model (please 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.

[17] 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, the level of LNG development in the province, and a stable climate. If any of the assumptions used prove incorrect, the resulting forecast could be affected.

> *"All models are wrong, but some are useful".*
> George Box

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

Model boundaries

It is important to delineate the objectives of gTech and IESD from what the models are not intended to do. The delineation for gTech is presented in Table 5 and Table 6.

Table 5: 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 3.3. The actions available to reduce emissions include: ■ Technological change. For every end-use characterized in the model, different technologies are available to alter the energy or emissions profile of that end-use. 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: o Changes in income. gTech explicitly simulates how policies affect provincial income, household income and income generated by each industry. Everything else equal, less/more income leads to less/more emissions. o 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. o 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.	gTech does not include all available actions to reduce GHG emissions. Of these, the most important are likely: ■ Afforestation/deforestation. 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 this source of emissions or carbon sinks. The BC Government adjusts gTech forecasts to include additional emissions from deforestations (see Appendix C: "Post-modelling modifications by the BC Government" 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 urban planning can affect how people both house and transport themselves. Changes in urban form, for example increased unit density, could lead to more energy efficient buildings and increase public transit ridership/active transport. 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 are 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.

Model dynamic	What gTech is intended to do	What gTech is not intended to do
Technological dynamics	gTech captures the following attributes for each technology in the model: ■ Capital costs; ■ Fuel requirements (e.g., GJ of electricity per electric vehicle); ■ Non-financial factors that are converted to a monetary value in order to simulate people's preferences; ■ Discount rates. Please note that 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 may decline over time (these costs decline at a fixed rate). ■ Various other parameters as described in Section 2.2.1.	gTech excludes some key attributes of technologies, including: ■ How and whether capital costs decline relative to cumulative experience with a technology. The literature confirms that this dynamic is important;[18] but it is not included in gTech. Part of the motivation for excluding this dynamic in gTech is that it could lead to greater instability in the results. Analogous to the "butterfly effect", a small change at the outset of the model's simulation can lead to large effects towards the end. Navius has deliberately chosen to avoid these dynamics in order to improve model stability. However, Navius expects to add this functionality at a later date. ■ How and whether non-financial costs may change in response to the market share for different technologies. The literature indicates that this dynamic is important[19], but it would likewise increase model instability and so Navius has deliberately excluded it.
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.

[18]Löschel, A. (2002). Technological change in economic models of environmental policy: a survey. *Ecological economics*, 43(2-3), 105-126.

[19]For example, see: 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.

Table 6: What gTech is intended and not intended to do (macroeconomics)

Model dynamic	What gTech is intended to do	What gTech is not intended to do
Full equilibrium dynamics	gTech ensures that every market simulated in the model returns to equilibrium.	While the equilibrium abilities of the model are generally viewed as an asset, it should be recognized that in reality some markets could remain out of equilibrium for a period of time. For example, labour markets can experience non-equilibrium unemployment, which would not be captured by gTech.
Sector detail	gTech includes 80 sectors of the economy. A list of these sectors is provided in Appendix A: "Covered sectors, fuels, end-uses".	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). The 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 tradeoff 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 simulate competitiveness dynamics. More information about this tradeoff is provided starting on page 29.	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 external data sources. More information about this tradeoff 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, gTech explicitly models Québec's mandate for electric vehicles.	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 of 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 or two parent household).

<table>
<tr><th>Model dynamic</th><th>What gTech is intended to do</th><th>What gTech is not intended to do</th></tr>
<tr><td>Solve periods</td><td>The version of gTech used in this study solves in 5-year increments. While Navius has developed versions that solve in smaller time increments, Navius uses 5-year increments for two reasons:
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).</td><td>By solving in five-year increments, gTech:
Is not intended to examine the short-term effect 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 impact 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.</td></tr>
<tr><td>Labour Supply</td><td>gTech captures two important labour dynamics, (1) the extent to which labour supply will change in response to real wages, and (2) simulates how the equilibrium level of unemployment changes in response to real wage rates.</td><td>gTech does not capture labour business cycles as it excludes a non-equilibrium unemployment function. gTech also does not explicitly include changes in how policies might affect migration between BC and other regions.</td></tr>
</table>

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 7).

Table 7: 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 from 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 residual 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 (although these impacts are likely to be small). More importantly, IESD does not provide regional disaggregation of British Columbia.
Temporal resolution	IESD simulates hourly variability in electricity demand and supply (e.g. how demand for lighting increases between 6am and 7am 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. British Columbia's Provincial Greenhouse Gas Emissions Inventory) or other forecasts (e.g., BC's GDP forecast until 2050). 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:

- British Columbia's Provincial Greenhouse Gas Emissions Inventory[20].
- Environment and Climate Change Canada's National Inventory Report[21].
- Statistics Canada's Supply-Use Tables[22].
- Natural Resources Canada's Comprehensive Energy Use Database[23].
- Statistics Canada's Annual Industrial Consumption of Energy Survey[24].
- Navius' technology database (see Table 30. List of Technologies in gTech).
- BC's Ministry of Energy, Mines and Petroleum Resources natural gas production forecast.
- Partial calibration to BC Hydro's 2019 load forecast. We've closely aligned electricity consumption with BC Hydro for some sectors but have allowed the model to endogenously forecast electricity consumption in others.

Each of these data sources is generated using different methods, and 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 reported by Natural Resources Canada's Comprehensive Energy Use Database. Further, energy expenditures are a function of consumption and prices, so if prices vary over the course of the year, it is difficult to perfectly align consumption and expenditures.

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

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

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[20] Government of British Columbia. Provincial Greenhouse Gas Emissions Inventory: 2017 Provincial Inventory. Available from: https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

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

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

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

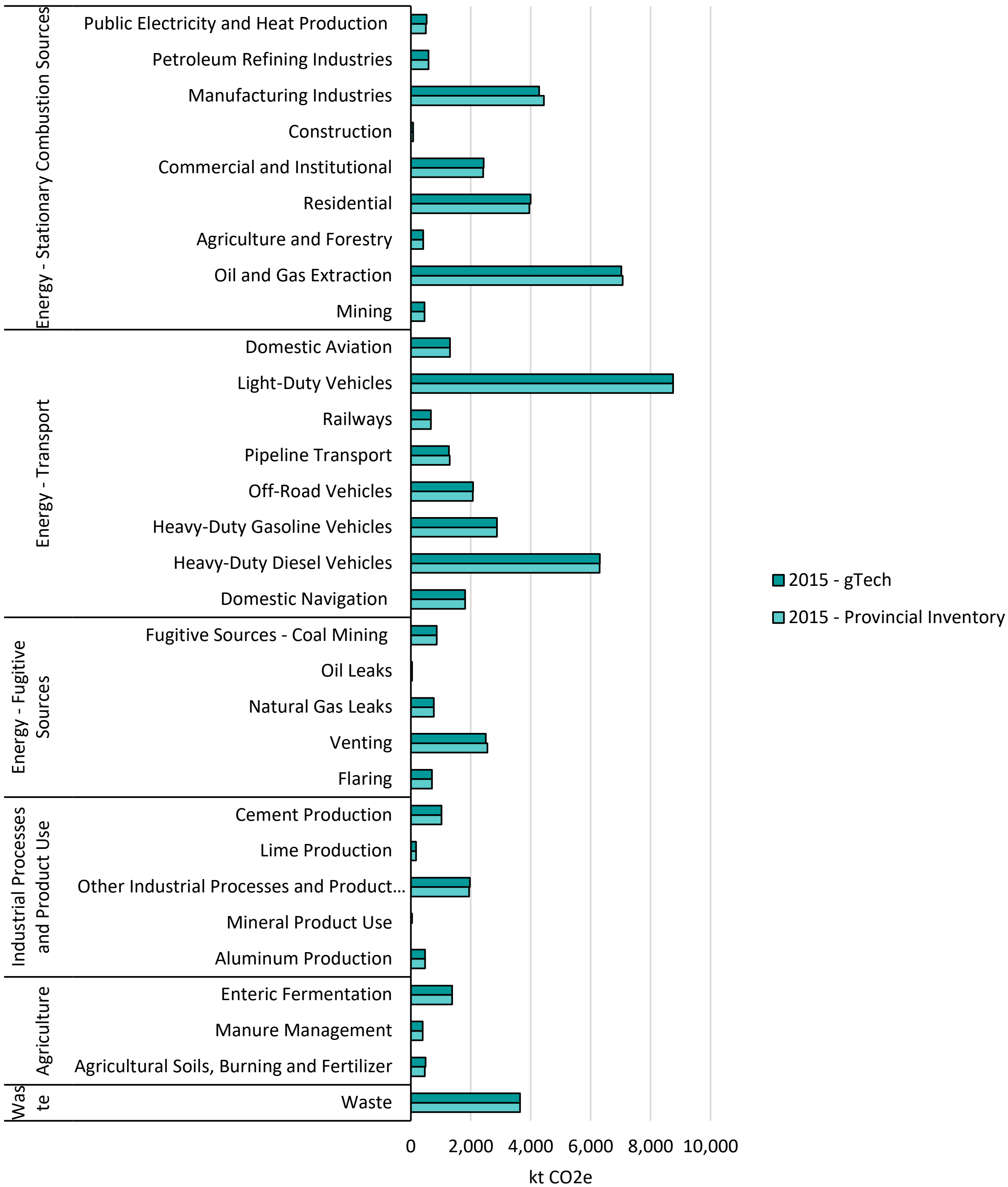
[24] Statistics Canada. Annual Industrial Consumption of Energy Survey. Available from: www.statcan.gc.ca

- British Columbia's 2017 Provincial Greenhouse Gas Emissions Inventory.
- Natural Resources Canada's Comprehensive Energy Use Database.
- Navius' technology database.

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

Figure 3 shows that modelled greenhouse gases in the 2015 base year align well with the Provincial Greenhouse Gas Emissions Inventory (PIR) by sector. The increase in emissions from 2015 to 2017 reported in the PIR is not reflected in the modelling because the model only outputs in timesteps of five years and this increase is within the average trend fluctuation on this timescale.

Figure 3: Calibration of greenhouse gas emissions by sector in 2015



Source for historical data: Government of British Columbia. Provincial Greenhouse Gas Emissions Inventory: 2017 Provincial Inventory. Available from: https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory. Note: Afforestation and deforestation emissions, which are not included in gTech, amount to 2.4 Mt CO_2e in 2017. 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 is comprised of 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
  - Light oil extraction
- *Other basic organic chemicals manufacturing* is comprised of:
  - 7 individual sectors representing different pathways for biofuels production
  - The rest of Other basic organic chemicals manufacturing
- *Electric power generation, transmission and distribution* is comprised of:
  - Electric generation from fossil fuels
  - Electric generation from hydro-electric or other renewables resources
  - Electric power transmission and distribution

Each of the above subsectors are 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 from "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 play essential roles in CleanBC do not yet exist. Of these, the following are most important:

- Liquified natural gas production
- Several pathways for liquid and gaseous renewable fuels production.

While these sectors are characterized based on the best available data (see Section 3.3), the exact characterization is uncertain until/if these sectors begin operation.

Competitiveness dynamics versus alignment with external data sources

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

This trade-off is best illustrated with an example. Statistics Canada's Supply-Use tables provide data on an aggregated sector for cement and concrete manufacturing. However, these two sectors are vastly different. Cement manufacturing is highly energy and 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 are 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 emission 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 British Columbia, 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, greenhouse gas emissions, and economic activity in BC as well as the rest of North America), many assumptions are required. Over the past two 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 activity (Section 3.1)
- Energy prices (Section 3.2)
- Key sector assumptions (Section 3.3)
- Technological choice (Section 3.4)

3.1. Economic activity

BC's economy is calibrated to grow at an annual average of 2.1% from 2019 to 2030, in line with the Ministry of Finance's projections in Budget 2019[25].

GDP by sector is largely determined by this rate of growth and the relative capital and labour productivity of that 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 3.3.

