City of Vancouver Energy and Emissions Forecast

Final Report

SUBMITTED TO

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Executive Summary

Rational for this work

The City of Vancouver's ("the City") Renewable City Strategy ("RCS") target to have 100% renewable electricity consumption in Vancouver before 2050 will change the quantity and type of energy consumed in the City, as well as the City's greenhouse gas (GHG) emissions. The nature of this change is of interest to the City and the energy utilities that must supply energy to Vancouver. As such, Navius has used a quantitative model of Vancouver's energy-economy system to forecast Vancouver's energy consumption and GHG emissions from the present to 2050 in response to policies that will achieve the RCS target.

Method

We used the CIMS energy-economy model to produce this forecast. CIMS models how consumers and firms choose the technologies they use to satisfy their demand for energy end-uses such as space heating, lighting and transportation. The model simulates how policy affects the evolution of the stock of energy-using technologies in Vancouver as a function of growth, energy prices, technology costs, technology energy consumption, and human behaviour. It has a detailed representation of the technologies in the following sectors: residential buildings, commercial and institutional buildings, industry, including the three large facilities (Molson, in the process of closing, Lantic Sugar, and West Coast Reduction) and light industry (e.g. bakeries, small breweries, light manufacturing), personal transportation (private vehicles and transit), freight transportation (commercial/delivery vehicles, heavy-trucks and rail).

This analysis includes four scenarios that vary according to the policies used to achieve the RCS target and the price and potential for bio-energy relative to electricity (TABLE S 1). The policy scenarios include one where policies are designed primarily to reduce the GHG intensity of the City, with energy efficiency and transportation-mode switching as a by-product of these policies (Called the Renewable City Strategy, or "RCS", scenario). The second policy scenario includes additional policies to increase energy efficiency and shifting away from personal vehicle travel (Called RCS + greater efficiency scenario). The bio-energy scenarios include one that is "likely", meaning it matches the common expectation that constraints on bio-energy supply will make bio-energy costly. The second is a bio-energy "optimistic" scenario where supply is greater and bio-energy prices remain relatively low, similar to current values, even with increased adoption.

TABLE S 1: Scenario summary matrix

		Policy Orientation	
Bio-energy cost and potential		**GHG Intensity (RCS scenario)**	**GHG Intensity with Greater Energy Efficiency and Mode Shifting (RCS + greater efficiency scenario)**
	Bio-energy, likely	Bio-energy likely +GHG intensity focused policy	Bio-energy likely +GHG intensity and efficiency focused policy
	Bio-energy, optimistic	Bio-energy optimistic +GHG intensity focused policy	Bio-energy optimistic +GHG intensity and efficiency focused policy

Energy and emissions results

We use the "Bio-energy likely and GHG intensity and efficiency focused policy" scenario as a base forecast to discuss overall trends in energy consumption as the city moves towards the RCS target.

Despite a growing population and economy, energy consumption in Vancouver decouples from growth. Technological change, energy policy, and city planning (e.g. actions to reduce private vehicle trips) reduce total energy consumption from 53 PJ/yr in 2015 to 44 PJ/yr in 2050. Energy consumption per capita, including industrial, falls from 85 GJ/person/yr to 43 GJ/person/yr, a decline of 50%. (FIGURE S 1).

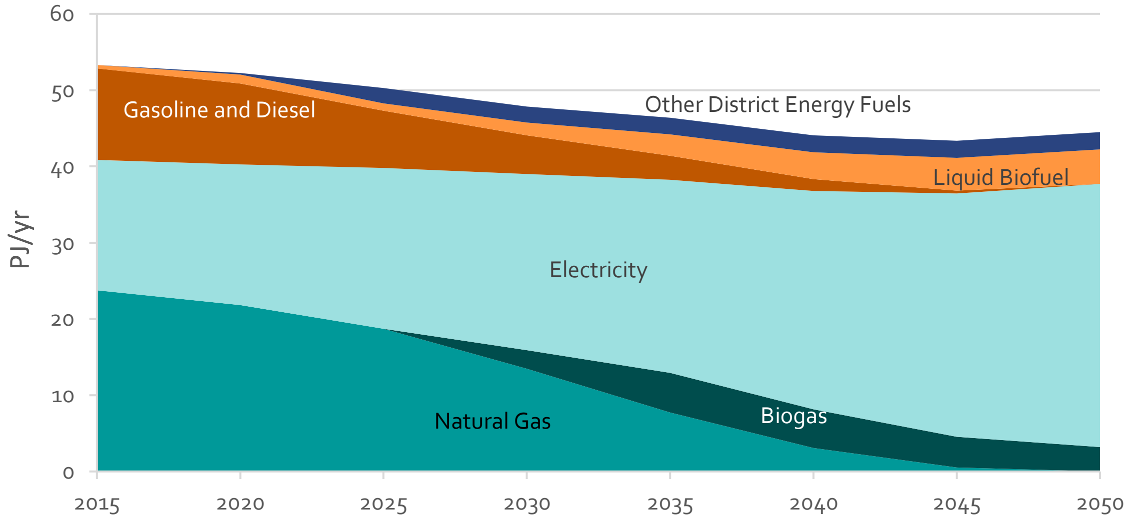
By 2050, fossil fuels are replaced with renewable electricity, delivered from the provincial grid, and bio-energy. During the forecast, a declining quantity of natural gas is substituted with electricity, biogas and other district energy fuels because of:

- The zero-emissions building policy, which requires new and redeveloped homes and buildings to be very energy efficient and emit little to no direct GHG emissions after 2025.
- A retrofit policy that requires mechanical systems to be replaced with zero-emissions systems at the end of their life and requires the retrofit of low-efficiency building envelopes.
- Further development of low-GHG district energy systems.
- A renewable fuel requirement that requires gaseous fuels to be 100% renewable by 2050.

Similarly, a declining quantity of gasoline and diesel is substituted for renewable electricity and liquid biofuel, which includes biodiesel and ethanol as well as drop-in renewable gasoline. Overall transportation energy consumption declines as a result of mode-shifting to transit and active transportation as well as increased vehicle energy efficiency. The fuel switch is driven by zero-emissions vehicle incentives and infrastructure support as well as a renewable fuel requirement to phases out fossil fuel use by 2050.

As a result of the decline in energy consumption and the fuel switch, direct GHG emissions (i.e. only those GHG emitted in Vancouver) are 50% lower in 2030 than in 2015 and are almost zero by 2050

FIGURE S 1: Total Energy Consumption in Vancouver by Fuel, PJ/yr



"District Energy Fuels" include biomass and waste heat

Cost impact results

Per capita energy expenditures fall from $1,800/yr in 2015 to $1,300/yr in 2050 (in 2015 CAD). Total annual energy-related expenditures, including capital expenditures, remain relatively constant over the forecast, showing that increased capital costs are being offset by reduced energy costs (e.g. increase upfront costs for electric vehicles that have significantly reduced operating costs). Because achieving the RCS target will increase capital expenditures, most consumers and firms will perceive it as cost. However, based on an analysis of the costs incurred by archetypal Vancouver citizens, most of the changes brought about by the RCS policies yield at least a 6% return on investment.

Impact of uncertainty in policy and bio-energy prices

Regardless of policy design or bio-energy prices, total energy consumption in Vancouver will decline and electricity consumption will grow, accounting for 65-75% of total consumption by 2050. Total energy consumption and electricity consumption are not highly sensitive to the policy and energy price variations tested in this analysis. In fact, the strength of policy on the building sector in both policy scenarios is such that the energy consumed in buildings becomes largely insensitive to these uncertainties. Using electricity demand as an example, the uncertainty in policy changes demand by 2.5 PJ/yr in 2050 (6% of forecast electricity consumption). Uncertainty in bio-energy prices creates a similar change in electricity demand. The combined uncertainty means electricity demand will be 32 to 37 PJ/yr in 2050, or +/- 8% around the average of those values.

The cost impacts of the RCS are also robust to the uncertainty tested in this analysis: Achieving the RCS will increase upfront capital expenditures for consumers and firms, but these costs will be offset over time with lower energy expenditures. While consumers and firms will perceive the RCS to impose a cost on them, the changes ultimately save them money and offer a positive return on investment.

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1. Introduction

The City of Vancouver's ("the City") Renewable City Strategy ("RCS") target to have 100% renewable electricity consumption in Vancouver before 2050 will change the quantity and type of energy consumed in the City. The potential future energy consumption in Vancouver is of interest to BC Hydro, as it is the electricity utility that provides power to customers in the city. Understanding the drivers of energy consumption will help with its electricity system planning. Similarly, the City also requires a good understanding of how policies and other drivers of energy consumption and greenhouse gas emissions (e.g. growth, energy prices, technology costs, human behaviour) will impact Vancouver as it sets interim targets under the RCS.

In 2015, Navius completed an analysis of how the RCS target may affect energy and GHG emissions in Vancouver. However, that analysis indicates just one of many possible outcomes of the RCS; it does not explore the varied policy and technological pathways that may lead to the RCS goal. Furthermore, it does not benefit from the improved modelling capacity that Navius developed for the City in 2016. In the analysis described here, we use the improved model to explore the range of possible outcomes that might arise from the RCS target.

The two primary objectives of this study are to:

- Characterize several potential ways in which the energy consumption in the City could change in response to the RCS.
- Use these scenarios to gain insight into how sensitive future energy consumption is to policy design as well as the relative potential to switch to bio-energy versus renewable electricity.

The remainder of this report contains a description of the methodology used in this analysis, including a brief overview of the energy-economy model used for the project, a description of the growth assumptions for the forecast, and a description of the policy, energy price and technology cost assumptions that define four different scenarios in which the RCS target is achieved. These scenarios vary with policy design and assumptions for the relative optimism or pessimism with which bio-energy potential is portrayed in the forecasts. The methodology is followed by the results, which are then discussed, drawing out conclusions and insights from this work. The report also contains an appendix describing the results of model calibration to energy and greenhouse gas (GHG) emissions data.

2. Methodology

This section contains a description of the methodology used in this analysis. Included in this description is a brief overview of the modelling framework used, with more detail provided in the appendix. It then presents the fundamental drivers of Vancouver's future energy consumption: growth and energy prices. This section describes the two policy scenarios and bio-energy scenarios used in this analysis to explore the potential future energy mix in the City.

Table 1 summarizes the four scenarios formed by the policy and bio-energy assumptions, described in full in section 2.4 and 2.5. The policy scenarios include one where policies are designed primarily to reduce the GHG intensity of the City, with energy efficiency and transportation-mode switching as a by-product of these policies (Called the Renewable City Strategy, or "RCS", scenario). The second policy scenario includes additional policies to increase energy efficiency and shifting away from personal vehicle travel (Called RCS + greater efficiency scenario). The bio-energy scenarios include one that is "likely", meaning it matches the common expectation that constraints on bio-energy supply will make bio-energy costly. The second is a bio-energy "optimistic" scenario where supply is greater and bio-energy prices remain relatively low, similar to current values, even with increased adoption.

Table 1: Scenario summary matrix

		Policy Orientation	
		GHG Intensity (RCS scenario)	**GHG Intensity with Greater Energy Efficiency and Mode Shifting (RCS + greater efficiency scenario)**
Bio-energy cost and potential	**Bio-energy, likely**	Bio-energy likely +GHG intensity focused policy	Bio-energy likely +GHG intensity and efficiency focused policy
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2.1. Modelling framework

Overview

We used the CIMS energy-economy model to produce this forecast. CIMS models how consumers and firms choose the technologies they use to satisfy their demand for energy end-uses such as space heating, lighting and transportation. The model simulates how policy affects the evolution of the stock of energy-using technologies in Vancouver as a function of growth, energy prices, technology costs and performance, as well as human behaviour. It has a detailed representation of the technologies in the following sectors:

- Residential buildings
- Commercial and institutional buildings
- Industry, including the three large facilities (Molson, now closed, Lantic Sugar, and West Coast Reduction) and light industry (e.g. bakeries, small breweries, light manufacturing)
- Personal transportation (private vehicles and transit)
- Freight transportation (commercial/delivery vehicles, heavy-trucks and rail)

Key inputs to the CIMS models include reference forecasts of energy prices and activity by sector, as well as technology parameters (e.g. cost, energy efficiency etc.). The model then simulates how capital stock is acquired, used to provide energy services (e.g. home heating, personal transportation, or electricity consumption), retrofitted and ultimately retired at the end of its useful life.

Technology choice decisions are based on financial costs as well as human behaviour. Specifically, CIMS accounts for how technology choices are affected by preferences for familiar technologies, perceived risks of new technologies, aversion to upfront costs, and the heterogeneity of human decision making.

Key outputs from the model are energy consumption, GHG emissions, energy costs, and capital expenditures. These results can be presented at the city level or may be disaggregated by sector, end-use or even technology. Results also include technology stocks (e.g. number of electric vehicles) or technology new market share (e.g. x% of private vehicle sales are electric vehicles). More details on the model can be provided upon request.

Limitations of the model

While the CIMS Vancouver model does an excellent job of simulating how technology choice affects future energy consumption and GHG emissions, it does have several limitations that need to be understood to properly interpret the results:

- **CIMS is not spatial.** It does not represent how technologies are positioned relative to one another. As such, it does not explicitly simulate how urban form and transportation infrastructure affect travel demand and transportation mode choice. It simulates these factors in a relatively simple manner based on the financial and perceived costs of travel by each mode (i.e. private vehicle, transit and active transportation).

- **The model only covers combustion GHG emissions.** Emissions resulting from industrial processes are not included, nor are methane leaks from the natural gas distribution system. However, there are no large facilities (GHG emissions greater than 10 ktCO_2e/yr) reporting process GHG emissions in Vancouver.[1] Methane leaks from distribution are low relative to the GHG emissions resulting from natural combustion in Canada. For example, in 2014, methane leaks from natural gas distribution were 1.2 MtCO_2e,[2] while natural gas combustion in industry and buildings was roughly 125 MtCO_2e (i.e. approximating demand from distribution connected customers at 2500 PJ/yr).[3]

- **The CIMS Vancouver model does not simulate anything outside of Vancouver.** Therefore energy prices and the renewable content of electricity are assumptions that are chosen to be consistent with the scenario being modelled. Likewise, the cost of emerging low-GHG technologies is mostly defined outside of the city (e.g. electric vehicle costs), and the trend in those costs is also an assumption within the CIMS Vancouver model.

- **The model has a limited representation of the rebound effect,** where the cost of an energy service affects demand for that energy service. The rebound effect in CIMS Vancouver only affects mode share, where reduced operating costs for private vehicles (e.g. with the adoption electric vehicles) will increase private vehicle travel somewhat. The rebound effect for other end-uses (e.g. lighting, space heating) is not modelled.

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[1] Government of British Columbia, 2016, Industrial Facility Greenhouse Gas Emissions:2015

[2] Environment Canada, 2016, National Inventory Report, Table A10-2

[3] Statistics Canada, CANSIM table 128-0016

Past use of the model and recent development

The CIMS Vancouver model was used to provide supporting analysis for the development of the 2015 Renewable City Strategy. The model has undergone further development and in this project it has been used to provide a greater depth of policy and sensitivity analysis. Changes to the model since 2015 include:

- **A more explicit representation of district energy.** While district energy areas are uncertain, the model allows a direct representation of any expected district energy developments
- **A more explicit representation of industry**, with the activity of the three major facilities represented. This allows the model to phase out the Molson facility, while keeping the rest of the industry sector active. Overall, the model allows a more flexible representation of industrial activity.
- **An updated representation of the purchase cost of plug-in electric vehicles.** Costs have declined faster than anticipated in 2015 and the updated assumptions result in greater electric vehicle adoption with fewer hybrid vehicles and less liquid biofuel consumption.
- **An improved representation of how policy affects new and existing buildings.** On one hand, the change reduces the impact of some policies on building energy consumption. For example, the model can now delay the application of low-GHG requirements to existing buildings and it can account for the delay between policy implementation, building permitting and actual construction. On the other hand, the addition of increased potential to retrofit building envelopes and more efficient new building envelopes can further reduce building energy consumption.
- **The addition of a freight transportation sector model**, giving the model near total coverage of Vancouver's direct GHG emissions, with the exclusion of those emissions resulting from solid and liquid waste.

2.2. Growth and sector activity

Table 2 shows Vancouver’s population growth assumption in this analysis. The growth rates are the annual average for the five-year period ending in the year shown. The 2015 value is consistent with the 2016 Census. Growth rates to 2040 are aligned with BC Hydro’s load forecast input for households growth rates in the Vancouver/Burnaby area. The same scenarios were also modelled using the City of Vancouver’s population growth rates, though the results are not discussed in this report.

Table 2: Population growth

	2015	2020	2025	2030	2035	2040	2045	2050	2015-2050 avg %/yr
Avg. Annual growth rate	0.91%	1.79%	2.37%	1.77%	1.34%	1.27%	1.35%	1.35%	
Population, 1000s	626	684	769	840	898	956	1023	1094	1.61%

Sector activity, except for heavy-freight and industry, is indexed to the city's population growth rate. Note that personal transportation mode share (e.g. transit vs. private vehicle) is a simulated result. Heavy freight transport (truck and rail) is currently indexed to a forecast of total port activity. Industrial activity is based on specific assumptions for the three large facilities and many small facilities in Vancouver.

More detailed assumptions for each sector can be found in the spreadsheet submitted with this report "Inputs Sheet Aug 3 (high pop)":

- Residential assumptions include people per dwelling, dwelling size by building type, and floor area by building type (starting in row 196), district energy assumptions (row 485). We assume the average area of residential households declines somewhat during the forecast as the share of people living in row houses and multi-unit buildings increases. Therefore, the average annual rate of growth in residential floor area from 2015 to 2050 is somewhat lower than for the population: 1.52% vs. 1.61%/yr. Residential building retirement age is not available to be defined in the user inputs, but this assumption results in between 0.8% and 1.5% of total residential floor area being torn down and replaced each year (average of 1.1%).
- Commercial and institutional building assumptions include floor area by building activity (starting row 260) and district energy assumptions (row 592). The growth in commercial floor area is somewhat decoupled from the growth in population, increasing at an average of 1.57%/yr between 2015 and 2020. Commercial and institutional building retirement age is not available to be defined in the user inputs, but this assumption results in between 1.4% and 2.1% of total commercial and institutional floor area being torn down and replaced each year (average of 1.7%).
- Personal transportation assumptions include person km travelled per capita and the fraction of transit that is serviced by the Skytrain system (starting in row 326). Personal transportation grows at the same rate as population. However, vehicle km/yr, which is a simulated result, can decouple from population growth if the share of travel by transit, walking and cycling increases.

- Freight transportation assumptions include tonne km travelled per year for light and heavy freight (row 389). Light freight activity grows at the same average annual rate as population. Heavy freight activity grows at an average of 2.65%/yr based on a forecast of total port activity.[4] More detail on heavy freight is in the sheet labelled "Heavy Freight Activity" within the model inputs spreadsheet.
- Industry assumptions include activity relative to 2015 by facility (starting in row 355).

