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A Plan for Climate Leadership in British Columbia

Forecasting the Benefits and Costs of Strengthening British Columbia's Greenhouse Gas Policies

SUBMITTED TO

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Oct 7th, 2015

SUBMITTED BY

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About Us

Navius Research Inc. ("Navius") is a private consulting firm with locations in both Vancouver (head office) and Toronto. Our consultants specialize in analysing government and corporate policies designed to meet environmental goals, with a focus on energy and greenhouse gas emission policy. We also assist clients with stakeholder consultation and engagement processes, and with the development of clear and effective communication strategies and materials. This combination of quantitative forecasting expertise and communication and engagement capabilities allows Navius to provide a complete and integrated solution to clients working on climate change and energy planning.

Our consultants have been active in the energy and climate change field since 1996, and are recognized as some of Canada's leading experts in modeling the environmental and economic impacts of energy and climate policy initiatives. Navius is uniquely qualified to provide insightful and relevant analysis in this field because:

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- We use unique in-house models of the energy-economy system as principal analysis tools
- We have significant experience developing and implementing communication and engagement strategies on energy, climate change, and environmental topics.
- We have a strong network of experts in related fields with whom we work to produce detailed and integrated climate and energy analyses.
- We have gained national and international credibility for producing sound, unbiased analyses for clients from every sector, including all levels of government, industry, labour, the non-profit sector, and academia.

We are proud to have worked with the following clients:

- The provincial governments of British Columbia, Alberta, Saskatchewan, Ontario, Newfoundland and New Brunswick
- The territorial government of the Northwest Territories
- Natural Resources Canada and Environment Canada
- The National Roundtable on the Environment and the Economy
- Utilities and the energy sector: BC Hydro, Manitoba Hydro, the Ontario Power Authority, the Power Workers' Union, the Canadian Gas Association, and Spectra Energy
- Non-Governmental Organizations (NGOs): The David Suzuki Foundation, Pembina Institute, and Carbon Management Canada
- The cities of Vancouver and Edmonton and the Federation of Canadian Municipalities

Executive Summary

This report summarizes a quantitative forecast of how British Columbia's (BC's) economy may respond to policies designed to achieve deep greenhouse gas (GHG) reductions. The results demonstrate that **BC's diverse economy can keep growing while provincial emissions fall by 80% from 2007 levels. However, this outcome requires an early and ongoing commitment to GHG abatement: stringent GHG reduction policies must be implemented in the short-term and maintained for decades thereafter.**

In this scenario, the resource sectors remain important to BC's economy, including the natural gas sector, whose GDP grows at 2% annually. However, the majority of current economic activity as well as more than 70% of future growth occurs in the service sector, a broad category that includes healthcare, education, entertainment, and technical and professional services among other activities. Furthermore, the existing low-GHG electricity system in BC gives mining and some light manufacturing sectors (e.g. food, beverage, machinery, electronic equipment) a competitive advantage in a world where GHG emissions are constrained. These sectors grow faster and create more jobs than under current emissions policies. Finally, reducing GHG emissions in BC is an affordable change for households. Even with rising energy prices and carbon costs, the policies that achieve BC's GHG target also result in households making investments that reduce their energy bill by an average of $1000/yr by 2050.

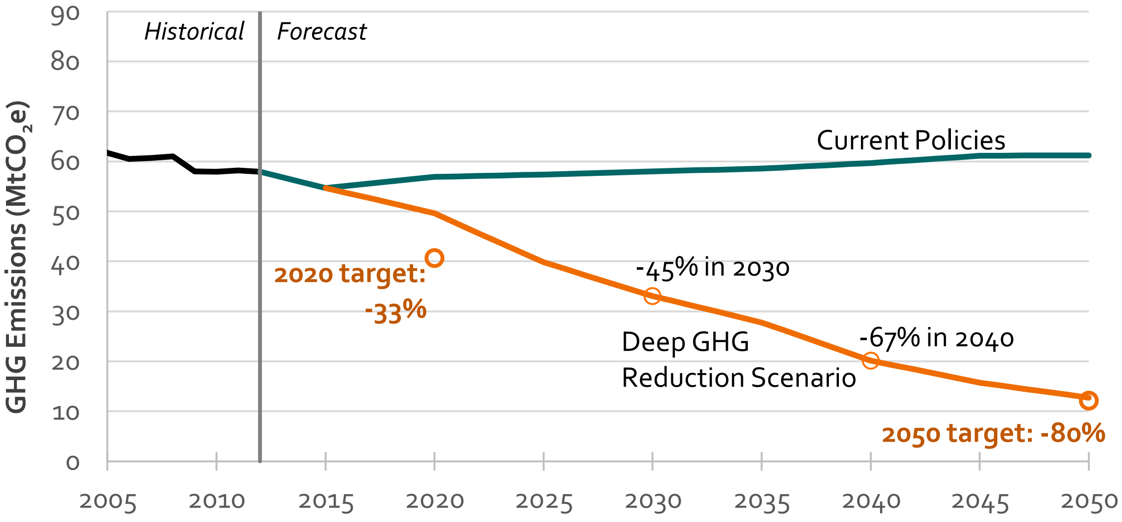
We used two models of BC's energy-economy system to explore the technological and economic impacts of a deep GHG reduction scenario, driven by strengthened climate policy in BC. We forecasted the effect of a strong policy package that is designed to access a broad range of emission reduction opportunities in all sectors of BC's economy between now and 2050. The policies used to achieve this target are more stringent versions of those that already exist in British Columbia, including a larger carbon tax and stronger sector specific regulations on buildings, transportation, energy supply, and industry. The policies are already defined with legislation which will facilitate their implementation and potentially improve their political acceptability. While BC may be a leader in reducing its GHG emissions, we assume other jurisdictions in North America follow suite and implement similarly stringent policies.

Despite the strength of these policies, BC will not achieve its 2020 emission target, a 33% reduction in GHG emissions relative to 2007 levels, equivalent to annual GHG emissions of 40 $MtCO_2e$/yr. Nonetheless, strengthening GHG policies in BC yields a much greater reduction in emissions than current policies. In 2020, emissions are

18% below 2007 levels and the 2020 target is achieved five years later in 2025 (Summary Figure 1).

However, BC can achieve the 2050 target, an 80% reduction in emissions relative to 2007. Over the long-term, the policies in the deep GHG reduction scenario dramatically reduce the province's emissions, which fall to less than13 $MtCO_2e$/yr in 2050, essentially achieving the GHG emission target for that year (Summary Figure 1).

Summary Figure 1: BC's GHG Emission Forecast



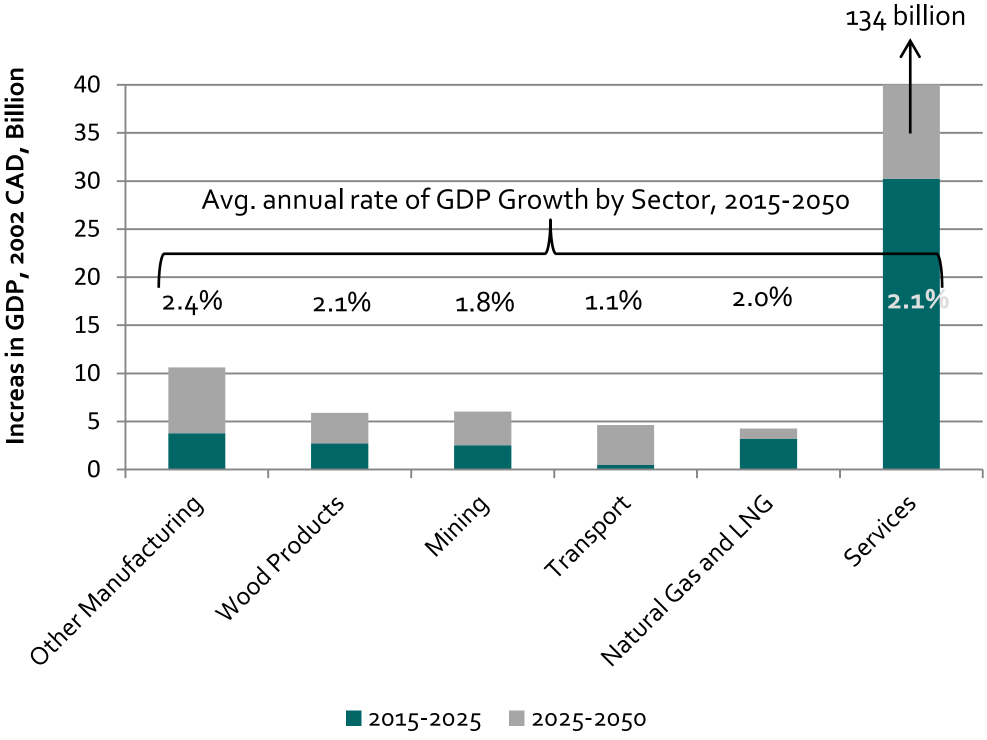
Achieving the emission targets is challenging due BC's growing population and economy. In our scenario, the population and number of households in BC increase at an average rate of 1.1%/yr, growing by 50% between 2015 and 2050. Our economic modelling shows the economy growing by just over 2% annually. Part of this growth relates to our reference assumption for natural gas production and liquefied natural gas (LNG) exports. With only current GHG policies in place, the output of the natural gas sector in BC doubles between 2015 and 2050, growing from 3.7 Bcf/day to 7.4 Bcf/day. This is driven by modest LNG exports reaching 16Mt/yr (equivalent to 2.1 Bcf/day). While our analysis does not attribute this LNG production to specific projects, the capacity is equivalent to two liquefaction trains at a large LNG facility on the North Coast of BC, plus a few other smaller facilities. With strong climate policies, natural gas production grows to 6.4 Bcf/day while LNG exports grow to 13 Mt/yr (1.7 Bcf/day)

Even with deep GHG reductions, our results show that BC's economy will remain healthy. The economy will continue growing at an average rate of 2% over the coming decades. A quarter million new jobs are added to the economy in the next ten years, with total jobs growing by 900,000 between 2015 and 2050.

A diverse economy allows BC to keep growing, even while reducing its GHG emissions. Many sectors contribute to this growth. While resource sectors are important to BC's economy, the majority of economic activity occurs in the service sectors, both now and in the future. Services is a broad category that includes healthcare, education, arts, entertainment, finance, technical and professional services, information, accommodation, food services, retail and wholesale trade, as well as government services. Services provide the greatest absolute addition to the economy between 2015 and 2025 (+$30 billion GDP) and from 2025 to 2050 (+$104 billion GDP), growing at an average annual rate of 2.1% annually (Summary Figure 2).

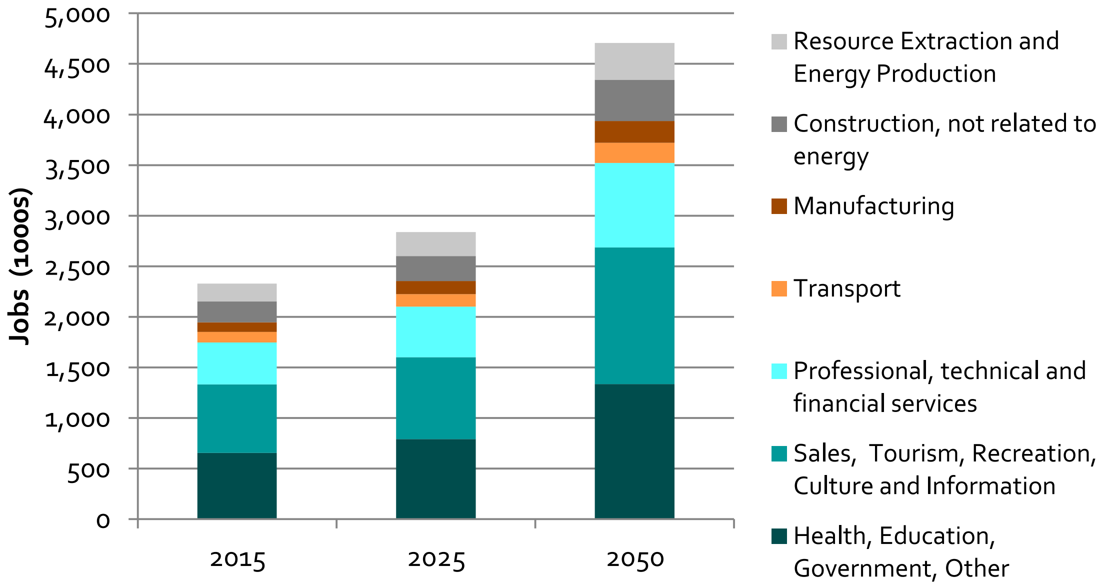
The natural gas sector, including liquefaction and the oil and gas service industry, grows somewhat more slowly with stronger GHG policies. However, this is primarily due to reduced demand outside of BC. With deep GHG reductions, the sector still grows at an average rate of 2.0% annually, adding approximately $4 billion in GDP to the provincial economy between now and 2050. Similar growth occurs in other industrial sectors such as mining or wood products (Summary Figure 2).

Summary Figure 2: Absolute contribution to BC's GDP (at basic prices) from 2015 to 2050 for Key Sectors in a Deep GHG Reduction Scenario



A growing economy creates new jobs. However, reducing BC's GHG emissions means some job growth will occur in different sectors. Between now and 2050, Job growth, like economic growth, occurs mostly within the service sectors. Employment in these sectors grows by 181,000 jobs by 2025, and by 676,000 jobs from now to 2050. Industrial Jobs, including construction and transportation (e.g. freight, warehousing, and couriers), grow substantially, collectively adding another 93,000 jobs to the economy by 2025, and 236,000 between 2015 and 2050. While there may be job losses in traditional energy industries, such as petroleum refining or natural gas distribution, these are more than offset by job growth in biofuel and renewable electricity production.

Summary Figure 3: Jobs in BC by Aggregate Sector in a Deep GHG Reduction Scenario



Clean energy is BC's competitive advantage. The mining and light manufacturing sectors (e.g. food, beverage, machinery, electronic equipment) in BC grow somewhat faster and create more jobs in a scenario with deep GHG reductions. BC's existing supply of zero-GHG electricity moderates the cost of electricity in BC relative to other regions. Consequently, these sectors have a competitive advantage over other regions.

For households, it is an affordable change. Retail energy prices will rise as will the embedded cost of GHG emissions in those prices. However, increasingly efficient homes and vehicles mean British Columbian households will, on average, spend $500/yr less on energy in 2025 than they do in 2015. By 2030, the average savings per household will increase to over $800/yr, then reaching almost $1000/yr in 2050. These changes can apply to urban, rural and northern British Columbians. However, to reduce energy costs, households must spend more upfront (i.e. on 'capital'): energy efficient homes and electric vehicles, for example, come at a premium. Compared with a scenario where no new GHG policies are implemented in BC, households will spend on average an additional $4,000 on capital between 2020 and 2050.

Making this scenario a reality requires immediate policy action. Over the next two to three years, BC needs to:

- Set a schedule for increasing the carbon tax to at least 80$/tonne.
- Continue improving building energy codes.
- Ensure that new drives providing gas compression for natural gas extraction, processing and transmissions emit no GHG emissions (i.e. are powered by electricity).
- Require the natural gas sector to cut its fugitive emissions intensity (i.e. the amount of leaked and vented GHG emissions per unit of gas produced) by 50% from today by 2020.
- Strengthen the regulation on the LNG industry to ensure that these facilities will at minimum use electricity from the BC grid for their ancillary power while supporting electrically powered liquefaction as much as possible.
- Prepare to regulate the emissions of all other industrial sectors in order to cut total emissions from these sectors by at least 50% by 2050. This regulation must include any new sectors that may arise between now and 2050, such as biofuel manufacturing.