3.2. Energy prices

Oil and gas prices are calibrated to the 2018 National Energy Board's Canada's Energy Futures Report[26][27] as shown in Figure 4:

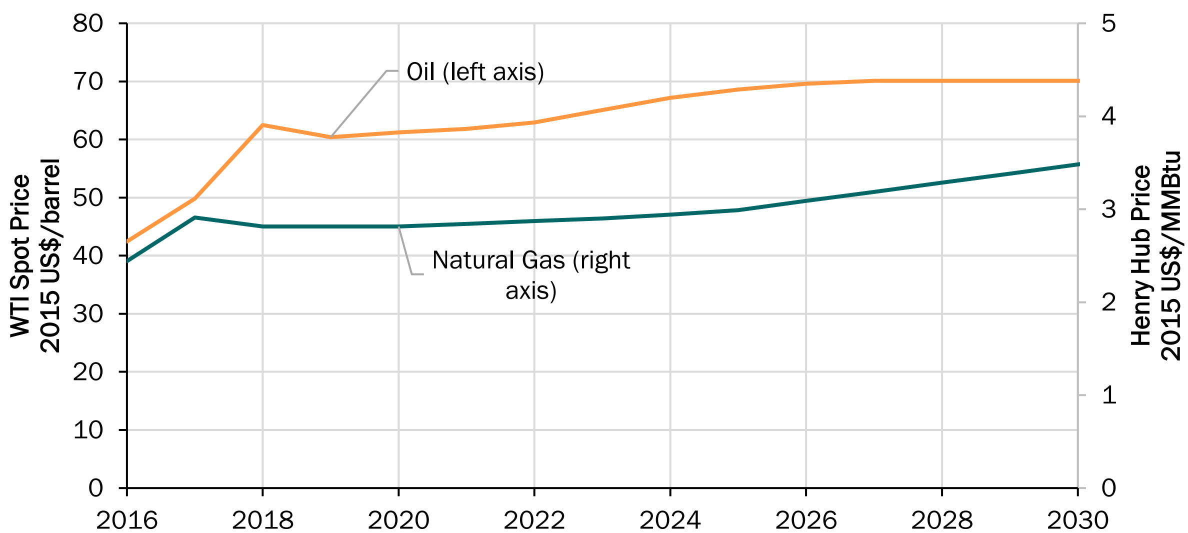
[25] Government of British Columbia. BC Budget 2019. Available from: www.www.bcbudget.gov.bc.ca

[26] National Energy Board. Canada's Energy Future 2018: Energy Supply and Demand Projections to 2040. Available from: https://www.cer-rec.gc.ca/nrg/ntgrtd/ftr/2018/index-eng.html

[27] US Energy Information Administration. Annual Energy Outlook 2018. Available from: https://www.eia.gov/outlooks/aeo/

- Natural gas prices rise to $3.48/MMBTU (2015 $USD) by 2030. After the model has been calibrated to the external forecast, the price for natural gas is determined endogenously in the model based on supply and demand for natural gas in North America.
- Crude oil prices rise to $70.10/barrel (2015 $USD) by 2030. The price for oil is an exogenous input to the model (i.e., based on an assumed global price).

Figure 4: Oil and natural gas price forecast



Source: National Energy Board. Canada's Energy Future 2018: Energy Supply and Demand Projections to 2040. Available from: https://www.cer-rec.gc.ca/nrg/ntgrtd/ftr/2018/index-eng.html

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.

3.3. Sector assumptions

This section reviews assumptions specific to each sector in gTech:

- Sector activity (i.e., 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 over a "back-casting" period, helping ensure results are reasonable. Tables in this section are derived from gTech which is calibrated against the provincial inventory report and other data sources. For example, base year emissions are calibrated to the provincial inventory report. However, 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.

3.3.1. Industry

The industrial sector in gTech is comprised of over 70 individual sectors. These sectors produce everything from natural gas, to electricity, to pulp and paper. A comprehensive list of all sectors is available in Appendix A: "Covered sectors, fuels, end-uses".

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 these sources. This means that the model has been calibrated to ensure activity for these sectors aligns with the external forecast in a specific scenario. 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 8: Industrial activity) 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 due to excess supply; 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 8 shows (1) which sectors are calibrated to external assumptions, and the external assumption; (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 8: Industrial activity

Sector	Unit	2015	2020	2025	2030	Source
Agriculture	Index 2015 = 1	1.00	1.14	1.29	1.44	gTech
Forestry	Index 2015 = 1	1.00	1.80	1.98	2.16	gTech
Natural Gas	Bcf per day	4.14	5.90	7.53	7.82	BC's Ministry of Energy, Mines & Petroleum Resources
Conventional	Bcf per day	0.64	0.38	0.19	0.10	
Montney	Bcf per day	3.09	5.31	7.24	7.66	
Horn River	Bcf per day	0.41	0.20	0.10	0.05	
Conventional Light Oil Production	Thousand barrels per day	21.24	17.89	15.71	16.10	NEB (2018)
Coal Mining	Index 2015 = 1	1.00	1.13	1.13	1.13	gTech
Mining	Index 2015 = 1	1.00	1.34	1.29	1.34	gTech
Oil and Gas Services	Index 2015 = 1	1.00	1.34	1.35	1.38	gTech
Electricity Generation	TWh	70.41	74.70	79.80	78.91	gTech & IESD
Electricity Distribution	Index 2015 = 1	1.00	1.00	1.03	1.11	gTech
Natural Gas Distribution	Index 2015 = 1	1.00	0.97	1.57	1.56	gTech
Construction	Index 2015 = 1	1.00	1.14	1.14	1.25	gTech
Paper	Index 2015 = 1	1.00	1.07	0.69	0.69	gTech
Petroleum Refining	Index 2015 = 1	1.00	0.99	0.99	0.99	gTech
Liquefied Natural Gas	MTPA			14.09	14.09	Based on funded LNG projects in BC
Chemicals	Index 2015 = 1	1.00	1.13	1.34	1.53	gTech
Non-Metallic Minerals	Index 2015 = 1	1.00	1.00	0.98	0.98	gTech
Metals	Index 2015 = 1	1.00	1.20	1.41	1.53	gTech
Other Manufacturing	Index 2015 = 1	1.00	1.08	1.23	1.35	gTech
Pipelines	Index 2015 = 1	1.00	1.53	1.44	1.46	gTech

Sources: National Energy Board (NEB). 2018. Canada's Energy Future 2018: Energy Supply and Demand Projections to 2040. Available from: www.cer-rec.gc.ca;

Key sources of emissions

Unlike the transportation, buildings, and communities sectors, that are discussed in greater detail below, GHG emissions originate from many sources in industry. Further, each source of emissions tends to be concentrated in a small group of sectors. Table 9 summarizes the relationship between sector (rows) and sources of GHG emissions (columns). GHGs are shown in 2015, the model's base year. The estimates in 2015 are direct assumptions that go into the model.

Table 9: GHG crosswalk for industry in 2015, Mt CO_2e[28]

Industry	Stationary Combustion	Transport	Fugitive Sources	Industrial Processes	Agriculture	Total (excluding transport)
Agriculture and Forestry	0.41	0.69			2.26	2.68
Oil and gas extraction	7.21	0.21	3.72			10.93
Mining	0.46	0.94	0.86			1.32
Electricity	0.36					0.36
Construction	0.07	0.34				0.07
Pulp and paper manufacturing	1.88					1.88
Petroleum refining	0.59					0.59
Cement manufacturing	0.57			1.02		1.59
Lime manufacturing	0.13			0.17		0.30
Aluminum smelting	0.04			0.48		0.52
Other manufacturing	1.66			0.11		1.76
Pipelines	1.27		0.29			1.56
Total (excluding transport)	14.64		4.87	1.77	2.26	23.55

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.

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 (0.41 Mt CO_2e in 2015). These emissions are primarily assumed to be for process heat.

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

- Transport (0.69 Mt CO_2e in 2015). Transport emissions associated with agriculture and forestry are discussed in greater detail in Section 3.3.2. However, emissions associated with farm tractors and forestry equipment are allocated to agriculture and forestry as an end-use.
- Enteric fermentation (1.38 Mt CO_2e in 2015). Enteric fermentation refers to methane emissions from the digestive process in livestock.
- Manure management (0.40 Mt CO_2e in 2015). This refers to managing manure from livestock.
- Agricultural soils (0.49 Mt CO_2e in 2015). The application of synthetic fertilizers causes the emission of nitrous oxide, which is a potent greenhouse gas.

Table 10 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 10: Agriculture and forestry sector emissions by end-use in 2015, Mt CO_2e

IPCC Category	Stationary combustion	Transport		Agriculture		Total (excluding transport)
End-use	Process heat (high-grade heat)	Transport	Agricultural soils	Manure management	Enteric fermentation	
Crop production	0.27	0.14	0.30			0.58
Animal production	0.12	0.04	0.19	0.40	1.38	2.08
Forestry	0.02	0.51				0.02
Total (excluding transport)	0.41	0.00	0.49	0.40	1.38	2.68

Oil and natural gas production

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

- Combustion sources. The natural gas industry consumes natural gas for several purposes, including direct drive and process heat. In 2015, these emissions accounted for 7.21 Mt CO_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 1.48 Mt CO_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 1.54 Mt CO_2e.
- Flaring. Some methane is flared during natural gas production and processing. Flaring is estimated at 0.70 Mt CO_2e in 2015.

In addition to the sources described above, GHG emissions from the different sources and resources have been calibrated to (1) a study by Clearstone Engineering[29], (2) Ministry of Energy, Mines and Petroleum Resources internal data[30], and then (3) adjusted in order to ensure near alignment with BC's Provincial Greenhouse Gas Emissions Inventory.[31]

Figure 5 shows the emissions intensity for natural gas production in the 2015 model base year. Table 11 provides details for each resource.

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

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

[31] Government of British Columbia. Provincial Greenhouse Gas Emissions Inventory: 2017 Provincial Inventory. Available from: https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

Figure 5: GHG intensity for natural gas production

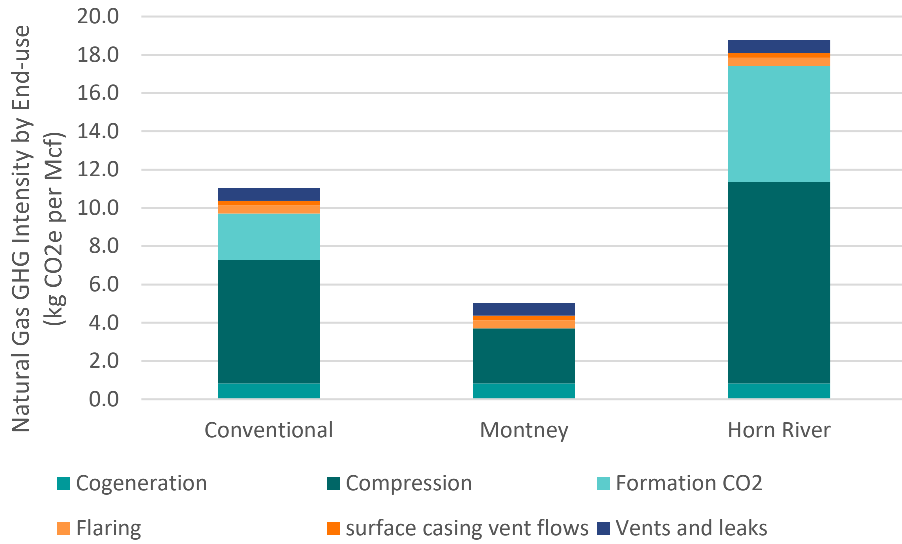


Table 11: GHG emissions for natural gas production in 2015, Mt CO_2e

IPCC Category	Stationary Combustion			Fugitive Sources				Total
End-use	Compression	Process heat (high-grade heat)	Industrial cogeneration	Flaring	Formation CO2	Vents and leaks	Surface Casing Vent Flows	
Crude oil	0.12	0.15		0.05		0.16	0.00	0.48
Conventional	1.51		0.10	0.10	0.57	0.16	0.06	2.48
Montney	3.24		0.47	0.48		0.75	0.28	5.22
Horn River	1.57		0.06	0.06	0.91	0.10	0.04	2.75
Total	**6.43**	**0.15**	**0.63**	**0.70**	**1.48**	**1.16**	**0.38**	**10.93**

Liquified natural gas production

Liquified 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 12). 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/t LNG, assuming 1% carbon dioxide in the natural gas by volume, equivalent to 2.7% by mass[32].

Table 12: LNG archetype direct GHG emissions intensity, tCO_2e/t LNG

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	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.

32 Union Gas. Chemical Composition of Natural Gas. Accessed from: https://www.uniongas.com/about-us/about-natural-gas/chemical-composition-of-natural-gas

Mining

British Columbia's mining sector consists of three sub-sectors: Coal mining, metal ore mining and non-metallic ore mining. Emissions from these sectors fall into 3 sources:

- Stationary sources (0.46Mt CO_2e in 2015), which are assumed to be from producing process heat.
- Transportation emissions (0.94Mt CO_2e in 2015). These emissions are discussed in greater detail in Section 3.3.2.
- Fugitive emissions from coal beds (0.86Mt CO_2e in 2015).

Table 13 shows the key sources of emissions for the mining sector.

Table 13: Mining sector emissions by sector and end-use in 2015, Mt CO_2e

IPCC Category	Stationary Combustion	Transport	Fugitive Sources	Total (excluding transport)
End-use	Process heat (high-grade heat)	Transport	Coalbed methane	
Coal mining		0.42	0.86	0.86
Metal ore mining	0.45	0.45		0.45
Mineral mining	0.01	0.07		0.01
Total (excluding transport)	0.46	0.00	0.86	1.32

Electric generation

Greenhouse gas 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 0.36 Mt CO_2e, while emissions for industrial cogeneration are estimated at 1.18 Mt CO_2e.

Construction

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

- Combustion (0.07 Mt CO_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 (0.34 Mt CO_2e in 2015). Please note that these emissions are discussed in the section on transportation (see Section 3.3.2) and are not discussed in detail here.

Petroleum refining

Petroleum refining emits greenhouse gases mostly from combustion emissions for producing process heat and other processes (estimated at 0.59Mt CO_2e in 2015).

The petroleum refining sector is an emission intensive and trade exposed sector. 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 emissions by source in 2015, Mt CO_2e

IPCC Category	Stationary Combustion
End-use	Process heat (high-grade heat)
Petroleum refining	0.59

Cement and lime manufacturing

Cement and lime manufacturing include two main sources of emissions: (1) combustion emissions from producing process heat (0.70Mt CO_2e in 2015) and (2) industrial process emissions associated with the calcination of limestone (1.19 Mt CO_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.[33] Emissions are then aligned to the Provincial Greenhouse Gas Emissions Inventory.[34]

Table 15 shows the emissions from the cement and lime sectors assumed in 2015.