Table 3: Activity by sector

	2015	2020	2025	2030	2035	2040	2045	2050	2015-2050 avg %/yr
Residential buildings, million m²	33.2	34.7	36.2	37.6	38.8	39.8	40.7	41.7	0.65%
Commercial and institutional buildings, million m²	12.3	12.9	13.4	14.0	14.4	14.9	15.3	15.7	0.71%
Personal transportation, million person km/yr	7,231	7,587	7,949	8,294	8,596	8,853	9,088	9,329	0.73%
Light freight transport, million tonne km/yr	129	135	142	148	153	158	162	166	0.73%
Heavy freight transport, million tonne km/yr	810	1,079	1,268	1,484	1,619	1,754	1,889	2,024	2.65%
Industry	Assumed activity is constant at 2015 levels, less the Molson Coors Brewery								

2.3. Energy prices

This section describes the energy price assumptions used in the "likely" bio-energy scenario, which corresponds to the base scenario results described in section 3.1. The changes to prices of electricity, biogas, liquid biofuel and solid biomass for the "optimistic" bio-energy scenarios are described in greater detail and compared to these "likely" scenario assumptions in section 2.5 where the bio-energy sensitivity analysis is fully described.

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[4] Ocean Shipping Consultants, 2016, Container Traffic Forecast Study – Port of Vancouver

Table 4 shows the assumed electricity price by sector, with assumptions for three customer groups: residential (which includes personal transportation), commercial (which includes freight transportation) and industrial. We assume the announced rate changes to 2018 are implemented and the electricity price is kept constant in real terms thereafter (i.e. adjusted for inflation).

Table 4: Electricity prices, 2015 CAD/MWh

	2015	2020	2025	2030	2035	2040	2045	2050
Residential, personal transport	106	116	116	116	116	116	116	116
Commercial, freight (e.g. medium general service)	87	95	95	95	95	95	95	95
Industry (e.g. large general service)	73	80	80	80	80	80	80	80

Table 5 shows the natural gas prices used in the analysis. The commodity price is based on the Henry Hub price forecast from the EIA 2017 Annual Energy Outlook reference scenario. Retail prices are based on Fortis adders for each customer class. For transportation, we assume a fuel tax is applied to the natural gas price after 2020, equivalent in $/GJ terms to the provincial and federal diesel fuel excise taxes ($9.4/GJ). Table 6 shows the retail price for biogas. We use the current Fortis price until 2020, after which we assume the price rises to $28/GJ by 2030 where it stays until 2050. This higher price is based on the highest marginal price estimate produced by Hallbar (2017)[5] for the B.C. Government. This price is consistent with thermal production of biogas from forestry waste.

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[5] Hallbar, 2017, *Resource Supply Potential for Renewable Natural Gas in BC*, available from www.gov.bc.ca

Table 5: Natural gas prices, 2015 CAD/GJ, including GST

	2015	2020	2025	2030	2035	2040	2045	2050
Henry Hub price	3.6	4.8	6.0	6.6	6.9	6.9	7.2	7.8
Residential	12.8	13.1	14.4	15.2	15.3	15.7	16.0	16.5
Commercial/Industrial	8.2	8.5	9.8	10.6	10.7	11.1	11.4	11.9
Transport	8.2	8.5	19.6	20.4	20.5	20.9	21.2	21.7

Table 6: Biogas prices, 2015 CAD/GJ, including GST

	2015	2020	2025	2030	2035	2040	2045	2050
Residential	19.8	19.0	21.4	23.6	23.4	23.7	23.7	23.8
Commercial/Industrial	15.2	14.4	16.8	19.0	18.8	19.1	19.1	19.2
Transport	15.2	14.4	26.7	28.8	28.6	28.9	29.0	29.0

Table 7 shows liquid transportation fuel prices. Retail prices are based on the price of oil (EIA 2017 Annual Energy Outlook reference price), fuel taxes in Metro Vancouver, and typical refining and distribution margins in the lower-mainland of British Columbia. We assume that the prices of ethanol and biodiesel increase as fuel demand drives up the price of the agricultural products used as feedstocks. The ethanol price assumption is based on corn ethanol with the price of corn rising from roughly $150/tonne to $250/tonne, typical of peak prices over the last decade. The biodiesel price assumption is based on the price of canola oil also rising from $800/tonne to $1000/tonne, also typical of recent peak prices. Renewable gasoline and diesel is based on Jones et al. (2013),[6] but we assume the capital cost is 50% higher than anticipated and the ligno-cellulosic feedstock (i.e. woody/grassy material) costs 120 $/bone dry tonne, typical of purpose grown feedstock.

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[6] Jones, S., Pimphan, M., Snowden-Swan, L., Padmaperuma, A., Tan, E., Dutta, A., Jacobson, J., Cafferty, K., 2013, Process Design and Economics for the Conversion of Ligno-Cellulosic biomass to Hydrocarbon Fuels, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Idaho National Laboratory.

Table 7: Crude oil and liquid fuel prices, 2015 CAD/L, including GST unless otherwise labelled

	2015	2020	2025	2030	2035	2040	2045	2050
Crude oil,2015 CAD/bbl	64	73	99	110	121	130	136	141
Gasoline	1.11	1.16	1.33	1.40	1.47	1.54	1.57	1.60
Diesel	1.06	1.11	1.28	1.35	1.42	1.49	1.52	1.55
Ethanol	1.00	1.29	1.29	1.29	1.29	1.29	1.29	1.29
Biodiesel	1.56	1.72	1.72	1.72	1.72	1.72	1.72	1.72
Renewable gasoline and diesel	1.86	1.85	1.85	1.85	1.85	1.85	1.85	1.85

Finally, we assume that solid biomass fuel, used only for some district energy supply technologies in this analysis, costs $4.7/GJ. This price is based on the delivered price of wood waste being $90/bone dry tonne, which is at the high end of the fuel price estimate for district energy systems in Metro Vancouver use in the downtown fuel switch feasibility study supply cost analysis.[7]

Additional detail on how the energy price assumptions are formed can be found in the user inputs spreadsheet (Inputs sheet Aug 3 (high pop).xlsx). Electricity price assumptions start in row 158 of the "User Inputs" sheet with more detail on "Elec price workings" sheet. Natural gas price assumptions start in row 39 in the "User Inputs" sheet with more detail on the "NG price workings" sheet. Liquid fuel price assumptions start in row 107 in the "User Inputs" sheet with more detail in the "Liquid fuel price workings" sheet.

2.4. Policy scenario definition

In this section, we describe the two policy scenarios that will be explored with the energy-economy model. Both scenarios are designed to achieve the renewable city strategy target by 2050. The first scenario takes existing policies and over time adds increasingly stringent policies focused predominantly on reducing GHG intensity (The RCS scenario). Improved energy efficiency will often result from these polices, but it is not an explicit objective. The second scenario takes the policies in the GHG Intensity scenario and adds additional policies broadly focused on energy efficiency (The RCS + greater efficiency scenario). This includes the energy efficiency of technologies,

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[7] Reshape Infrastructure Ltd., 2017, A Low-Carbon Legacy for Downtown Vancouver: Final Feasibility Report for the Creative Energy Fuel Switch

buildings and vehicles, and the efficiency of land-use and transportation networks, in terms of how they affect transportation mode choice.

We assume this set of policies includes a mix of policies implemented by either the federal, provincial, or City of Vancouver governments. In this analysis, we are not attempting to attribute responsibility for a policy to any specific level of government. In some cases, a policy clearly maps to one level of government or another, such as the carbon tax which is already a provincial policy with a price floor set nationally by the federal government. But in other cases, similar policies, or policies with similar impacts, could be implemented by any level of government.

Table 8 outlines these two policy scenarios. Regarding the representation of policies in the model, some are simulated while others will inform model inputs that lead a prescribed outcome in the model (e.g. a target for the percent of trips by private vehicle). Policies that are simulated will either be directly represented or implicitly included. An example of a policy with a direct representation is a fuel standard specifying a required GHG intensity by a given date, while a policy that might be implicitly included is support for plug-in electric vehicle (PEV) charging stations that is sufficient to allow the simulated PEV adoption to occur (i.e. Availability of charging should not be somehow represented as constraint on the adoption of PEVs in the model). The following sections elaborate on how the policies are represented in the analysis.

Table 8: Policy Summary Table

	Policy Orientation	
Sector	**GHG Intensity (RCS scenario)**	**GHG Intensity with Greater Energy Efficiency and Mode Shifting (RCS + greater efficiency scenario)**
Cross-sector	Carbon price, applied as a modest increase to the BC carbon tax over time	Same

	Policy Orientation	
Sector	**GHG Intensity (RCS scenario)**	**GHG Intensity with Greater Energy Efficiency and Mode Shifting (RCS + greater efficiency scenario)**
Light-duty vehicles	Federal vehicle emission standard to 2025 Current electric vehicle subsidy and Implicit ZEV incentive (e.g. reduced parking rate, increased availability) Implicit roll-out of EV charging that would allow the EV adoption that occurs Low-carbon fuel policy, trending towards ~50-75% reduction in lifecycle GHG emissions by 2050, implying almost 100% renewable energy in liquid and gaseous transport fuels Transport 2040 plan mode shares and implied vkm/pkm achieved by 2040	Same vehicle emission standard Same degree of ZEV/EV support Same low-carbon fuel policy Transport 2040 plan mode shares and implied vkm/pkm achieved by 2035, trend in reduced vehicle trips continues to 2050
Heavy-duty vehicles	Current HDV vehicle emission standard Same low-carbon fuel policy specified above	Same
Buildings: District Energy	Identified areas are developed, with a steady development of future district energy areas from 2030 to 2050 The district energy assumptions are consistent with those used in the 2015 analysis. However, these assumptions are outdated and updated assumptions were not yet available for this analysis.	Same district energy assumption

	Policy Orientation	
Sector	GHG Intensity (RCS scenario)	GHG Intensity with Greater Energy Efficiency and Mode Shifting (RCS + greater efficiency scenario)
Buildings: Envelope	Current TEDI and GHG requirements for new and redeveloped buildings	Current TEDI and GHG requirement, extending TEDI towards passive house levels Building envelope retrofit required for least-efficient buildings (pre-year 2000 stock) when building permits for major renovations are given (e.g. those affecting the envelope). Begins after 2025.
Buildings: Mechanical and fuels	Current TEDI and GHG requirements for new and redeveloped buildings Low-carbon fuel policy requiring 0% fossil GHG by 2050 Replacement of gas-fired mechanicals with heat-pumps when these systems reach the end of their useful life. Begins after 2025.	Current TEDI and GHG requirements. Phase-out of resistance electric equipment, except for Passive House equivalent residential dwelling envelopes (sub 18 kWh/yr TEDI). Same low-carbon fuel policy. Same mechanicals retrofit policy.
Buildings: Appliances/plug-load	Current energy efficiency regulations	Enhanced energy efficiency regulations

Cross-sectoral policy: Carbon price

Both policy scenarios include a carbon price. We assume this is an increase to the BC carbon tax which rises by \$5/tCO_2e annually until it reaches the federal carbon price floor of \$50/tCO_2e. Thereafter, we assume the carbon price is kept constant in real terms, meaning it is also adjusted for inflation (Table 9).

Table 9: Carbon Price Assumption, 2015 CAD/tCO$_2$e

	2015	2020	2025	2030	2035	2040	2045	2050
BC Carbon tax	30	45	50	50	50	50	50	50

Personal transportation

Light-duty vehicle emissions standards

The policy scenarios include the federal *Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations*. The regulation specifies the fleet average GHG emissions per km, with the policy requiring that vehicle have hybrid-like energy efficiency on average by 2025.

Plug-in electric vehicle subsidy and incentives

The policy scenarios include a plug-in electric vehicle purchase incentive modelled on the Clean Energy Vehicles for BC program, where the provincial government currently offers a $5,000 subsidy on the purchase of a plug-in electric vehicle (PEV). We assume there is a $5,000 per vehicle subsidy offered until 2020, after which it falls to $2,000 per vehicle until 2025. We assume ongoing activity, such as prioritized parking availability and low-cost electricity, incentivized PEV ownership, equivalent to a value of $1,000/vehicle for the remainder of the study period to 2050.

Implicitly, we assume that the roll-out of PEV charging infrastructure keeps pace with the adoption of PEVs. In other words, we assume that there is no ongoing constraint to PEV use related to lack of charging locations.

Low-carbon fuel policy: Transportation

The policy scenarios include a low-carbon fuel policy that ultimately requires no fossil fuel consumption (i.e. gasoline, diesel, natural gas) for transportation by 2050. In practice, if this were a low-carbon fuel standard like BC's *Renewable and Low-Carbon Fuel Regulation Requirement*, it would require a roughly 75% reduction in the lifecycle GHG intensity of transportation energy consumption, depending on the upstream GHG intensity of the biofuels that are substituted for gasoline and diesel. In the model, ethanol and biodiesel may be blended with gasoline and diesel to 15% and 10% by volume. While higher blends may be possible, for simplicity, the model only allows further compliance through electrification and the use of drop-in biofuels, either pyrolysis or hydrogenation derived renewable gasoline and diesel with ligno-cellulosic feedstocks. The low-carbon fuel policy phases out fossil-fuel derived gasoline and diesel consumption linearly between 2025 and 2050.

Transportation mode switching

Both policy scenarios include some degree of transportation mode switching relative to current levels. The mode switch occurs due to an assumed improvement in transit, walking and cycling networks within Vancouver as well as the application of congestion pricing. The extent of the switch differs by policy scenario:

- **The GHG intensity focussed policy scenario (RCS scenario)** sees the Transportation 2040 plan targets achieved. This involves reducing the % of trips by car from over 50% in 2011 to 33% by 2040. Total vehicle km (vkm) travelled obviously depends on population growth and trip length. Assuming no change in average trip lengths and that population grows on average by 1.61% annually during the study period, achieving this target means that vkm only grows by 40% to 2050, or by 1%/yr. This is equivalent to a 18% reduction in vkm/capita from 2015.
- **The GHG intensity and energy efficiency focussed policy scenario (RCS + greater efficiency scenario)** sees the Transportation 2040 plan targets achieved by 2035. Furthermore, the trend in mode shift continues to 2050 such that trips by vehicle fall to 25% of the total by 2050. With the same assumptions as above, total vkm generally stays constant during the study period and vkm/capita declines by 38% between 2015 and 2050.

Heavy-duty vehicles

Policies affecting heavy duty vehicles include:

- The heavy-duty vehicle emissions standard, which affects heavy-duty vehicles starting with model year 2014, with a schedule extending to 2017. By 2018, new vehicles must on average emit 23% fewer GHG emissions than the base model year vehicle (2011).
- The same low-carbon fuel policy that also applied to light-duty vehicle energy consumption

Buildings

District energy

The district energy assumptions are consistent with what was assumed in the Navius analysis that supported the 2015 Renewable City Strategy (see "User Inputs" row 485 to 590). These assumptions are currently being updated by the City, but a more current view of the development of district energy was not yet available for this analysis. There are several specific assumptions that are important for interpreting the results. First, we assume the downtown fuel switch by 2025, with 75% of annual energy coming from biomass combustion. Second, for all other low-GHG district energy systems, we assume that one third of annual energy comes from peak energy capacity which may be fuelled by either natural gas or biogas. The model has no other technological pathways that could provide peak energy, such as thermal storage or electric resistance heating.

Building energy intensity and greenhouse gas intensity for new buildings

In both of the policy scenarios, building energy intensity and GHG intensity is constrained by the Zero Emissions Building Policy. That policy sets a declining schedule for the GHG intensity (i.e. the GHG emissions per building area each year, "GHGI") and the thermal energy demand intensity (i.e. the useful heat required per building area each year, "TEDI"). The actual policy specifies different criteria depending on whether a building fits within the existing zoning (in which case the Vancouver Building Bylaw applies), or if the building is part of a re-zoning application (in which case the Green Building Policy for Rezoning applies). The building code most often applies to detached row houses and MURBs six storeys and less (i.e. low-rise), while the re-zoning requirement most often applies to MURBS taller than six storeys and large commercial. For simplicity, the policy requirements for detached houses, row houses and low-rise MURBS are based on the building code bylaw, while the requirements for MURB are based on the re-zoning requirements. The policy criteria are those provided by the City of Vancouver during the summer of 2015 (Table 10).

Note that for MURBS, the criteria are those that apply when the building is permitted. Due to the time lag between building and permitting, we assume that buildings are built according to the policy requirements from five years earlier. For example, a building built in 2025 would meet the criteria set out in 2020. This also applies to office buildings.

The main difference in the application of the Zero-Emissions building policy between RCS scenario and the RCS + greater efficiency scenario is that the latter only allows new residential detached and attached homes to use baseboard electric heating if they can achieve Passive House level TEDI (less than 18 kWh/m^2/yr). As well, although resistance electric heating is rarely used in large buildings, these technologies for new commercial and institutional buildings are phased out after 2025.

Table 10: Zero-Emissions Buildings Policy parameters used in the modelling in the RCS policy scenario. The RCS + greater efficiency scenario has additional TEDI requirements for detached and attached homes built with resistance electric heating.

	Measure	Unit	Max. after 2015	Max. after 2020	Max. after 2025	Notes
Detached homes	GHGI	KgCO$_2$/m^2/yr	12	7	2.5	Based on building code. Also applied to attached homes
	TEDI	kWh/m^2/yr	84	55	30	
Low-rise MURB	GHGI	KgCO$_2$/m^2/yr	6	6	0	Based on building code
	TEDI	kWh/m^2/yr	35	35	10	
Low-rise MURB, DE	GHGI	KgCO$_2$/m^2/yr	5	4	0	While the city does not expect many low-rise DE connected MURBS, they have less stringent TEDI requirements
	TEDI	kWh/m^2/yr	35	35	35	
High-rise MURB	GHGI	KgCO$_2$/m^2/yr	6	5	0	Based on re-zoning requirement
	TEDI	kWh/m^2/yr	32	18	10	
High-rise MURB, DE	GHGI	KgCO$_2$/m^2/yr	6	5	0	Less stringent TEDI requirements for district-energy connected buildings
	TEDI	kWh/m^2/yr	40	40	40	
Commercial buildings	GHGI	KgCO$_2$/m^2/yr	3	1	0	Based on re-zoning requirement
	TEDI	kWh/m^2/yr	27	21	21	
Commercial buildings, DE	GHGI	KgCO$_2$/m^2/yr	3	1	0	Less stringent TEDI requirements for district-energy connected buildings
	TEDI	kWh/m^2/yr	27	27	27	

Retrofit to existing building envelopes

The RCS + greater efficiency scenario includes a retrofit policy that requires the oldest building stock (equivalent to the least efficient buildings with the highest TEDI in the model) to retrofit the building envelope to reduce the TEDI at the time of any major renovation. In the model, the policy is applied to pre-2000 building stock, at a rate of 5% of buildings per year, approximating a 20-25 year interval for major renovations to these buildings that involve a repair, change or upgrade to the building envelope and require building permits. The retrofit reduces the TEDI of residential buildings by 20% at a cost of roughly \$75/m^2 of floor area (approximately \$10,000 for a retrofit to a detached home). This cost assumption is uncertain, but notionally based on the cost of upgrading basement/crawlspace and attic insulation while adding exterior cladding insulation. It also includes and the incremental cost of higher performance windows and air-sealing.