By 2020, the government should:

- Have a working zero-emission vehicle mandate that set a minimum threshold for zero and near-zero-emissions vehicles. Similar the Californian mandate, the mandate should be 5% of sales in 2020 and it should rise to 15% by 2025.
- Build select public building that are net-zero energy ready (i.e. use so little energy that they could offset annual energy consumption with onsite renewable generation) to provide leadership for upcoming requirements for all buildings.
- Require that all CO_2 that is removed from natural gas as it is process is captured and stored rather than vented to the atmosphere. CO_2 that would be removed and vented at LNG facilities must instead be captured and stored upstream.
- Set an end-of life date for gas powered drives in the upstream natural gas sector such that they will all be retired by 2050.

- Implement a policy requiring nearly complete (90%) landfill gas capture and destruction or utilization from large landfills.
- Reduce the required GHG intensity of transportation fuels to -15% relative to 2010 under the existing clean fuel standard (i.e. the Renewable and Low Carbon Fuel Regulation Requirement).

In 2025 and thereafter, the government should

- Continue reducing the required GHG intensity of transportation fuels to -20% in 2030 with an end-point of close to -100% by 2050.
- Ensure the real value of the carbon tax is not eroded by inflation by adjusting based on the rate of inflation.
- Continue raising the zero-emission vehicle mandate to 23% of new sales in 2030 and 33% of new sales by 2035.
- Set a building code that requires new homes and most new buildings to be net-zero energy ready.
- Implement a zero-emissions standard for buildings that requires new and replacement space and water heating equipment in buildings to produce zero direct GHG emissions. The government should support retrofits to building envelopes or other systems as necessary to accommodate the zero-emission building standard.
- Ban the development of any new fossil fuel-fired electricity generation unless it can capture and store the carbon that would otherwise be release to the atmosphere.
- Ban organic matter from all landfills in BC.

In addition to the province-wide GHG emissions targets, the government should achieve the following energy and emissions goals for key sectors:

Buildings

- Reduce direct GHG emissions from buildings by 20% in 2020 relative to 2015, 50% in 2030 and 100% after 2045.
- Facilitate this goal with continual improvement to the energy efficiency of all buildings. After 2025, most new homes and buildings should be built to a net-zero energy ready standard with the goal of having 25% of total building floorspace net-zero by 2030 and 60% by 2050.

Transportation

- Reduce direct GHG emissions from passenger, freight and off-road transportation by 3% relative to 2015 in 2020, by 45% in 2030, and by almost 100% in 2050.

- Put 300,000 zero-emission vehicles (e.g. electric vehicles) and near-zero-emission vehicles (e.g. plug-in hybrid vehicles) on the road by 2030, using a zero-emission vehicle mandate supported by incentives as necessary.

- Maintain long-term fuel GHG intensity goals that are communicated and implemented through the clean fuel standard.

Renewable Energy Supply: Electricity and Biofuels

- Increase renewable and non-emitting generation by 40% from 2015 by 2030. Double renewable and non-emitting generation by 2050.

- Dramatically increase the supply of biofuels without increasing the upstream emissions from this sector that occur either in BC or outside.

Natural Gas and LNG

- Eliminate all routine venting of the CO_2 that is removed from the natural gas stream by 2020, including formation CO_2 removed during gas processing and prior to liquefaction.

- Reduce the emission intensity of upstream gas production, processing and transmission by a factor of 10 by 2050 (i.e. from 11 $ktCO_2e$ /Bcf in 2015 to 1.1 $ktCO_2e$/Bcf in 2050) by:

    - Cu the fugitive emissions intensity the from upstream gas production, processing and extraction sectors by 50% before 2020.

    - Have 30% of gas compression in the upstream natural gas sector powered by electric drives in 2020, rising to 40% by 2030 and 100% by 2050.

- Avoid technologically locked-in GHG emissions in the LNG sector that would compromise the 2050 emissions target (i.e. emissions from very long-lived investments) and reduce the GHG emissions from this sector to less than 1 $MtCO_2$/yr by 2050.

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1. Introduction

In 2008, British Columbia adopted legislated targets to reduce greenhouse gas emissions by 33% relative to 2007 by 2020 and by 80% by 2050. At the same time the 2008 provincial government introduced a climate action plan with policies and regulations to reduce emissions. The government is now looking to reinvigorate that plan to meet the 2020 target and push towards the 2050 target. However, climate action must not come at the expense of economic growth and job creation in British Columbia: the BC Government has dual goals of being a leader in reducing GHG emissions and growing the economy.

In this analysis, we explore the costs and benefits of deep reductions in BC's GHG emissions. Broadly speaking, we view reduced GHG emissions and reduced risks from climate change as a benefit. On the other hand, strong policies are required to achieve deep GHG reductions and these policies create implicit cost, either financial or perceived cost associated with adopting new, low-GHG technologies or practices. More specifically, our goal is to produce a quantitative forecast that will help answer the following questions:

- How much and what kind of energy will BC use if there is a deep reduction in provincial GHG emissions?
- What energy technologies will be needed and what policies can produce this change?
- How will economic growth and structure evolve from the present to 2050 while working towards these reductions?
- What sectors may grow and where will job growth occur in BC's low-carbon economy?
- How will energy costs and energy related expenditures change in a deep GHG reduction scenario?

The focus of this analysis will be on the changes from 2015 to 2050 in BC under a deep GHG reduction scenario. While analyse the impact of continuing with only BC's current emissions policies, our modelling does not account for the cost of climate change. Therefore, in this analysis, we have taken it as a given that no further action is not a viable choice. We instead focus on the changes through time, comparing to the current policy scenario only where it provides a useful frame of reference.

The remainder of this report presents our methodology and results. We first provide a brief overview of our modelling approach and modelling inputs. We then describe the policies we included in the deep GHG reduction scenario. Following this, we describe the forecast results starting with total provincial emissions, then providing more detail at the sector level and finishing with a discussion of three indicators of economic impact.

2. Methods and Inputs

Analytic Approach

To conduct this analysis, we employ two of Navius' energy-economic models, the CIMS technology simulation model and the GEEM computable general equilibrium model. More information about each model as well as how the models interact is available in Appendix A: Overview of the CIMS and GEEM Models.

The models are structured differently in order to focus on different elements of the energy-economy system. CIMS focuses on specific technologies and processes within energy consuming sectors in BC. On the other hand, GEEM takes a broader view and focuses on the linkages between sectors and regions with the broader economy of Canada, North America, and the world. Linking these two models allows us to make use of each model's strengths and provide a more complete evaluation of climate policies in BC. Table 1 lists some examples of the types of policy questions each model can address.

Table 1: Examples of policy questions addressed with each modelling tool

GEEM	CIMS
Economic structure How does policy impact the structure of economic activity in the province? For example, does a given policy reduce the competiveness of manufacturing and hence reduce its output?	Abatement action Which abatement actions are undertaken in response to policy? For example, will firms elect to improve energy efficiency or switch to less carbon intensive fuels in response to the carbon tax?
Regional energy prices How does a policy affect the demand and supply for natural gas in Western Canada?	Electricity prices How does a policy affect the demand and supply for electricity in the province?

Modelling Inputs

Historical Energy and Emissions Data for Calibration

We calibrate our models to historical data over a back-casting period (2000-2014) using several sources including Natural Resources Canada, The Canadian Industrial Energy End-Use Data and Analysis Centre, Statistics Canada, Environment Canada, and Clearstone Engineering's inventory of the upstream oil and gas sector's emissions. Please see Appendix B: for more information.

Energy Prices

We use an external forecast for oil and natural gas prices. For this analysis we have used the US Energy Information Agency's reference scenario forecast from the 2015 Annual Energy Outlook. This forecast has the North American wholesale gas prices rising from around $4/GJ currently to 8$/GJ in 2040 (current dollars, i.e. does not include inflation). We extrapolate that to 10$/GJ by 2050. The oil prices forecast has oil at $60/bbl currently but rising to 140 $/bbl in 2040. Again, we have extrapolated to 2050, assuming the price will reach 160 $/bbl (current dollar). See Appendix B: for the oil and gas benchmark price forecasts as well a description of how we converted these to retail energy prices in BC used in the reference scenario (i.e. current policy scenario).

Electricity prices are based on announced prices changes to 2018 from BC Hydro and the government. These prices are largely consistent with those produced with Navius' electricity system model, which informs the reference price of electricity from 2018 onwards.

Biofuel prices were indexed to diesel prices based on historical data from the US Department of Energy.[1] Table 2 shows the reference retail energy prices used in our analysis.

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[1] The Alternative Fuels Data Center: http://www.afdc.energy.gov/fuels/prices.html

Table 2: Reference BC Retail Energy Prices, 2014 CAD (excl. sales tax and carbon tax)

	2010	2020	2030	2040	2050
Natural Gas, $/GJ					
Residential	18.6	17.1	18.1	19.1	20.4
Commercial	16.8	15.3	16.3	17.3	18.6
Industrial	12.8	11.3	12.3	13.3	14.6
Electricity, $/MWh					
Residential	9.2	11.9	12.0	13.2	14.1
Commercial	7.6	10.0	10.1	11.2	12.2
Industrial	5.2	7.1	7.2	8.4	9.3
Gasoline and Diesel, $/L	1.02	1.03	1.19	1.38	1.59
Biofuel, $/L	1.34	1.23	1.41	1.64	1.90

Technology Assumptions

See Appendix B: for an overview of our assumptions for the cost and/or emissions of key technologies.

Sector Activity Outputs/Inputs

Table 3 shows the reference scenario (i.e. current policy) sector activity forecast used for our scenario modelling. Most of this activity data is produced by the GEEM model based on four key inputs:

- The price for key global commodities (e.g. natural gas and oil).
- The current structure of the economy and the substitutability of various inputs to economic activity (e.g. labour, capital, energy) and the extent to which goods and services are tradable as defined in the GEEM modelling framework, based on benchmark input/output data from Statistics Canada.
- Labour productivity growth, which is comprised of population growth and labour productivity. National population is set according to the forecast used by the

National Energy Board,[2] but allocation of that population by province is a modelled result.

- The reference scenario assumption for LNG exports from the upcoming National Energy Board Energy Futures projection (18.5 Mt/yr export capacity built by 2025).[3] Production is just over 16 Mt/yr (Table 3), based on a capacity utilization of 87%.

Our forecast for electricity generation is based on electricity consumption within the CIMS model. By 2030, our modelling shows electricity generation at 88 TWh/yr for all of BC, while the current BC Hydro Integrated Resource Plan estimates generation would need to be roughly 80 TWh/yr for that same year (without demand side management). Our result is currently higher than expected by BC Hydro. However, it does include all electricity consumption in BC, not just within the BC Hydro service area. Generation by resource is based on those listed in the Integrated Resource Plan and includes the Site C hydroelectric project.

Like electricity generation, activity in the petroleum refining sector is tied to energy consumption in BC. Current policies will reduce total gasoline and diesel consumption in BC by around 85 PJ/yr between 2015 and 2020. Refining activity in BC falls by around 16 PJ/yr over that period (500,000 bbl/yr) and a reduction in imports from Alberta and the US accounts for the remainder of that change. Crude oil production is not directly linked to refining activity in BC. Activity in this sector is already insignificant in terms of provincial energy consumption and GHG emissions. Output declines according to a trend that is consistent with projections from the National Energy Board.

The sector activity forecasts shown in Table 3 can change with the application of climate policies. Specifically, the competiveness of sectors can be impacted. The extent of the impact is determined in our methodology through two key dynamics:

- **The trade of goods and services between regions.** An increase in the costs of producing a good or services in one region relative to another can affect the trade of that good or service. This only applies to goods and services that can be traded, which is determined using Statistics Canada input/output data.
- **The flow of capital.** We assume capital used for new investments is fully mobile between all regions in the world (note that installed capital in previous periods is not mobile). If the costs of producing a good or service increase in one region relative to another, “investors” have the ability to move capital for new investments

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[2] National Energy Board, 2013, Canada’s Energy Future 2013 – Supply and Demand Projections to 2035 – An Energy Market Assessment.

[3] National Energy Board, 2015, 2015 Energy Futures Report: Preliminary Results. Presented April 28 2015 in Vancouver.

to the region with lower costs in order to get a higher return on their investment. Again, this only applies to goods and services that are tradable.

Table 3: Reference Scenario Sector Activity, from the GEEM Model

	Units	2015	2020	2025	2030	2035	2040	2045	2050	Avg. Annual Growth 2015-2050
Energy Demand Sectors										
Residential	*thousand households*	1,885	2,199	2,348	2,485	2,620	2,660	2,710	2,776	1.1%
Commercial	*million m^2 floorspace*	103	108	111	115	120	124	129	133	0.7%
Transportation										
Passenger	*billion pkt/yr*	67	70	74	76	79	81	84	86	0.7%
Freight	*billion tkt/yr*	142	169	190	210	221	232	243	254	1.7%
Chemical Products	*million tonnes/yr*	0.5	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.9%
Industrial Minerals	*million tonnes/yr*	2.9	2.5	2.8	3.2	3.5	4.1	4.8	5.7	2.0%
Metal Smelting	*million tonnes/yr*	0.4	0.6	0.7	0.7	0.8	0.9	1.0	1.1	3.1%
Mining	*million tonnes/yr*	98.7	104.5	110.0	115.4	121.2	127.3	133.5	139.3	1.0%
Pulp and Paper	*million tonnes/yr*	2.4	2.9	3.3	3.7	4.2	5.0	6.3	8.6	3.8%
Other Manufacturing	*billion $ 2005 GDP*	16.9	21.5	23.8	26.7	29.8	32.5	34.7	36.8	2.3%
Energy Supply Sectors										
Electricity Generation	*TWh/yr*	65	74	82	88	94	101	110	120	1.8%
Petroleum Refining	*million m^3/yr*	2.6	2.5	2.3	2.2	2.1	2.0	2.0	2.0	-0.8%
Crude Oil	*thousand barrels per day*	21	16	12	9	7	6	4	3	-5.1%
Natural Gas	*billion cubic feet per day*	3.7	5.0	5.9	6.4	6.8	7.3	7.7	7.4	2.0%
LNG exports	*million tonnes/yr*	0.0	6.4	14.5	16.1	16.1	16.1	16.1	16.1	n/a
Coal Mining	*million tonnes/yr*	27.9	27.9	28.0	28.1	28.2	28.3	28.5	28.7	0.1%
BC GDP (basic prices)	*2002 billion CAD (chained)*	168.2	187.9	208.3	231.4	256.2	283.1	312.6	343.5	2.1%

3. Deep GHG Reduction Scenario Design

The deep GHG reduction scenario was designed to move BC's emissions closer to the 2020 target while achieving the 2050 target. The scenario includes a suite of policies that build on the current Climate Action Plan while including existing and announced federal policies. The policies in the scenario are strong: many are compulsory and designed to completely decarbonize a sector or energy end-use by 2050. As well, the policies are generally implemented early. All of them are in force by 2025 and they are maintained for many decades.

While BC may be a leader in climate policy, we assume it is not acting alone. For our economic modelling, we assume other North American Jurisdictions and are enacting similarly stringent policies. There are many indications that other provinces and states will soon be doing more to reduce GHG emissions. Quebec is developing a suite of climate change policies and Ontario will join Quebec and California's emissions cap and trade system. Alberta has begun strengthening its climate policy, and is developing a more aggressive climate plan. On the Pacific coast Washington, Oregon and California are moving ahead with climate policies. The US federal government's Clean Power Plan will transform the American electricity system, reducing coal consumption while increasing investment in renewable electricity. Stronger tailpipe standards in the US will reduce emissions from transportation and new regulation will reduce methane emissions throughout the natural gas sector. Policies outside of BC are not modelled with the same detail as policies within BC. However, we assume the strength of policy in other regions grows until it has an implicit impact that is equal to a carbon price of 300$/t$CO_2$e by 2030.