[33] Environment and Climate Change Canada. National Inventory Report. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html; Statistics Canada. Annual Industrial Consumption of Energy Survey. Available from: www.statcan.gc.ca

[34] Government of British Columbia. Provincial Greenhouse Gas Emissions Inventory: 2017 Provincial Inventory. Available from: https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

Table 15: Cement and lime manufacturing emissions by source in 2015, Mt CO_2e

IPCC Category	Stationary Combustion	Industrial Processes	Total
End-use	Process heat (high-grade heat)	Limestone calcination	
Cement manufacturing	0.57	1.02	1.59
Lime manufacturing	0.13	0.17	0.30
Total	0.70	1.19	1.89

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 (0.04Mt CO_2e in 2015).
- Carbon dioxide from anode decomposition (0.38 Mt CO_2e in 2015). The aluminum sector uses carbon anodes to smelt aluminum. These anodes decompose during the smelting process, emitting carbon dioxide.
- Perfluorocarbons (0.09 Mt CO_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 Greenhouse Gas Emissions Inventory, (2) the National Inventory Report, and (3) national industrial fuel consumption by industry.[35] Table 16 shows estimated emissions from the aluminum sector in 2015.

Table 16: Aluminum sector emissions by source in 2015, Mt CO_2e

IPCC Category	Stationary Combustion	Industrial Processes		Total
End-use	Natural Gas Combustion	Aluminum CO_2	Aluminum PFCs	
Aluminum smelting	0.04	0.38	0.09	0.52

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 17. As a reminder, the

[35] Government of British Columbia. Provincial Greenhouse Gas Emissions Inventory: 2017 Provincial Inventory. Available from: https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory; Environment and Climate Change Canada. National Inventory Report. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html; Statistics Canada. Annual Industrial Consumption of Energy Survey. Available from: www.statcan.gc.ca

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 17: Other manufacturing emissions in 2015, Mt CO_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	
Food	0.15	0.13				0.28
Beverage	0.02	0.02				0.05
Clothes and textiles	0.00	0.01				0.01
Wood products	0.09	0.50				0.59
Pulp and paper	1.11	0.31	0.46			1.88
Coal products						0.00
Chemicals	0.11	0.02	0.10	0.07	0.04	0.33
Plastics	0.03	0.00				0.04
Other non-metallic minerals	0.12					0.12
Steel	0.00	0.00				0.00
Other smelting	0.06	0.00				0.06
Foundries	0.10					0.10
Fabricated metals	0.06	0.00				0.06
Machinery	0.05	0.00				0.05
Electronics	0.02	0.01				0.03
Vehicles	0.02	0.00				0.02
Other	0.02	0.01				0.03
Total	**1.95**	**1.03**	**0.56**	**0.07**	**0.04**	**3.64**

Pipelines

The main sources of emissions for pipelines align closely with those of the natural gas sector (see above). These emissions are shown in Table 18. These emissions align almost perfectly with the Provincial Greenhouse Gas Emissions Inventory and the National Inventory Report.[36]

[36] Government of British Columbia. Provincial Greenhouse Gas Emissions Inventory: 2017 Provincial Inventory. Available from: https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory; Environment and Climate Change Canada. National Inventory Report. Available from: www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html

Table 18: Natural gas pipeline emissions in 2015, Mt CO_2e

IPCC Category	Stationary Combustion	Fugitive Sources	Total
End-use	Compression	Vents and leaks	
Natural gas pipelines	1.22	0.23	1.45
Natural gas distribution	0.05	0.05	0.11
Total	**1.27**	**0.29**	**1.56**

Key options for GHG abatement

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 transportation emissions in agriculture, mining and construction are discussed in Section 3.3.2.

Table 19 summarizes the key abatement opportunities and the sources for the data.

Table 19: Abatement opportunities in industry

Economic Sector	2015 GHG (Mt CO_2e)	Key GHG abatement opportunities	Data sources (see reference list in section 3.3.4)
Stationary Combustion			
Electric generation	0.36	Renewables	See Section 2.2.2
		Electricity efficiency	gTech
Process heat (high-grade heat)	4.37	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)	1.03	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	7.70	Electrification	Greenblatt (2015)
		Electrification of LNG	ABB (2010)

Industrial cogeneration	1.18	No cogeneration	gTech
Fugitive Sources			
Coalbed methane	0.86	No abatement available	
Vents and leaks	1.83	Various leak detection and reduction measures	ICF International (2015), Clearstone Engineering (2014)
Formation CO_2	1.48	Carbon capture and storage	CIMS
Flaring	0.70	For oil facilities: Natural gas production For natural gas facilities: no abatement	Johnson & Coderre (2012)
Industrial Processes			
Hydrogen production	0.07	Carbon capture and storage	US DOE (2014)
		Electrolysis	US DOE (2014)
Limestone calcination	1.23	No abatement available	
Aluminum CO_2	0.38	No abatement available	
Aluminum PFCs	0.09	Computer controls to reduce PFCs	CIMS
Other process	0.00	No abatement available	
Agriculture			
Enteric fermentation	1.38	No abatement available	
Manure management	0.40	Anaerobic digestion to produce RNG	IEA ETSAP (2013)
Agricultural soils	0.49	No abatement available	

3.3.2. 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 "inputs" from each parent sector (and households in the case of passenger transport). For example, the mining sector requires a certain amount of heavy-duty vehicle activity as part of its extraction activities. If mining activity were to double, it would demand twice the amount of heavy-duty vehicle activity. Likewise, a growing number of households will demand more passenger travel by car, transit, air, etc.

The forecasted transport activity is shown for a variety of modes in Table 20, including light and heavy-duty vehicles, transit, air and rail. Activity in each mode may be distributed among multiple sectors. For example, agriculture, mining, construction and trucking all require the operation of different types of heavy-duty vehicles. Likewise, households, courier services and taxis require the use of light-duty vehicles.

Table 20: Transport activity forecast

Type	Unit	2015	2020	2025	2030	Source
Truck	Index (2015 = 1)	1.00	1.13	1.19	1.27	gTech
Passenger Vehicles	Index (2015 = 1)	1.00	1.04	1.06	1.11	gTech
Transit	Index (2015 = 1)	1.00	1.11	1.20	1.34	gTech
Air	Index (2015 = 1)	1.00	1.25	1.37	1.50	gTech
Rail	Index (2015 = 1)	1.00	1.21	1.41	1.58	gTech
Other Transportation	Index (2015 = 1)	1.00	1.10	1.12	1.27	gTech

Sources of emissions

Table 21 identifies key sources of transport greenhouse gas emissions in 2015, the model's start year. These emissions are those reported by gTech, which have been calibrated to the BC Provincial Greenhouse Gas Emissions Inventory[37].

Most emissions in the sector (23.80 Mt CO_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 (i.e., "energy-related" emissions). A smaller amount (0.83 Mt CO_2e (3%)) is categorized as "industrial processes and product use", arising from hydrofluorocarbons associated with air conditioning in vehicles. These non-combustion emissions are not disaggregated by sector in the provincial inventory.

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[37] Government of British Columbia. Provincial Greenhouse Gas Emissions Inventory: 2017 Provincial Inventory. Available from: https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory

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, heavy-duty vehicles and buses in proportion to their fuel consumption.

The two largest sources of emissions are light-duty and heavy-duty vehicles, which together account for 20.8 Mt CO_2e, or 85% of total transport emissions in 2015 (including buses). Navigation (i.e., marine activity), aviation and railways account for most remaining emissions.

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

Table 21: Transport emissions by end-use in 2015 (Million tonnes carbon dioxide equivalent)

Type	Energy - Transport	Industrial Processes and Product Use	Total
Light-Duty Vehicles	8.75	0.18	8.92
Heavy-Duty Vehicles	10.83	0.57	11.40
Buses	0.42	0.09	0.51
Domestic Navigation	1.82	0.00	1.82
Domestic Aviation	1.31	0.00	1.31
Railways	0.67	0.00	0.67
Total	23.80	0.83	24.63

Source: gTech as calibrated to the BC PI.

Several of the end-uses shown in Table 21 include "nested" end-uses below that provide gasoline and diesel services. 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 where fuel switching is simulated.

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 and medium/heavy duty vehicles.
- The blending of renewable fuels into the gasoline, diesel and other fossil fuel pools.
- Switching from light-duty passenger vehicles to transit.

Table 22 summarizes sources used to parameterize transport abatement opportunities in the model.

Table 22: Data sources used to characterize low carbon technologies in transport

Greenhouse gas source	2015 emissions (Mt CO_2e)	Key abatement opportunities	Data sources (see reference list in section 3.3.4)
Energy – Transport			
Light and heavy-duty vehicles	19.58	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)
Domestic navigation	1.82	Efficiency improvements	CIMS
Domestic aviation	1.31	No abatement options are available	CIMS
Railways	0.67	Renewable fuels	See list for renewable fuels above
Industrial Processes and Product Use			
Light and heavy-duty vehicles	0.75	Abatement is fixed to align with the federal policy to reduce HFCs	

3.3.3. Buildings and communities

Sector activity

As with transportation, activity in the building sector is not an assumption, but a result of the model. Regardless, the forecasted activity is shown for commercial and institutional buildings, residential buildings and waste in Table 23. 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 forecast 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 reference case (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 23: Buildings and communities activity forecast

Type	Unit	2015	2020	2025	2030	Source
Commercial and institutional	Million m^2	102	115	125	138	gTech
Residential	Million m^2	280	308	315	334	gTech
Waste	Index (2015 = 1)	1	0.93	0.91	0.88	gTech

Sources of emissions

Table 24 identifies the key sources of greenhouse gas emissions from buildings and communities in 2015, the model's start year. These emissions are those reported by gTech and reflect (1) the Provincial Greenhouse Gas Emissions Inventory 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 (4.35 Mt CO_2e in 2015).
- The combustion of natural gas for water heating (2.04 Mt CO_2e in 2015).

- The release of hydrofluorocarbons from air conditioning (0.34 Mt CO_2e in 2015).
- The release of methane from landfills as organic matter decomposes or is incinerated (3.65 Mt CO_2e in 2015). When simulating policies for landfills, the modelling incorporates assumptions about the portion of methane emissions from municipal solid waste (MSW) and wood waste (WW). These assumptions were based on information received from the BC Government.

Table 24: Buildings and communities emissions by source in 2015 (Million tonnes carbon dioxide equivalent)

Source	Stationary Combustion	Industrial Processes and Product Use	Waste	Total
Residential buildings				
Space heating	2.32			2.32
Water heating	1.64			1.64
Air conditioning		0.20		0.20
Cooking	0.05			0.05
Clothes drying				0.00
Total Residential Buildings	4.02	0.20		4.21
Commercial and institutional buildings				
Space heating	2.04			2.04
Water heating	0.39			0.39
Air conditioning		0.14		0.14
Auxiliary equipment		0.71		0.71
Total Commercial and institutional buildings	2.43	0.85		3.27
Waste				
Waste			3.65	3.65
Total Buildings and Communities	**6.44**	**1.04**	**3.65**	**11.13**

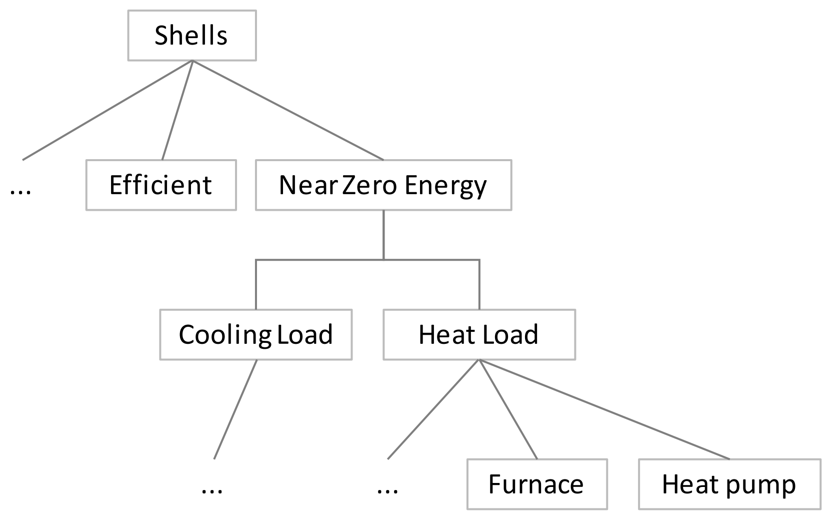
Source: gTech.

Interactions between end-uses

More so than in other sectors, the model captures relationships between end-uses in the buildings sector. gTech simulates the interaction 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.