For commercial and institutional buildings, the retrofit makes the building roughly equivalent to the performance of a building that complies with the Model National Energy Code for buildings 1997 (MNECD 1997). This is equivalent to TEDI declining by 10-60% depending on the building activity. The cost is also assumed to be $75/m^2, based on the detached home archetype. Again, this cost estimate is quite uncertain and it could be lower: a Vancouver case study shows that a 20% improvement in the TEDI of MURB was achieved at a cost of only $12/m^2.[8]

Retrofit to existing building mechanical systems

In both policy scenarios, when homes and buildings retire their gas-fired space and water heating systems that are at the end of their useful life, they will have to switch to low-energy and low-GHG mechanical systems (i.e. heat pumps). The policy begins after 2025 and applies to both scenarios.

Low-carbon fuel policy: stationary fuel consumption

As for transportation, we assume there is a low-carbon fuel regulation that applies to stationary fuels. In practice, this applies only to natural gas consumption in buildings and industry within this analysis. This policy phases out fossil-based natural gas consumption by 2050, though it may be directly substituted with biogas. Biogas assumptions that apply in each scenario are described in the following section detailing the sensitivity analysis. Like the policy on gasoline and diesel, fossil-based natural gas consumption is phased out linearly between 2025 and 2050.

Enhanced energy efficiency regulations for appliances and plug-loads

The RCS scenario includes the existing minimum energy performance standard for appliances and equipment used in buildings. They set minimum energy efficiency standards for these goods, essentially removing the worst performing models from the market place. However, other policies, such as the phase -out of gas-fired heating equipment, can impose additional requirements that make this policy non-binding. This policy specifically affects new purchases of:

- Gas-fired water heaters with energy factor (EF) 60 phased out after 2010, EF 65 phased out after 2015.
- Gas-fired furnaces sized for typical homes must be at least 90% energy efficient
- Low efficiency washing machine and dishwashers are phased out after 2010

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[8] Pape-Salmon, A., 2015, RDH Technical Bulleting No. 008: Deep Energy Retrofit of the Belmont, RDH Engineering Ltd., http://rdh.com/wp-content/uploads/2015/08/TB-8-Deep-Energy-Retrofit.pdf

The scenario with an increased focus on energy efficiency includes additional energy efficiency standards for household appliances and plug-loads. These standards essentially require the current best in class energy performance from new equipment purchased after 2025 (i.e. Energy Star, or Energy Star "most efficient"):

- Clothes washers: New models have a further 40% reduction in water use and drying required relative to current standard
- Fridges: New models use 300 kWh/yr
- Freezers: New models use 330 kWh/yr
- Dishwasher: New models use 20% less water and electricity than the current standard.
- Other plug-load: These devices, represented in aggregate in the model, must be 15% more efficient than current "typical devices, either through more efficient operation or through reduced standby power consumption.

2.5. Bio-energy sensitivity analysis definition

An uncertainty in this analysis is the extent to which bio-energy and electricity will be used in response to the policies described above. In other words, will biogas and liquid biofuels play a significantly larger role in the energy mix if we shift their price? We will bound the impact of this uncertainty by testing the policy scenarios under two different sets of technology cost and energy price assumptions that will change the extent of electrification/bio-energy consumption.

Key uncertainties include:

- The future cost of electric vehicles including battery-electric, plug-in hybrid and hydrogen fuel cell vehicles.
- The price of bio-energy: Solid biomass (for district energy), biogas (as a substitute for natural gas), and liquid biofuels including additives, ethanol and biodiesel, and drop fuels (i.e. renewable gasoline and diesel).
- The price of electricity

The two sensitivity scenarios will include one that is more optimistic about the cost of electrification, hence more pessimistic about the use of bio-energy (e.g. lower electric vehicle and heat pump costs, higher bio-energy prices) and one that is more optimistic about the cost of using bio-energy (e.g. lower bio-energy prices and higher electric vehicle and heat pump costs). The sensitivity analysis will be performed for both scenarios described in Table 8. The parameters of the sensitivity analysis are summarized in Table 11 and explained in more detail below.

Table 11: Sensitivity Analysis Scenarios

Attribute	Likely bio-energy	Optimistic bio-energy
Energy prices		
Biomass fuel price for DE	$4.7/GJ	$3.2/GJ
Biogas price	Price on higher end of supply curve?	Current Fortis Commodity price: 10.
Electricity price	Constant in real terms after announced rate increases	Rising, based on past CoV work
Ethanol price	Based on high feedstock price	Based on low-feedstock price, with full octane value
Biodiesel price	Based on high feedstock price	Based on low-feedstock price
Renewable gasoline and diesel (ligno-cellulosic feedstock)	Based on capital cost *1.25 and high cost feedstock ($80/tonne)	Based on reported capital cost and low-feedstock cost ($6-/tonne)
Technology Costs		
PEVs	Min $100/kWh, lowest cost reached in 2024	Min $125/kWh, lowest cost reached in 2029

Biomass price

Again, biomass prices apply to biomass used in district energy systems that can supply heating to residential and commercial buildings. The "optimistic" scenario price is based on the lower price estimate used for the downtown district energy biomass conversion study, consistent with price of $60/bone dry tonne of biomass (Table 12).[9]

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[9] Reshape Infrastructure Ltd., 2017, A Low-Carbon Legacy for Downtown Vancouver: Final Feasibility Report for the Creative Energy Fuel Switch

Table 12: Biomass prices by bio-energy scenario for residential and commercial buildings, 2015 CAD/GJ

Bio-energy scenario	Customer	2015	2020	2025	2030	2035	2040	2045	2050
Likely	Residential/Commercial	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Optimistic	Residential/Commercial	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2

Biogas price

Table 6 shows the biogas price in each bio-energy scenario. In the "optimistic" scenario, we converted the current Fortis wholesale price to 2015 dollars and assumed the price rises only to $15/GJ, a price that is thought to be more typical of anaerobic biogas supply in Canada.[10] This is almost half the value used in the "Likely" scenario where the marginal supply of biogas comes from thermal processing of forestry waste. Retail prices include the wholesale price plus other markups.

Table 13: Retail biogas prices by bio-energy scenario, 2015 CAD/GJ, including GST

Bio-energy scenario	Customer	2015	2020	2025	2030	2035	2040	2045	2050
Likely	Residential	19.8	19.0	28.4	36.6	36.4	36.7	36.7	36.8
Likely	Commercial/Industrial	15.2	14.4	23.8	32.0	31.8	32.1	32.1	32.2
Likely	Transport	15.2	14.4	33.7	41.8	41.6	41.9	42.0	42.0
Optimistic	Residential	19.8	19.0	21.4	23.6	23.4	23.7	23.7	23.8
Optimistic	Commercial/Industrial	15.2	14.4	16.8	19.0	18.8	19.1	19.1	19.2
Optimistic	Transport	15.2	14.4	26.7	28.8	28.6	28.9	29.0	29.0

Electricity price

Table 14 compares the electricity prices used in the two bio-energy scenarios. Electricity prices in our base scenario, the "likely" bio-energy scenario, are based on announced rate increases to 2018, adjusted for inflation thereafter. The "Optimistic" bio-energy scenario uses a rising electricity price, based on earlier modelling work done by Navius for the City of Vancouver. In this scenario, the electricity price is consistent with increased electrification in response to GHG reduction policy that results in new higher-cost renewable electricity capacity being added to the grid.

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[10] Based on correspondence with Canadian Gas Association

Table 14: Retail electricity prices by bio-energy scenario, 2015 CAD/GJ, including GST

Bio-energy scenario	Customer	2015	2020	2025	2030	2035	2040	2045	2050
Likely	Residential/Transport	106	116	116	116	116	116	116	116
Likely	Commercial/Freight	87	95	95	95	95	95	95	95
Likely	Industrial	73	80	80	80	80	80	80	80
Optimistic	Residential/Transport	106	116	117	117	124	129	134	139
Optimistic	Commercial/Freight	87	95	96	97	104	109	114	119
Optimistic	Industrial	73	80	81	81	89	94	99	104

Ethanol price

Ethanol prices used in the analysis are shown in Table 15. While the "Likely" scenario price assumes that fuel demand will drive corn prices to $250/tonne corn (like past peak prices), the "Optimistic" scenario assumes that the feedstock price remains at a more typical recent price or $130/tonne corn.

Table 15: Retail ethanol prices, by bio-energy scenario, 2015 CAD/L, including GST, excluding carbon tax

Bio-energy scenario	2015	2020	2025	2030	2035	2040	2045	2050
Likely	1.00	1.29	1.29	1.29	1.29	1.29	1.29	1.29
Optimistic	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99

Biodiesel price

Biodiesel prices are shown in Table 16. The "Likely" scenario price assumes that fuel demand will drive canola oil prices to $1000/tonne corn (like past peak prices). The "Optimistic" scenario assumes that the feedstock price remains at a more typical recent price or $820/tonne canola oil.

Table 16: Retail biodiesel prices, by bio-energy scenario, 2015 CAD/L, including GST, excluding carbon tax

Bio-energy scenario	2015	2020	2025	2030	2035	2040	2045	2050
Likely	1.56	1.72	1.72	1.72	1.72	1.72	1.72	1.72
Optimistic	1.56	1.55	1.55	1.55	1.55	1.55	1.55	1.55

Renewable gasoline and diesel

Renewable gasoline and diesel prices are shown in Table 17. The "Optimistic" scenario price is based on the estimated cost for a production facility once the fuels are commercialized[11] (i.e. capital costs are not for a first of its kind plant) and assumes a feedstock cost for ligno-cellulosic material of $80/bone dry tonne, consistent with delivered wood waste.

Table 17: Retail drop-in renewable gasoline and diesel prices, by bio-energy scenario, 2015 CAD/L, including GST, excluding carbon tax

Bio-energy scenario	2015	2020	2025	2030	2035	2040	2045	2050
Likely	1.86	1.85	1.85	1.85	1.85	1.85	1.85	1.85
Optimistic	1.56	1.55	1.55	1.55	1.55	1.55	1.55	1.55

Plug-in electric vehicle costs

The high cost scenario assumes battery costs fall to $125/kwh by 2029. E.g. a 150 km range BEV costs $4,200 more than a conventional vehicle in 2029. The low-cost scenario assumes battery costs fall to $100/kwh by 2030. E.g. a 150 km range BEV costs $3,300 more than a conventional vehicle in 2024. Non-financial costs, e.g. lack of familiarity or lack of supply still exist but decline as sales increase.

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[11] Jones, S., Pimphan, M., Snowden-Swan, L., Padmaperuma, A., Tan, E., Dutta, A., Jacobson, J., Cafferty, K., 2013, Process Design and Economics for the Conversion of Ligno-Cellulosic biomass to Hydrocarbon Fuels, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Idaho National Laboratory.

3. Results

This section begins with the energy, emissions and technology market share results for the RCS + greater efficiency scenario, with "likely" bio-energy assumptions, labelled in short "P2_pess_bio". Recall that this scenario also includes more optimistic assumptions regarding electrification: lower electricity prices in the long-run (after 2020, where prices only rise due to inflation), and lower cost plug-in electricity vehicles (lowest cost is based on battery cost falling to $100/kWh by 2024).

We use P2_pess_bio as the primary scenario in this report because it is most consistent with the expectations that low-cost bio-energy will be limited and widespread adoption would lead to elevated supply costs and that City policies will result in additional energy efficiency as they drive a switch to renewable energy. However, these are expectations and a low-level of bio-energy adoption in this scenario could result in lower bio-energy prices. Given the uncertainty in expectations and because this analysis does not automatically link bio-energy consumption with price (i.e. prices are fixed external assumptions), the choice to use P2_pess_bio as the primary scenario does indicate that it is more probable.

The results of the P2_pess_bio scenario explain many aspects of the forecast that are common across all scenarios. Most insights derived from these results will hold true regardless of the uncertainty in policy and bio-energy potential. In the second half of the results section, we present the sensitivity analysis across these uncertainties, highlighting key differences and similarities amongst the four scenarios.

This section also includes a cost analysis for archetypal households and businesses. This analysis illustrates hypothetical examples of the cost of achieving the RCS target on citizens of Vancouver, indicating specific costs and benefits that are not evident when looking at the average cost impacts. The results section concludes with a brief comparison to the 2015 Vancouver energy consumption forecast, also produced by Navius.

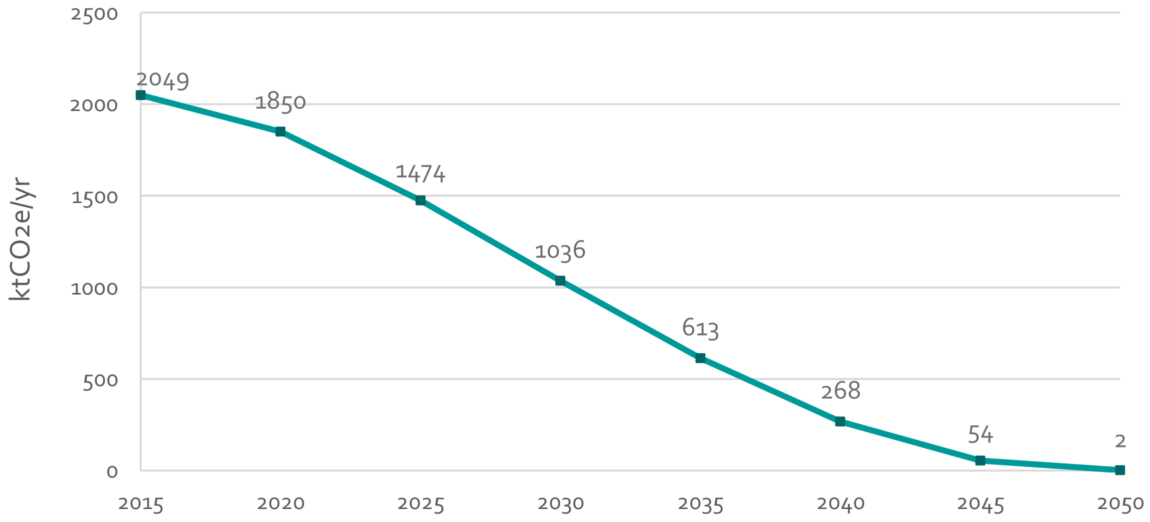
3.1. Renewable city strategy + greater energy efficiency scenario results

This section presents city-wide results for the RCS + greater efficiency scenario with "likely" bio-energy assumptions (P2_pess_bio). Specifically, we show direct GHG emissions, energy consumption by fuel, per capita energy consumption and GHG emissions, renewable fuel shares, and city-wide energy related expenditures to 2050. Second, this section presents detailed sector-level results. For buildings, this includes energy consumption by fuel and end-use, the status of buildings with regards to zero-emissions performance (i.e. building ZEB status) and the market share of space-heating equipment. Results are shown separately for residential buildings and commercial/institutional buildings. For transportation, results include energy consumption by fuel as well as transportation by mode and technology. Transportation results are also disaggregated into personal transport and freight transport.

City-wide results

Vancouver's simulated direct GHG emissions in 2015, excluding those from solid and liquid waste, are 2049 kt (Figure 1). This differs from a comparable value from the City's inventory by 186 kt (8% lower), largely due to the difficulty in calibrating commercial and institutional energy consumption (see Appendix A: Model calibration results for more details). By 2030, GHG emissions are roughly 50% lower than in 2015. This steep decline has several causes. First, even without new policies to achieve the RCS goal, the average energy efficiency of buildings and transportation will decline, putting downward pressure on GHG emissions. Second, by 2030, approximately a third of existing buildings have been either replaced with zero-emissions buildings, or retrofitted to become a zero-emissions building (including the downtown district energy fuel switch). Third, in that year, half of private vehicles on the road would qualify as "zero-emissions". Finally, roughly one fifth of the remaining fossil fuel consumption has been substituted with renewable fuels. GHG emissions decline to almost 0 by 2050 due to reduced energy consumption and substitution or remaining fossil energy with electricity and bio-energy.

Figure 1: City of Vancouver direct GHG emissions, excluding waste GHG



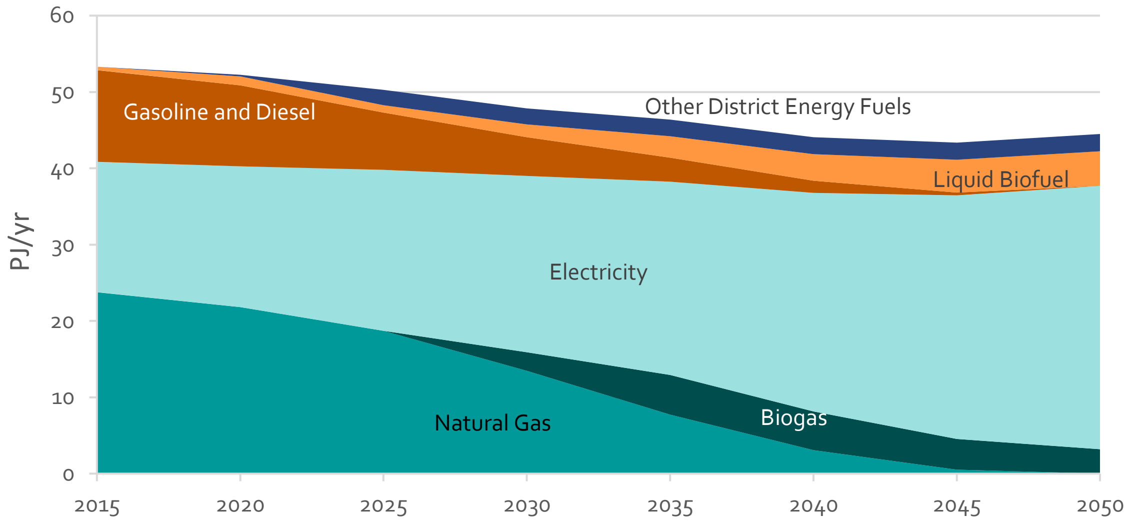
The direct GHG emissions shown in Figure 1 only account for those GHG released within the City, excluding any biologically derived carbon dioxide (i.e. from bio-energy). However, even renewable energy consumption or energy that results in no direct GHG emissions will produce GHG emissions on a lifecycle basis. This is true for liquid biofuels that have upstream GHG emissions related to agricultural land-use and fuel production. Electricity is a lesser concern in Vancouver given that the current British Columbian grid is almost entirely powered by renewable electricity generation with policy commitments from the provincial government to keep it that way. In either case, consideration of these upstream GHG emissions is outside the scope of this study.