Many of the policies in our deep GHG reduction scenario are based on existing legislation. They include:

- An increase to the BC carbon tax, made under the existing Carbon Tax Act. In 2018, it increases by roughly 8 $/t each year until it reaches approximately 80$/t$CO_2$ in 2025 and remains at that value in real terms (i.e. is adjusted for inflation). The carbon tax remains revenue neutral. Revenue is recycled back to households and firms as it is currently: through corporate and personal income tax cuts and credits, as well as through tax credits to low income citizens and benefits to rural and northern British Columbians.

- Incremental improvements to building energy codes, made to the upcoming BC Building Act. By 2025, new buildings and homes are built to be net-zero energy ready. In other words, with typical energy requirements within the home or building, occupants could theoretically offset their annual energy use with on-site solar photovoltaic generation. Energy intensive buildings such as hospitals may not be able to achieve net-zero energy, but the policy ensures they would have a significant improvement in energy performance. Select public sector buildings (e.g. education and health care facilities) are built to this standard from 2020 onward. Our analysis does not account for the rate of compliance with the energy buildings codes.

- A zero-emission building standard, also made under the BC Building Act, where after 2025, space and water heating equipment within buildings may not emit GHG emissions. Unlike the standard above, this applies to equipment installed in new buildings as well as replacement equipment in existing buildings.
- The current and upcoming federal minimum-energy performance standards for household and building appliance and equipment (e.g. energy efficiency standards for fridges, clothes washers etc.). While we do not include changes to appliance efficiency standards after 2015, the average energy efficiency of appliances continues to decline through time as the older stock of equipment is replaced.
- The current Landfill Gas Management Regulation where landfills with 100,000 tonnes or more of waste in place, or with an acceptance rate greater than 10,000 tonnes per year, must capture and destroy their landfill gas. Our assumption is that these large landfills account for 70% of the waste disposal in BC. The regulation is set so that by 2020, 90% of the GHG emissions from these landfills are destroyed.
- A ban on land-filling organic waste, with 95% of organics diverted from landfills after 2025, implemented as part of the Landfill Gas Management Regulation. Based on a typical decay rate for organic matter in BC landfills, by 2050, this ban reduces landfill gas emissions by 90%.
- The federal light-duty vehicle emission standard to 2025 (based on the draft rule) which requires the fleet average emissions to fall to 100 gCO_2/km for cars and 140 gCO_2/km for light trucks. This standard is ultimately 50% below the fleet average in the year 2000 and will likely require the efficiency of hybrid drive-trains.
- The federal heavy-duty vehicle emission standard which requires emissions from 2018 model year vehicles to be roughly 25% less than 2010 model year vehicles
- A light-duty zero-emission vehicle (ZEV) mandate that requires 5% of new vehicles to be zero-emissions or near zero-emissions in 2020 (plug-in hybrid vehicles qualify). The mandate increases to 14% in 2025, 23% in 2030, and ultimately to 60% by 2050. The initial market share requirements in 2020 and 2025 are modelled on the rate of ZEV sales that will likely occur if automakers comply with the existing California ZEV mandate. This policy could be implemented under the Greenhouse

Gas Reduction (Vehicle Emissions Standards) Act which outlines a ZEV mandate that is not yet in force.

- An aggressive and long-term schedule for BC's clean fuel standard (the Renewable and Low Carbon Fuel Requirement Regulation). Currently the policy requires a 10% reduction in the lifecycle GHG emissions for most transportation fuels, relative to 2010. We assume that this policy will be expanded to all fuel consumption (marine, rail, off-road), excluding aviation fuels. By 2030, the lifecycle GHG emission intensity of transportation energy must be 20% below the 2010 benchmark, falling to almost 100% less than the benchmark by 2050.

- A change to the Clean Energy Act that allows no new fossil fuel generation to be built after 2025 unless carbon emissions are captured and stored. Under this policy, 93% of generation must be renewable and BC must have zero-net electricity imports. With these constraints and the effect of the carbon tax, some new gas-fired generation without carbon capture is added to supply peak electricity loads, but it accounts for less than 1% of total generation by 2050.

- A zero-emission standard for the natural gas sector (extraction, processing and transmission) where new motive power (e.g. for compression) must be powered by electric drives. This equipment can last 30 to 50 years. Therefore, early policy action is required to avoid investing in technologies that will still be emitting GHG emissions by 2050. Existing equipment is given a 30 year end of life, and all gas-fired motive power must be retired by 2050. Formation CO_2 must be captured and stored by 2020, and gas extraction, processing and transmission operations must reduce their vented and leaked emissions by 50% by 2020 through equipment modifications and thorough leak detection and repair programs. This sector specific set of regulations could be implemented under the Greenhouse Gas Industrial Reporting and Control Act (GGIRC)

- A strengthened regulation on the LNG sector, also through the GGIRC act which prevents the removal and venting of CO_2 at the LNG facility by 2020, meaning it must be separated and stored upstream with the rest of the formation CO_2. Furthermore, the GHG intensity standard on the sector is immediately strengthened to prevent facilities from being built so as to use gas-fired generation for their ancillary power. Our assumption is that a firm threshold of 0.14t tCO_2/tLNG for compression and power, without the option to comply by paying into a technology fund, would require facilities to use grid electricity for their ancillary loads.

- Finally, regulate the emissions from industries not already covered by a sector specific policy. This policy could be implemented under the GGIRC act such that emissions from the mining and manufacturing industries must be 8% below 2015 levels by 2020, 30% lower by 2025 and ultimately 50% lower by 2050. Emissions from metal smelting, cement manufacturing, pulp and paper, wood products, liquid fuel refining, mining and other manufacturing are roughly 9 $MtCO_2e/yr$ today (2015) and need to fall around 4.5 $MtCO_2e/yr$ by 2050.

Table 4 summarizes the additional policy actions that are implemented by the BC Government in the deep GHG reduction scenario, showing the schedule for these changes. Immediate policy actions to be taken over the next two to three years include increasing the carbon tax, continuing to improve the building energy codes, ensuring new drives in the upstream natural gas sector are powered by electricity rather than gas combustion, and working to mitigate the lock-in of GHG emissions at LNG facilities while developing an emissions regulation for the mining and manufacturing sectors. Policies that must be implemented by 2020 include the ZEV mandate, a limited requirement for net-zero energy ready public buildings, and requirements to reduce the vented and leaked emissions from the LNG and upstream gas sector. By 2025, all of the necessary policies are in place and the policies that change through time are generally at their full strength.

Table 4: Summary of New BC Policy Actions in the Deep GHG Reduction Scenario

Sector	Policy	Action by 2018	Actions by 2020	Actions by 2025	Actions by 2030	Post 2030 Action
All sectors	Carbon Tax	Begin 8$/t annual increase	Continue 8$/t increase	Increase the tax to 80$/t	Maintain the real value of the tax by adjusting for inflation	Continue adjusting for inflation
Transport	Clean Fuel Standard			Require a 15% reduction in lifecycle GHG intensity of fuels	Require 20% reduction in GHG intensity	GHG intensity must continue falling by 4% annually, expand policy to all fuels, excluding aviation
	Zero-Emission Vehicle Mandate		Zero-emission vehicles must account for 5% of new sales	Increase mandate to 14%	Increase mandate to 23%	Mandate continues rising by 1.8% annually
Buildings	Building Codes	Continue improvements to building energy codes	Select public buildings are built so they could consume net-zero energy	New homes and buildings must be built so they could consumer net-zero energy if they install onsite energy generation		

Sector	Policy	Action by 2018	Actions by 2020	Actions by 2025	Actions by 2030	Post 2030 Action
	Zero-emission standard for buildings			New space and water heating equipment installed in all buildings may not produce direct GHG Emissions		
Electricity	Clean Energy Act			No new construction of fossil fuel generation without carbon capture		
Upstream Natural Gas	Formation CO_2 capture and storage		All formation CO2 must be captured and stored			
	Reduction of fugitive emissions		Fugitive emissions (e.g. leaks, venting) must be reduced by 50% relative to 2015 levels			
	Zero-emission standard	New drives must be powered by electricity	Existing gas-fired direct drive equipment is given a 30 year end of life			All gas-fired direct drive equipment must be retired
LNG	GHG intensity standard	Set a threshold such that facilities will at least use grid electricity for ancillary power				
	No CO_2 venting		CO_2 must be removed and stored upstream rather than at the facility			

Sector	Policy	Action by 2018	Actions by 2020	Actions by 2025	Actions by 2030	Post 2030 Action
Mining and manufacturing	GHG emission cap or other regulation	Establish emissions regulations by sector	8% reduction in emissions relative to 2015 levels	30% reduction	45% reduction	50% reduction
Solid Waste	Landfill gas capture		90% of landfill gas at large sites is captured and destroyed			
	Diversion of organic matter from landfills			Achieve diversion rate of 95%		

4. Results and Discussion

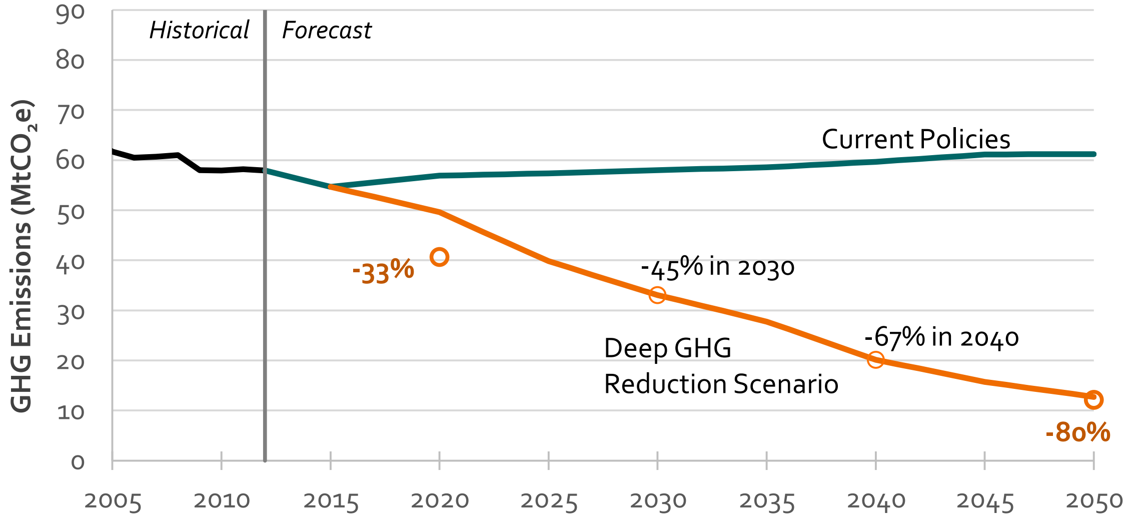
Below, we present and discuss the results of this forecasting analysis, beginning with province-wide GHG emission results. We then provide more detail for the buildings, transport, electricity generation and natural gas sectors to explain the overall trends and highlight the changes in energy and emissions that policies must achieve in each sector. This section concludes with some indicators of how moving BC towards its 2050 emissions target will affect the economy as a whole, the growth of some specific sectors, jobs and household energy spending.

Provincial Greenhouse Gas Emission Forecast

What are BC's future GHG emissions?

While current policies will hold BC's GHG emissions roughly constant over the coming decades, the policies in the deep GHG reduction scenario yield a substantial reduction. They drive GHG emissions from roughly 60 $MtCO_2e$ today to less than 13 $MtCO_2e$ by 2050, equivalent to a 79% reduction relative to 2007 (Figure 1). This change happens in the context of a growing population and an economy that doubles in size. However, even the enhanced policies fall well short of the 2020 emission target. In 2020, annual GHG emissions are only 18% below the 2007 levels. The 33% reduction is achieved five years later in 2025. By 2030, emissions are 45% below 2007 levels, and by 2040, GHG emissions have fallen by 67%. Ultimately, the deep GHG reduction scenario narrowly misses the 2050 target of 12 $MtCO_2e$/yr (-80% relative to 2007, excluding deforestation emissions).

Figure 1: BC's GHG Emission Forecast, With the 2020 and 2050 Emission Targets

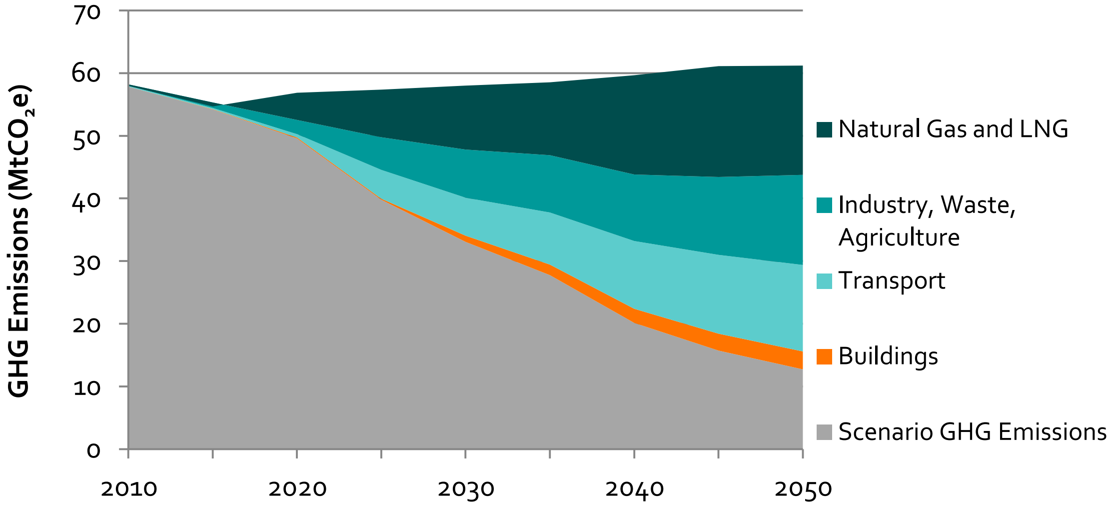


Note that the GHG emissions and targets in this figure do not include GHG emissions resulting from deforestation, (roughly 3 $MtCO_2e$ in 2007).

What sectors reduce their GHG emissions?

Figure 2 shows in which sectors reduce their GHG emissions. The sum of the areas in the figure represents the GHG emission trend with only current policies in force. In 2020, total abatement relative to this trend is 7.3 $MtCO_2e$/yr. 60% of this change comes from the LNG and natural gas sector, demonstrating the importance of short-term policy action to constrain the emission from these sectors. By 2050, the policies in the deep reduction scenario will decrease GHG emissions by roughly 49 $MtCO_2e$/yr compared with current policies. About 30% of this change (14 $MtCO_2e$/yr) comes from the transportation sector (light and heavy duty). Two third of the change comes from industry (32 $MtCO_2e$/yr) split amongst the natural gas sector (including liquefaction), and other manufacturing and extractive industries. Another reduction of 3 $MtCO_2e$/yr, comes from buildings.

Figure 2: GHG Abatement by Sector Relative to the Reference Scenario



Can BC meet its 2020 emission target?