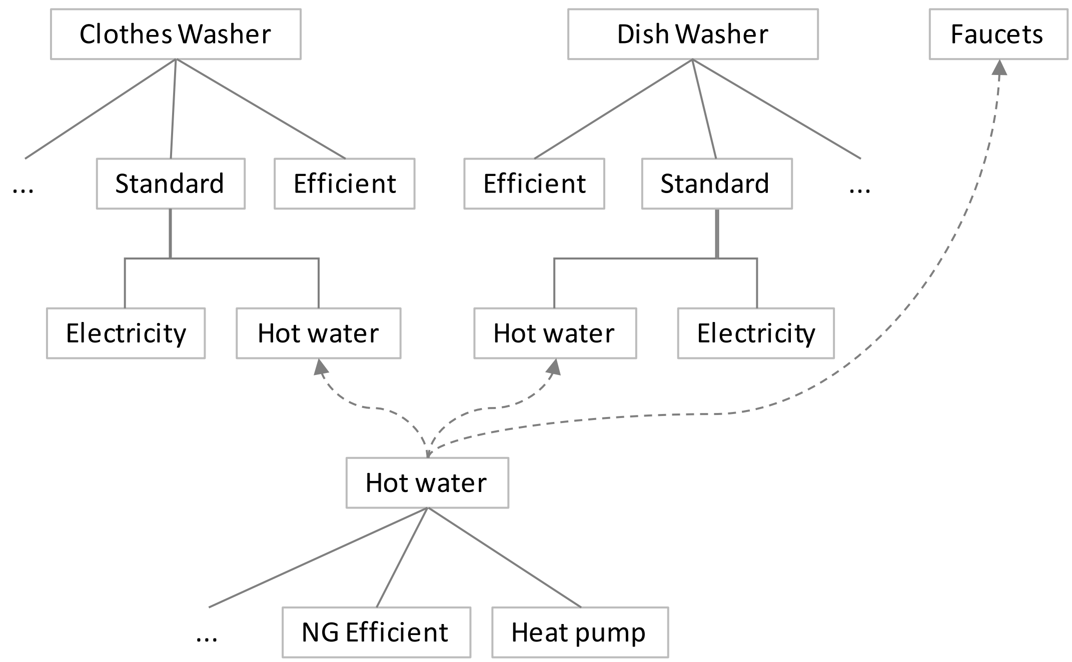
Figure 6 shows the relationship between various end-uses in the commercial building sector (the relationships for residential buildings are similar, but slightly more complicated). gTech simulates three decisions that affect building efficiency and GHG emissions. At the top level, gTech simulates the choice for 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 for heating system. For example, space heating can be met with a heat pump, a natural gas furnace, among other options.

Figure 6: 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 of 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 7 for schematic of the demand for hot water.

Figure 7: Residential demand for hot water



Emissions abatement opportunities

gTech models the following ways to reduce greenhouse gas emissions from buildings and communities:

- The adoption of more thermally efficient building shells.
- Improvements to the energy efficiency of natural gas furnaces and boilers.
- Blending renewable gas 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 the purpose of 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 greenhouse gas 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 greenhouse gas intensity of electricity generation in BC.

Table 25 summarizes sources used to parameterize abatement opportunities in buildings and communities in the model.

Table 25: Data sources used to characterize low carbon technologies in buildings and communities

Greenhouse gas source	2015 emissions (Mt CO_2e)	Key abatement opportunities	Data sources (see reference list in section 3.3.4)
Stationary combustion			
Space heating	4.35	Thermal improvements to building shells	RDH (2018)
		More energy efficient natural gas furnaces and boilers	EIA (2016), NREL (2018)
		Renewable gas	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)
		Electric space and water heating (resistance and heat pump)	EIA (2016), NREL (2018)
Water heating	2.04	More energy efficient natural gas water heaters and boilers	EIA (2016), NREL (2018)
		Renewable natural gas	See list for renewable gas above
		Electric water heaters (resistance and heat pump)	EIA (2016), NREL (2018)
Cooking	0.05	Electric ranges or renewable gas	EIA (2016), NREL (2018)
Industrial Processes			
Air conditioning	0.34	Thermal improvements to building shells	RDH (2018)
		Abatement is fixed to align with the federal policy to reduce HFCs	
Auxiliary equipment	0.71	Efficiency	CIMS
Waste			
Waste	3.65	Capture of methane for flaring, generating electricity or supply into natural gas distribution network	BC MOE (2017)
		Organic waste diversion	BC MOE (2017)

3.3.4. Reference list for sector assumptions

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3.4. Technology choice

The previous section identified various pathways for reducing greenhouse gas emissions that are included in the model. These pathways are represented as technologies, which households and firms can select in order to alter their greenhouse gas 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 Production (CES) function, where the inputs into each the function are individual technologies. The production function is specified as:

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

Where γ is a constant production adjustment factor; t is a set representing technologies for an end-use; α_t is a distribution parameter specific to each technology; T_t is the physical consumption of a specific technology; ρ is a parameter representing the substitutability between different technologies where $\rho = 1 - {}^{1}/_{\sigma}$; and σ is the elasticity of substitution between different technologies.

Skipping several steps, but by 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:

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

Where P_t^T is the price or life-cycle cost for a technology and all other parameters and variables are defined above.

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

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

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:

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

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

$$P_{t,y}^T = capex_{t,y}^T \times \frac{r}{1-(1+r)^{-life}} + \sum_f \left(fuel_{t,f}^T \times PF_f\right) + \sum_p \left(polReq_{t,p}^T \times PPOL_p\right)$$

Where $capex_{t,y}^T$ is technology *t*'s capital cost per unit of service output in year *y*, r is the discount rate used to amortize capital costs, $life$ is the lifespan for the technology in years, $fuel_{t,f}^T$ is the fuel requirement for fuel *f* by technology *t*, PF_f is the fuel price for fuel *f* (which is determined by gTech), $polReq_{t,p}^T$ is the policy requirement for policy *p* by technology *t* and $PPOL_p$ is the explicit or implicit price for the policy (which is determined by gTech).

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 ($capex_{t,y}^{T}$).

4. Reference case policies

The impact of CleanBC is measured relative to a reference case or "business as usual" forecast. This forecast includes policies implemented in BC prior to July, 2017[38]. 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*). These policies are summarized in Table 26.

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 zero-emission vehicle 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 British Columbia. For example, the zero-emission vehicle 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.

[38] 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, the BC Government accounted for them when estimating the impact of CleanBC.

Table 26: Summary of reference case policies (implemented prior to July 2017) in British Columbia and how they are modelled

Sector	Policy	Description of how policies are modelled
Multi-sector		
	Carbon tax[39]	The carbon tax is set at $30 per tonne carbon dioxide equivalent. Revenue raised by the tax is used to lower personal and corporate income taxes and transferred directly to households through rebates.
Electricity		
	Clean Energy Act[40]	A minimum of 93% of provincial electricity generation must be provided by clean or renewable sources. The modelling assumes the current level of 98% is maintained to 2030.
	PST Exemption[41]	Use of electricity in residential and industrial buildings is exempt from provincial sales tax.
Industry		
	Cement Low Carbon Fuel Program[42]	$27M Cement Low Carbon Fuel Program announced in Budget 2015/16 that comprises investments enabling increased use of low carbon fuels; and payments for achievement of annually decreasing emissions intensity benchmarks.

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[39] BC Reg. 125/2008. Carbon Tax Act. Available from: www.bclaws.ca

[40] SBC 2010, Section 22. Clean Energy Act. Available from: www.bclaws.ca

[41] Government of British Columbia. 2017. Provincial Sales Tax (PST) Bulletin: Energy, Energy Conservation and the ICE Fund Tax. Available from: https://www2.gov.bc.ca/gov/content/taxes/sales-taxes/pst

[42] Government of British Columbia. Industry Innovation & Regulation. Available from: www2.gov.bc.ca/gov/content/environment/climate-change/industry

Sector	Policy	Description of how policies are modelled
Transport		
	Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations[43]	New light-duty passenger vehicles sold in Canada must meet fleet-wide greenhouse gas emission standards. Cars and light trucks/SUVs face different standards. The weighted average requirement (i.e., accounting for the current share of cars and light trucks) declines from 200 g/km in 2015 to 119 g/km by 2025.
	Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations[44]	New heavy-duty vehicles sold in Canada must meet greenhouse gas emissions standards between 2014 and 2018. The regulations require that greenhouse gas emissions from 2018 model-year vehicles are reduced by an average of 10%.
	Renewable and Low Carbon Fuel Requirements Regulation[45]	This policy includes two components: 1) a minimum renewable fuel content for gasoline (5% by volume) and diesel (4% by volume); and 2) a decrease in average carbon intensity of fuels by 10% by 2020 relative to 2010. The maximum price for permits under the low carbon fuel standard is $200 per tonne carbon dioxide equivalent (2017$). The second component of the RLCFRR 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.
	Clean vehicle incentives[46]	Incentives are provided for zero- and low-emissions light-duty vehicles

[43] SOR/2010-201. Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations. Available from: http://laws-lois.justice.gc.ca

[44] SOR/2013-24. Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations. Available from: http://laws-lois.justice.gc.ca

[45] B.C. Reg. 287/2016. Renewable and Low Carbon Fuel Requirements Regulation. Available from: www.bclaws.ca

[46] Clean Energy Vehicles for BC. Available from: www.cevforbc.ca

Sector	Policy	Description of how policies are modelled
Buildings		
	Energy Efficiency Regulations[47]	Federal standards exist for new space conditioning equipment, water heaters, household appliances, and lighting products. The modelling accounts for the most important of these standards, 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 ban of incandescent light bulbs.
	BC Building Code[48]	New buildings must be increasingly thermally efficient in BC. This policy is modelled by 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. The policy is strengthened in 2031, requiring that new buildings are "net zero energy ready". An interim strengthening of the building code is introduced in 2021.
Waste		
	Organic Waste Diversion Initiatives[49]	This policy is implemented at the local government level with large variation in diversion rates across local governments. The modelling assumes that 30% of total provincial organic waste is diverted from landfills by 2025.
	Landfill Gas Management Regulation[50]	This policy is modelled by assuming that large landfills reduce methane emissions by 35% by 2020.

[47] Natural Resources Canada. 2017. *Guide to Canada's Energy Efficiency Regulations*. Available from: www.nrcan.gc.ca

[48] Government of British Columbia. Building Codes & Standards: Energy Efficiency. Available from: www.gov.bc.ca

[49] Government of British Columbia. Organic Waste Diversion Initiatives. Available from: https://www2.gov.bc.ca/gov/content/environment/waste-management

[50] B.C. Reg. 391/2008. Environmental Management Act: Landfill Gas Management Regulation. Available from: http://www.bclaws.ca

5. CleanBC policies

This Section describes how CleanBC[51] policies were modelled. As many policies are in development, their final design may differ from the assumptions used to model them at this time. Please note that not all CleanBC policies were modelled by Navius because they were out of scope of the model used for this work (please see Table 5 for a description of model boundaries). In addition, 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 C: "Post modelling modifications by the BC Government".

5.1. Multi-sector

5.1.1. Carbon pricing

In 2018, BC's price on carbon increased for the first time since 2012 to $35 per tonne carbon dioxide equivalent. It will continue to increase by $5 per tonne annually until it reaches $50 per tonne in 2021. This price signal is modelled as an incentive for firms and consumers to reduce their greenhouse gas 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 per tonne.** Under CleanBC, revenue earned from the carbon tax below $30 per tonne 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 per tonne on households**. Revenue above $30/t 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 (i.e., to ensure that 80% of households are made better off with the carbon tax).

[51] CleanBC. Available from: www.cleanbc.gov.bc.ca

- **Carbon revenue raised from the carbon tax above $30 per tonne on businesses** is used to fund several initiatives to reduce greenhouse gas emissions in industry and businesses (discussed below in Section 5.3.1).

5.1.2. Renewable gas standard

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). The modelling assumes a Renewable Portfolio Standard (RPS) for natural gas utilities that starts at 2% in 2020 and increases linearly to reach 15% by 2030, allowing for contractual agreements outside of BC.

5.2. Electricity

The analysis assumes that the Clean Energy Act[52] is updated to require all new resources to be provided by clean or renewable sources. This update is an increase from the reference case mandating 93% of provincial electricity generation to be provided by clean or renewable sources, reaching 98% by 2030.

5.3. Industry

5.3.1. CleanBC program for Industry: Industrial incentive and clean industry fund

As described above, carbon revenue is used for several government priorities depending on who pays the tax. All carbon revenue collected from industry that is above $30/t is divided into two categories in the modelling:

- **Revenue from businesses that emit less than 10 kilotonnes carbon dioxide equivalent annually** is used to invest in low carbon technologies and programs in these sectors. This policy is designed to mimic the **CleanBC Industry Fund**.
- **Revenue from businesses that emit more than 10 kilotonnes carbon dioxide equivalent annually (i.e., "large final emitters")** is used in the following fashion:
    - **CleanBC Industrial Incentive Program.** This program provides an additional incentive for facilities to reduce their greenhouse gas emissions. Already, the

[52] SBC 2010, Section 22. Clean Energy Act. Available from: www.bclaws.ca

carbon tax provides an incentive for firms to reduce their greenhouse gas emissions, because as they do so firms pay less tax. The Industrial Incentive Program provides an additional incentive by returning carbon tax revenue for facilities that reduce their emissions relative to a global best-in-class benchmark. The benchmark 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 internal modelling conducted by the BC Government on how the benchmark might work. Final benchmarks were not established at the time of modelling and will be incorporated in the future.