This trend in energy consumption is shown in Figure 2. Despite a growing population and economy, technological change, energy policy, and city planning (e.g. the achieving transportation 2040 target) energy consumption decouples from growth. Between 2015 and 2050, city-wide energy consumption per capita, including industrial, falls from 85 GJ/person/yr to 43 GJ/person/yr, a decline of 50% (Table 18). The remaining natural gas consumption is substituted for electricity, biogas and other district energy fuels because of the district energy strategy, the zero-emissions building policy, the retrofit policy and ultimately, the renewable fuel requirement that requires gaseous fuels to be 100% renewable by 2050.

Similarly, the remaining gasoline and diesel are substituted for electricity and liquid biofuel, which include biodiesel and ethanol as well as drop-in renewable gasoline and diesel that have no blending constraints (i.e. they are completely vehicle compatible and can account for 100% of the fuel volume).

Table 19 shows the resulting renewable fuel share, as well as the percent of gaseous fuel that biogas and the percent of liquid fuel that is biofuel.

Figure 2: City of Vancouver energy consumption by fuel, PJ/yr



"District Energy Fuels" include biomass and waste heat

Table 18: Per capita energy and GHG emissions

	2015	2020	2025	2030	2035	2040	2045	2050
Energy (GJ/yr/person)	85	76	65	57	52	46	42	41
GHG (t/yr/person)	3.3	2.7	1.9	1.2	0.7	0.3	0.1	0.0

Table 19: Renewable energy share of City energy consumption

	2015	2020	2025	2030	2035	2040	2045	2050
Total % renewable	33%	38%	48%	61%	77%	89%	98%	100%
Biogas % of gaseous fuel	0%	0%	0%	15%	40%	62%	88%	100%
Biofuel % of liquid fuel	4%	10%	11%	25%	47%	69%	92%	100%

Despite the change in energy consumption, and the underlying technological changes, energy expenditures, carbon costs and energy-related capital expenditures (expressed in un-discounted annual terms) do not change substantially between 2015 and 2020 Figure 3. Note that the retirement of capital stock as well as new demand for capital stock can result in different capital expenditures per year during the forecast, producing the minor peaks in capital costs in 2025 and 2045 in the figure. Also note that capital costs do not include all capital costs, only those directly related to energy consumption. For example, capital costs for the residential sector do not include land-costs or the cost flooring or roofing, unless those components affect energy consumption (e.g. a solar roof).

On average, energy expenditures decline, and are 26% lower in 2050 than in 2015. The reduction in energy expenditures is not as great as the reduction in total energy consumption; energy prices rise during the study period and the low-GHG fuels used in 2050 are generally more costly than conventional fuels (e.g. biogas is costlier than fossil-based natural gas).

While energy expenditures fall relative to 2015, capital expenditures increase; energy policy and technological change drive this substitution of energy for capital. For example, our technology cost assumptions mean an electric vehicle, even at its lowest cost, is still roughly $3,500 more expensive than a conventional vehicle. Again, this is based on a battery pack costs falling to $100/kWh by 2025, net of other vehicle components that are present or absent such as motors, electronics and transmissions, based on the method used by Axsen and Kurani (2013).[12] Nonetheless, the reduced energy expenditure associated with PEVs offsets the higher capital costs. This is consistent with the findings of the UBS investment bank through its 2017 teardown of the Chevrolet Bolt electric Car. This process led UBS to conclude that total cost of ownership (TCO) over a typical three-year lease contract for electric and conventional cars would be equal in the North American Market by 2025.[13] In other words, the fuel cost savings of the PEV would offset its higher capital costs (i.e. more depreciation and interest) during the lease period.

Carbon costs are a minor component of energy-related expenditures. Furthermore, because the British Columbian carbon tax is revenue neutral, on average, consumers and firms incur no net-carbon cost. Carbon costs decline in step with the City's GHG emissions.

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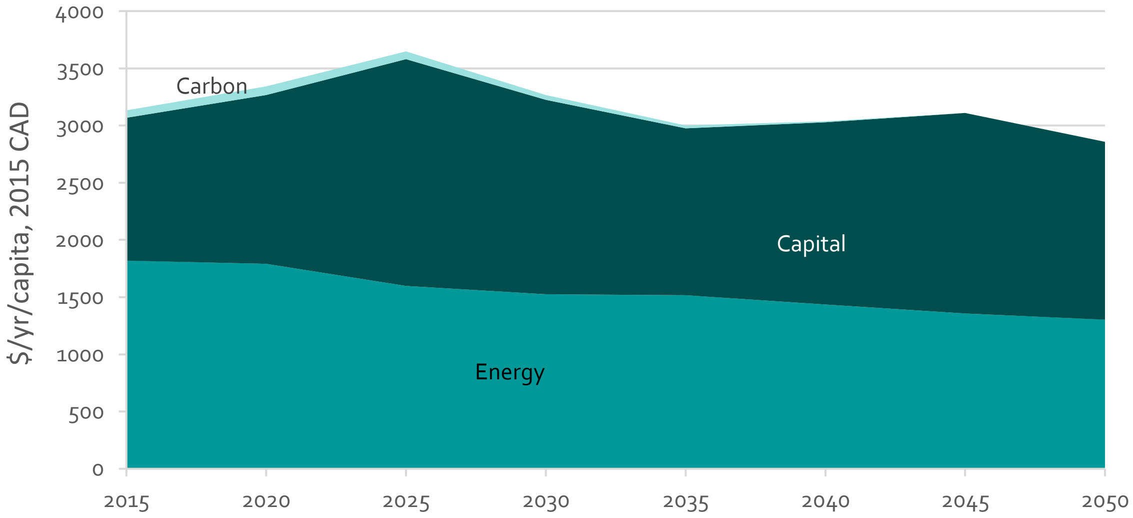
[12] Axsen, J., & Kurani, K., 2013, *Hybrid, plug-in hybrid, or electric—What do car buyers want? Energy Policy, 61, 532-543*, available from www.sciencedirect.com

[13] UBS Global Research, 2017, *UBS Evidence Lab Electric Car Teardown – Disruption Ahead*

Figure 3: Energy related costs, expressed in annual terms per capita, un-discounted



The energy-related costs can be compared with a continuation of the status quo (i.e. 2015 annual costs) expressed in net-present terms by discounting future costs. We discount the future using two discount rates: 25%, to reflect the way a consumer implicitly values the future (i.e. not much compared to the present), and 2%, to reflect social costs. With a 25% discount rate, the net-present value (NPV) of energy related expenditures from 2015 to 2050 is 5%, greater than a continuation of the status quo. At a 2% discount rate, where future energy expenditure savings have a greater value, the policies only increase the NPV of energy related expenditures by 3% compared to a continuation of the status quo. However, it would be incorrect to say that on average, achieving the RCS target increases costs. Energy prices are expected to rise, rather than remain at the status quo, so it is likely that achieving the RCS has no impact on, or would reduce, the costs accounted for in this analysis relative to a scenario with no further policy action.

Detailed results: Buildings

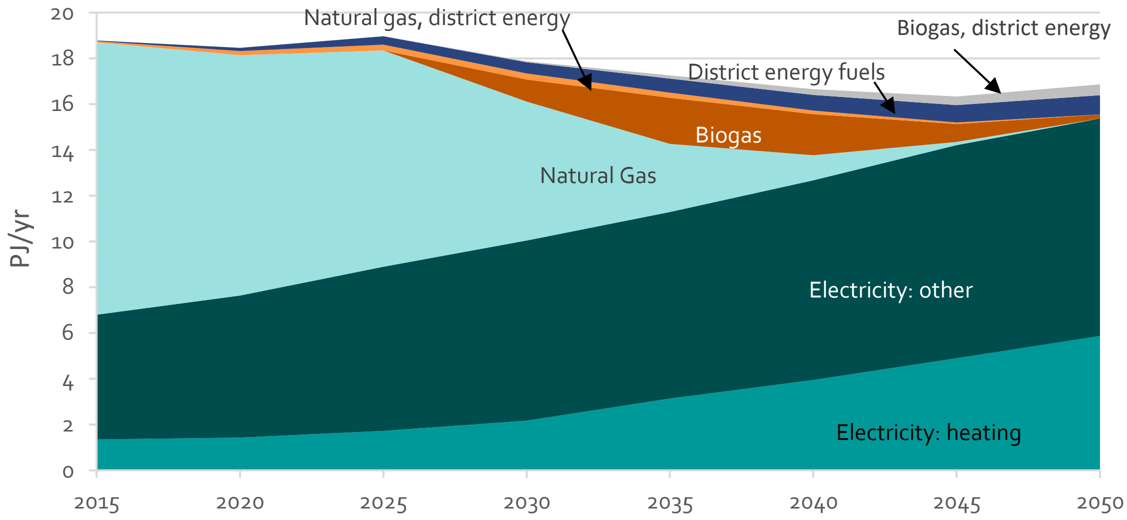
This section provides more detailed results for residential commercial/institutional buildings. Figure 4 shows the residential fuel mix by end-use and Figure 5 shows the same data for commercial/institutional buildings. Note that building energy consumption excludes electricity use for plug-in electric vehicles, even if these would add to plug-loads.

The trend in building energy consumption is like the overall trend in city-wide energy consumption: Energy consumption declines even as the total floor area increases. Electricity consumption increases, due to increased electric space- and water-heating, but also due to increased loads from other end-uses, especially from plug-loads (i.e. electronics, minor appliances etc.) serving a growing population and economy.

The zero-emissions building policy and retrofit policy, as well as the high price of biogas in this scenario (i.e. commodity cost of $28/GJ) ultimately drive gaseous fuel consumption close to zero by 2050. Until then, for example in 2030, biogas is a substitute for fossil-natural gas used for space and water heating in buildings that are not yet “zero-emissions”. By the end of the forecast, almost all of the biogas consumption in buildings is for peak energy production in district energy systems.

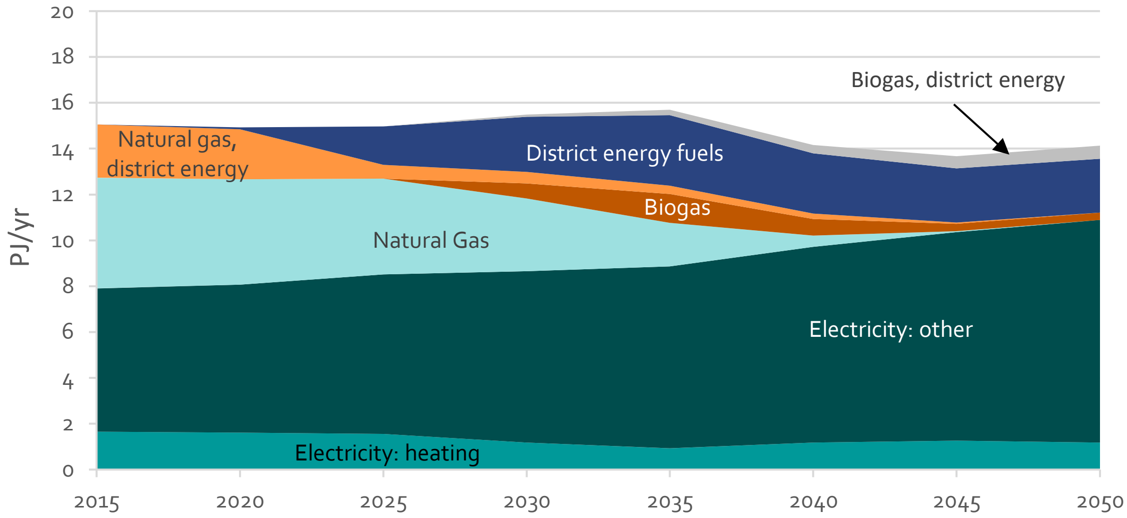
There is some uncertainty in whether there would be any biogas consumption in this scenario in 2050. First, the only technology option in the model for peak district-energy production is gas-fired boiler. However, it is possible that these would be replaced with some other option if it were represented in the analysis, such as a resistance electric boiler, or increased baseload capacity with thermal energy storage. Second, gas consumption drops so low in Vancouver that one might expect the cost of the distribution system to dominate an already high retail energy price, further incentivizing a switch away from gas consumption. This outcome would depend on what happens to gas consumption outside of Vancouver. Also, given that most gas consumption comes from a handful of large consumers (i.e. district energy systems), other financially viable distribution systems could be possible, such as delivery of liquefied gas by truck.

Figure 4: Residential energy consumption by fuel and end-use



"District Energy Fuels" include biomass and waste heat. Electricity used for district energy is classified under “Electricity: Heating” because the quantity is too small to display as its own area.

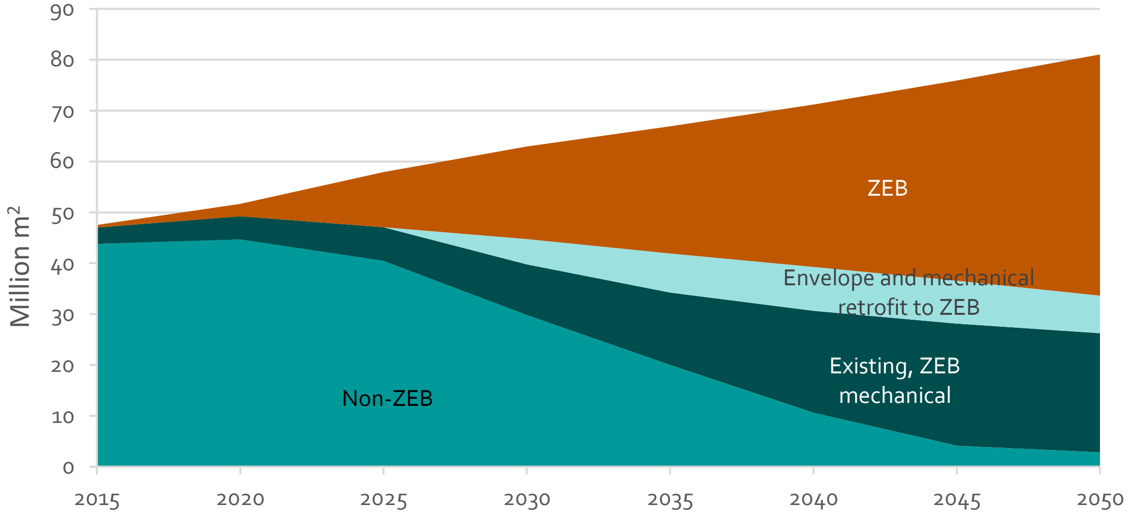
Figure 5: Commercial/institutional energy consumption by fuel and end-use



"District Energy Fuels" include biomass and waste heat. Electricity used for district energy is classified under "Electricity: Heating" because the quantity is too small to display as its own area.

The reduction in building energy consumption and the switch to electrical space heating is driven by the construction of new zero-emissions buildings (ZEBs) and the retrofit of existing buildings to be ZEBs (Figure 6). Again, policies in this scenario require buildings to retrofit to ZEBs when undergoing a major renovation (e.g. one that modifies the building structure, envelope, cladding, roof or window). The policy requires replacing outgoing gas-fired heating equipment with electric heating equipment. For older buildings, it also requires retrofitting the envelope to reduce thermal energy demand intensity (TEDI, i.e. the amount of useful heat they require for space heating each year). By 2050, almost 60% of building floor area is a new ZEB or an existing building connected to a low-GHG district energy system. Most of the remaining 40% of floor area is contained in buildings where just the mechanical systems (i.e. heating equipment) or both the building envelope and the mechanical systems have been retrofitted to achieve ZEB status, albeit with a higher TEDI than many of the new buildings.

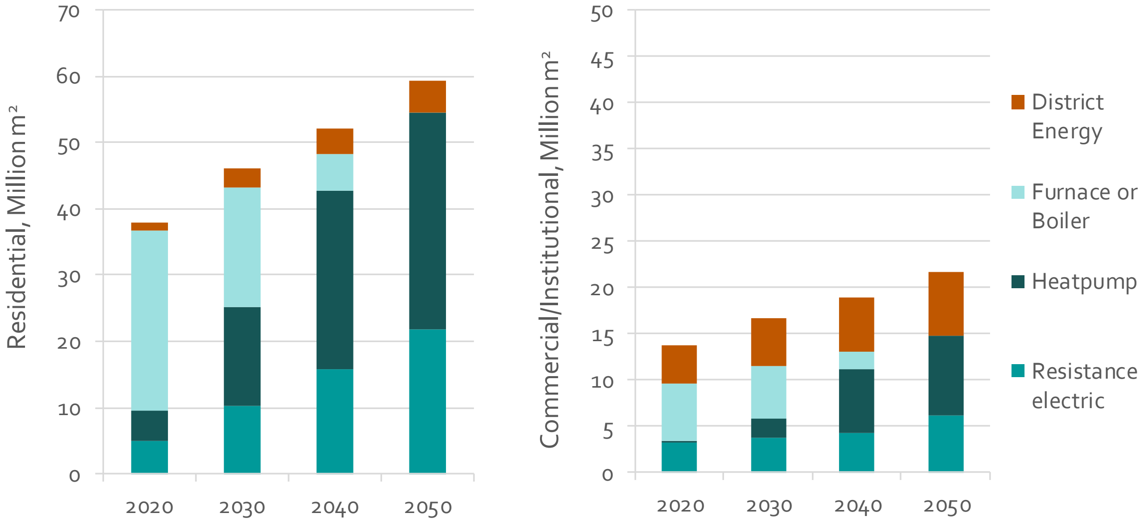
Figure 6: Residential, commercial and institutional floor area by zero-emissions building (ZEB) status



Note that buildings connected to a low-GHG district energy system counts as ZEB floor area. This includes the existing downtown district energy system *after* the fuel switch to biomass. ZEB status buildings are those built with high-performance envelopes (e.g. net-zero energy ready or passive house) and electric heating systems.

The electrical space heating in the ZEBs is largely supplied by heat-pumps (Figure 7). However, existing buildings with resistance electric heating remain. Furthermore, there is some growth in resistance electric heating, especially in the residential sector, where after 2025, homes that will achieve the Passive House target of less than 15 kWh/m²/yr may still use resistance electric space-heating.