It is very unlikely that BC can directly achieve the 2020 GHG target. However, the policies in the deep GHG reduction scenario can close the gap from 17 $MtCO_2e$ per year to 10 $MtCO_2e$ per year. Despite the size of this gap, this is an ambitious scenario for GHG abatement over the next five years (from 2015 to 2020) given the expected growth in the population and the economy. Even without the expected growth in the natural gas industry, emissions would still be over the target. Further abatement would be required from buildings and transportation, but any appreciable reduction in emissions not already included in the deep GHG reduction scenario would require a broad and compulsory retrofit of homes and buildings as well as the widespread adoption of transportation technologies that are just entering the market (e.g. electric vehicles).

Where do the residual emissions in 2050 come from and could they be avoided?

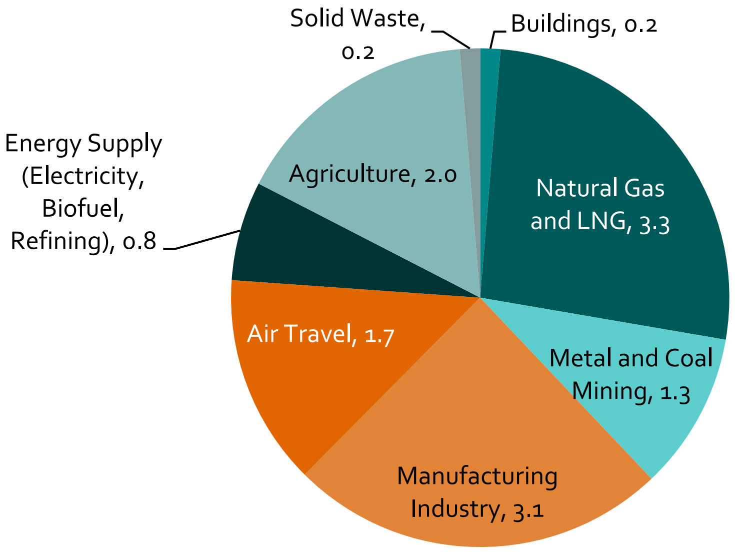
- The natural gas sector, including LNG, accounts for 25% of the remaining GHG emissions in 2050. They come from fugitive emissions that are not controlled and combustion emissions for process heating in the upstream industry as well as long-lived gas-fired drives that power the liquefaction at LNG facilities. Emissions could fall further with tighter controls on fugitive emissions (we assume best practices result in 50% fewer fugitive emissions than current practices), or after 2050 as gas-fired drives at LNG facilities are retired or replaced with electric drives. We provide more detail on the natural gas sector in our sectoral analysis.

- Air travel accounts for another 14% of the remaining emissions. Our analysis currently contains few emissions abatement options for this transportation mode, but biofuel or hydrogen fuelled aircraft could mitigate these emissions.

- Agriculture also accounts for 16%, with emissions primarily coming from agricultural soils and enteric fermentation (methane from animal digestion). Some abatement options exist for these sources, but with the growing demand for biofuels, it is likely that agricultural emissions will persist.
- Buildings, electricity generation and biofuel supply are essentially decarbonized by 2050 and account for only 8% of total emissions.
- Manufacturing, combined with the mining sectors account for 35% of the residual emissions with significant sources being methane emitted from coal seams as they are mined and remaining process heat and steam generation fuelled by natural gas without carbon capture at small and medium sized industrial facilities.

Further GHG reductions in 2050 could occur primarily with increased electrification in industry, for example with the early retirement and retrofit of LNG facilities to use electric drive rather than gas-fired drives, or using electric heating technologies rather than gas combustion for manufacturing. While technically possible, the cost of these actions is high and the suite of policies applied in the scenario is not strong enough to drive the change.

Figure 3: Remaining Emissions by Sector, $MtCO_2e$ in 2050

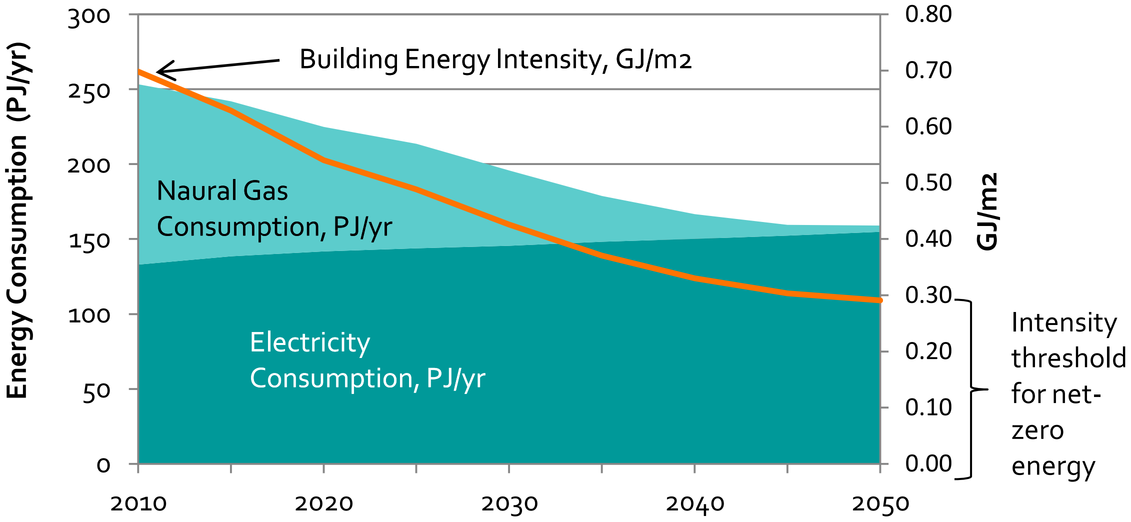


Energy, Emissions and Technologies by sector

Buildings

Due to improved standards for new building construction and the zero-emission building standard, natural gas consumption in buildings falls to essentially zero, while electricity consumption grows slowly (Figure 4). By 2050, total building energy consumption is about 34% lower than it is today, even with total residential, commercial, and institutional floor area growing by 50%. Consequently, the average energy intensity (energy consumption per area of the building) falls to 0.29 GJ/m²/yr. That puts buildings on average just below where net-zero energy consumption could be possible with on-site solar electricity generation.[4]

Figure 4: Energy Consumption and Energy Intensity in Buildings



The threshold for net-zero energy is a function of the efficiency of solar photovoltaic generation (i.e. energy production per area of panel) and the ratio of south facing building surface area to the total floor area.

While GHG emissions from buildings are effectively zero, their energy consumption, which is almost entirely renewable electricity by 2050, could fall further. Even though

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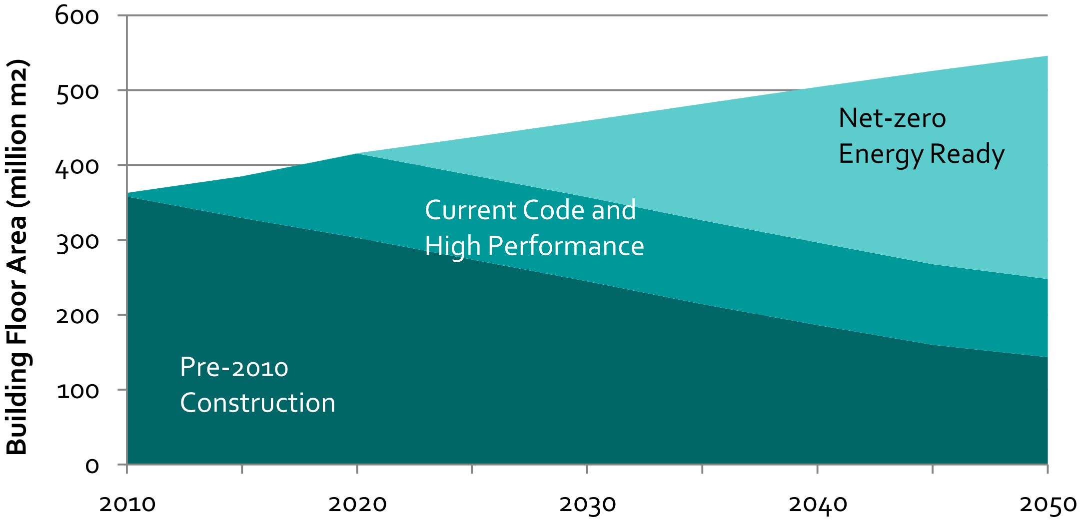
[4] The energy intensity at which net-zero energy consumption in a building is possible depends on the ratio of a building's floor area and south-facing surface area. Buildings with more surface area relative to their floor area (e.g. fewer stories) could achieve net-zero energy consumption with higher energy intensity. The threshold also depends on the efficiency of the solar cells. More efficient solar cells generate more electricity for a given area. Buildings with energy consumption intensity of less than 0.3 GJ/m²/yr might be able to consume net-zero energy. However, for a multi-story building, that value would typically have to be closer to 0.15 GJ/m²/yr.

the equipment within buildings is replaced relatively frequently (e.g. heating, lighting, appliances), building envelopes are long-lived. In 2050, only half of homes and buildings would make net-zero energy consumption possible. Because the policies in the deep reduction scenario did not require or incentivize retrofits to building envelopes, by 2050 about 25% of floor area still pre-dates current building energy codes. The eventual retirement of these buildings after 2050 will further reduce energy consumption, easing the demand for potentially limited sources of renewable energy.

Figure 5: Commercial and Residential Floor Area, Grouped by Building Envelope Energy Performance



Sectoral Targets

The key sectoral target for buildings should be to reduce their direct GHG emissions by 20% in 2020 relative to 2015, and by 50% in 2030. By 2045, there should be no direct GHG emissions from buildings.

Maintaining a 2-3% annual reduction in the average energy intensity of buildings will facilitate achieving the sector's emissions targets. Total energy consumption from buildings in 2020 should be fall by 7% relative to 2015 even as the total stock of buildings increases. By 2030, total building energy consumption should fall by 20% relative to 2015. In the long term, there should be a 33% reduction in building energy consumption from today. Ultimately, the relative cost and availability of energy efficiency versus zero-carbon energy sources should determine the degree to which this goal is pursued.

To achieve the absolute reductions in building energy consumption, the government needs to ensure some buildings are built to a net-zero energy ready standard by 2020, with all new construction built in this way from 2025 onward. 25% of total building floor space should be net-zero ready by 2030, with this goal rising to 60% in 2050.

Transportation

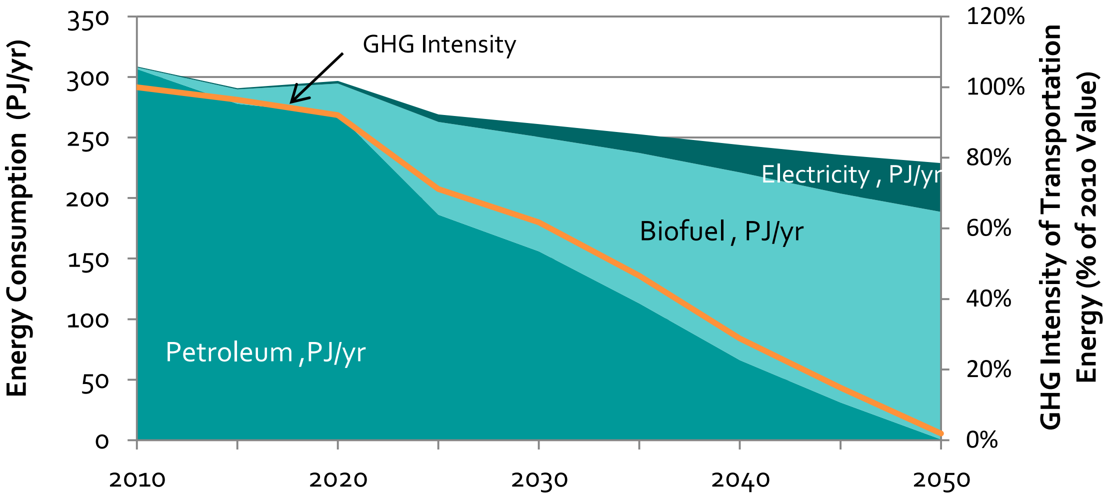
Under the influence of BC's clean fuel standard, carbon tax and the zero-emission vehicle (ZEV) mandate, the GHG emission intensity of transportation continues its downward trend from 2015 to 2020. By 2020, the emission intensity of transportation fuels has fallen by 10% relative to 2010 and total energy consumption is 4% lower. These policies, which become stronger through time, almost eliminate the GHG emissions of the sector by 2050. The average GHG intensity of transportation fuels, including fuel production, falls by 98% relative to 2010 (Figure 6). This figure excludes fuel for air travel and does not account for land-use emissions associated with biofuel production.

Greater use of electricity, biofuel and energy efficiency drive this change. In 2050, transportation energy consumption is 25% less than it is today, even though personal transportation demand grows by 30% and freight transportation grows by 80% over that period. Renewable biofuel is a key opportunity to decarbonize heavy-duty transportation and electrification is used for light-duty vehicles.

It is worth noting that we have assumed "drop-in" biofuels are further commercialized and there is no limit on how they are blended with petroleum fuels. However, if this technology cannot be further commercialized, for example due to constraints on biofuel feedstocks, hydrogen fuel cell technology is another possibility for low-carbon freight transportation. Both options were included in our analysis, but hydrogen technologies saw little adoption due to the relative lower-cost of biofuels and the additional costs and difficulties of deploying hydrogen technology and fuelling infrastructure. However, all of these assumptions are uncertain and either technology could be used to reach the 2050 emission target.

Another uncertainty is the magnitude of upstream GHG emissions associated with biofuels, resulting from agricultural land-use. If biofuel is produced from annual crops (e.g. canola) on existing farmland, the land-use emissions can be relatively low. If new land is cleared for biofuel production, the land-use emissions can be very high. However, biofuel can also be produced on marginal lands from perennial crops (e.g. Switchgrass) whose root systems sequester atmospheric carbon in the landscape, or it can be produced from organic wastes which have no associated land-use emissions. Estimating the land-use emissions is outside the scope of this analysis, but is clear that the amount of biofuel required in the deep GHG reduction scenario would require careful stewardship of land and agricultural resources. Altogether, this uncertainty reaffirms the importance using a fuels policy that accounts for upstream GHG emissions, as does the current BC clean fuel regulation.

Figure 6: Transport (Light and Heavy Duty) Energy Consumption and GHG Intensity



Because the CIMS and GEEM model do not track land-use emissions, the GHG intensity of transportation energy does not include land-use emissions.

Electricity accounts for under a fifth of transportation energy consumption, but due to the efficiency of electric mobility, the fuel share under-represents its role in the transportation sector (Figure 6). The zero-emission vehicle (ZEV) mandate supports electrification of light-duty transportation, and also facilitates complying with the ambitious clean fuel regulation. Interestingly, the ZEV mandate is not binding after 2035 within the context of other policies on transportation GHG emissions. Our analysis shows that the policy effectively removes barriers to electric vehicle adoption: The mandatory minimum market share improves familiarity with plug-in vehicles while creating a large enough market to warrant greater vehicle variety and access as well as charging infrastructure. By 2030, plug-in vehicles account for 25% of new passenger vehicle sales, even though the mandate only requires 23% (Figure 7). However, without any new policies, zero or near-zero-emissions vehicles do not gain significant market share.

Much of the vehicle charging infrastructure to support this change already exists. A survey of new vehicle owners in British Columbia demonstrated that two thirds of them could already charge an electric vehicle at home.[5] Therefore, in the short term, a lack

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[5] Axsen, J., Bailey, H.J., Kamiya, G., 2013, The Canadian Plug-in Electric Vehicle Survey (CPEVS 2013): Anticipating Purchase, Use, and Grid Interactions in British Columbia. Energy and Materials Research Group, Simon Fraser University.

of public and workplace charging infrastructure will not constrain the adoption of ZEVs. However, by 2040 increased charging infrastructure, especially for those who park in commonly owned parking lots (i.e. apartment and condominiums) will be needed for the new market share of electric vehicles to increase beyond 60-70%.