- **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 Clean Industry Fund was determined in consultation with the BC Government. These technologies were selected such that their abatement costs exceed $50 per tonne, and only technologies with a greenhouse gas impact are eligible (i.e., no electrical efficiency technologies).

5.3.2. Reduce emissions from methane

The analysis assumes that starting in 2020, all new oil and gas facilities implement best practices and technologies for reducing methane venting and leaks in accordance with new regulations.[53].

This policy is expected to reduce methane emissions in the upstream production of natural gas by 45% by 2025 relative to 2014.

Not all best practices regulated by the methane regulation are currently available in gTech. Although our technology archetypes align well will abatement options in venting, we have not included reduction options for surface casing vent flows. The reason these are not included in our technology options is because of limited data surrounding the distribution of emissions by well, and cost and success rate for fixing a leaky well. We plan to parameterize abatement options for surface casing vent flows in future modelling. Additionally, we noted that we have not included leaks as part of the policy. This is an error on our part which will need to be addressed in future modelling.

[53]B.C. Reg. 282/2010. Drilling and Production Regulation. Available from: http://www.bclaws.ca/civix/document/id/regulationbulletin/regulationbulletin/Reg286_2018

5.3.3. Industrial electrification

The analysis assumes increased electricity consumption in the upstream natural gas sector in keeping with BC Hydro's load forecast. By aligning to BC Hydro data, we implicitly align with their assumptions, including connecting to (1) the completed Dawson Creek/Chetwynd Area Transmission (DCAT) project and (2) the Peace Region Electricity Supply (PRES) project. Modelled electricity consumption in the upstream natural gas sector is slightly higher than what is forecast by BC Hydro. In future modelling, we plan to keep working with BC Hydro to ensure continued appropriate alignment.

5.3.4. Carbon capture and storage

This policy establishes a regulatory framework for the geological sequestration of formation carbon dioxide separated from natural gas during processing. Policy specifications and modelling method are both currently under review and will be included in future modelling.

5.4. Transport

5.4.1. Zero-emission vehicle mandate

Light-duty vehicles

The design for the zero-emission vehicle mandate was modelled based on the credit concept implemented in the Québec[54] and California systems[55], but the per vehicle credits and credit requirements were assumed to be more stringent and are therefore based on different calculations[56]. The analysis assumes that automakers earn a minimum percentage of their credits exclusively from the sale of battery-electric vehicles. It is assumed that the requirement for battery-electric vehicles reaches almost 30% of new vehicle sales in 2030 and almost 100% in 2040. Although

[54]Government of Québec. 2018. The zero-emission vehicle standard. Available from: http://www.environnement.gouv.qc.ca/changementsclimatiques/vze/index-en.htm

[55] California Air Resources Board. 2018. Zero emission vehicle (ZEV) program. Available from: https://www.arb.ca.gov/msprog/zevprog/zevprog.htm

[56]The policy is modelled by increasing credit requirements over time, reaching 40% of light-duty vehicle sales by 2030. Credits are calculated based on all-electric vehicle range, such that a battery-electric car with a range of 150 km earns 1.0 credits, while a plug-in hybrid car with a range of 60 km earns 0.5 credits.

hydrogen-powered vehicles would also qualify for credits under this policy, they were not included in this modelling, but may be added in the future.

Medium and heavy-duty vehicles

The analysis assumes the following minimum sales requirements that are linearly ramped up from 2019 to the following level in 2030:

- 10% of heavy-duty vehicles (excluding buses) are electric.
- 16% of heavy-duty vehicles (excluding buses) are powered by LNG.
- 94% of buses are electric.

5.4.2. Zero-emission vehicle rebates

This policy was modelled as financial incentives of $14 million per year through 2030 for the purchase of plug-in hybrid electric and battery electric light duty vehicles.

In addition to the incentives described above, the incentives for zero- and low-emissions heavy duty vehicles are $3.33 million per year through 2030. These incentives target both electric and natural gas-fueled vehicles.

5.4.3. Strengthened Renewable & Low Carbon Fuel Requirements

BC's current low carbon fuel standard requires transport fuel suppliers to reduce the average carbon intensity of transport fuels by 10% by 2020 from 2010 levels. The strengthened policy that was modelled assumes an increase to 20% by 2030 and expanded coverage to domestic aviation and marine fuels. It removes electricity as a compliance option and removes the price ceiling on credits starting in 2021. BC's Ministry of Energy, Mines & Petroleum Resources is considering amendments to the low carbon fuel standard, although none were passed at the time of modelling.

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. renewable gas).

- While Part 3 Agreements may be available under the actual policy, these were not modelled.

5.4.4. Tailpipe emissions standard

This policy is modelled as an extension of the federal *Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations*[57]. Under the federal policy, new light-duty passenger vehicles sold in Canada must meet fleet-wide GHG emission standards through 2025. The weighted average requirement (i.e., accounting for the current share of cars and light trucks) declines from 200 grams of carbon dioxide equivalent per kilometre in 2015 to 119 grams per kilometre by 2025.

The provincial policy strengthens the standard after 2025 and is modelled such that the emissions intensity of new light-duty vehicles sold in BC declines by over 10% to 105 grams per kilometre in 2030. It also disallows battery-electric and plug-in hybrid electric vehicles as a compliance option, preventing automakers from offsetting zero-emission vehicle sales (which are required by the zero-emission vehicle mandate) with less efficient conventional vehicles.

5.4.5. Amendments to heavy-duty vehicle regulations

This policy applies additional efficiency standards from 2021 onwards in line with the EPA's standards for on-road heavy-duty vehicles and engines[58]. According to the amendments, 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.

Please note that because this policy was implemented after July 2017 it is not included in the reference case forecast presented in this report (but it is included in the CleanBC forecast).

[57] SOR/2010-201. Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations. Available from: http://laws-lois.justice.gc.ca

[58] 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: https://pollution-waste.canada.ca

5.5. Buildings

5.5.1. Heat pump incentives

The modelled policy assumes $38 million (2015$) is provided annually for the purchase of heat pumps in buildings between 2021 and 2030. The incentives are modelled to apply to electric heat pumps for space and water heating, in both residential and commercial/institutional buildings. No assumptions have been made about how the incentives are allocated among building types or end-uses.

5.6. Waste

5.6.1. Organic waste diversion

The modelled policy assumes the organic waste diversion rate increases to 95% by 2025 and is adopted by all local governments in BC.

5.6.2. Landfill gas capture

The modelled policy strengthens landfill gas controls to capture 75% of landfill gas from all large municipal sites by 2025.

5.7. Policy adjustments for future modelling

In the late stages of developing this analysis, we identified the following adjustments to be included in future modelling:

- Activity in the paper sector was calibrated to data supplied by BC Hydro. After calibration was completed, BC Hydro revised the forecast from 7,300 to 6,300 GWh in 2030. This adjustment will be included in future modelling. This future revision will reduce GHG emissions from the pulp and paper sector from what is currently forecasted.
- Future modelling will be calibrated to the updated GDP forecast which is slightly lower than the estimate in *Budget 2019*.
- Hydrogen as a fuel will be considered in gTech for future modelling. Currently hydrogen is only available as a chemical feedstock in industries such as refining and chemicals manufacturing. Hydrogen pathways may include several low-carbon

production technologies (biomass gasification, electrolysis and steam methane reformation with carbon capture) and end-use applications in transport.

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

Table 27: 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
Hydro-electric and other 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

Sector	NAICS code
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	
HDRD (or HRD) 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	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, electronic product and equipment, appliance and component manufacturing	334 and 335
Transportation equipment manufacturing	336
Other manufacturing	Rest of 31-33
Wholesale and retail trade	41-45
Air transportation	481
Rail transportation	482
Water transportation	483

Sector	NAICS code
Truck transportation	484
Transit and ground passenger transportation	485
Pipeline transportation of crude oil	4861 and 4869
Pipeline transportation of natural gas	4862
Other transportation, excluding warehousing and storage	4867-492
Landfills	Part of 562
Services	Rest of 51-91
Liquified natural gas	N/A
Renewable natural gas	N/A

Table 28: 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-transportation)
Spent pulping liquor
Wood
Wood waste (in industry)
Renewable gas
Renewable fuels (transportation)
Ethanol produced from corn
Ethanol produced from wheat
Cellulosic ethanol
Biodiesel produced from canola
Biodiesel produced from soy
Hydrogenated renewable diesel (“hdrd”)
Renewable gasoline and diesel from pyrolysis of biomass

Table 29: 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)
Cogeneration
Compression for natural gas production and pipelines
Large compression for LNG production
Electric motors (in industry)
Other electricity consumption
Transportation
Air travel
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 process
Mineral product GHG emissions
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
Process CH_4 for which no know abatement option is available (enteric fermentation)
Manure management
Agricultural soils
Waste
Landfill gas management

End use
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
Warehouses (shells)
Other commercial shells
Commercial heat load
Commercial hot water
Commercial lighting
Commercial air conditioning
Auxiliary equipment
Auxiliary motors (in commercial buildings)

Table 30. List of Technologies in gTech

End-use	Technology
Agricultural soils	Existing
Air travel	Existing New
Aluminum electrolysis	Existing

	New Inert anodes in aluminum manufacturing Low PFC emitting technology
Apartment building shells	Near zero New New efficient Post 2000 Post1980 Pre-1980
Auxiliary equipment	Existing New New efficient
Auxiliary motors (in commercial buildings)	Existing New New efficient
Buses	Compressed natural gas Diesel new Existing Hybrid vehicle Pure electric vehicle
Cement CO2	Carbon capture and storage Existing
Cement heat	Baseline coal Baseline coal with CCS Baseline coke Baseline heavy fuel oil Baseline natural gas Baseline natural gas with CCS Baseline wood
Clothes dryers	Existing Existing natural gas New New efficient
Clothes washers	Existing New New efficient
Cogeneration	Baseline natural gas No cogeneration
Commercial air conditioning	Air conditioning efficient

	Air conditioning high efficiency Air conditioning new Existing
Commercial heating load	Air source heat pump Electric new Existing Gas high efficiency Gas new Gas standard efficiency Ground source heat pump Oil efficient Oil new
Commercial hot water	Electric new Existing Gas new Gas standard efficiency Heat pump Oil new
Commercial lighting	Existing New New efficient
Compression	Electric (used for compressors) Existing
Diesel services	Canola-based biodiesel HDRD Pure diesel Renewable gasoline or diesel Soy-based biodiesel
Direct Air Capture	Carbon capture and storage
Dishwashers	Existing New New efficient
Electric motors (in industry)	Efficient Existing New
Electricity generation	Baseline coal Baseline coke Baseline heavy fuel oil Baseline natural gas

	Coal Coal CCS Coke Natural gas combined cycle Natural gas combined cycle CCS Natural gas combustion turbine Wood stove
Elementary or secondary school building shells	Near zero New New efficient Post 2000 Post1980 Pre-1980
Faucets	Existing
Flaring in areas close to natural gas pipelines	Existing
Flaring in areas far from natural gas pipelines	Existing Reduce methane flaring from oil wells
Formation CO2 from natural gas processing	Carbon capture and storage Existing
Freezers	Existing New New efficient
Furnaces	Air source standard efficiency HP Existing Gas air source heat pump Gas new Gas standard efficiency Oil efficient Oil new Wood stove
Gasoline services	Cellulosic ethanol Corn-based ethanol Pure 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 new Heavy fuel oil new High efficiency natural gas New natural gas
Heat (in remote areas)	Baseline coal Baseline diesel technology for producing heat Baseline heavy fuel oil Baseline natural gas Baseline natural gas liquids
Heavy-duty vehicles that consume gasoline	Diesel efficient Diesel new Existing LNG efficient Pure electric vehicle Very efficiency diesel motors
Household air conditioning	Air conditioning efficient Air conditioning high efficiency Air conditioning new Existing
Household heating load	Electric baseboard Furnaces Ground source standard HP
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
Hydrogen	Carbon capture and storage 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 New efficient single cycle gas turbine Single cycle gas turbine
Leaks	Existing Low leaked and vented CH4 measures Lowest leaked and vented CH4 measures
Light rail for personal transport	Existing
Low-temp 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 new Heavy fuel oil new High efficiency natural gas

	Industrial heat pump New natural gas
Manure management	Anaerobic digestion small Existing
Marine transport	Diesel new Existing Fuel cell electric vehicle Heavy fuel oil new LNG efficient
Medium-duty diesel vehicles	Compressed natural gas Diesel efficient Diesel new Existing Hybrid vehicle Plugin hybrid electric vehicle Pure electric vehicle Very efficiency diesel motors
Natural gas services	Pure natural gas Renewable natural gas
Nitric acid production	Existing
Non-fuel consumption of energy	Existing
Office building shells	Near zero New New efficient Post 2000 Post1980 Pre-1980
Off-road vehicles	Diesel new Existing Pure electric vehicle
Other appliances	Existing New New efficient
Other building shells	Near zero New New efficient Post 2000 Post1980

	Pre-1980
Other electric	Existing
Process CH4	Existing
Rail freight	Diesel new Existing Fuel cell electric vehicle
Ranges	Electric efficient Electric new Existing Existing natural gas Natural gas
Refrigerators	Existing New New efficient New highly efficient
Retail building shells	Near zero New New efficient Post 2000 Post1980 Pre-1980
Retail food building shells	Near zero New New efficient Post 2000 Post1980 Pre-1980
Single family attached building shells	Near zero New New efficient Post 2000 Post1980 Pre-1980
Single family detached building shells	Near zero New New efficient Post 2000 Post1980 Pre-1980

Surface casing vent flows	Existing
Trucking freight	Diesel efficient
	Diesel new
	Existing
	Fuel cell electric vehicle
	LNG efficient
	Pure electric vehicle
	Very efficiency diesel motors
Vehicle motor choice	Existing
	Fuel cell electric vehicle
	Gas new
	Gas standard efficiency
	Hybrid vehicle
	Plugin hybrid electric vehicle
	Pure electric vehicle
Vehicle size choice	Cars
	Passenger Trucks
Venting	Existing
	Low leaked and vented CH4 measures
	Lowest leaked and vented CH4 measures
Warehouse building shells	Near zero
	New
	New efficient
	Post 2000
	Post1980
	Pre-1980

Appendix B: Model forecasts

The following tables provide results for the reference case and CleanBC forecast. Please note that the BC Government made modifications to some of the greenhouse gas reduction estimates based on differences in policy design. These are not included in the results presented here (which show raw model results) but are summarized in Appendix C: "Post modelling modifications by the BC Government".