Figure 7: Space-heating equipment market share, measured by floor area served



Detailed results: Transportation

Transportation energy consumption also declines despite a growing population and economy. Like city-wide energy consumption, there is substantial electrification of the sector with residual fossil fuels ultimately replaced by biofuels (Figure 8). Furthermore, transit and active transportation grow as a share of total trips (Figure 9). Note that personal transportation includes the energy consumed by transit vehicles, which accounts for almost all the electricity used for transportation in 2015. By 2050, energy consumption for personal transportation is evenly split between electricity and biofuel, the latter being used in plug-in hybrids as well as hybrid vehicles. Freight energy consumption, also sees some electrification of commercial vehicles by 2050 (i.e. light truck freight operating solely in an urban environment), while heavy freight uses consumer biofuel (e.g. rail, heavy truck servicing the port or other warehousing and transport depots).

The results show no gaseous fuel consumed for transportation. Gas engine trucks are available in the model, but only as liquefied natural gas (LNG) fueled heavy trucks, so the results will not show the potential for compressed natural vehicles (e.g. transit vehicles, garbage trucks, shorter range trucks). Furthermore, the LNG trucks are currently constrained by non-financial costs in the simulation. These costs reflect the current lack of LNG engine suppliers in North America as of 2014[14], but they are dynamic and will decline as the market share of LNG trucks increases. However, given the high cost of biogas in this scenario, this barrier is not overcome and the simulation does not show any adoption of LNG trucks.

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[14] www.trucknews.com/products/cummins-to-pause-development-of-15l-nat-gas-engine-leaving-void-in-marketplace/

www.trucknews.com/transportation/volvo-revises-lng-engine-plans/1003060322/

Figure 8: Transportation energy consumption by fuel

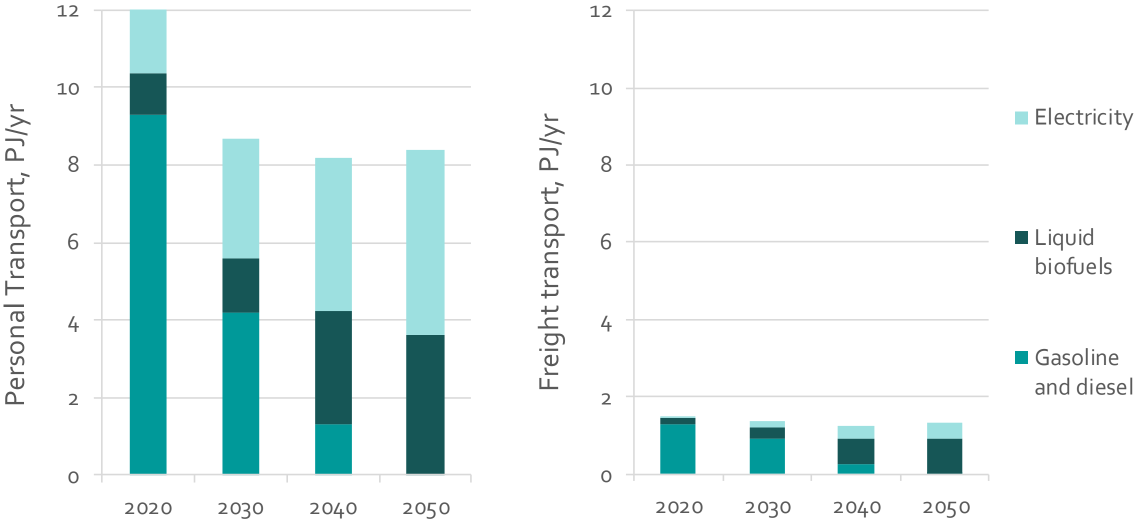
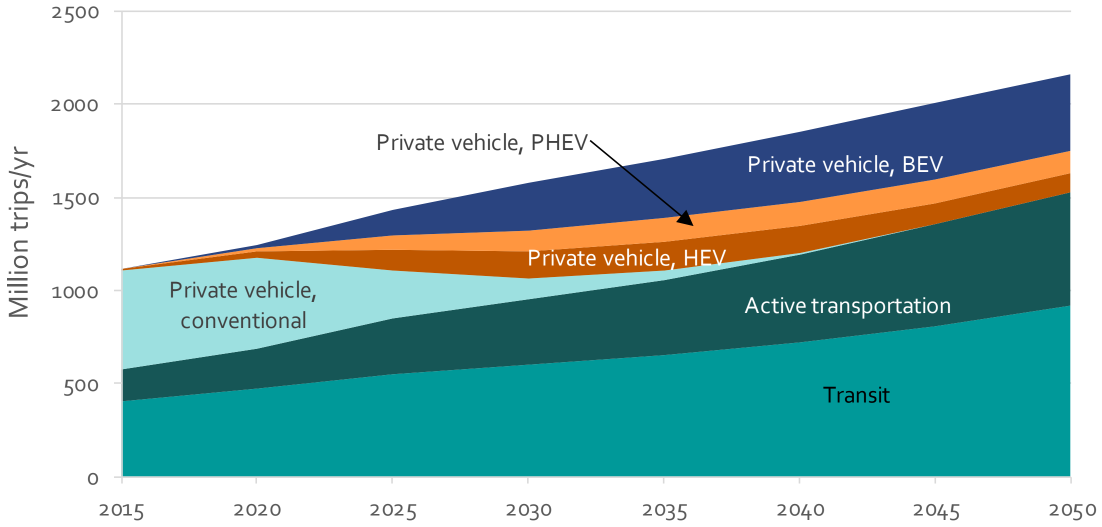


Figure 9 further explains the trend in personal transportation energy consumption by showing trips broken down by transportation mode and vehicle technology. First, this scenario assumes the City uses measures such as densification, congestion charges and improved transit and cycling infrastructure to achieve and surpass the transportation 2040 goal or reducing trips by private vehicle to roughly one third of the total by 2040. While the total number of trips grows in step with population, trips by private vehicle and vehicle kilometers travelled each year remains constant from 2015 to 2050, mitigating an increase in energy consumption. Second, federal vehicle emissions standard requires that after 2025, that new light-duty vehicles are, on average, as efficient as current hybrid electric vehicles. This further increases the energy efficiency of personal transportation. Finally, the falling cost of both battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs) combined with the rising cost of liquid fuel and the ongoing zero-emissions vehicle incentives, result in substantial adoption of electric vehicles, accounting for 83% of vehicles by 2050. The number of these vehicles rises to roughly 179,000 in 2030 and 263,000 in 2050. These vehicle counts assume a declining rate of vehicle ownership but with constant annual vkm/vehicle. However, with increased use of transit and active transportation, it is also possible that vehicle ownership would see a smaller decline if vkm/vehicle are smaller.

Figure 9: Personal transportation trips by mode and technology

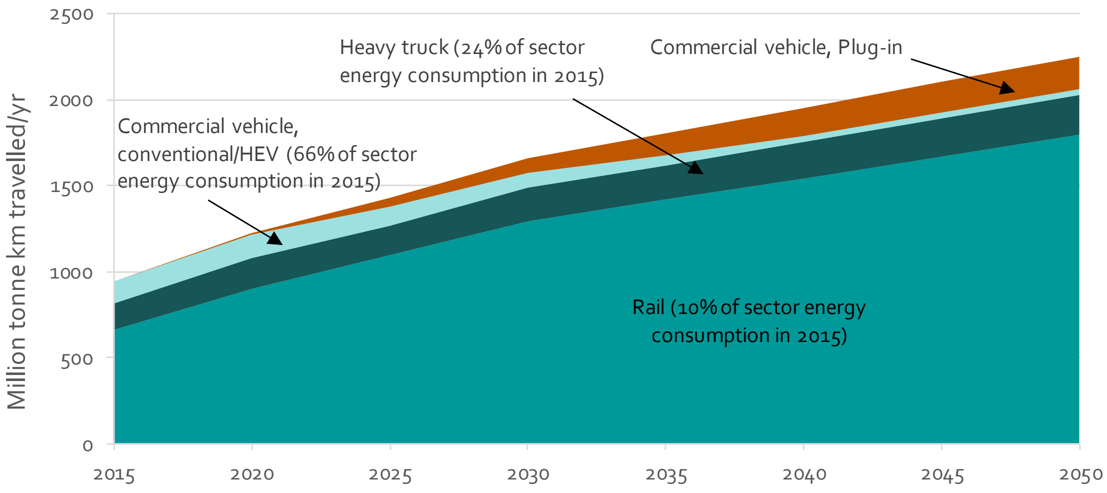


PHEV are plug-in hybrid electric vehicles, BEV are battery electric vehicles and HEV are hybrid vehicles.

Figure 10 show freight transportation activity, tonne km travelled each year, by mode and technology. The trend towards electrification in this sector is a result of the adoption of plug-in commercial vehicles. Note that while activity is dominated by rail and heavy truck transportation, based on the model calibration data (i.e. inferred from Metro Vancouver rail and truck air emissions allocated to Vancouver), these two modes account for only 35% of current freight transportation's energy consumption. In other words, they use substantially less energy per tonne km/travelled than commercial vehicles.

While there is substantial uncertainty in the future activity of rail versus heavy trucks, it is important to remember that these modes are not substitutes for commercial vehicles. The rail and heavy truck bring goods to the port as well as the city, while commercial vehicles move goods around in the city. Despite the uncertainty in rail activity, these results at least indicate that rail transport will be an important determinant to the energy-use of heavy trucks, which is largely outside the jurisdiction of the City; Rail may reduce the non-renewable fuel liability associated with vehicles serving the port.

Figure 10: Freight transportation by mode and technology



3.2. Sensitivity analysis on policy design and bio-energy assumptions

The results in this section highlight how the outcome of achieving the RCS target may or may not differ with different policy design or with different assumptions about the potential for bio-energy. The previous results described the forecast for the RCS +greater efficiency with "likely" bio-energy assumptions (P2_pess_bio) and this section compares that scenario with the three-other scenarios analyzed in this report. These scenarios are:

- **P1_opt_bio**: The RCS scenario, with policies designed to reduce non-renewable energy consumption in the City but not specifically targeting enhanced energy efficiency and mode shifting. This scenario has optimistic bio-energy assumptions, most notably that the commodity price of biogas does not surpass $15/GJ, electricity prices rise gradually in real terms, and the cost of electric vehicles is somewhat higher than assumed in the central policy scenario, with the lowest cost occurring around 2030 rather than 2025.
- **P1_pess_bio**: The same policies as in the previous scenario, but with the same bio-energy assumptions as in the central policy scenario described in detail in section 3.1, most notably that the commodity price for biogas reaches $28/GJ, electricity prices remain constant in real terms after 2018, and the electric vehicles reach their lowest cost before 2025
- **P2_opt_bio**: The RCS scenario with an additional policy focus on increasing energy efficiency and mode shifting, but with the optimistic set of bio-energy assumptions.

Figure 11 shows the total energy consumption, and the energy consumption from electricity, biogas, and liquid biofuel for all four scenarios. Figure 12 provides additional results that explain the similarities and differences in Figure 11.

Total energy consumption

As expected the policy scenarios with a greater focus on energy efficiency result in lower total energy consumption (i.e. in Figure 11, energy consumption P2 scenarios is lower than in the equivalent P1 scenarios). This is largely a consequence of greater mode shift to transit and active transportation (Figure 12 panel A), and retrofits of existing building envelopes to reduce space heating requirements (Figure 12 panel B).

Less optimistic bio-energy assumptions, those in the "likely" bio-energy scenario, also result in lower total energy consumption (i.e. in Figure 11, energy consumption of a "pess_bio" scenario is lower than in the equivalent opt_bio scenario), largely due to greater adoption of plug-in vehicles in the (Figure 12 panel A). Space heating equipment is mostly the same across all scenarios (Figure 12 panel C) and building ZEB status does not differ as a function of bioenergy's potential and cost.

The portion of total energy consumption that is renewable (including electricity), is relatively constant between the scenarios rising from roughly 33% in 2015 to 62% in 2030 and then almost 100% in 2050. While the type of renewable energy used varies (e.g. biogas vs. electricity), the overall proportion is largely a function of policies that are the same across all scenarios, such as the low-carbon fuel regulation.

Electricity consumption

Electricity consumption is somewhat sensitive to policy design and the potential for bio-energy with "likely" bio-energy assumptions resulting in more electricity consumption. Most of this difference is attributable to industrial energy use, where a higher biogas price increases the sector's electricity consumption by 2 PJ/yr in 2050 (Figure 12 panel D), roughly 65% of the difference in electricity consumption between what the results show for an optimistic bio-energy future and a pessimistic one. The remainder of the difference comes from increased adoption of electric vehicles with the pessimistic. As expected, a greater policy focus on energy efficiency and mode shifting result in less electricity consumption.

Biogas consumption

Biogas consumption tends to move in opposition to electricity consumption. Lower biogas costs result in more biogas consumption. However, by 2050, 85% of the difference in biogas consumption between low- and high- cost biogas scenarios comes from industry where electricity is used in place of biogas to generate process heat and steam if the biogas price is high. There is substantial uncertainty in this result. Industrial energy consumption in Vancouver is not well understood and consequently, it is represented quite generically in the model; there could be other means of producing heat and steam that are not represented that would make industrial biogas and electricity consumption less sensitive to those respective energy prices. For example, low temperature processes (e.g. some food and drink manufacturing) could use heat pumps, or there could be an opportunity to use solid bio-energy for process heat. For buildings, the strength of policy on that sector makes its energy consumption less sensitive to energy prices. In all scenarios, biogas consumption peaks in 2030 or 2035 and then declines as both policy and energy prices drive the adoption of electric heating equipment once gas-fired equipment is retired.

Liquid biofuel consumption

Liquid biofuel consumption varies mainly as a function of plug-in vehicle adoption. With greater adoption, for example in response to higher biofuel costs and lower electric vehicle costs, biofuel consumption in 2050 does not surpass 4 PJ/yr, or approximately 33% of current liquid fuel consumption (2015).

Figure 11: Sensitivity analysis, energy results

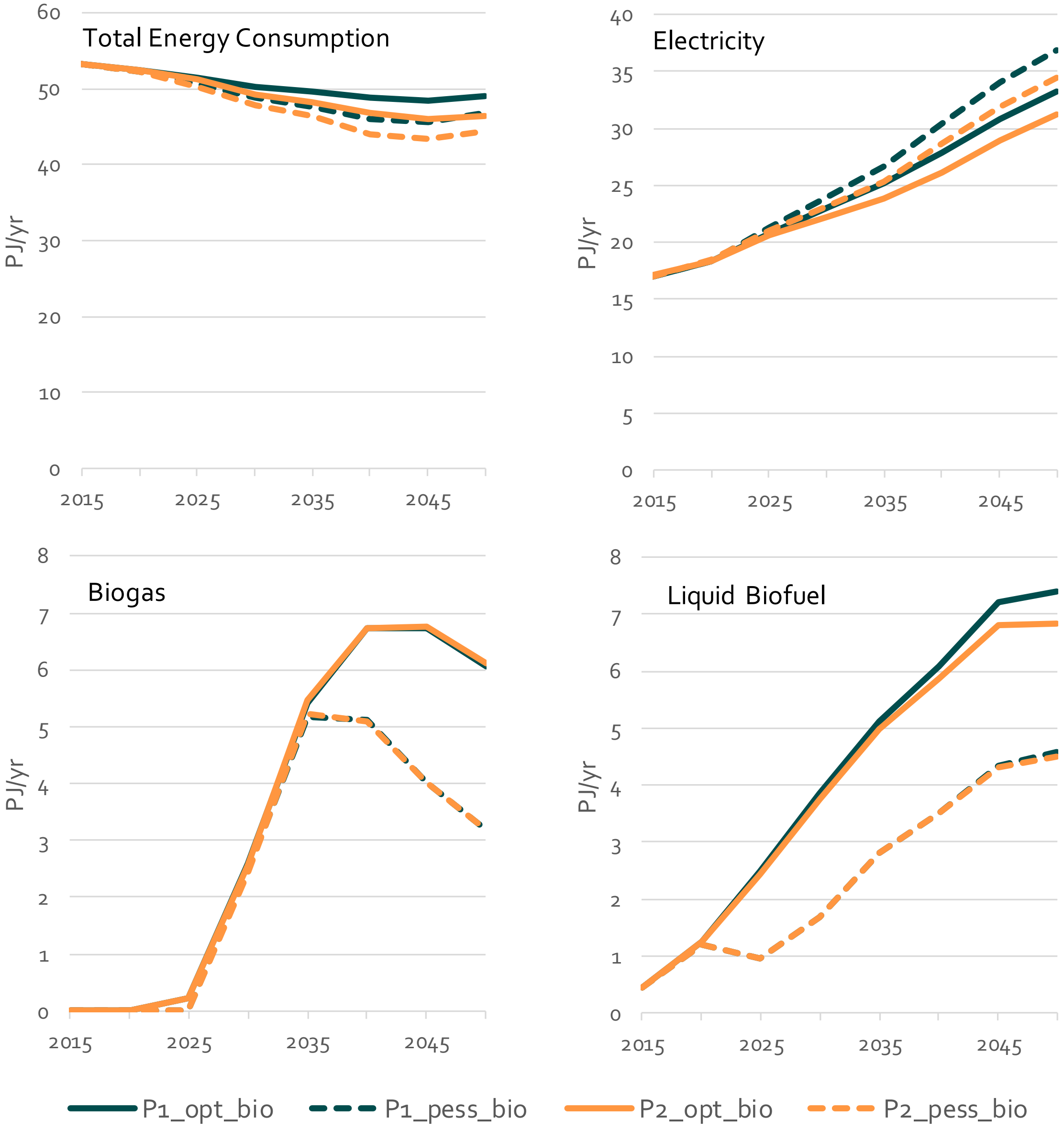


Figure 12: Sensitivity analysis, explanatory results in 2050 showing (**A**) Personal transport trips by mode and technology, (**B**) Zero-emissions building (ZEB) status, (**C**) Building space heating equipment by floor area served, (**D**) Industrial energy consumption by fuel.