Figure 7: ZEV Mandate vs. ZEV New Market Share and ZEV market share without policy

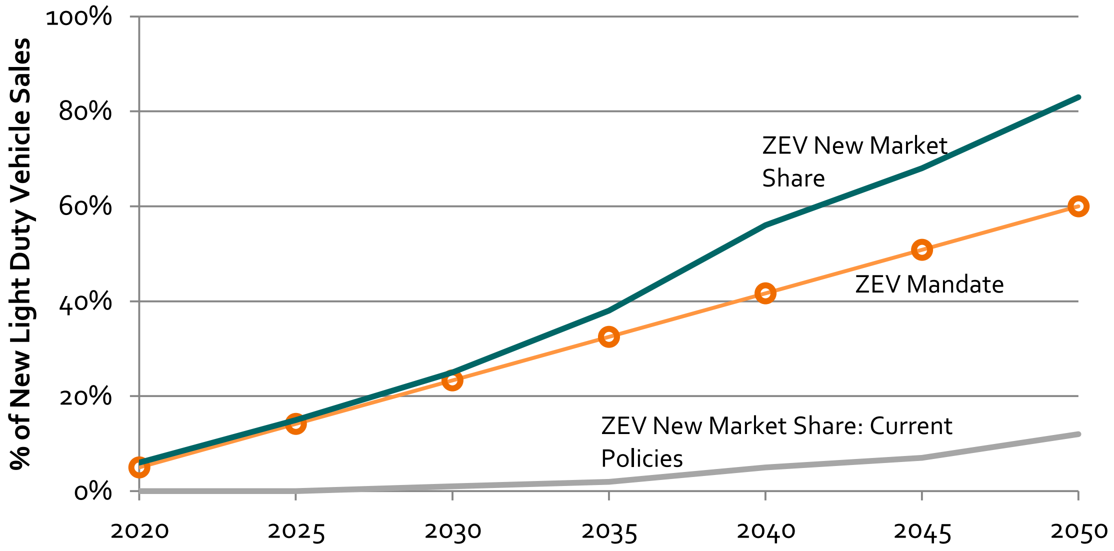
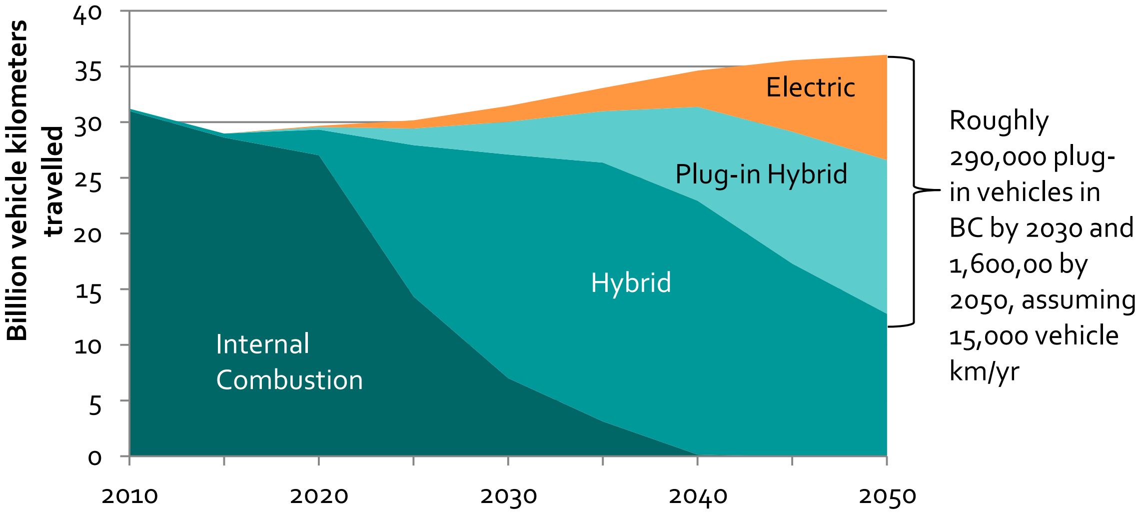


Figure 8 shows the composition of the light-duty vehicle fleet in BC through time in the deep GHG reduction scenario (based on vehicle kilometers travelled). Driven by the ZEV-mandate, plug-in vehicles account for 14% of all vehicles in 2030 (about 290,000 vehicles) and 64% in 2050 (about 1,600,000 vehicles). Plug-in hybrid vehicles that use another fuel to extend their range, account for two thirds of the electric vehicles, but this share is dependent on the relative cost and storage capacity of future vehicle batteries (i.e. lower cost batteries with a longer range would lead to more electric vehicles and fewer plug-in hybrids).

Figure 8: Stock of Light Duty Vehicles, Measure by Vehicle Kilometers Travelled



Significant electrification of medium-duty freight transportation also occurs (e.g. delivery fleets and urban freight vehicles). By 2030 40% of these vehicles are electrified, rising to 90% by 2050. This rate of adoption is contingent on these vehicles actually being available for sale in BC. However, assuming this is not a constraint, electric freight vehicles are a competitive choice in the deep GHG reduction scenario, given that they typically travel a known route and have high annual kilometres. Therefore, they can benefit from greater annual fuel savings without being limited by their driving range. Nonetheless, electricity plays a small role in powering the freight transportation sector: medium-duty vehicles account for only 10-15% of the total tonnage moved by road freight.

Sectoral Targets

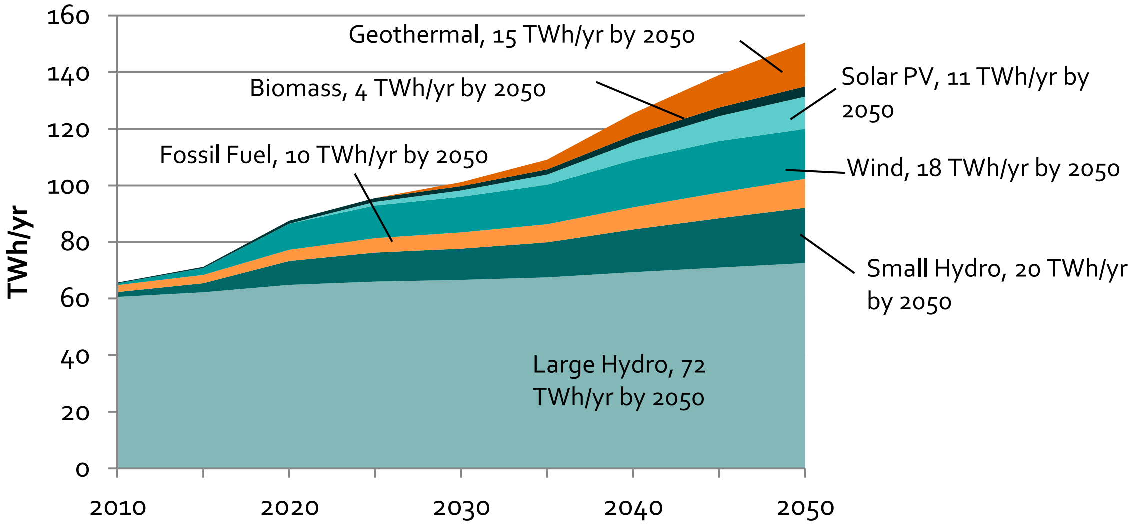
Like the building sector, the key target for the transportation sectors should be a nearly complete reduction of their direct GHG emissions. By 2020 GHG emissions from transportation must fall by 3-5% relative to 2015. By 2030, the reduction should be 45% and almost 100% by 2050. For passenger transportation, the government should aim to have roughly 300,000 zero-emission vehicles (e.g. electric vehicles) and near-zero-emission vehicles (e.g. plug-in hybrid vehicles) on the road by 2030. A supply focused policy, such as a zero-emission vehicle mandate, will likely be needed to achieve this goal and may need to be supplemented by a demand focused policy such as vehicle subsidies. For freight and off-road transportation, as well as passenger transportation, the government should maintain long-term fuel GHG intensity goals that are communicated and implemented through the clean fuel standard.

Electricity Generation

Deep GHG reductions in BC require substantial growth in electricity demand. This demand, supplied by non-emitting generation, is a means to substitute renewable energy for fossil energy throughout the economy, from building heating, mobility, to process heat and motive power in industry.

Total electricity generation increases to 150 TWh/yr in 2050 (Figure 9). Non-hydro renewable generation accounts for a third of this power. Wind power grows substantially from now until 2030. After 2030, resources not yet used in BC, such as geothermal and solar photovoltaic, may be developed to provide an additional 23 TWh/yr in 2050.

Figure 9: Electricity Generation by Source



Because new electricity generation is costlier than the existing generation in BC, increased electricity demand results in higher averages prices. In the deep GHG reduction scenario, there is less existing low-cost power to dilute the new high-cost power. Consequently, electricity prices are about 10-15 $/MWh higher (1 to 1.5 cent/kWh) than with current policies (Table 5). However, as we demonstrate in our discussion of the economic impacts of the policy, actual energy expenditures are likely to decline over time.

Table 5: Residential Electricity Prices, 2014 cent/kWh with Enhanced Policies vs. with Current Policies

	2020	2030	2040	2050
Current Policies	12.1	12.2	13.3	14.3
Enhanced Policies	11.7	12.8	14.2	15.6

The electricity model used in this analysis is not a perfect representation of an electricity grid: An electricity grid needs the capacity to meet demand in real-time whereas this analysis models total annual electricity generation. The problem with this method is that does not explicitly account for how intermittent and non-dispatchable resources such as wind and solar are integrated into the rest of the grid.

With deep GHG reductions, wind and solar generation grow from less than 5% of generation in 2015 to around 20% by 2050. If the average capacity utilization for wind power is 25% and 13% for solar power, then roughly 45% of the generation capacity is non-dispatchable by 2050. There are many technical solutions to accommodate this change, including increasing the transmission connectivity within BC and between BC and other regions, incorporating flexible generation (i.e. the fossil fuel, biomass and geothermal generation), incorporating flexible loads, such as electric vehicles with utility influenced charging, and building electricity storage such as the pumped hydro resources that have been mapped in the Lower Mainland.

Because it is technically possible to integrate large amounts of non-dispatchable generation, the more important issue is the associated cost. This integration cost will increase the cost of electricity, but it will not change the general trend in the electricity prices in the deep GHG reduction scenario. BC Hydro currently applies a 10 $/MWh integration cost to wind and solar generation options. Even if by 2050 the integration cost for wind and solar are 2.5 times larger than this, the total integration cost spread over the entire rate base would be 0.5 cent/kWh, equivalent to a 3% increase in the price of residential electricity.

Sectoral Targets

The goal for the electricity sector is to meet growing demand while reducing the sector's already low GHG emissions. Our analysis shows that by 2030, renewable and non-emitting electricity generation must increase by 40% relative to 2015. By 2050 this electricity generation must double. This forecast is not a specific endorsement of any one source of renewable and non-emitting electricity, rather it is demonstrating that a range of resources will need to be developed to provide a stable and cost effective system.

Similarly, the supply of biofuel will need to expand dramatically from today. This fuel may be produced in BC or imported to BC, as is the majority of transportation fuel today. In either case, the goal for the biofuel sector is the same as for the electricity sector: expand without increasing its GHG emissions within BC or elsewhere.

Natural Gas Extraction, Processing Transportation, and Liquefaction

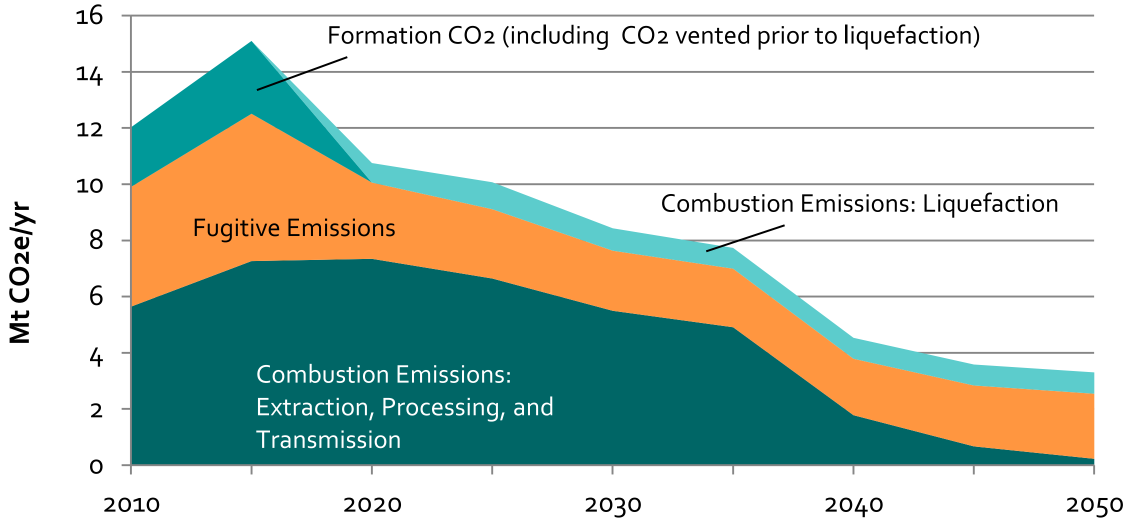
Under the influence of strong GHG emissions policies, the natural gas sector sees changes to both its output the technologies used for production. If there are deep GHG reductions, there is less demand for natural gas within BC, North America and globally relative to the current policy scenario. Accordingly, the output of the natural gas and LNG sectors in the deep reduction scenario is about 5% lower in 2020, and 25% lower thereafter (Table 6).

Table 6: Output of the natural gas and LNG sectors in the deep GHG reduction scenario

	2015	2020	2025	2030	2035	2040	2045	2050
Natural Gas Production								
Current policies	3.7	5.0	5.9	6.4	6.8	7.3	7.7	7.4
Deep GHG reduction scenario	3.7	4.9	5.3	4.7	4.6	5.2	5.9	6.4
LNG production, BCf/day								
Current policies	0.0	0.9	1.9	2.1	2.1	2.1	2.1	2.1
Deep GHG reduction scenario	0.0	0.8	1.8	1.7	1.6	1.6	1.6	1.7
LNG production, Mt/yr								
Current policies	0.0	6.4	14.5	16.1	16.1	16.1	16.1	16.1
Deep GHG reduction scenario	0.0	6.1	13.3	12.9	12.0	12.1	12.2	12.5

In the deep GHG reduction scenario, emissions for the natural gas and LNG sectors have already peaked by 2015 at 15 $MtCO_2e$/yr. By 2020, capturing and storing formation CO_2, including the residual CO_2 that would normally be removed at LNG facilities, and controlling fugitive emissions all reduce the sectors' GHG emissions to 11 $MtCO_2e$/yr. With greater use of grid electricity at LNG facilities for compression of the gas as well as ancillary power, the growing export industry adds only another 1 $MtCO_2e$/yr (Figure 10). After 2015, all new motive power for gas compression in the upstream production, processing and transmission must use electric drive (i.e. electric motors) rather than natural gas-fired turbines. As the stock of gas-fired equipment is retired and replaced with electrically power equipment, the combustion emissions decline. By 2050 the sector's emissions at just over 3 $MtCO_2e$/yr.