Numbers in this section represent modelling results estimated in 5-year intervals, and do not account for all possible range of values associated with these point estimates. Further, these values are estimated based on the parameters, assumptions, and policy designs described in this document and thus are likely to deviate from observations. These forecasts should be interpreted within this context and should be used for reference only.

Results are provided for the following metrics:

- Greenhouse gas emissions
- Gross domestic product
- Investment
- Energy consumption (by sector and energy source)
- Electricity generation
- Commodity prices
- Vehicle activity (vehicle-kilometres-traveled and tonne-kilometres-traveled)

Note about HFCs

Hydrofluorocarbons (HFCs) are a powerful greenhouse gas that originates from many applications, such as air conditioning and fire extinguishers. However, the data required to allocate these emissions to various sectors of the economy are only partially available. The process used to allocate these emissions to each sector is described below:

- Data from ECCC's National Inventory Report enable an understanding of non-combustion GHG emissions from the residential and commercial sectors. These emissions are the difference between emissions reported by economic sector and combustion emissions reported by IPCC category. While non-combustion emissions in residential buildings are exclusively HFCs, non-combustion emissions are comprised of HFCs and CO_2. The source of the CO_2 is not properly understood. Navius is waiting for clarification from ECCC.

- Remaining HFCs are distributed among the transportation sectors in proportion to their fuel consumption.

- Finally, the economy has several other sources of HFCs and other non-combustion emissions in a variety of sectors that are not covered by the model. In total, these emissions amount to less than 0.3 Mt CO_2e. These have been added to HFCs for simplicity.

Table 31 shows a breakdown of HFCs in 2015 in the model.

Table 31: HFCs in gTech in 2015

	HFCs (kt CO_2e)	"Other" (kt CO_2e)
gTech estimation of HFCs		
Transportation		
On-road light-duty	183	
On-road heavy-duty	568	
Off-road	98	
Buildings		
Commercial and institutional	588	259
Residential	196	
gTech total	1,634	259
Actual HFCs	1,442	

Table 32: Reference case emissions by IPCC sector

Emission in Mt CO_2e	2015	2020	2025	2030
Energy - Stationary Combustion Sources	**19.81**	**20.72**	**22.38**	**21.81**
Public Electricity and Heat Production	0.54	0.49	0.45	0.21
Petroleum Refining Industries	0.59	0.44	0.46	0.47
Oil and Gas Extraction	7.03	7.47	9.63	9.02
Mining	0.46	0.65	0.60	0.63
Manufacturing Industries	4.27	4.59	4.38	4.84
Construction	0.07	0.14	0.15	0.17

Commercial and Institutional	2.43	2.44	2.38	2.35
Residential	4.02	4.04	3.82	3.61
Agriculture and Forestry	0.41	0.46	0.49	0.52
Energy - Transport	**25.06**	**25.09**	**23.69**	**23.38**
Domestic Aviation	1.31	1.64	1.79	1.96
Light-Duty Vehicles	8.75	8.63	7.90	6.88
Heavy-Duty Gasoline Vehicles	2.88	2.81	2.69	2.54
Heavy-Duty Diesel Vehicles	6.31	5.39	4.88	5.12
Railways	0.67	0.65	0.68	0.87
Off-Road Vehicles	2.07	1.91	1.73	1.91
Pipeline Transport	1.27	2.08	1.92	1.89
Domestic Navigation	1.82	1.98	2.09	2.22
Energy - Fugitive Sources	**4.87**	**4.85**	**5.18**	**4.88**
Coal Mining	0.86	0.97	0.97	0.97
Oil Leaks	0.04	0.04	0.03	0.03
Natural Gas Leaks	0.77	0.92	0.95	0.82
Venting	2.50	2.03	2.11	1.90
Flaring	0.70	0.89	1.12	1.16
Industrial Processes and Product Use	**3.68**	**3.41**	**2.97**	**2.42**
Cement Production	1.02	1.01	1.00	1.00
Lime Production	0.17	0.19	0.17	0.17
Mineral Product Use	0.04	0.04	0.05	0.06
Other Industrial Processes and Product Use	1.97	1.79	1.34	0.79
Aluminum Production	0.48	0.38	0.40	0.40
Agriculture	**2.26**	**2.59**	**2.93**	**3.26**
Enteric Fermentation	1.38	1.61	1.85	2.08
Manure Management	0.40	0.46	0.52	0.58
Agricultural Soils, Burning and Fertilizer	0.49	0.52	0.55	0.59
Waste	**3.65**	**2.85**	**2.72**	**2.56**
Total	**59.33**	**59.51**	**59.86**	**58.32**

Table 33: CleanBC emissions by IPCC sector

Emission in Mt CO_2e	2015	2020	2025	2030
Energy - Stationary Combustion Sources	**19.81**	**19.26**	**17.91**	**15.80**

Public Electricity and Heat Production	0.54	0.49	0.43	0.19
Petroleum Refining Industries	0.59	0.34	0.27	0.25
Oil and Gas Extraction	7.03	6.72	7.00	5.69
Mining	0.46	0.63	0.61	0.64
Manufacturing Industries	4.27	4.32	3.78	4.06
Construction	0.07	0.14	0.15	0.16
Commercial and Institutional	2.43	2.26	1.88	1.58
Residential	4.02	3.91	3.36	2.80
Agriculture and Forestry	0.41	0.45	0.44	0.42
Energy - Transport	**25.06**	**23.56**	**20.47**	**16.92**
Domestic Aviation	1.31	1.64	1.77	1.90
Light-Duty Vehicles	8.75	8.50	7.49	5.81
Heavy-Duty Gasoline Vehicles	2.88	2.80	2.63	2.43
Heavy-Duty Diesel Vehicles	6.31	4.53	3.11	1.78
Railways	0.67	0.54	0.45	0.30
Off-Road Vehicles	2.07	1.63	1.19	0.82
Pipeline Transport	1.27	1.98	1.80	1.77
Domestic Navigation	1.82	1.94	2.02	2.11
Energy - Fugitive Sources	**4.87**	**4.61**	**4.38**	**3.94**
Coal Mining	0.86	0.97	0.96	0.96
Oil Leaks	0.04	0.04	0.03	0.03
Natural Gas Leaks	0.77	0.92	0.90	0.78
Venting	2.50	1.80	1.42	1.07
Flaring	0.70	0.89	1.06	1.10
Industrial Processes and Product Use	**3.68**	**3.35**	**2.88**	**2.34**
Cement Production	1.02	1.00	0.99	0.99
Lime Production	0.17	0.18	0.16	0.16
Mineral Product Use	0.04	0.04	0.05	0.06
Other Industrial Processes and Product Use	1.97	1.76	1.31	0.77
Aluminum Production	0.48	0.36	0.36	0.36
Agriculture	**2.26**	**2.57**	**2.85**	**3.15**
Enteric Fermentation	1.38	1.60	1.81	2.04
Manure Management	0.40	0.45	0.49	0.53
Agricultural Soils, Burning and Fertilizer	0.49	0.52	0.55	0.59

Waste	**3.65**	**2.70**	**2.09**	**1.78**
Total	59.33	56.06	50.58	43.94

Table 34: Reference case emissions by Economic Sector

Emissions in Mt CO_2e	2015	2020	2025	2030
Resources	**16.77**	**17.50**	**18.25**	**17.76**
Agriculture	2.84	3.20	3.54	3.91
Forestry	0.53	0.46	0.43	0.48
Natural Gas	10.64	10.90	11.60	10.64
Conventional Light Oil Production	0.50	0.41	0.34	0.34
Coal Mining	1.28	1.33	1.28	1.29
Mining	0.98	1.19	1.05	1.10
Utilities	**0.46**	**0.45**	**0.45**	**0.29**
Electricity Generation	0.36	0.35	0.31	0.16
Natural Gas Distribution	0.11	0.10	0.14	0.13
Manufacturing	**6.64**	**6.76**	**8.52**	**9.02**
Paper	1.88	1.95	1.36	1.46
Petroleum Refining	0.59	0.44	0.46	0.47
Biofuels Production		0.08	0.12	0.10
Chemicals	0.33	0.40	0.47	0.52
Metals	0.58	0.51	0.54	0.54
Non-Metallic Minerals	1.89	1.89	1.85	1.85
Other Manufacturing	1.37	1.48	1.79	2.12
Liquefied Natural Gas			1.93	1.95
Transportation	**10.67**	**11.42**	**10.96**	**11.40**
Air	1.31	1.64	1.79	1.96
Truck	4.30	3.76	3.40	3.74
Rail	0.67	0.65	0.68	0.87
Transit	0.51	0.44	0.37	0.05
Pipelines	1.45	2.38	2.13	2.08
Other Transportation	2.43	2.54	2.58	2.71
Construction	**0.41**	**0.44**	**0.41**	**0.45**
Services	**12.63**	**11.43**	**10.73**	**10.06**
Households	**11.75**	**11.52**	**10.55**	**9.33**

Total	59.33	59.51	59.86	58.32

Table 35: CleanBC emissions by Economic Sector

Emissions in Mt CO_2e	2015	2020	2025	2030
Resources	**16.77**	**16.27**	**14.48**	**12.60**
Agriculture	2.84	3.14	3.37	3.63
Forestry	0.53	0.40	0.31	0.19
Natural Gas	10.64	9.94	8.38	6.51
Conventional Light Oil Production	0.50	0.41	0.31	0.31
Coal Mining	1.28	1.28	1.18	1.08
Mining	0.98	1.09	0.92	0.87
Utilities	**0.46**	**0.44**	**0.40**	**0.23**
Electricity Generation	0.36	0.35	0.28	0.13
Natural Gas Distribution	0.11	0.09	0.11	0.10
Manufacturing	**6.64**	**6.35**	**7.51**	**7.81**
Paper	1.88	1.79	1.07	1.16
Petroleum Refining	0.59	0.34	0.27	0.25
Biofuels Production		0.06	0.09	0.07
Chemicals	0.33	0.38	0.39	0.43
Metals	0.58	0.49	0.49	0.49
Non-Metallic Minerals	1.89	1.87	1.80	1.78
Other Manufacturing	1.37	1.42	1.62	1.82
Liquefied Natural Gas			1.79	1.82
Transportation	**10.67**	**10.44**	**9.00**	**7.78**
Air	1.31	1.64	1.77	1.90
Truck	4.30	3.20	2.15	1.17
Rail	0.67	0.54	0.45	0.30
Transit	0.51	0.37	0.25	0.04
Pipelines	1.45	2.22	1.93	1.89
Other Transportation	2.43	2.47	2.45	2.47
Construction	**0.41**	**0.39**	**0.33**	**0.30**
Services	**12.63**	**10.90**	**9.14**	**7.61**
Households	**11.75**	**11.28**	**9.73**	**7.60**
Total	59.33	56.06	50.58	43.94

Table 36: Reference case emissions by sector bundles

Emissions in Mt CO_2e	2015	2020	2025	2030
Buildings and communities	10.88	9.97	9.39	8.78
Energy - Stationary Combustion Sources	6.45	6.48	6.20	5.96
Commercial and Institutional	2.43	2.44	2.38	2.35
Residential	4.02	4.04	3.82	3.61
Industrial Processes and Product Use	0.78	0.64	0.47	0.26
Waste	3.65	2.85	2.72	2.56
Transportation	24.66	23.80	22.34	21.81
Energy - Transport	23.81	23.01	21.76	21.50
Domestic Aviation	1.31	1.64	1.79	1.96
Light-Duty Vehicles	8.75	8.63	7.90	6.88
Heavy-Duty Gasoline Vehicles	2.88	2.81	2.69	2.54
Heavy-Duty Diesel Vehicles	6.31	5.39	4.88	5.12
Railways	0.67	0.65	0.68	0.87
Domestic Navigation	1.82	1.98	2.09	2.22
Off-Road Vehicles	2.07	1.91	1.73	1.91
Industrial Processes and Product Use	0.85	0.79	0.58	0.31
Industrial	23.83	25.74	28.09	27.73
Energy - Stationary Combustion Sources	14.64	16.32	18.08	17.75
Public Electricity and Heat Production	0.54	0.49	0.45	0.21
Petroleum Refining Industries	0.59	0.44	0.46	0.47
Mining	0.46	0.65	0.60	0.63
Upstream Oil and Gas Production	7.03	7.47	9.63	9.02
Manufacturing Industries	4.27	4.59	4.38	4.84
Construction	0.07	0.14	0.15	0.17
Agriculture and Forestry	0.41	0.46	0.49	0.52
Pipeline Transport	1.27	2.08	1.92	1.89
Energy - Fugitive Sources	4.87	4.85	5.18	4.88
Coal Mining	0.86	0.97	0.97	0.97
Oil Leaks	0.04	0.04	0.03	0.03
Natural Gas Leaks	0.77	0.92	0.95	0.82
Venting	2.50	2.03	2.11	1.90
Flaring	0.70	0.89	1.12	1.16
Industrial Processes and Product Use	2.05	1.98	1.91	1.85