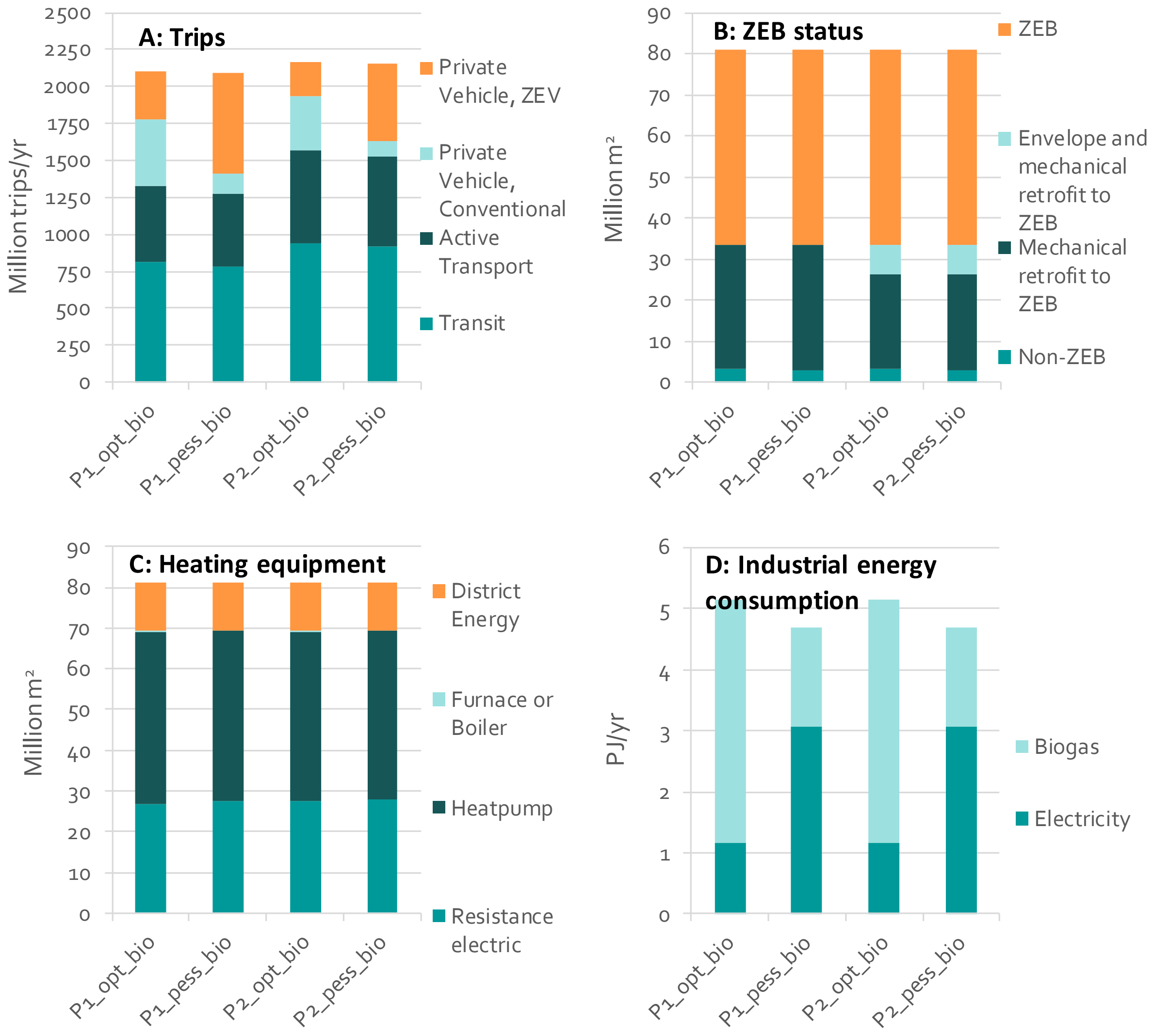
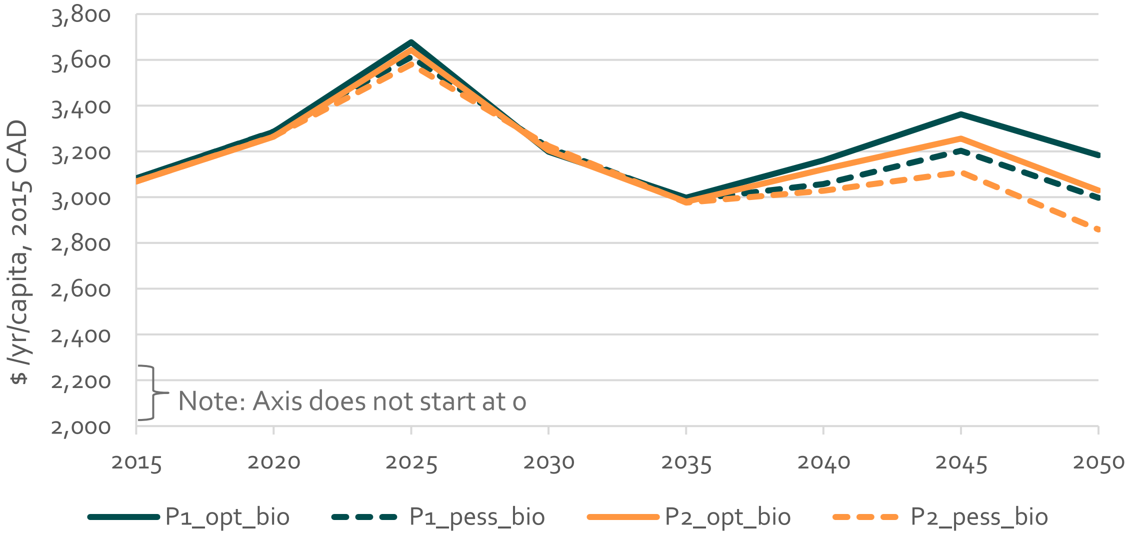


Figure 13 compares the energy expenditures and energy-related capital expenditures in each of the four scenarios. Again, costs are shown in un-discounted per capita costs incurred each year. Also note that the y-axis does not start at 0, accentuating the difference between scenarios.

These costs are slightly sensitive to policy design and bio-energy potential. Expressed in net-present terms, the difference between the most and least costly scenario is $35 (2015 CAD), or 0.5% when using a discount rate implied by typical human behaviour (25%). When using a social discount rate of 2%, the net present value of that difference increases to $1,500 (2015 CAD), or 2%, incurred over 35 years, with a stronger policy focus on energy efficiency and mode shifting resulting in slightly lower costs. Note that these total costs, averaged across the entire population may hide specific costs and benefits. These are illustrated by hypothetical cost analyses for archetypal Vancouver citizens in the next section.

Figure 13: Energy costs and energy-related capital costs, expressed in annual terms per capita, un-discounted



3.3. Archetypal cost analyses

The archetypes for the cost analysis include two households, a commercial truck driver and the owner of a small office building. The archetypes are described below with additional details given in Table 20:

- **Household 1: New MURB.** In the scenario where the RCS target is achieved, this household moves into a new high-efficiency MURB heated with a heat pump in 2020. Water heating is provided by resistance electric heating. In 2025, the household replaces its car with an electric vehicle, driving it 12,000km/yr. In a business-as-usual (BAU) scenario, the household would have moved into a new MURB with lower envelope efficiency, where space and hot water heating is provided by high-efficiency gas-fired equipment. In 2025, when they replace their car, they would buy another high-efficiency conventional vehicle with the same utilization.
- **Household 2: Existing detached home.** This household lives in a detached home built prior to the year 2000. In the scenario where the RCS is achieved, the home undergoes a renovation in which the building envelope is retrofitted to reduce its thermal energy demand intensity (TEDI, GJ/m^2) by 20%. The home continues to use

gas-fired space and water heating. The household owns and uses two vehicles until the year 2035, when we assume that densification and new transit infrastructure allows the household to downsize its fleet to one vehicle. In that same year, the residents buy an electric car and thereafter spend an additional $2,000/yr on transit and car-sharing services. The BAU assumption is that the house is not retrofitted and the household continues to own and operate two conventional vehicles travelling 15,000 km/yr.

- **Commercial truck.** The commercial truck makes deliveries within the city, travelling 20,000km/yr with an average payload of 1.1 tonnes. In the scenario where the RCS is achieved, we assume the truck is replaced with a battery-electric truck after 2030. The BAU assumption is that it is a conventional vehicle for the duration of the study period.
- **Commercial building.** The commercial building is a new office building with an area of 4,000 m^2, in which the building owner also pays for its energy costs. In the scenario where the RCS target is achieved, the building envelope is more efficient and space and water heating are provided by a heat pump. The BAU assumption is that the building has larger heating needs and uses efficient gas-fired equipment.

Table 20 provides additional details on the archetypes. Note that energy costs are defined by scenario in section 2. Technology lifetimes are also considered in this analysis, the most important of which is the 15-year life for all vehicles. Therefore, this analysis captures the depreciation cost of vehicle ownership, which is most relevant for the household in existing detached home, where there is a difference in the number of vehicles owned between the RCS and BAU assumptions.

Table 20: Key archetypal cost analysis assumptions

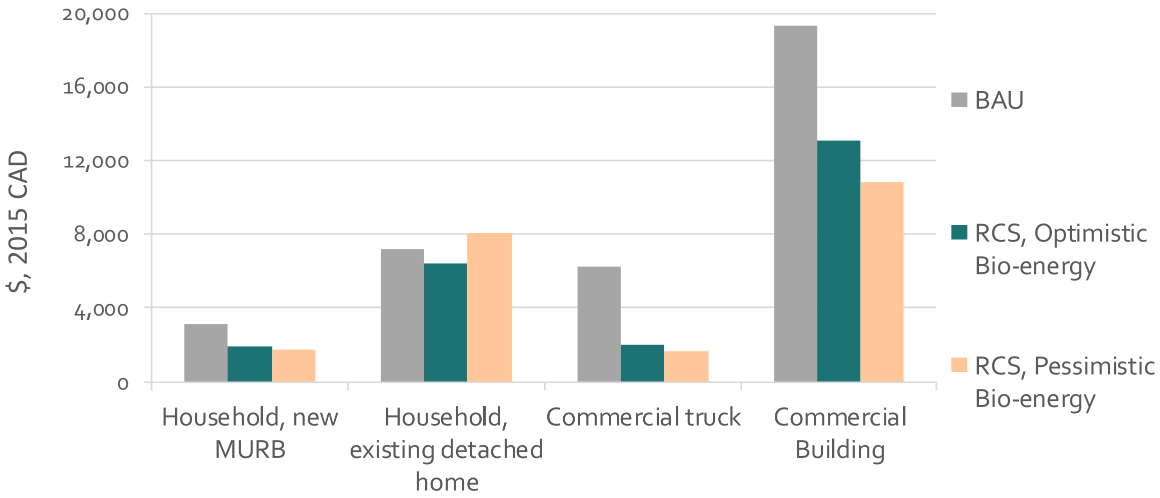
	Household 1: New MURB		Household 2: Existing Detached Home		Commercial Truck		Commercial Building	
	RCS scenario	BAU scenario	RCS scenario	BAU scenario	RCS scenario	BAU scenario	RCS scenario	BAU scenario
Building:								
Floor area (m^2)	130	130	202	202	n/a	n/a	4,000	4,000
Building TEDI (GJ/m^2/yr)	0.05	0.15	0.39 after 2025	0.49	n/a	n/a	0.10	0.75
Envelope capital cost premium	$10,300	-	$10,000 (extra retrofit cost in 2025)	-	n/a	n/a	$84,000	-

	Household 1: New MURB		Household 2: Existing Detached Home		Commercial Truck		Commercial Building	
	RCS scenario	BAU scenario	RCS scenario	BAU scenario	RCS scenario	BAU scenario	RCS scenario	BAU scenario
Space heating equipment	Heat pump	Gas furnace	Gas furnace	Gas furnace	n/a	n/a	Heat pump	Gas furnace
Space heating capital cost premium	$3,500	-	-	-	n/a	n/a	$32,000	-
GJ/GJ heat	0.40	1.1	1.1	1.1	n/a	n/a	0.25	1.1
Vehicle:								
vkm/yr per vehicle	12,000	12,000	15,000	15,000	20,000	20,000	n/a	n/a
# vehicles	1	1	1 after 2035	2	1	1	n/a	n/a
Fuel	Elec. after 2025	Gasoline	Elec. after 2035	Gasoline	Elec. after 2030	Gasoline	n/a	n/a
MJ/km	0.63	2.43	0.63	2.43	2.6	6.5	n/a	n/a
Electric vehicle cost premium*	$2.9k to $3.9k	-	$2.9k to $3.9k	-	$8.5k to $10.5k	-	n/a	n/a

*Recall that electric vehicle costs vary by scenario: they are lower in the bio-energy pessimistic scenarios and higher in the bio-energy optimistic scenarios. The cost premium is applied in the year the electric vehicle is first purchased, and in all subsequent years when it is replaced.

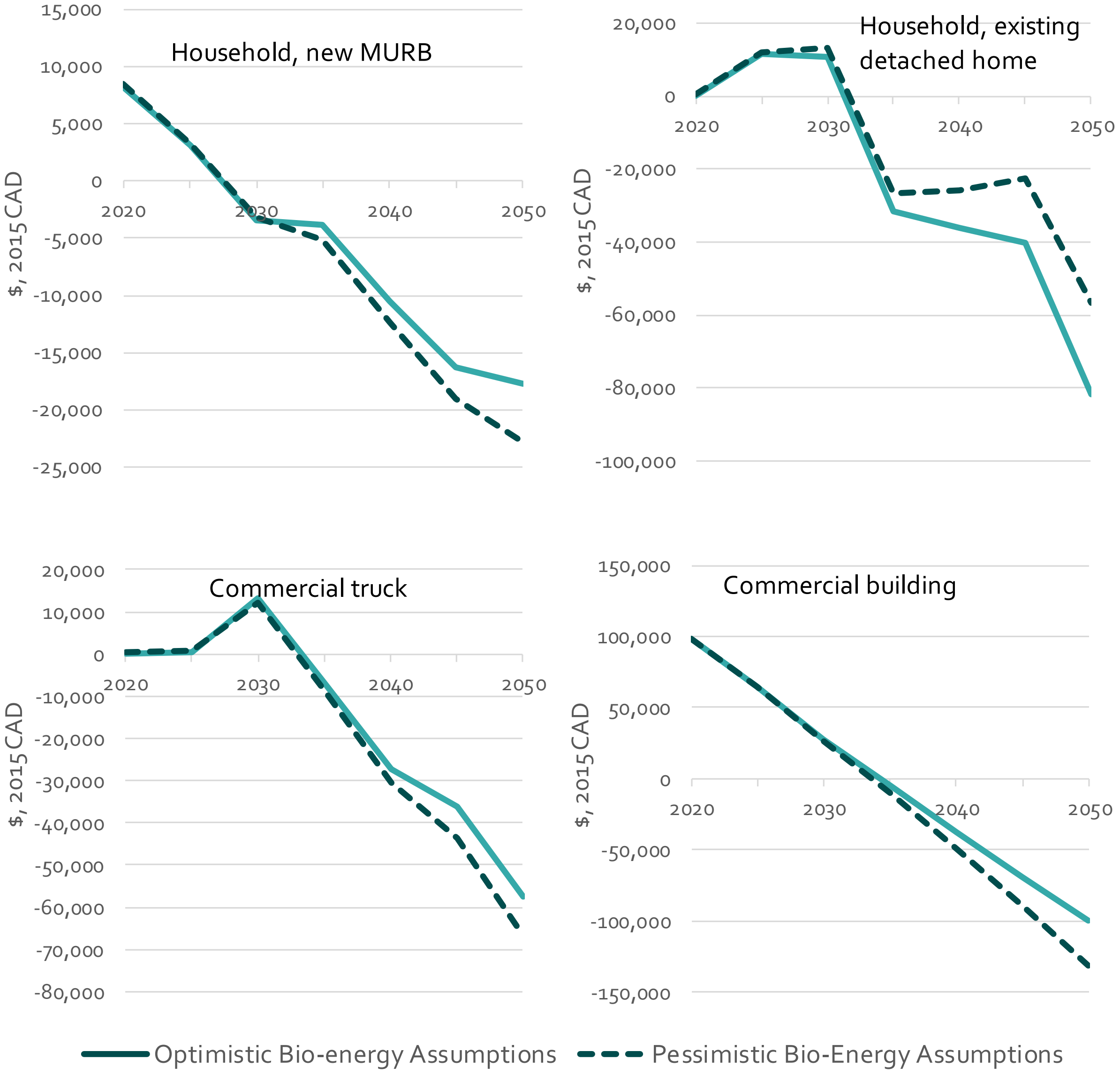
Figure 14 shows the annual energy costs for each archetype relative to the BAU assumptions in 2050. In general, achieving the RCS scenario reduces the annual energy cost for all archetypes except the household in the existing detached home: with pessimistic bio-energy assumptions, this household uses a substantial amount of bio-gas, costing over $30/GJ. Conversely, for the other three archetypes, the energy costs are lower with the pessimistic bio-energy assumptions because that scenario also has somewhat lower electricity prices.

Figure 14: Annual energy costs in 2050, by archetype with the optimistic and pessimistic bio-energy assumptions



Reducing energy costs involves spending more upfront. Figure 15 shows cumulative energy-related capital costs and energy costs. The costs are shown for the RCS scenario relative to BAU in each year, where positive values indicate that costs are higher than BAU, while negative values indicate a savings. All archetypes incur higher capital costs which are then compensated for with reduced energy costs over time. By 2050, all archetypes see a net-savings regardless of the energy price assumptions. The trend in cumulative costs for the household in the existing detached home is worth noting. Despite rising home heating costs, cumulative costs drop sharply in 2035 and again in 2050 because the household purchases only one vehicle rather than two in each instance.

Figure 15: Cumulative energy expenditures and energy-related capital cost in the RCS scenario relative to BAU, 2020-2050, undiscounted.



Additional details on the cumulative costs for the household in the existing detached home are shown in Figure 16. The values are calculated using the pessimistic bio-energy assumptions, showing that because of rising price of natural gas (i.e. due to greater biogas content) the household spends an additional $20,000 on home heating over the 30 years from 2020 to 2050 (2015 CAD, undiscounted). However, the net-cost to the household is negative due to the significant amount of money saved by owning only one vehicle from 2035 onward, rather than two. The costs include an additional $2,000/yr spent on transit or car-sharing services, but they do not include savings due to reduced auto insurance, so the estimate is conservative. While this is a hypothetical example, and a similar household might still choose to own two vehicles, it does illustrate the financial benefit of designing a city and transportation system that reduces car ownership.