Figure 10: GHG Emissions by Source, Natural Gas Extraction, Processing, Transportation, and Liquefaction



The effectiveness of the policies acting on the natural gas and LNG sectors depends on their ability to prevent technological lock-in to GHG emissions. Long-lived equipment such as gas-fired reciprocating engines (e.g. for extraction) or gas-fired drives for liquefaction installed prior to 2020 can persist past 2050. Therefore, achieving deep reductions in the sector's emissions by 2050 requires implementing strong policies in the present.

This risk of technological lock-in to GHG emissions is especially relevant in the LNG sector. The LNG facilities that are built over the next ten years will still be operating in 2050. Therefore they must be compatible with BC's long-term GHG emission target. Figure 11 shows the LNG production in the deep GHG reduction scenario, broken down by the technology and energy source used. In order to achieve the 2050 emission target, LNG must be produced from facilities that are entirely electrically powered, or, if they use gas-fired turbines to drive their liquefaction processes, they must at least use grid electricity to power their ancillary loads. If the output of the LNG sector is larger than we have assumed, the sector will need to further reduce its emissions intensity.

Table 7 shows the resulting average GHG intensity of the LNG sector in BC. With a mix of electric and gas-powered facilities, and all CO_2 removed and stored upstream of the facility, the emissions intensity of the sector falls to 0.06 $tCO_2e/tLNG$. By contrast, typical emissions intensity for existing LNG facilities is roughly 0.25 tCO_2e/t LNG.

Note that the results in Figure 11 do not explicitly represent individual LNG projects. Instead they are the outcome of our simulation which allocates production to various production archetypes using a probabilistic representation of production costs.

Nonetheless, the LNG exports in this scenario could be attributed to some of the smaller projects that plan to use electrically powered liquefaction trains, such as Woodfibre and Tillbury, as well as one or two trains from a larger project proposed for the north coast, such as LNG Canada in Kitimat. If these three projects went forward, with no CO_2 vented at the facility, the industry in BC would have an average emissions intensity of 0.06 $tCO_2e/tLNG$.

Figure 11: LNG Production by Power Source

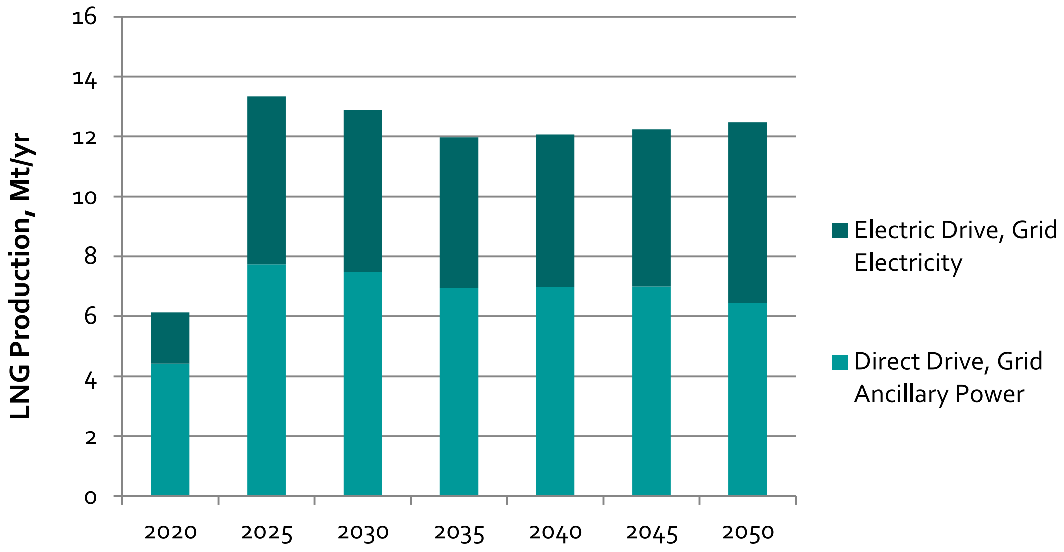


Table 7: LNG GHG Intensity

	2020	2030	2040	2050
Combustion Emissions, $tCO2_e/tLNG$	0.11	0.06	0.06	0.06
Process Emissions, $tCO2_e$ /tLNG	0.00	0.00	0.00	0.00
Total, $tCO2_e$ /tLNG	**0.11**	**0.06**	**0.06**	**0.06**

Sectoral Targets

Emissions goals for the natural gas and LNG sectors should include eliminating all routine venting of the CO_2 that is removed from the natural gas stream by 2020, including formation CO_2 removed during gas processing and prior to liquefaction. A further goal for 2020 is to reduce the fugitive emissions from upstream gas production, processing and extraction sectors by 50% per unit of gas produced.

Combustion emissions must be reduced by using electric drives rather than gas-fired turbines to power gas compression. If the upstream natural gas sector expands rapidly over the next five years, the government should aim to have roughly 30% of drives, measured by installed capacity, powered by electricity by 2020, rising to 40% by 2030 and 100% by 2050. Ideally LNG facilities would fall under this target. While some gas-fired direct drives may be installed at LNG facilities over the next decade, it is important to avoid locked-in GHG emissions from these long-lived investments; BC's 2050 emissions target will be very difficult to achieve if these drives emit more than 1 $MtCO_2$/yr by 2050.

Overall, the emissions intensity of upstream gas production, processing and transmission must fall by a factor of 10 by 2050 (i.e. from 11 $ktCO_2e$ /Bcf in 2015 to 1.1 $ktCO_2e$/Bcf in 2050).

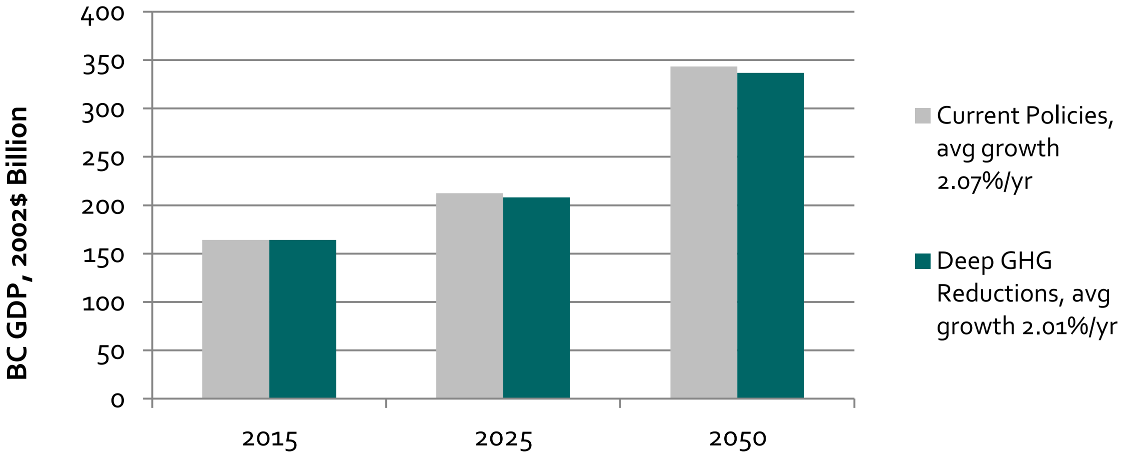
Economic Impact

In this section we provide three indicators of how deep GHG reductions in BC may affect the economy. First, we compare economic growth in the enhanced policy scenario with the current policy scenario, using BC's provincial GDP as an indicator of overall economic health. We also analyse the changes in the structure of the economy, specifically which sectors grow and which contract over the course of the forecast. Third, we highlight jobs growth by sector in the deep reduction scenario. Finally, we quantify how deep GHG reductions will affect household expenditures for energy as well as energy consuming goods, using this as an indicator of how reaching deep GHG reductions will most directly affect individuals and families.

Economic Growth and Structure

Our results show that BC's economy will continue to grow with deep GHG reductions, assuming the rest of North America is also subject to similarly stringent climate policies. Provincial GDP continues to grow in the deep GHG reduction scenario at an average rate of 2.01% annually between 2020 and 2050, compared with 2.07% annually with current climate policies. The reduced rate of economic growth is largely related to slower growth in the natural gas sector in BC, driven by a reduction in natural gas demand across North America.

Figure 12: BC GDP, with Current Policies and Deep GHG Reductions



*GDP is shown at basic prices

Many sectors are likely to contribute to economic growth in the deep reduction scenario, with services (e.g. education, health care, finances, entertainment, construction) providing the greatest absolute addition to the economy by 2050.

For context, Figure 13 shows BC's GDP in the deep GHG reduction scenario broken down by sector. These data are results from our analysis, but the 2015 results are closely calibrated to historical data from Statistics Canada.[6] Currently, resource extraction industries, which include natural gas extraction, account for about 6% of GDP. Manufacturing industries, which include LNG production, are another 9%. Utilities, which include natural gas distribution and electricity generation and distribution, are 2% of GDP. Transportation of people and goods, including pipeline transportation, accounts for 6% of GDP. Meanwhile government services and activities produce 17% of GDP. The remaining 60% comes from services. This composition changes only slightly from now to 2050 in the deep GHG reduction scenario.

Services is broad category that includes industries such as healthcare, education, arts, entertainment, finance, information, accommodation, food services, construction, retail and wholesale trade. Some services are related to energy industries, such as oil and gas construction, which accounts for about 1.5% of GDP. We have categorized these services within the oil and gas sector. The rest of the services sector is not related to energy industries, nor does it require large amounts of energy per unit of GDP.

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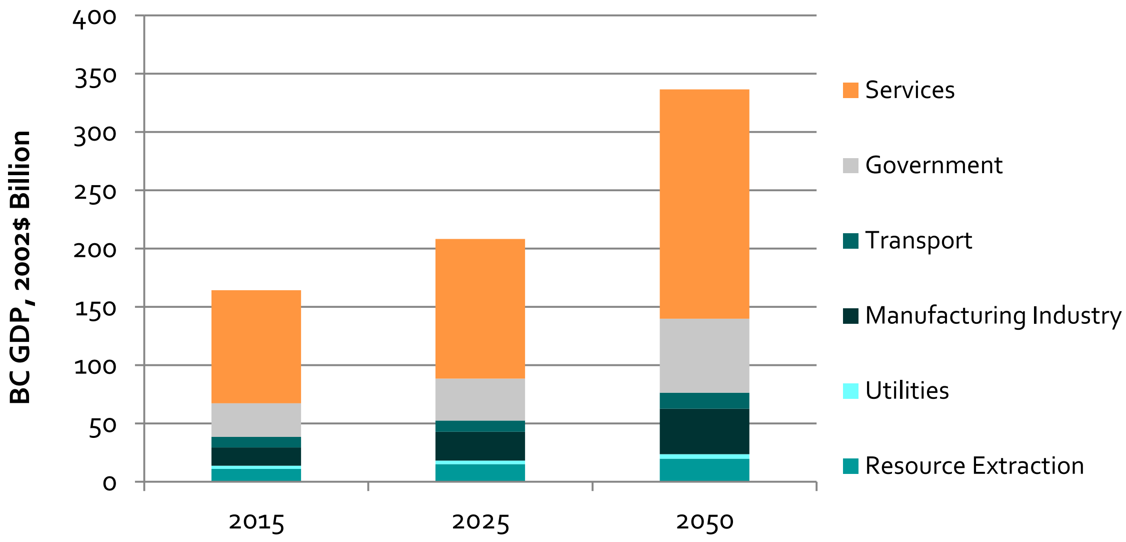
[6] Statistics Canada, CANSIM Table 326-0025

Figure 13: GDP by Sector in British Columbia in the Deep Reduction Scenario

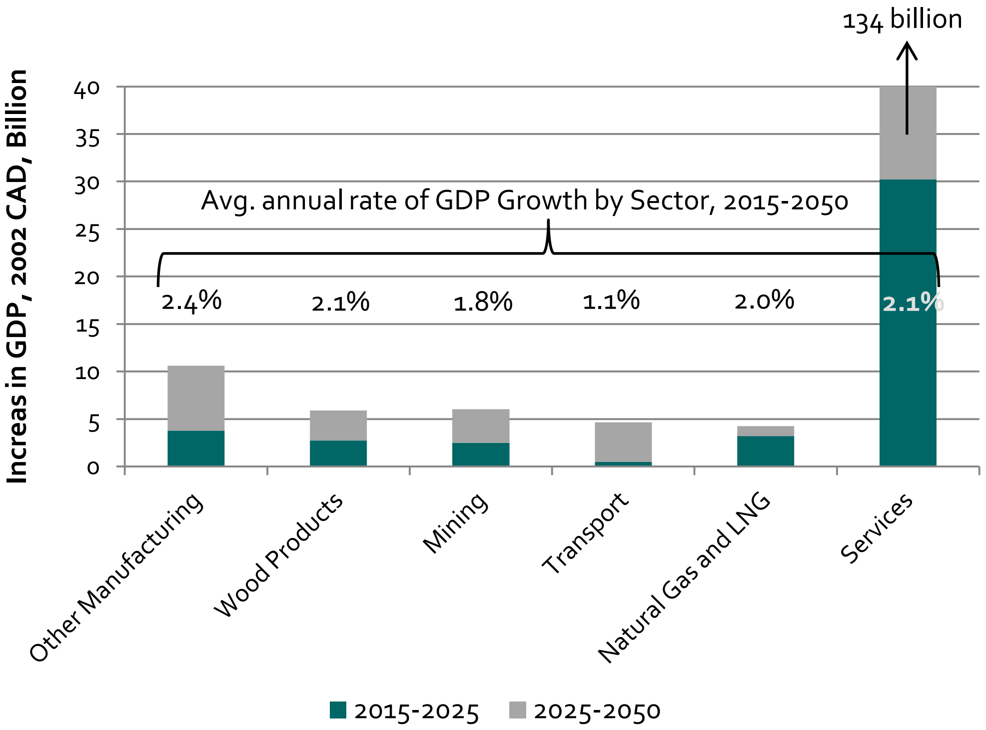


*GDP is shown at basic prices

The natural gas and LNG sectors are a potential new source of economic growth, government revenue and jobs, but many sectors will contribute to economic growth, even with deep GHG reductions. The gas sectors, including the oil and gas service industry, will add approximately $4.3 billion to the provincial economy between now and 2050, growing at an average of 2% annually over that period. Similar growth occurs in other industrial sectors such as mining or wood products (Figure 14).

Ultimately, BC's economy is dominated by the service sectors and will remain that way to 2050. Over the next 35 years, services add $134 billion to the provincial economy, accounting for 80% of GDP growth.