Emissions in Mt CO_2e	2015	2020	2025	2030
Cement Production	1.02	1.01	1.00	1.00
Lime Production	0.17	0.19	0.17	0.17
Aluminum Production	0.48	0.38	0.40	0.40
Other Industrial Processes and Product Use	0.38	0.40	0.34	0.28
Agriculture	2.26	2.59	2.93	3.26
Enteric Fermentation	1.38	1.61	1.85	2.08
Manure Management	0.40	0.46	0.52	0.58
Agricultural Soils, Burning and Fertilizer	0.49	0.52	0.55	0.59
Total	59.33	59.51	59.86	58.32

Table 37: CleanBC emissions by sector bundles

Emissions in Mt CO_2e	2015	2020	2025	2030
Buildings and communities	10.88	9.51	7.80	6.42
Energy - Stationary Combustion Sources	6.45	6.17	5.24	4.38
Commercial and Institutional	2.43	2.26	1.88	1.58
Residential	4.02	3.91	3.36	2.80
Industrial Processes and Product Use	0.78	0.64	0.47	0.26
Waste	3.65	2.70	2.09	1.78
Transportation	24.66	22.37	19.22	15.45
Energy - Transport	23.81	21.58	18.66	15.15
Domestic Aviation	1.31	1.64	1.77	1.90
Light-Duty Vehicles	8.75	8.50	7.49	5.81
Heavy-Duty Gasoline Vehicles	2.88	2.80	2.63	2.43
Heavy-Duty Diesel Vehicles	6.31	4.53	3.11	1.78
Railways	0.67	0.54	0.45	0.30
Domestic Navigation	1.82	1.94	2.02	2.11
Off-Road Vehicles	2.07	1.63	1.19	0.82
Industrial Processes and Product Use	0.85	0.79	0.56	0.30
Industrial	23.83	24.18	23.54	22.06
Energy - Stationary Combustion Sources	14.64	15.07	14.48	13.18
Public Electricity and Heat Production	0.54	0.49	0.43	0.19

Emissions in Mt CO_2e	2015	2020	2025	2030
Petroleum Refining Industries	0.59	0.34	0.27	0.25
Mining	0.46	0.63	0.61	0.64
Upstream Oil and Gas Production	7.03	6.72	7.00	5.69
Manufacturing Industries	4.27	4.32	3.78	4.06
Construction	0.07	0.14	0.15	0.16
Agriculture and Forestry	0.41	0.45	0.44	0.42
Pipeline Transport	1.27	1.98	1.80	1.77
Energy - Fugitive Sources	4.87	4.62	4.37	3.94
Coal Mining	0.86	0.97	0.96	0.96
Oil Leaks	0.04	0.04	0.03	0.03
Natural Gas Leaks	0.77	0.92	0.90	0.78
Venting	2.50	1.80	1.42	1.07
Flaring	0.70	0.89	1.06	1.10
Industrial Processes and Product Use	2.05	1.92	1.84	1.78
Cement Production	1.02	1.00	0.99	0.99
Lime Production	0.17	0.18	0.16	0.16
Aluminum Production	0.48	0.36	0.36	0.36
Other Industrial Processes and Product Use	0.38	0.38	0.33	0.27
Agriculture	**2.26**	**2.57**	**2.85**	**3.15**
Enteric Fermentation	1.38	1.60	1.81	2.04
Manure Management	0.40	0.45	0.49	0.53
Agricultural Soils, Burning and Fertilizer	0.49	0.52	0.55	0.59
Total	59.33	56.06	50.58	43.94

Gross domestic product by income

Table 38: Reference case GDP by income

Basic prices; billion 2015$	2015	2020	2025	2030
Manufacturing	**15.6**	**17.2**	**21.3**	**23.2**
Paper	2.5	2.7	1.7	1.7
Petroleum Refining	0.7	0.7	0.7	0.7
Biofuels Production		0.0	0.0	0.0
Chemicals	0.6	0.7	0.9	1.0
Metals	0.3	0.4	0.5	0.5
Non-Metallic Minerals	0.7	0.7	0.7	0.7
Other Manufacturing	10.7	11.9	13.8	15.5
Liquefied Natural Gas			3.0	3.0
Resources	**13.0**	**17.7**	**20.1**	**21.4**
Agriculture	1.5	1.8	2.2	2.6
Forestry	3.4	4.5	5.0	5.5
Natural Gas	3.9	6.2	7.8	8.1
Conventional Light Oil Production	0.3	0.3	0.2	0.2
Oil and Gas Services	0.3	0.5	0.5	0.5
Coal Mining	1.2	1.4	1.4	1.4
Mining	2.3	3.1	3.0	3.2
Transportation	**13.7**	**16.1**	**17.2**	**19.3**
Air	2.3	2.9	3.1	3.4
Truck	3.1	3.5	3.7	4.2
Rail	1.8	2.2	2.6	2.9
Transit	0.2	0.2	0.3	0.4
Pipelines	1.0	1.6	1.5	1.5
Other Transportation	5.2	5.8	6.0	6.8
Utilities	**4.9**	**5.2**	**5.6**	**5.8**
Electricity Generation	3.6	3.9	3.9	4.0
Electricity Distribution	0.6	0.6	0.6	0.7
Natural Gas Distribution	0.7	0.7	1.1	1.1
Services	**169.3**	**190.6**	**206.6**	**227.6**
Construction	**17.4**	**19.8**	**19.8**	**21.8**
Total	233.8	266.6	290.6	319.0

Table 39: CleanBC GDP by income

Basic prices; billion 2015$	2015	2020	2025	2030
Manufacturing	**15.6**	**16.8**	**20.4**	**22.1**
Paper	2.5	2.5	1.3	1.5
Petroleum Refining	0.7	0.5	0.4	0.3
Biofuels Production		0.0	0.1	0.1
Chemicals	0.6	0.7	0.8	1.0
Metals	0.3	0.4	0.5	0.5
Non-Metallic Minerals	0.7	0.7	0.7	0.7
Other Manufacturing	10.7	11.9	13.7	15.2
Liquefied Natural Gas			2.9	2.9
Resources	**13.0**	**17.6**	**19.5**	**20.5**
Agriculture	1.5	1.8	2.2	2.5
Forestry	3.4	4.5	5.0	5.4
Natural Gas	3.9	6.2	7.3	7.4
Conventional Light Oil Production	0.3	0.3	0.2	0.2
Oil and Gas Services	0.3	0.5	0.5	0.5
Coal Mining	1.2	1.4	1.4	1.4
Mining	2.3	3.0	3.0	3.1
Transportation	**13.7**	**15.8**	**16.4**	**17.9**
Air	2.3	2.9	3.1	3.3
Truck	3.1	3.3	3.3	3.3
Rail	1.8	2.1	2.5	2.7
Transit	0.2	0.2	0.2	0.4
Pipelines	1.0	1.5	1.4	1.4
Other Transportation	5.2	5.8	5.9	6.7
Utilities	**4.9**	**5.2**	**5.5**	**6.0**
Electricity Generation	3.6	3.9	3.9	4.3
Electricity Distribution	0.6	0.6	0.6	0.7
Natural Gas Distribution	0.7	0.7	1.0	1.0
Services	**169.3**	**190.1**	**206.0**	**226.4**
Construction	**17.4**	**19.7**	**19.6**	**21.5**
Total	233.8	265.2	287.4	314.4

Investment by type

Table 40: Reference case investment by type

Basic prices; billions 2015$	2020	2025	2030
Green	2.7	2.3	3.1
Rest of energy	6.9	9.8	7.1
Non-energy	28.7	27.5	31.5
Total	38.3	39.6	41.7

Table 41: CleanBC investment by type

Basic prices; billions 2015$	2020	2025	2030
Green	3.0	3.2	4.4
Rest of energy	6.5	8.8	6.7
Non-energy	28.3	27.2	30.7
Total	37.8	39.2	41.8

Energy consumption

Energy consumption is aggregated into "clean energy" (e.g. electricity and bioenergy) and "fossil energy".

Table 42: Reference case clean energy consumption

Clean energy consumption in PJ	2015	2020	2025	2030
Manufacturing	**171**	**182**	**135**	**132**
Paper	143	149	96	93
Petroleum Refining	1	1	1	1
Biofuels Production		0	0	0
Chemicals	3	3	4	4
Metals	8	12	13	13
Non-Metallic Minerals	1	1	1	1
Other Manufacturing	15	15	16	17
Liquefied Natural Gas			4	4
Resources	**27**	**36**	**36**	**32**
Agriculture	8	9	10	10
Forestry	1	2	3	2
Natural Gas	2	3	4	3
Conventional Light Oil Production	0	0	0	0

Coal Mining	2	3	3	3
Mining	12	17	15	14
Oil and Gas Services	1	1	1	1
Transportation	**15**	**28**	**33**	**24**
Truck	4	13	16	9
Rail	1	3	4	2
Transit	3	4	4	5
Pipelines	5	5	5	5
Other Transportation	2	2	2	2
Air	1	1	1	1
Utilities	**0**	**0**	**0**	**0**
Electricity Generation	0	0	0	0
Natural Gas Distribution	0	0	0	0
Construction	1	1	2	1
Households	84	81	78	80
Services	62	68	72	74
Total	359	396	357	345

Table 43: Reference case fossil energy consumption

Fossil energy consumption in PJ	2015	2020	2025	2030
Manufacturing	**88**	**90**	**116**	**126**
Paper	35	35	23	25
Petroleum Refining	10	9	9	9
Biofuels Production		2	2	2
Chemicals	6	7	8	9
Metals	2	2	2	3
Non-Metallic Minerals	9	9	9	9
Other Manufacturing	26	27	32	38
Liquefied Natural Gas			31	31
Resources	**185**	**195**	**206**	**194**
Agriculture	10	11	11	12
Forestry	7	6	6	7
Natural Gas	142	151	164	150
Conventional Light Oil Production	6	5	4	4

Coal Mining	6	5	4	4
Mining	15	18	16	17
Oil and Gas Services	0	0	0	0
Transportation	**175**	**196**	**193**	**205**
Truck	57	49	45	51
Rail	9	9	9	12
Transit	6	5	4	0
Pipelines	24	41	37	36
Other Transportation	34	36	37	39
Air	44	56	61	67
Utilities	**8**	**8**	**8**	**5**
Electricity Generation	7	7	6	3
Natural Gas Distribution	1	1	2	2
Construction	**6**	**6**	**5**	**6**
Households	**187**	**186**	**172**	**155**
Services	**128**	**124**	**120**	**118**
Total	778	805	821	808

Table 44: Reference case energy consumption by energy type

Energy consumption in PJ	2015	2020	2025	2030
Biofuels	11	33	38	20
Electricity	243	254	245	255
Natural Gas	381	388	419	406
Refined Petroleum	382	374	356	351
Coal, Coke, and Coal Products	9	7	7	7
Natural Gas Liquids	7	35	39	44
Biomass	106	110	73	70
Renewable Natural Gas		0	0	0
	1,138	1,201	1,178	1,153

Table 45: CleanBC clean energy consumption

Clean energy consumption in PJ	2015	2020	2025	2030
Manufacturing	**171**	**177**	**118**	**126**

Paper	143	144	78	84
Petroleum Refining	1	1	1	0
Biofuels Production		0	0	1
Chemicals	3	3	4	4
Metals	8	12	12	12
Non-Metallic Minerals	1	1	1	2
Other Manufacturing	15	16	17	19
Liquefied Natural Gas			5	5
Resources	**27**	**44**	**58**	**63**
Agriculture	8	10	11	12
Forestry	1	3	5	6
Natural Gas	2	8	20	21
Conventional Light Oil Production	0	0	0	0
Coal Mining	2	4	5	5
Mining	12	18	17	17
Oil and Gas Services	1	1	1	1
Transportation	**15**	**38**	**50**	**61**
Truck	4	21	29	37
Rail	1	4	6	10
Transit	3	5	6	4
Pipelines	5	5	5	5
Other Transportation	2	3	3	4
Air	1	1	1	1
Utilities	**0**	**0**	**1**	**1**
Electricity Generation		0	1	1
Natural Gas Distribution	0	0	0	0
Construction	**1**	**2**	**3**	**3**
Households	**84**	**83**	**85**	**94**
Services	**62**	**72**	**82**	**92**
Total	359	415	397	439