Figure 16: Additional detail on the cumulative costs for the household in the existing detached home, shown in 2050 relative to BAU, undiscounted (pessimistic bio-energy assumptions)

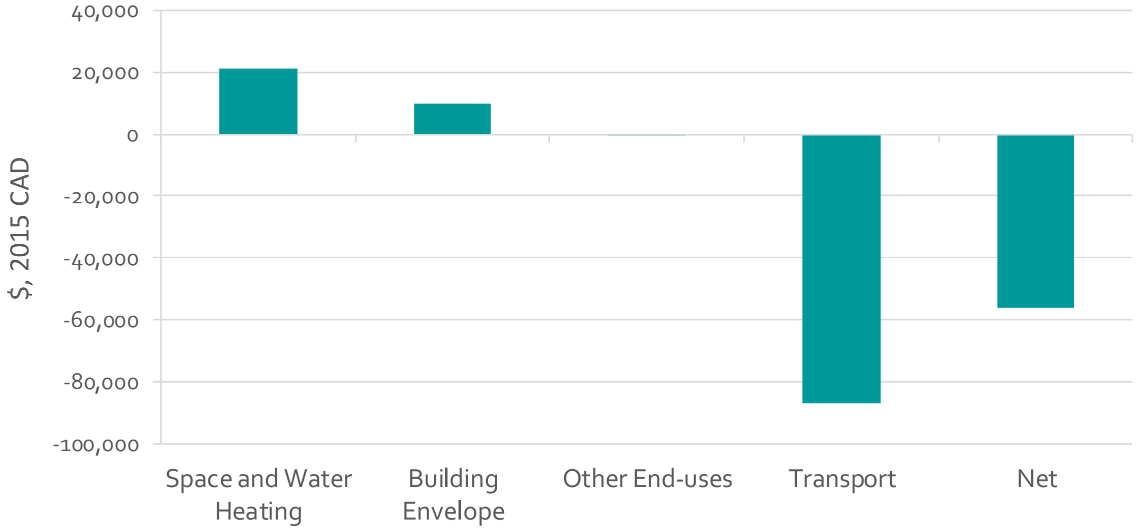
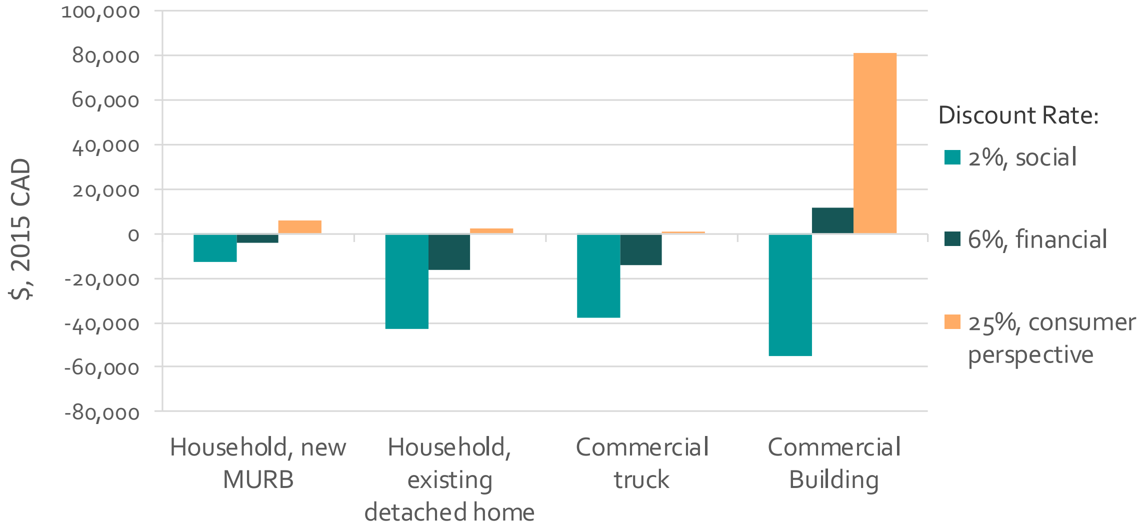


Figure 17 shows the discounted present value of the cumulative costs shown in Figure 15. The costs are discounted according to three perspectives, with discount rates that are notionally appropriate for each perspective:

- A consumer's perspective, which reflects how most people implicitly value current savings over future savings (discount rate= 25%). This perspective shows that for all archetypes, the changes brought about by policies increase a consumer's perceived costs by forcing them to make current investments to get future returns.
- A financial perspective, where the discount rate reflects the cost of capital, or the opportunity cost of not investing that capital in some other low-risk investment. This perspective shows that for all but the commercial building, the changes resulting from RCS policies create a financial savings. The commercial building would yield a financial saving at a slightly lower discount rate, e.g. 5%. Alternatively, this archetype might improve the investment by spending less on the building envelope to take greater advantage of the high-efficiency heat pump used for heating.
- Finally, the social perspective, which favours investments that benefit future society (discount rate =2%), shows that all the changes that might occur if the RCS is achieved can yield a net-present reduction in social costs.

The commercial building archetype shows the greatest variation across the three discounting perspectives because the improvements included in this example are capital intensive, but also long-lived, offering large cumulative energy savings.

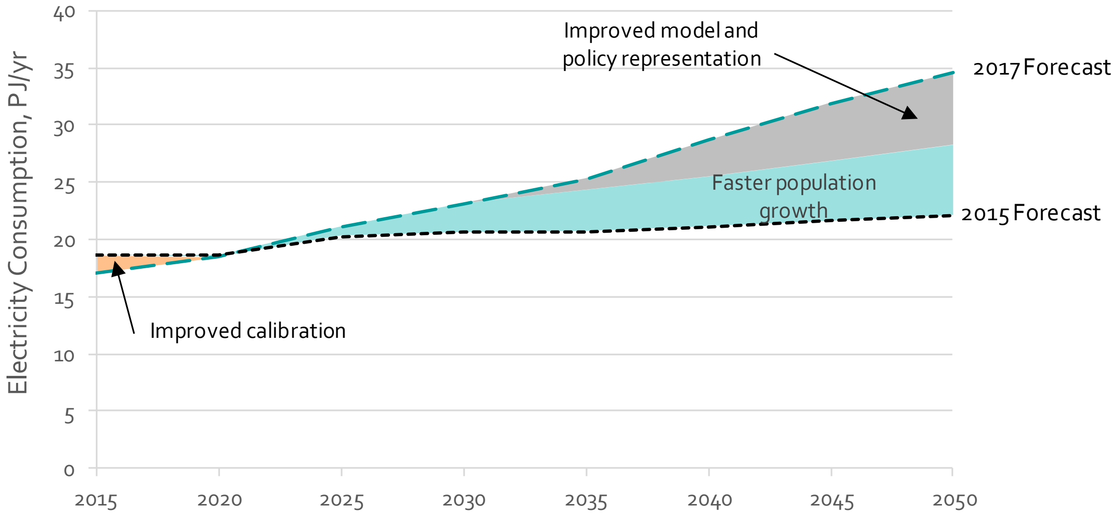
Figure 17: Net present value of cumulative costs in the RCS scenario relative to BAU according to three perspectives on discount rate. Negative values indicate a savings in the RCS scenario relative to BAU.



3.4. Comparison to past results

Compared to the 2015 forecast, the current forecast (made in 2017) shows greater overall energy consumption, with greater growth in electricity consumption. The 2017 forecast shows that electricity consumption in 2050 will be 12.5 PJ/yr greater than the 2015 forecast (Figure 18). Half of this difference is caused by assuming more rapid population growth, at an average of 1.6%/yr in this forecast vs. 0.07%/yr in the 2015 forecast. Also, the 2017 forecast is made with an improved model that has a more realistic representation of buildings and building related energy policy. For example, the policies in the current forecast do not require using a heat pump when building envelopes are very efficient. Furthermore, the building shell energy requirements are phased in as per the zero-emissions building plan, which was not previously modelled. The modelling now accounts the time between the permitting and construction of MURBS, which further delays the year in which more efficient building envelopes are required in the 2017 forecast compared to the 2015 forecast. Finally, the current model explicitly includes commercial and heavy-duty vehicles, which add a small amount to the forecasted electricity consumption (+1.5% in 2050). In contrast, electricity consumption in 2015 in the current forecast is lower than in the previous forecast. This is a result of improving the calibration of the model to energy consumption data.

Figure 18: Comparison of Vancouver electricity consumption forecast in 2017 and 2018 (dashed lines). The areas approximate the reasons for the difference between the two forecasts.



4. Discussion and conclusions

4.1. Sensitivity to policy design and bio-energy optimism and pessimism

The results demonstrate that regardless of policy design or bio-energy assumptions, total energy consumption in the City will decline, while electricity consumption is likely to grow. These two metrics are not highly sensitive to the uncertainties tested in this analysis. The policies on the building sector make the quantity and type of energy consumed in the residential, commercial and institutional sectors insensitive to the uncertainties in policy design and bio-energy potential. Consequently, light-duty vehicle choice and industrial energy consumption create the largest variation in the results. Regarding vehicle choice, lower-cost electric vehicles, in the long-run, result in less liquid fuel consumption and more electricity consumption. Similarly, higher-cost biogas will increase industrial electricity consumption, increasing city-wide electricity consumption on the order of 5%.

4.2. Bio-gas consumption in context

Biogas consumption in the RCS scenarios peaks at between 5 and 6.5 PJ/yr between 2030 and 2035, at a wholesale price of $15/GJ and $28/GJ respectively. For context, this quantity is roughly one quarter to one fifth of current natural gas consumption in Vancouver. Unfortunately, there is no publicly available and comprehensive study of biogas supply in British Columbia that we can use to evaluate these results. However, there are several price and quantity estimates that give context to the results and demonstrate that the price assumptions are reasonable.

Currently, FortisBC produces 0.3 PJ/yr of biogas from several landfills and anaerobic digesters[15], and as of January 1st, 2017, it sells biogas at $10.54/GJ.[16] Given the expansion of supply needed to reach this quantity and that Vancouver will not be alone in consuming biogas, it is reasonable to expect that some of that supply would come from smaller and potentially more costly sources of biogas (e.g. smaller scale production at smaller landfills and agricultural sites). For example, the Canadian Gas Association (CGA) estimates that while biogas costs $8/GJ to produce from large sites

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[15] FortisBC, 2017, *Renewable Natural Gas: Our Suppliers*, www.fortisbc.com/NaturalGas/RenewableNaturalGas/OurSppliers/Pages/default.aspx

[16] FortisBC, 2017, *Renewable Natural Gas: Calculate your contribution*, available from www.fortisbc.ca

such as landfills, it could cost between $15 and $20/GJ to produce from smaller landfills and anaerobic digesters.[17] Therefore, the "optimistic" assumption for the biogas price in this analysis, $15/GJ, is reasonable for a situation where the province-wide share of biogas within natural gas is not as high as in Vancouver, and where new supply is available with at cost that approximates the average production cost from of large landfills and anaerobic digesters.

Significantly greater biogas demand could result in higher average biogas productions costs and prices. Hallbar Consulting (2017) estimates up to half of current British Columbian natural gas could be replaced with biogas at a marginal cost of $28/GJ (roughly 90 PJ/yr) by 2035 if emerging biogas technologies are used. These technologies included pyrolysis of forestry or other wood wastes.[18] This estimate does not indicate the shape of the supply curve that leads to this marginal cost, so it is not possible to estimate the average cost of biogas implied by the analysis. Also, the estimate only includes waste material and does not include any use of energy crops. Nonetheless, it shows that our "likely" assumption for biogas price is consistent with a scenario where there is high demand for biogas or where bio-waste is in high demand for other bio-energy end-uses such as transportation or electricity generation.

4.3. Limitations of the analysis

Key limitations and uncertainties in this analysis are that:

- **Energy prices are exogenous** (i.e. external assumptions), so changes in demand (e.g. for biofuel) do not result in changes in price. Similarly, our method does not explicitly model how lower utilization of natural gas-distribution infrastructure could increase the price of natural gas. For example, if gaseous fuel consumption declines substantially, then the cost of the distribution system will be spread over fewer sales, increasing the retail price of that fuel. While this dynamic is not included in the analysis, it is partially addressed with the sensitivity analysis on biogas prices in this report.
- **Some policy impacts are not explicitly simulated.** For example, our representation of the transportation 2040 is based on the expectation that the actions taken to achieve that plan will change the real or perceived costs of private vehicle travel versus transit or active transportation. However, we do not model the specific

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[17] Canadian Gas Association, 2014, *Renewable Natural Gas Technology Roadmap for Canada*, available from www.cga.ca

[18] Hallbar, 2017, *Resource Supply Potential for Renewable Natural Gas in BC*, www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/transportation/renewable-low-carbon-fuels/resource_supply_potential_for_renewable_natural_gas_in_bc_public_version.pdf

policies that will change those costs. Consequently, the results are a good indication of how the transportation 2040 target will change energy consumption and GHG emissions, but they do not represent the impact of currently planned actions. This was a reasonable method because the CIMS model is not spatial and because the City has not yet specified all actions it will take to achieve the targets.

- **Technologies are uncertain.** This analysis includes forecasts of emerging technology costs which can be updated as new and improved information becomes available. Still, the future costs and potential of key technologies, like plug-in vehicles or building retrofits, are uncertain which adds uncertainty to the results. While this uncertainty cannot be eliminated, we have tested its impact on the results in the sensitivity analyses.
- **Industrial activity in the city is poorly understood** and is represented very generically in this analysis, but the analysis shows that industrial energy consumption is most sensitive to uncertainties in energy prices. Despite this uncertainty and sensitivity, industrial energy consumption will remain a minor component of total city energy consumption.
- **Heavy freight activity is difficult to forecast** as it depends on the economic growth of the city as well as the Port of Vancouver. Furthermore, the role of rail versus truck in moving freight is uncertain and not well characterized in the model.
- **Changes in energy use per household are uncertain.** Specifically, we refer to energy used for minor appliances, electronics, and health and recreation devices (e.g. patio heaters, fire pits). Our assumption for the future is calibrated on the past two decades, with a steadily increasing amount of this energy consumption per household: new technology has created new end-uses within the household and may continue to do so. Alternatively, new technology could collapse many end-uses into fewer devices that ultimately use less energy than separate devices (e.g. smart phones replacing cameras, phones, and some computers).

4.4. Risks to achieving the RCS target

This analysis indicates that there are risks to achieving the RCS target. These risks are listed below from greatest to least, informally evaluated based on their probability of occurrence and the degree to which they will reduce the share of renewable energy consumption in 2050:

- **Jurisdiction over liquid fuel mix**, especially for heavy freight (i.e. what is serving the port). The city will have to work with the provincial and federal governments as well as the port to ensure the transition to renewable energy consumption in heavy freight vehicles occurs. Jurisdiction over technology choice and energy consumption for commercial trucks (i.e. delivery within Vancouver) and light-duty vehicles is less of an issue: plug-in technologies are emerging and are expected to become cost competitive, therefore the city could more easily incentivize their use.

- **The downtown district energy fuel switch.** This is a risk because of the amount of energy and number of buildings in question. However, new buildings and retrofit based-policies could still mitigate the impact of the fuel switch not happening, as would increasing the blend of biogas into natural gas.

- **Jurisdiction over gaseous fuel mix.** The city will have to work with provincial and federal governments as well as energy utilities to ensure that a transition to renewable gaseous fuel happens. This is less of a risk than jurisdiction over liquid fuel because the city can largely eliminate gaseous fuel consumption through new building and retrofit policies. Furthermore, if the gaseous fuel does not become 100% renewable, the city can implement additional policies on industry to eliminate gas consumption (e.g. potentially through business licenses or through air permits from Metro Vancouver).

- **Incentivizing private and commercial zero-emissions vehicle ownership.** The city can implement policies to increase the demand of vehicles. However, the measures available to the city are not as direct as they would be for other levels of government. For example, incentives will likely be through preferred parking rates, business licenses, and availability of charging and refueling infrastructure. As well, the city is still limited to implementing policies that increase the demand for these vehicles. It cannot easily affect vehicle supply and if supply is insufficient, this could constrain the effectiveness of demand-based policies. Therefore, the city will need to work with other levels of government to ensure there are sufficient zero-emissions vehicles available.

- **Jurisdiction over building retrofits and feasibility of retrofits.** The city will need to expand its retrofit requirement policy to achieve the results seen in this analysis, or work with other levels of government and energy utilities to achieve similar policy outcomes. As well, there could be issues of technical feasibility for some retrofits, especially switching steam based heating systems to heat pump systems: it is possible, but is most challenging for existing MURBS with gas boilers providing both space and water heating. Nonetheless, the instances where there are technical difficulties for fuel switching will decline as the building stock is gradually replaced over the next 30 years.

- **Costs of renewable energy sources and renewable energy technologies.** If biogas, biofuels and renewable electricity are more expensive than we have assumed, then it will become more difficult to achieve the positive financial cost outcomes shown in this analysis. The same risk arises from higher-cost technologies (e.g. PEVs and heat pumps). However, given the broad range of prices and costs tested in this analysis, it is a small risk.

4.5. Future work

This analysis has tested the impact of several policy approaches in combination with varied assumptions for the future potential of bio-energy. However, further analysis is bound to deliver additional insights. First, the forecast can be updated as new information becomes available to better represent policies, city growth, energy prices and technologies. Second, there are several specific uncertainties and scenarios that could be explored, for example:

- What if energy efficiency efforts are unsuccessful? What does the worst-case energy demand growth look like if efforts on energy efficiency in buildings and transportation fall significantly short of what is forecasted in this analysis?
- What if the city implements a policy package that is less restrictive on buildings? What sort of technology choices do we see if the transition to renewable energy is entirely driven by a carbon price?
- What if there is a policy package focused on maintaining a role for gaseous fuels? This package would have a heavy emphasis on substituting fossil natural gas with biogas and hydrogen in the gas network and less fuel switching to electricity, essentially exploring a step beyond the optimistic bio-energy scenarios.
- What if the price of electricity from a 100% renewable grid is higher than we have assumed?

Appendix A: Model calibration results

To calibrate the CIMS Vancouver model to energy consumption and GHG emission data, we run the model over past years and adjust activity and energy-intensity by end-use until it approximately simulates past data. In the following section, we compare the CIMS results against data and discuss the model calibration and any issues arising from this calibration.

The primary source used for comparison is the City of Vancouver's energy and emissions inventory (labeled CoV Inventory in the figures below). Electricity consumption data in this inventory was originally provided by BC Hydro, and natural gas consumption data was provided by Fortis. We also compare to the Community Energy and Emissions Inventory, produced for 2007 and 2010 by the BC government (labelled CEEI in the figures with data for 2008 and 2009 interpolated). Note that CIMS solves in five year increments (2000, 2005, 2010 etc.) and the results for years in between has been interpolated linearly.

Uncertainty in calibration comes from uncertainty in the data. For example, the CoV inventory and the CEEI do not always agree. Furthermore, energy consumption by sector is not always consistently defined. Energy consumption in multi-unit residential buildings (MURBS) may be defined as either residential or commercial energy consumption depending on the data source. Likewise, some light industrial energy consumption may be classified as commercial energy consumption and vice versa.

In calibrating the model we have done our best to deal with these uncertainties and nuances. Model calibration is never perfect as all models are imperfect representations of reality. The point of calibration is to ensure the model reasonably approximates reality and identify any issues that need to be corrected to ensure that the model's forecast can provide useful insights for current decisions.

4.6. Residential buildings

Figure 19 shows residential electricity consumption, including consumption from MURBS. The model is well calibrated to the data. Current BC Hydro estimates show residential electricity consumption in 2014 at 7.1 PJ/yr, placing the CIMS results between the BC Hydro and CoV inventory values.