Figure 14: Absolute contribution to GDP Growth from 2015 to 2050 for Key Sectors with Deep GHG Reductions (Average annual % growth shown above sector column)



*GDP is shown at basic prices

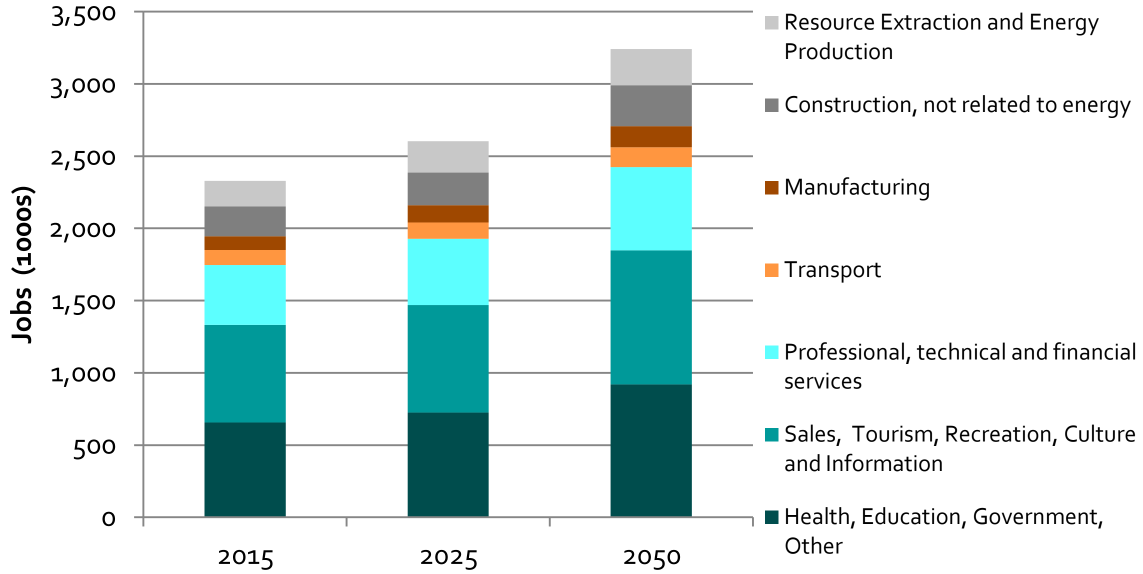
While this analysis assumes strong climate policies are implemented across North America, there are many actions the government of BC could take if a GHG policy makes a sector or industry uncompetitive. If BC has stronger climate policies than other jurisdictions, the government could support trade exposed and emissions intensive industries, preventing the job losses and carbon leakage that will happen if production leaves BC. For example, revenues from the carbon tax could be used to give output based subsidies to affected industries or be used to directly invest in GHG abatement in those industries. Alternatively, if a sector is covered by an emissions cap and trade policy, it could be given a free allocation of emissions permits rather than having to buy them through an auction.

Job Growth

Economic growth in the deep GHG reduction scenario creates new jobs across all sectors. Between 2015 and 2025, 274,000 thousand jobs are added to the economy in the deep GHG reduction scenario (12% increase from 2015). By 2050, this figure grows to almost one million jobs (39% increase from 2015, Figure 15). Because this analysis uses an economy-wide model to account for total jobs in BC from all sectors, we do not need to account for indirect jobs or induced jobs that occur in a sector due to activity in other sectors. Therefore, we discuss only direct jobs, but from all sectors.

Over the next decades most employment in BC exists within service oriented sectors such as health care, education, retail, activities related to tourism and recreation, and technical, professional or financial services. Employment in these sectors grows by 181,000 jobs by 2025, and by 676 thousand jobs from now to 2050. This is equivalent to 8% more total jobs by 2025 and 29% more by 2050, relative to 2015.

Figure 15: Jobs by Aggregate Sector, Deep GHG Reduction Scenario



Industrial Jobs, including construction and transportation (e.g. freight, warehousing, and couriers), grow substantially, collectively adding another 93,000 jobs to the economy by 2025, and 236,000 between 2015 and 2050. Relative to 2015, this is an increase in total jobs by 4% and 10% respectively. Table 8 shows a more detailed breakdown by industrial sector, with employment growth to 2050 at 51,000 in manufacturing, 35,000 in transport, 78,000 in construction, and 72,000 in resource and energy production.

Table 8: Additional Industrial Jobs in BC, 1000s

Sector	New Jobs 2015-2025	New Jobs 2015-2050
Manufacturing	**24**	**51**
Transportation	**9**	**35**
Construction (not related to energy sectors)	**21**	**78**
Resource extraction and energy production	**39**	**72**
Agriculture and agrifoods	15	29
Forestry, paper, wood products	16	32
Mining	1	1
Renewable electricity	4	7
Natural gas	3	2
Biofuel and Petroleum Fuel Refining	0	1
Total	**93**	**236**

Many of the jobs in the renewable electricity sector are related to construction. The expansion of renewable electricity generation capacity in the deep GHG reduction scenario creates 1,600 new construction jobs in 2025 compared with today. By 2025, another 2,300 new jobs are created to operate and maintain the electricity system. Continued additions to generation capacity increase the number of additional electricity construction jobs to 2,100 by 2050.[7] Total new jobs for operating and maintaining the system amount to 4,600 by 2050. Relative to 2015, the number of jobs in the electricity sector grows by 36% by 2025 and 62% by 2050.

While new jobs emerge in the natural gas sector in the deep GHG reduction scenario, job growth is slower in this sector than in other sectors for several reasons. First, our reference assumption for natural gas production and LNG exports has most growth in the sector occurring before 2025. Therefore, the relatively large numbers of construction jobs in the sector do not show up when looking at 2025 and 2050. Second, natural gas consumption in BC declines throughout the forecast as residential and commercial customers switch their energy consumption to low-GHG electricity, resulting in fewer jobs related to natural gas distribution. Third, in response to strong GHG reduction policies, natural gas demand is lower across North America in the deep

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[7] Annual construction jobs are derived from the cumulative capacity additions estimated in each five year period from the forecast results. The capacity added in each five year period is divided by five to represent annual construction. We have assumed 2.6 person years of direct employment per MW wind energy built, 7.1 per MW solar PV, 5.7 per MW hydro, 4 per MW geothermal. Based on direct local construction jobs estimated in:

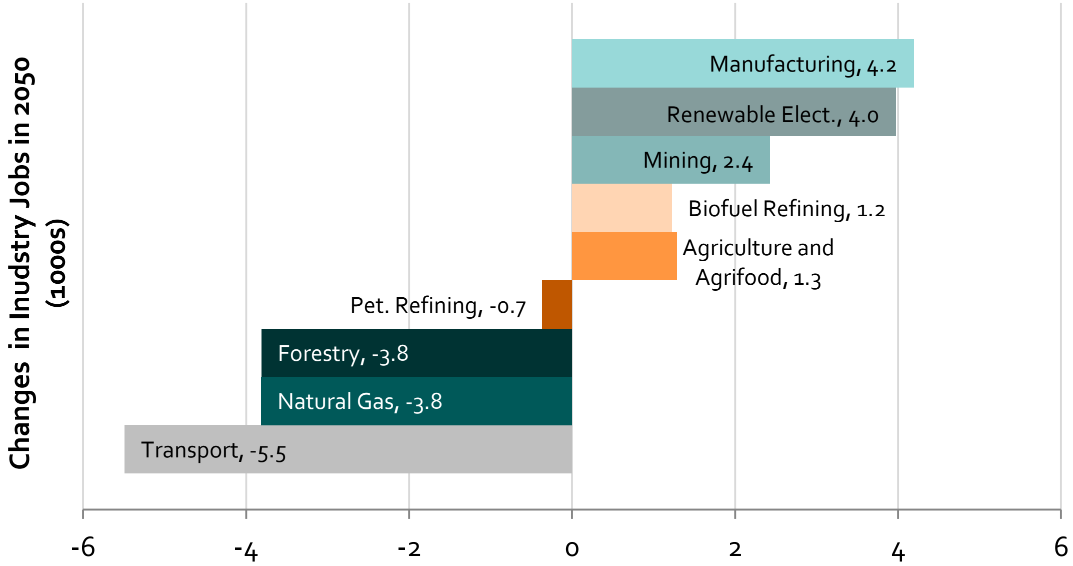
Electric Power Research Institute (EPRI) and California Energy Commission (CEC), 2001. California Renewable Technology Market and Benefits Assessment. EPRI 100119, Palo Alto , CA and Sacramento, CA.

GHG reduction scenario, slowing the growth of the BC natural gas sector and reducing the rate of job growth for extraction, processing and related services.

Achieving deep GHG reduction in BC has little impact on the rate of job growth in the province. With either current policies or the policies designed to reach BC's 2050 GHG target, total jobs in the province grow to roughly 3.25 million in 2050. The rate of job growth is slightly slower in the deep GHG reduction scenario, averaging 0.95% annually between 2015 and 2050, compared to 0.97% annually with current policies.

While the total number of jobs differs by less than 1% in 2050, there are differences in where these jobs occur, especially within the industrial sector (Figure 16). However, while the differences between the scenarios by sector are in the thousands, they are small relative to the total number of jobs in BC, at most +/- 0.2% of the total. With strong GHG policies applied across North America, manufacturing and mining appear to have a competitive advantage relative to other jurisdictions and see somewhat greater job growth than with current GHG policies applied only in BC. There is also more job growth in the renewable electricity sector, again driven by the need to build more generation capacity. Biofuel refining, which also supports the agriculture sector, sees more growth, while jobs in the petroleum refining sector decline, driven by the switch from fossil fuel to biofuel. Job growth in the natural gas sector is also slower, though again, this change is more related to climate policy outside of BC than within BC. Finally forestry and transportation also see slower job growth. Specifically for transportation, higher energy costs for transport will reduce demand for this activity from other sectors. Nonetheless, the sector still grows and employment in transportation grows by 35,000 jobs, or 33%, between 2015 and 2020.

Figure 16: Changes in jobs within industrial sectors with deep GHG reductions relative to current policies.



While not shown in Figure 16, job growth in the service sectors grows at 2.01% annually in the deep GHG reduction scenario, compared with 2.05% annually with current polices. This change does not necessarily represent greater unemployment (i.e. people without jobs that want them), but instead a reduction in the supply of labour. The supply of labour changes in response to the incentive to work, that being wages. In the deep GHG reduction scenario, real wages grow somewhat slower than in other scenarios, reducing the incentive to work relative to not working. Concrete examples of this trade-off would be people choosing when to first enter the work force, when to return to work after having kids, when to retire and when to work part-time or full-time. If the supply of labour falls, the cost of labour rises. Employers will then make do with less labour, by relying on other inputs to their business (e.g. capital or energy), reducing the rate of job growth.

Household Energy Expenditures

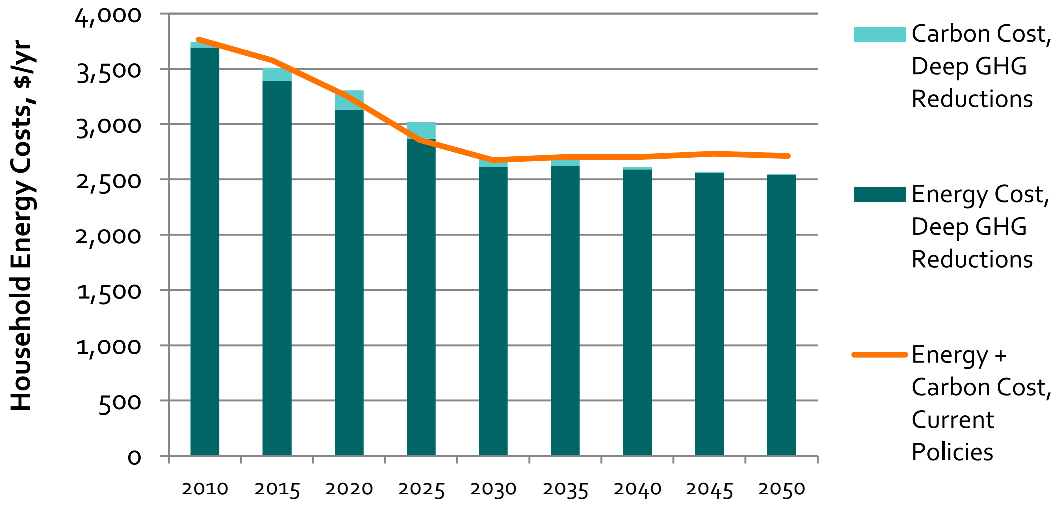
Even though retail energy prices will rise, household energy expenditures for all British Columbians will decline with deep GHG reductions. Due to our baseline assumptions for energy prices and the impact of GHG reduction policies (e.g. rising carbon cost, increased cost of energy production), we forecast that retail energy prices will rise by up 74% (Table 9). However, average energy consumption per household will fall steadily in the coming decades and this trend will be accelerated by stronger GHG reduction policies. Consequently, average energy expenditures per household decline from about $3,700/yr currently to $2,500/yr by 2050 in the deep GHG reduction scenario (Figure 17).

Table 9: Energy Prices including Carbon Cost for Households, 2014 CAD (Excl. Sales Tax)

	2010	2020	2030	2040	2050	% increase 2010-2050
Electricity, $/MWh	90.1	117.2	128.3	141.5	156.5	74%
Natural Gas, $/GJ	19.1	19.8	22.1	23.1	24.4	28%
Petroleum Fuel, $/L	1.04	1.17	1.39	1.57	1.78	71%
Biofuel, $/L	1.34	1.23	1.41	1.64	1.90	42%

For context, Figure 17 compares annual energy costs per household in the deep GHG reduction scenario with the current policies scenario. We see that initially, energy costs are lower with only current policies. However, much of the difference can be attributed to the increased carbon cost. This cost can be recycled back to households through income tax cuts or other transfers from the government. By 2040, energy expenditures are less in the deep GHG reduction scenario and this difference grows larger by 2050. Net of carbon costs, each household saves $1,800 ($52/yr) on energy between now and 2050 if BC pursues deep GHG reductions rather than keeping current policies.

Figure 17: Household Energy Expenditures, 2014 CAD/yr



However, to reduce energy costs, households must spend more upfront: energy efficient homes and electric vehicles, for example, come at a premium. Between now and 2050, we forecast that on average, each household will spend an additional $4,000 for capital, equivalent to about $115/yr in current dollars. Deep GHG reductions mean households will spend less on energy and more on energy consuming equipment relative to a current policy scenario.

We illustrate this change for two archetypal households in 2015 and 2020. The archetypes are a low energy-use household, representing an urban family, and a high energy-use household, representing a northern and rural family. We have provided these archetypes to help visualize the change in overall household energy costs. They are not a statistically representative estimation of urban versus rural or northern household energy costs. While these examples do reflect the changes in technologies that occur in the deep GHG reduction scenario, they may not represent how all households would respond to the policies and energy prices in that scenario.

The energy consumption of the archetypal high and low-energy consumption households are inspired by data from the 2010 BC Community Energy and Emissions Inventory for the city of Vancouver and the unincorporated areas of the Peace River Regional District (Table 10). Household energy consumption (i.e. in the home and for transportation) is different between these regions because:

- A family in Vancouver is more likely to live in a townhouse or apartment, whereas a family in the Peace River region is more likely to live in a detached home.
- A family in Vancouver is more likely to drive a smaller vehicle, whereas a family in the Peace River region is more likely to drive a larger vehicle.
- Individual vehicles in Vancouver are driven 35% fewer kilometers in a year than in the Peace River region, but the rate of car ownership is higher, meaning per capita vehicle kilometers travelled is similar in the two regions.
- Per capita household energy consumption (for homes and passenger vehicles) in Vancouver is 39% lower than in the Peace River region. The difference is primarily due to energy consumption in the home, which is 55% lower in Vancouver, presumably due to the milder climate and prevalence of smaller homes that share walls with other buildings.

Table 10: Household Energy use in an Urban versus Rural/Northern Community

	Vancouver	Peace River, Unincorporated
Distribution of dwelling types:		
Detached home	19%	86%
Attached home (town or row home)	22%	2%
Apartment	59%	1%
Mobile home	0%	12%
Type of vehicle by class:		
Small Car	47%	20%
Large Car	18%	12%
Light Truck, Van, SUV	36%	68%
Annual vehicle travel, km		
Per vehicle	13,804	21,026
Per capita	5,693	4,901
Household Energy consumption, GJ/yr per capita		
Gasoline or diesel	23	22
Electricity	10	20
Natural gas/fossil fuel for heating*	15	25
Wood	0	11
Total	**47**	**78**

Source: 2010 BC Community Energy and Emissions Inventory. *For the Peace River region, the natural gas value also includes about 10% heating oil and propane.