Table 46: CleanBC fossil energy consumption

Fossil energy consumption in PJ	2015	2020	2025	2030
Manufacturing	**88**	**83**	**99**	**102**
Paper	35	32	18	19
Petroleum Refining	10	7	5	4
Biofuels Production		1	2	1
Chemicals	6	7	6	7
Metals	2	2	2	2
Non-Metallic Minerals	9	9	8	8
Other Manufacturing	26	26	29	32
Liquefied Natural Gas			28	29
Resources	**185**	**176**	**148**	**115**
Agriculture	10	10	10	9
Forestry	7	5	4	3
Natural Gas	142	135	113	84
Conventional Light Oil Production	6	5	4	4
Coal Mining	6	4	3	2
Mining	15	17	14	14
Oil and Gas Services	0	0	0	0
Transportation	**175**	**182**	**166**	**153**
Truck	57	41	27	15
Rail	9	7	6	4
Transit	6	4	3	0
Pipelines	24	39	35	34
Other Transportation	34	35	35	35
Air	44	56	60	65
Utilities	**8**	**8**	**7**	**4**
Electricity Generation	7	7	6	3
Natural Gas Distribution	1	1	1	1
Construction	**6**	**5**	**4**	**4**
Households	**187**	**182**	**158**	**125**
Services	**128**	**118**	**104**	**90**
Total	778	754	686	593

Table 47: CleanBC energy consumption by energy type

Clean energy consumption in PJ	2015	2020	2025	2030
Biofuels	11	48	66	78
Electricity	243	257	256	275
Natural Gas	381	364	335	286
Refined Petroleum	382	353	308	253
Coal, Coke, and Coal Products	9	7	7	8
Natural Gas Liquids	7	30	36	47
Biomass	106	106	61	63
Renewable Natural Gas		4	14	23
	1,138	1,170	1,083	1,032

Utility and industrial electricity generation

Table 48: Reference case electricity generation

Generation in TWh	2015	2020	2025	2030
Renewable	**67.6**	**73.3**	**78.4**	**78.4**
Existing Hydro	55.4	55.4	55.4	55.4
Wind	1.3	4.7	4.7	4.7
Run-of-River	5.0	6.6	6.6	6.6
Solar	0.0	0.0	0.0	0.0
Large Hydro			5.1	5.1
Cogeneration	5.9	6.5	6.5	6.5
Fossil Fuel	2.8	1.4	1.4	0.5
Total	70.4	74.7	79.8	78.9

Table 49: CleanBC electricity generation

Generation in TWh	2015	2020	2025	2030
Renewable	**67.6**	**74.1**	**79.2**	**80.8**
Existing Hydro	55.4	55.4	55.4	55.4
Wind	1.3	5.6	5.6	7.2
Run-of-River	5.0	6.6	6.6	6.6
Solar	0.0	0.0	0.0	0.0
Large Hydro			5.1	5.1
Cogeneration	5.9	6.5	6.5	6.5

Fossil Fuel	2.8	1.4	1.4	0.5
Total	70.4	75.6	80.7	81.4

Commodity prices

Table 50. Reference case commodity prices

	2015	2020	2025	2030
United States (eq to a province)				
Henry Hub Natural Gas (2015 USD per mmBTU)	2.16	2.81	2.99	3.48
WTI Oil (2015 USD per barrel)	45.76	57.28	64.14	65.50
Alberta				
AECO Natural Gas (2015$ per mmBTU)	2.70	2.45	2.79	4.13
Edmonton Par (2015$ per barrel)	57.21	65.40	76.52	79.41
Western Canadian Select (2015$ per barrel)	48.23	55.74	64.01	66.37
British Columbia				
Crude Oil (2015$ per barrel)	57.20	66.61	76.32	78.65
Station #2 (2015$ per mmBTU)	2.70	2.44	2.72	3.37
Wholesale Electricity (2015$ per GJ)	26.26	32.90	37.58	38.33

Table 51.CleanBC Commodity Prices

	2015	2020	2025	2030
United States (eq to a province)				
Henry Hub Natural Gas (2015 USD per mmBTU)	2.16	2.82	2.99	3.48
WTI Oil (2015 USD per barrel)	45.76	57.28	64.14	65.50
Alberta				
AECO Natural Gas (2015$ per mmBTU)	2.70	2.44	2.79	4.13
Edmonton Par (2015$ per barrel)	57.21	65.41	76.55	79.44
Western Canadian Select (2015$ per barrel)	48.23	55.76	64.03	66.39
British Columbia				
Crude Oil (2015$ per barrel)	57.20	66.53	76.30	78.45

Station #2 (2015$ per mmBTU)	2.70	2.43	2.73	3.35
Wholesale Electricity (2015$ per GJ)	26.26	33.61	38.72	41.74

Vehicle activity

Table 52. Reference case vehicle activity

	unit	2015	2020	2025	2030
Light-duty vehicles	Vehicle kilometers	39.31	42.00	43.27	46.00
Heavy-duty vehicles	Tonne kilometers	69.47	77.13	80.70	84.52

Table 53. CleanBC vehicle activity

	unit	2015	2020	2025	2030
Light-duty vehicles	Vehicle kilometers	39.31	41.67	42.88	44.61
Heavy-duty vehicles	Tonne kilometers	69.47	76.47	78.20	81.43

Appendix C: Post modelling modifications by the BC Government

The BC Government used Navius' modelling results to inform the development of CleanBC. In the process of policy development, policies are often modelled with various design options. After the modelled package of policies was finalized, results were adjusted to account for differences in policies and other factors. Specifically, the following modifications have been made to total 2030 GHG emissions in the CleanBC case by the BC government (the results presented in Appendix B: "Model forecasts" are unaltered):

- CleanBC Program for Industry was estimated to achieve 2.5 Mt CO_2e reductions in 2030. This is a middle-range GHG reduction estimate from several different methodologies 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 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; (b) in-progress work on identifying the current intensities, benchmark and threshold intensities, and selection of eligible technologies; and (c) potential for multiple funding sources and inter-sectoral projects. These factors are expected to influence a new type of enhanced signal to reduce GHG emissions.
- Land-use GHG emissions from deforestation at 2.4 Mt CO_2e were added to total emissions because gTech does not include land-use activities and associated emissions. The estimate is a middle-range estimate of historical land-use deforestation emissions from the Provincial Inventory Report and is assumed constant into the future.

Appendix D: CleanBC reductions in 2018 and 2019 modelling

Initiative	Description	Fall 2018 GHG reductions in 2030 (Mt CO_2e)	Fall 2019 GHG reductions in 2030 (Mt CO_2e)	Comment
IMPROVE WHERE WE LIVE AND WORK				
Better Buildings	Incentives to make homes more energy-efficient and heat pumps more affordable	0.5	0.2	In the 2019 modelling, GHG reductions are estimated to be 0.3 Mt CO_2e lower than in the 2018 modelling. Annual program funding from 2021-2030 was revised to align with current funding in *Budget 2019*.
Renewable Gas	Make residential natural gas consumption cleaner by putting in place a minimum requirement of 15% to come from renewable gas	1.5	1.6	The renewable gas mandate is modelled as a single policy (2.1 Mt CO_2e of total reductions) and impact is subsequently split out by sector (1.6 Mt CO_2e in residential, 0.4 Mt CO_2e in industrial). The policy's combined reductions in the residential and industrial sectors has decreased by 0.4Mt CO_2e in the 2019 vs 2018 modelling. Total reductions have decreased because the 2019 modelling has slightly lower natural gas consumption in the reference case. The policy is now achieving a higher proportion of reductions in the residential sector, increasing the total modelled reductions. Allocation of reductions between sectors has changed because in the 2018 modelling, renewable content was scaled up from 10% (a value used in prior model runs) to 15% through post-modelling adjustments. The adjustment

				leads to a different allocation of reductions relative to 2019 which was modelled at 15%.
	Subtotal[59]	2.0	1.8	
CLEANER TRANSPORTATION[60]				
Bring down the price of clean vehicles	By 2040, every new car will be a zero-emission vehicle (ZEV) with phased-in increases to the ZEV standard	1.3	1.0	In the 2019 modelling, GHG reductions are estimated to be 0.3 Mt CO_2e lower than in the 2018 modelling. The main difference between the 2018 and 2019 modelling occurs in the reference case. There are more EVs on the road in 2030 under the reference case in the 2019 modelling, while the number of EVs is similar under the CleanBC case. As a result, the ZEV standard is credited with fewer emission reductions relative to the reference case.
Bring down the price of clean vehicles	Help people to afford cleaner cars and save money on gasoline bills with ZEV incentives	0.3	0.3	2019 modelling achieves very similar emission reductions to 2018 modelling.
Speed up the switch to cleaner fuels	Make our fuel cleaner by increasing the low carbon fuel standard to 20% by 2030 and increasing the production of renewable transportation fuels	4.0	4.0	2019 modelling assumes the same policy design as 2018 modelling and achieves very similar emission reductions.
Tailpipe Standard	Make vehicles run cleaner by increasing tailpipe emissions standards for vehicles sold	0.4	0.7	In the 2019 modelling, GHG reductions are estimated to be 0.3 Mt CO_2e higher than in the 2018 modelling Similar to the discussion of the ZEV mandate,

[59] While policies presented in this table have been grouped together under sectoral headings, emission reduction estimates represent the difference between reference case and policy case emissions across the entire economy. Subtotals, therefore, represent the net effect of reduction policies, including effects in other sectors.

[60] Emission reductions under cleaner transportation include post-modelling adjustments made by the Province as described in Appendix C.

	after 2025			the difference in reductions achieved by the Tailpipe Standard are due to differences in the reference case. In the 2018 modelling, the share of hybrid vehicles is lower and therefore the tailpipe standards achieve fewer reductions in emissions. The difference in reference case projections is due to the interaction between changes in the forecasted oil price, the federal vehicle emissions standard and the relative cost of complying with the federal vehicle emissions standard with EVs and hybrids.
	Subtotal	6.0	6.0	
REDUCE WASTE				
Reduce waste and turn it into a clean resource	Achieve 95% organic waste diversion for agricultural, industrial, and municipal waste -- including systems in place to capture 75% of landfill gas	0.7	0.7	2019 modelling achieves very similar emission reductions to 2018 modelling.
	Subtotal	0.7	0.7	
CLEANER INDUSTRY				
Ramp up the clean growth program for industry	Direct a portion of BC's carbon tax paid by industry into incentives for cleaner operations	2.5	2.5[61]	As industrial incentive program benchmarks had not yet been set at the time of modelling, the policy design in the 2018 modelling was maintained.
Reduce emissions of methane	Reduce methane emissions from upstream oil and gas operations by 45%	0.9	0.6	In the 2019 modelling, GHG reductions are estimated to be 0.3 Mt CO_2e lower than in the 2018 modelling. The 2019 modelling has a lower level of upstream natural gas emissions in the 2030 reference case due to updates described in Table 1. As a result, there are fewer emissions targeted by this policy and fewer reductions.
Industrial Electrification	Provide clean electricity to planned	3.5	2.9	In the 2019 modelling, GHG reductions are estimated to be

[61] This figure includes a post-modelling adjustment made by the Province as described in Appendix C.

	natural gas production in the Peace region. Increase access to clean electricity for large operations with new transmission lines and interconnectivity to existing lines			0.6 Mt CO_2e lower than in the 2018 modelling. The difference between the 2018 and 2019 modelling is due to two factors:1) electricity consumption in the upstream natural gas sector under CleanBC was aligned to BC Hydro's forecast, resulting in less electrification and fewer GHG reductions, and 2) the total amount of fuel gas consumed by the natural gas sector is lower in the 2019 modelling.
Carbon Capture and Storage	Ensure a regulatory framework for safe and effective underground CO_2 storage and direct air capture	0.6	0.7	2019 modelling achieves similar emission reductions to the 2018 modelling.
Renewable Gas	Make industrial natural gas consumption cleaner with a minimum 15% to come from renewable gas	0.9	0.4	The renewable gas mandate is modelled as a single policy (2.1 Mt CO_2e of total reductions) and impact is subsequently split out by sector (1.6 Mt CO_2e in residential, 0.4 Mt CO_2e in industrial). The policy's combined reductions in the residential and industrial sectors has decreased by 0.4Mt CO_2e in the 2019 vs 2018 modelling. Total reductions have decreased because the 2019 modelling has slightly lower natural gas consumption. The policy is now achieving a lower proportion of reductions in the industrial sector, decreasing the total modelled reductions. Allocation of reductions between sectors has changed because in the 2018 modelling, renewable content was scaled up from 10% (a value used in prior model runs) to 15% through post-modelling adjustments. The adjustment leads to a different allocation of

				reductions relative to 2019 which was modelled at 15%.
	Subtotal	8.4	7.1	
EXPAND CARBON PRICING				
Expand carbon pricing	Continue the successful carbon pricing framework, with rebates for low- and middle-income British Columbians and support for clean investments	1.8	1.1	In the 2019 modelling, GHG reductions are estimated to be 0.7 Mt CO2e lower than the 2018 modelling. The 2019 emission reduction estimate has decreased relative to 2018 estimate due to 1) a lower reference case total, particularly in the upstream natural gas sector, resulting in fewer taxed emissions and 2) adjustments to correct overestimation of reductions in some sectors in the 2018 modelling.
	Subtotal	1.8	1.1	
	CleanBC Total Reductions	18.9	16.7	

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