Figure 19: Residential electricity consumption

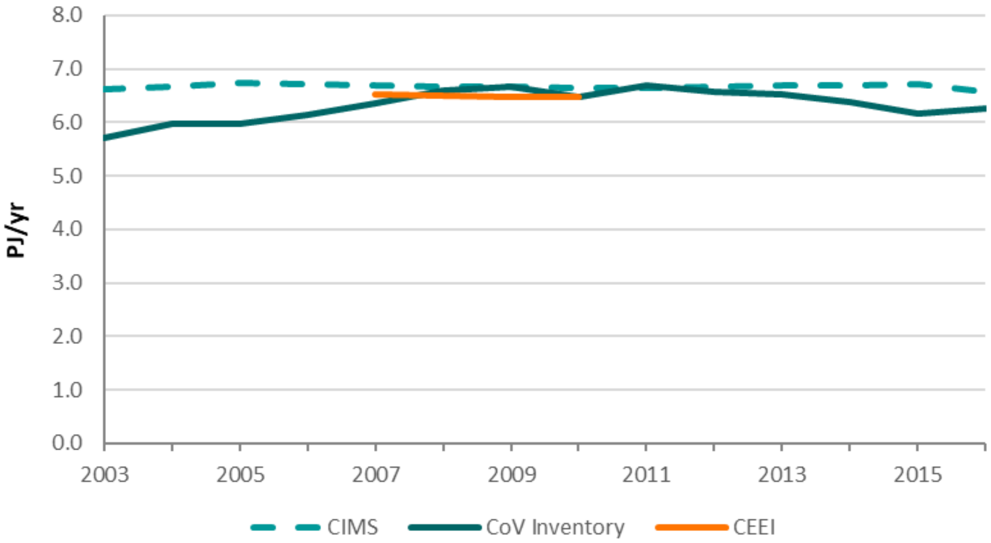
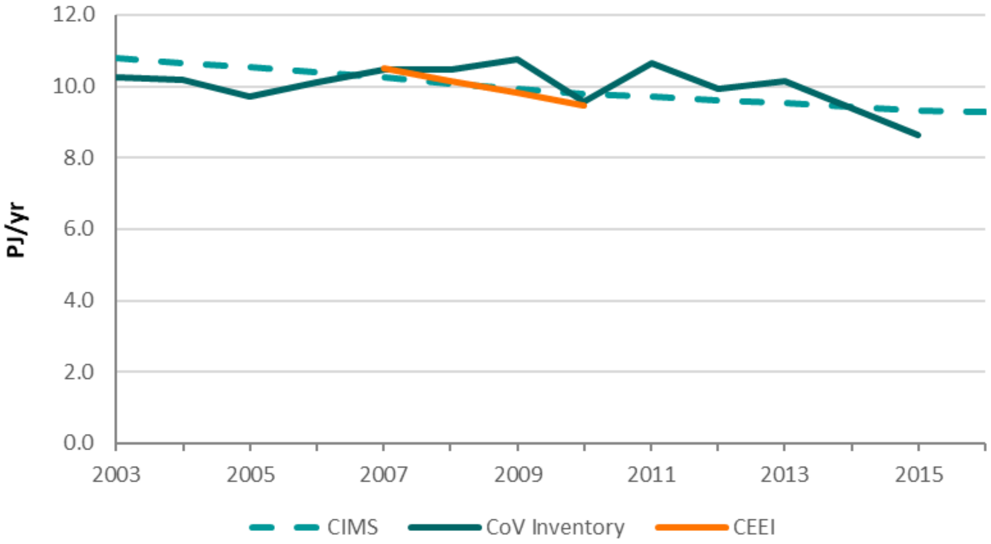


Figure 20 shows residential natural gas consumption. Note that to compare natural gas consumption against the CoV Inventory and the CEEI, we have excluded the quantity consumed in MURBS. The model is well calibrated to historic data and shows a downward trend in natural gas consumption resulting from increased efficiency in gas-fired furnaces and water heaters. This trend exists in the CEEI data and the CoV inventory.

Figure 20: Residential natural gas consumption



4.7. Commercial and institutional buildings

Figure 21 shows electricity consumption in commercial and institutional buildings. For this sector and fuel, the CIMS model produces a substantially different result from the CEEI and the CoV inventory, but is well calibrated with the BC Hydro (BCH) estimate of electricity consumption in Vancouver commercial and institutional buildings. The discrepancy in electricity consumption between data sources is likely a result of different definitions of what is commercial/institutional electricity consumption.

Figure 21: Commercial/institutional electricity consumption

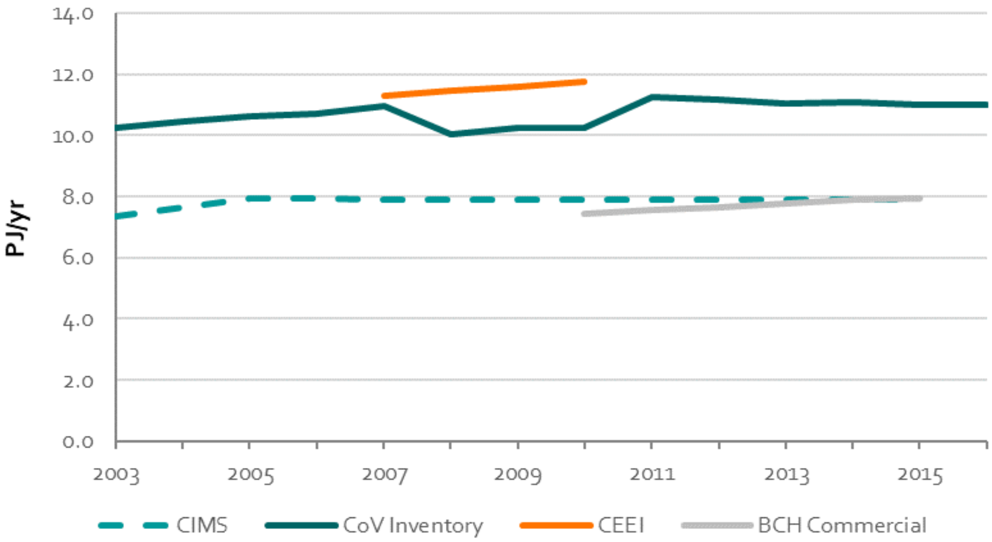
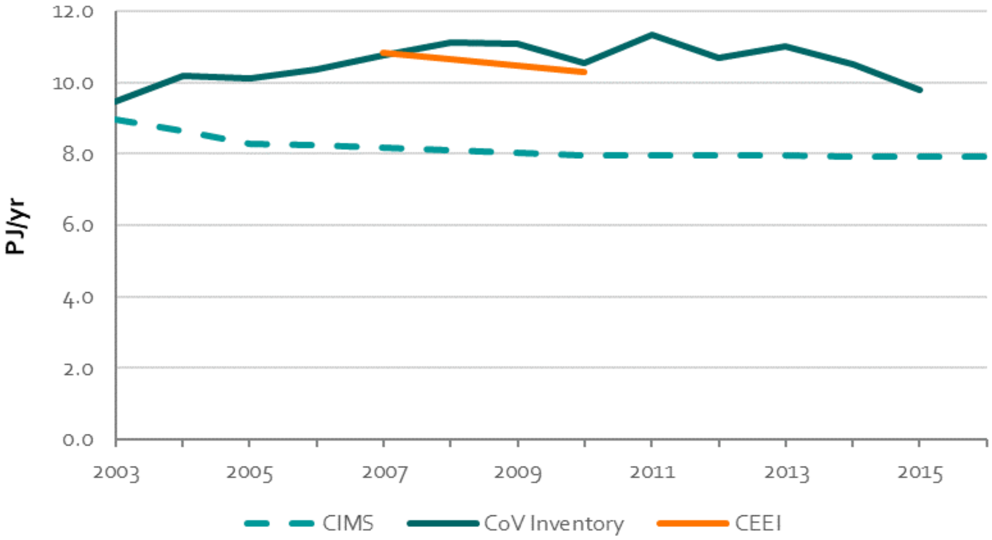


Figure 22 shows natural gas consumption in commercial and institutional buildings, including MURBS and district energy consumption. The model results do not match the data for this fuel either. However, there is some uncertainty as to what is included in the CoV and CEEI data. These likely include small industry, whose energy consumption is accounted for in the CIMS industrial sector. However, with the available data from two separate sources, it is not possible to know for certain how natural gas consumption should be allocated. Commercial and institutional natural gas consumption in the CEEI and CoV inventory is based on Fortis data, while small industrial natural gas consumption in the model is derived from the Metro Vancouver air emissions inventory (for 2010, category: industrial heat attributed to Vancouver) and Metro Vancouver facility air permit data. The sum of the natural gas consumption implied by these two data sources likely double counts some consumption, therefore we should expect the CIMS results to be low for either commercial/institutional consumption or industrial consumption.

Figure 22: Commercial/institutional natural gas consumption



4.8. Transportation

Figure 23 compares the modelled personal travel demand by transportation mode in 2011 with data derived from Shakouri et al. (2015)[19] showing that the model is well calibrated in terms of both total travel demand and travel by mode.

Figure 24 compares gasoline and diesel consumption in light-duty vehicles. The model is calibrated to the CoV inventory. While total energy consumption is somewhat low in the CIMS results, it shows the same slight downward trend that appears in the data. However, the CEEI result is substantially higher. This difference highlights the uncertainty in the transportation fuel consumption data for Vancouver: it is based on regional sales, which are allocated to different municipalities while trying to account for fuel purchased in one location and consumed in another. The assumptions behind the allocation may differ from one inventory to another, leading to different accounts of how much fuel was used in Vancouver.

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[19] H. Shakouri, M. Kandlikar, J. Lerner, M. Namazu, M. Rouhany, B. Clevenger, M. Vasey & H. Dowlatabadi (2015). Greenest City Initiative: Developing Defensible Methodologies for Transportation Targets: Final Report. Institute for Resources Environment & Sustainability, UBC.

Figure 23: Travel demand by mode in 2011

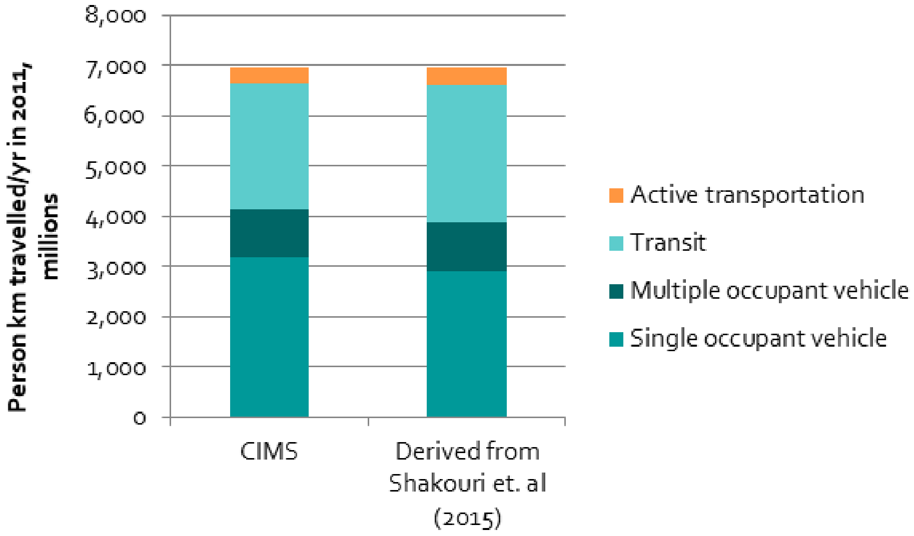

Figure 24: Gasoline and diesel consumption by light-duty vehicles

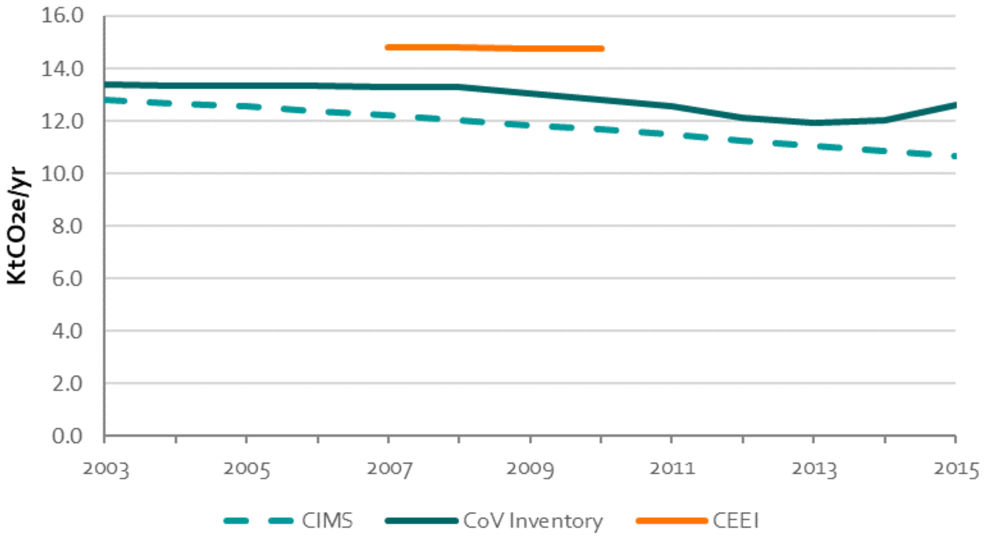

Figure 25 shows GHG emissions resulting from both heavy and light freight trucks. The model is calibrated to on-road freight GHG emissions allocated to Vancouver in the 2010 Metro Vancouver air emissions inventory.[20] When calibrating, we assume light and heavy freight truck energy intensity in Vancouver matches the provincial average in the NRCAN Comprehensive Energy Use Database. Incidentally, this is the same energy intensity implicit within the CEEI. The allocation of emissions to light- versus heavy- freight trucks is based on the CEEI. We then adjusted truck activity to match

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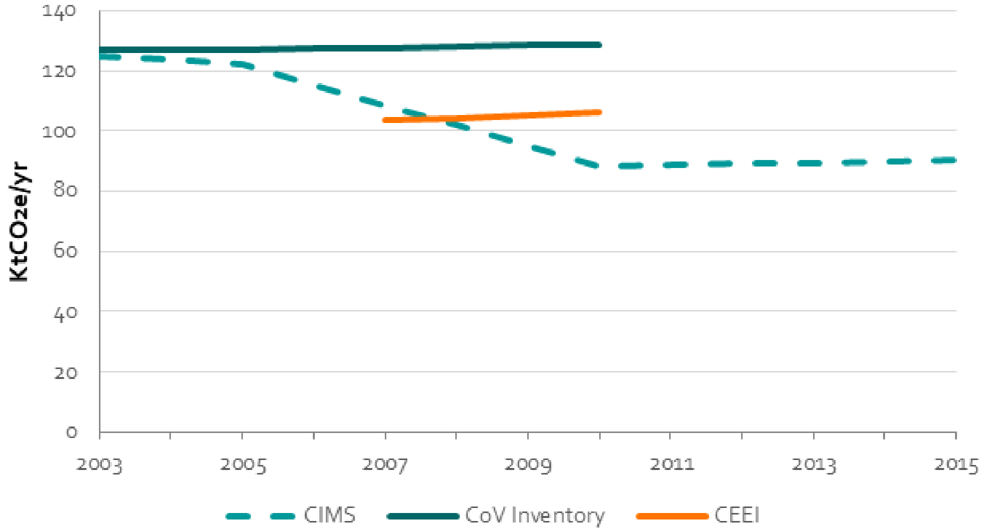
[20] Metro Vancouver (2013). 2010 Lower Fraser Valley Air Emissions Inventory and Forecast and Backcast.

the GHG emissions data. However, the CoV inventory was updated since the model was calibrated leading to the difference in emissions between the CoV inventory and CIMS from 2006 to 2010. Future work will recalibrate this sector.

The Metro Vancouver inventory also allocates some rail GHG emissions to Vancouver (12 kt/yr in 2010). Assuming a typical GHG intensity for rail freight, the Metro Vancouver inventory indicates that there is substantial rail activity, with trains accounting for 70% of the tonnes km travelled through Vancouver in 2010.

Figure 25: On-road Freight Transportation GHG Emissions



4.9. Industry

Figure 26 shows industrial electricity consumption. The data from the CoV inventory is originally from BC Hydro (labelled "large industrial" in the inventory). We have calibrated to the overall trend rather than trying to replicate the irregular consumption during 2008 to 2010. BC Hydro has provided input to this project indicating that industrial electricity consumption in 2014 was roughly 1.5 PJ. The discrepancy between this value and the model results could be the result of year-to year variation in industrial production, but it is likely a matter of how industrial electricity is defined. For example, light manufacturing electricity consumption could be part of commercial electricity consumption in the calibration data we have used.

Figure 26: Industrial Electricity Consumption Calibration

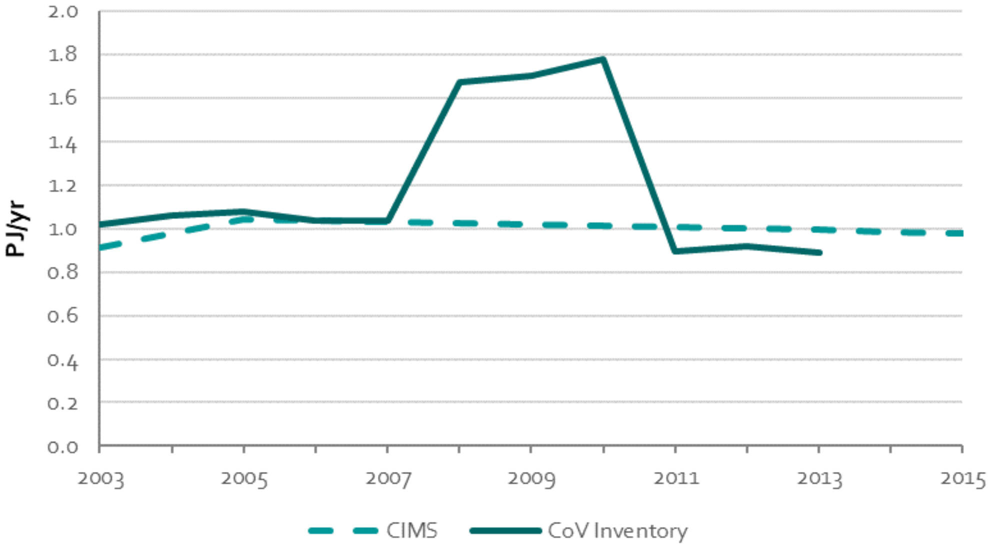


Figure 27 shows the calibration of industrial natural gas consumption. The energy consumption data is based on 2010 GHG emissions data collected for Metro Vancouver air permits, supplemented by government of BC facility GHG emissions reports. Energy consumption for small facilities, also included in the figure, is based on the total industrial natural gas consumption reported by Fortis in the CoV inventory (2013 data for customers of 5,000 GJ), less the natural gas used for district energy (included in commercial/institutional) and less the energy allocated to large facilities using the Metro Vancouver air permit data.

Figure 27: Industrial Natural Gas Consumption Calibration