The assumptions for how the energy costs of the two archetypal households will change in the deep GHG reduction scenario are listed in Table 11. Energy prices are the same as in Table 9 and we assume wood fuel costs 12$/GJ (2014 CAD) throughout the forecast. The key assumptions are:

- Each household has one vehicle, with the low-energy consumption household driving theirs 14,000km/yr and the high energy consumption household driving theirs 21,000 km/yr. In order to contrast these two archetypal household, this assumption purposely does not reflect the different rate of vehicle ownership in Vancouver and the Peace Region. The low-energy household has a small car and buys an electric car by 2030. The high-energy household has a truck and buys a hybrid truck by 2030.

- The heat load of the low-energy household is 0.19 GJ/m^2 in 2015. This is 20% lower than the average for townhomes in BC in 2012.[8] The reduction from the average is meant to account for the home being in the milder climate of the Metro Vancouver area. We assume the household does not move to a newer and more energy efficient home. However, the heat load falls by 20% by 2030 due to normal replacement of building envelope components over the life of the house (e.g. new windows and cladding).
- The heat load of the high-energy household is 0.60, based on residential energy consumption data for the Peace River region from the Community Energy and Emissions Inventory. We also assume the heat load falls by 20% by 2030.
- In both household, gas-fired space heating is replaced with heat pumps by 2030. The heat pump is 250% energy efficient for the low-energy household. The high-energy household is in a colder climate that will reduce the performance of the heat pump, so we assume it is 170% efficient over a year. The high-energy home provides 25% of its heat with a wood stove.
- By 2030, gas-fired water heating (80% energy efficient) is replaced with electric water heating and the homes are retrofitted with drain water heat recovery pipes, reducing the energy consumption for water heating by 25%.
- The energy intensity for lighting, appliances, electronics and other plug loads are the provincial averages for 2015 and 2030, taken from the results of the deep GHG reduction scenario.

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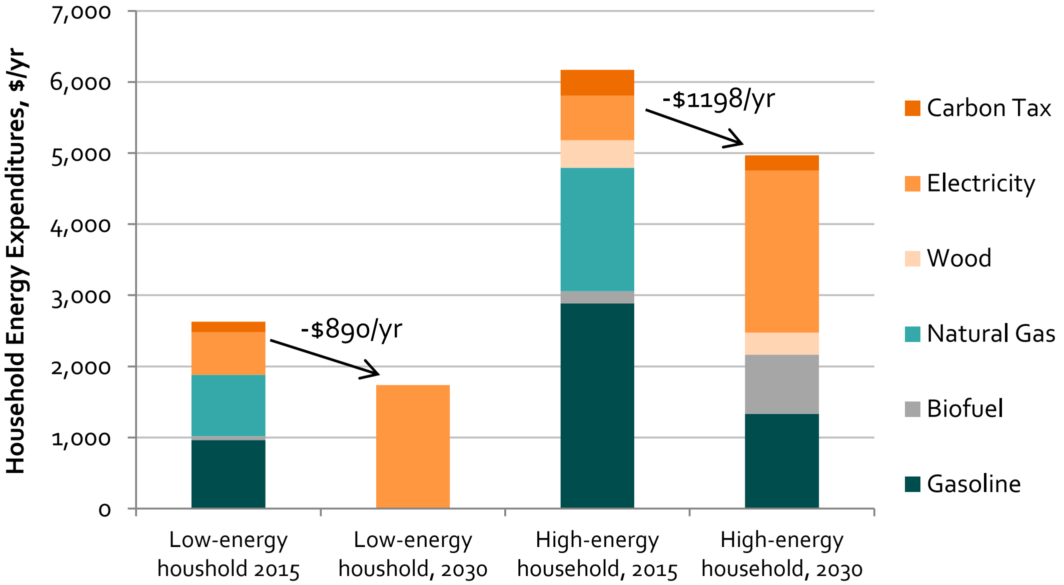
[8] Natural Resources Canada, 2015, Comprehensive Energy Use Database

Table 11: Assumptions for Archetypal Household Energy Consumption

	Low Consumption Household, 2015	**Low** Consumption Household, 2030	**High** Consumption Household, 2015	**High** Consumption Household, 2030
Personal Transport:				
Vehicles per household	1	1	1	1
Vehicle Type	Small car	Small electric car	Truck	Hybrid truck
L/100km	7.0	1.8 (equivalent)	14.0	8.0
% biofuel mix	5%	n/a	5%	33%
Vehicle km/yr	14,000	14,000	21,000	21,000
Home Energy:				
Dwelling type	Townhome	Townhome	Detached house	Detached house
Floor area, m^2	130	130	150	150
Heat load, $GJ/m^2/yr$	0.19	0.15 (-20% from 2015)	0.60	0.48 (-20% from 2015)
Fraction wood heat	0%	0%	25%	25%
Efficiency of wood heat	n/a	n/a	70%	70%
Space heating equipment	80% efficient gas	250% efficient heat pump	80% efficient gas	170% efficient heat pump
Water heating equipment	80% efficient gas	95% efficient electric with 25% drain pipe heat recovery	80% efficient gas	95% efficient electric with 25% drain pipe heat recovery
Lighting, GJ/m^2	0.039	0.007	0.039	0.007
Appliances, GJ/home	8.5	7.9	8.5	7.9
Electronics and other plug loads, GJ/home	7.4	9.9	7.4	9.9

Between 2015 and 2030, annual energy expenditures for the low-energy consumption household fall by $890/yr, from $2,629/yr to $1,739 (2014 CAD). For the high-energy consumption household, energy expenditures fall by $1198/yr, from $6,168/yr to $4,971/yr (Figure 18). By 2030, the low-energy household uses only electricity, reducing its exposure to the carbon tax to almost zero. The high-energy consumption household is still affected by the carbon tax, but through energy efficiency and fuel switching, it's annual carbon costs fall from $363/yr to $220/yr, even though the carbon price rises from 30$/t to 80$/t.

Figure 18: Annual Energy Expenditures for Archetypal Households, 2014 CAD/yr



To estimate the incremental capital cost for each archetypal household, we need to construct a counterfactual scenario. For the low-energy use household, we assume that under current policies they would have purchased a hybrid car rather than an electric car. They would have continued using gas fired heating rather than installing a heat pump and they would have not installed the heat recovery drain pipe to reduce their energy consumption for water heating. Based on the assumptions in our model, the incremental cost for an electric car relative to a hybrid in 2030 is $2,700. The incremental cost for the heat pump and heat recovery pipe are $1,100 and $850 respectively. Because we assume the improvements to the home envelope are part of required maintenance and renovation (i.e. incremental cost is 0), the incremental cost for the low-energy consumption household is $4,650 (2014 CAD). As a package, the internal rate of return (IRR) for this investment 14%.

For the high-energy consumption household, we assume they would have bought a conventional truck rather than a hybrid truck. Again, based on the model inputs used for the deep GHG reduction scenario, the incremental cost for this difference is $1,430 in 2030. We again assume they would not have installed an air-source heat pump or the drain water heat recovery pipe, bringing the incremental capital cost for the high-energy consumption household to $3,310 (2014 CAD). The IRR for the high-energy consumption household is 34%.

Appendix A: Overview of the CIMS and GEEM Models

Overview of CIMS

The CIMS energy-economy model is used to estimate the impacts of policy on energy consumption, air emissions, and capital, operating, and energy costs. The CIMS model is a technologically explicit energy-economy model that captures equilibrium feedbacks for the supply and demand of energy and energy intensive goods and services. CIMS requires external inputs – forecasted demand for products, services and energy prices. These drivers determine the processes, technologies and energy required to meet demand, enabling CIMS to produce regional and sector emissions forecasts.

The CIMS model is based on a disaggregated sector structure and technologically explicit framework, which allow it to simulate both price policies (e.g. British Columbia's Carbon Tax) and technology regulation (e.g. the federal transport emissions intensity regulations). CIMS models all the major energy supply and demand sectors in the economy as well as the main processes within those sectors (where demand for each process is satisfied by current and emerging technologies). The model captures most emissions, energy consumption and energy production in the economy; thus, it is well positioned to provide a realistic forecast of abatement opportunities in Canada.

CIMS has a detailed representation of technologies that produce goods and services throughout the economy and attempts to simulate capital stock turnover and choice between these technologies realistically.

CIMS simulations reflect the energy, economic and physical output and GHG emissions from its sub-models as shown in Table 12. Please contact the project leader at Navius Research for detailed description of the model (see inside cover for contact information).

Table 12: Sector Sub-models in CIMS

Sector	BC	Alberta	Sask.	Manitoba	Ontario	Québec	Atlantic
Residential	▨	▨	▨	▨	▨	▨	▨
Commercial/Institutional	▨	▨	▨	▨	▨	▨	▨
Personal Transportation	▨	▨	▨	▨	▨	▨	▨
Freight Transportation	▨	▨	▨	▨	▨	▨	▨
Industry							
Chemical Products	▨	▨			▨	▨	
Industrial Minerals	▨	▨			▨	▨	▨
Iron and Steel					▨	▨	
Non-Ferrous Metals	▨			▨	▨	▨	▨
Metals and Mineral Mining	▨		▨	▨	▨	▨	▨
Other Manufacturing	▨	▨	▨	▨	▨	▨	▨
Pulp and Paper	▨	▨			▨	▨	▨
Energy Supply							
Coal Mining	▨	▨	▨				▨
Electricity Generation	▨	▨	▨	▨	▨	▨	▨
Natural Gas Extraction and liquefaction	▨	▨	▨	▨	▨	▨	▨
Crude Oil Extraction	▨	▨	▨		▨		▨
Petroleum Refining	▨	▨	▨		▨	▨	▨
Agriculture & Waste	▨	▨	▨	▨	▨	▨	▨

Overview of GEEM

The analysis relies on the GEEM macroeconomic model to generate an economic forecast for British Columbia's economy. GEEM is a computable general equilibrium (CGE) model of Canada and the United States, which simulates how the economy evolves under different economic conditions. In the GEEM model, households and sectors that produce goods and services (e.g., electricity generation, pulp and paper, and petroleum refining) are explicitly represented. Each sector is characterized by what it produces (e.g., electricity) and the inputs required in production (i.e., capital, labour, energy and materials). Commodities that are produced can then be sold to other producers (as intermediate inputs), to households (the final consumers of goods produced in the economy), or to other regions and the rest of the world as exports. Commodities can also be imported from other regions or the rest of the world.

As the model steps through time, it ensures that markets clear for all commodities and factors by adjusting prices. For example, growth in pulp and paper production may increase demand for electricity in a single region, which must be generated provincially or imported. The price for electricity increases or decreases until supply matches demand.

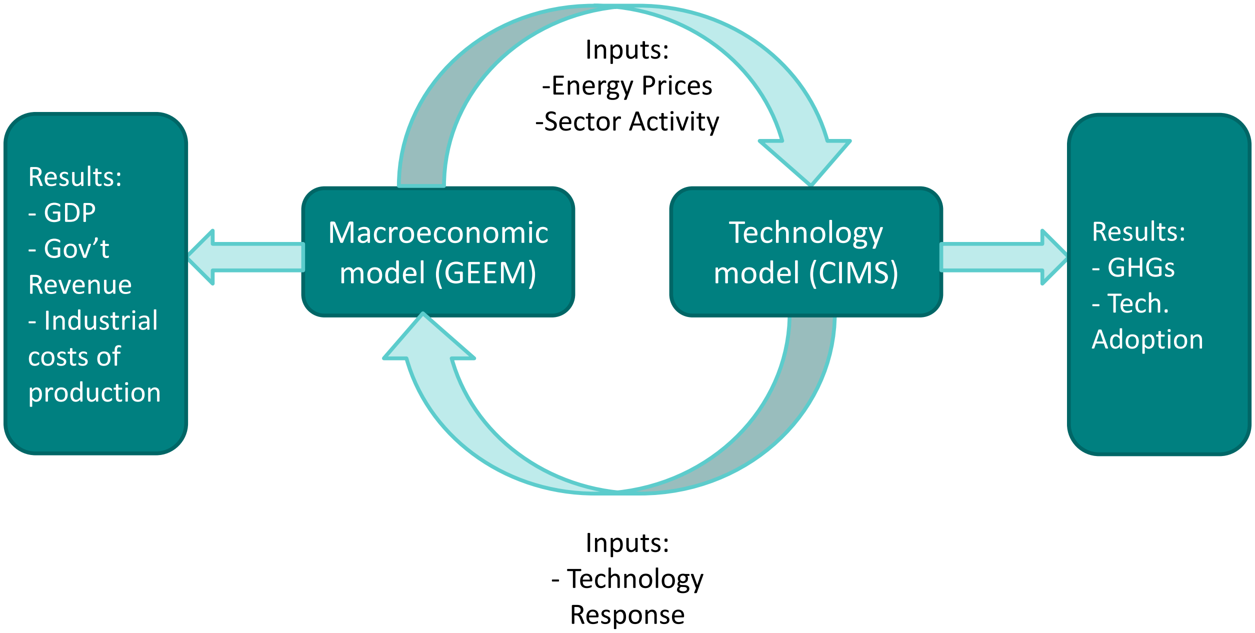
Due to their framework, CGE models show how policies or different economic conditions alter the structure and growth of the economy. A policy leading to the contraction of one sector has a ripple effect throughout the economy as all sectors of the economy return to equilibrium. For example, a policy causing an increase in the cost of producing pulp and paper or refined petroleum products (assuming the prices for these goods remain constant) can lead to a loss of competitiveness and lower production levels. In turn, lower production would reduce the output from sectors that supply these sectors with goods and services, and capital and labour would be reallocated throughout the economy. Please contact the project leader at Navius Research for detailed description of the model (see inside cover for contact information).

Linking CIMS and GEEM

This study employs an integrated modeling framework with two separate models, providing insight into the impact of BC climate policy. The rationale for using different models is that different tools have strengths and weaknesses. By combining two separate models, we are able to benefit from the strengths of each model.

The GEEM model, as described above, is designed to show how policies affect the economic structure of British Columbia. The model can show how any policy change will affect each sector of the economy in terms of levels of activity (i.e., physical production) as well as income generated by activity (i.e., gross domestic product). The CIMS model is a technology simulation model that simulates how policies affect the technological choices of households and firms.

Figure 19: Integrated modeling framework



Integrating the two models occurs in two stages:

Stage 1: Informing the technological responses in GEEM by using CIMS

The technological parameters in GEEM are estimated such that they provide a reasonable approximation of the technological responses observed from CIMS. This process ensures that GEEM characterizes the high level of technological detail contained in CIMS.

To complete this process, the CIMS model was simulated from 2005 until 2050 under different combinations of energy prices. Once the simulations in CIMS were complete, we manipulated the CIMS outputs into the end-use categories in GEEM. We were then able to statistically estimate the elasticities of substitution and capital value shares for the energy end-uses in GEEM.

Stage 2: Informing activity and energy prices in CIMS by using GEEM

The CIMS model requires an external forecast for activity from each sector of the economy as well as energy prices for every scenario simulated in this project. Every scenario begins with a simulation of the GEEM model to provide a forecast for activity as well as energy prices through 2050. This information is then fed to the CIMS model to simulate the technological choices and GHG emissions in BC's economy.

At the conclusion of each simulation, the GEEM model provides insight into how policies affect:

- Gross domestic product (provincial total at basic prices as well as by sector);
- Activity levels by sector;
- Energy prices;
- Government revenue;
- Industrial costs of production;
- Trade flows;
- Distributional impacts (forthcoming in subsequent analyses);
- Employment (forthcoming in subsequent analyses); and
- Other key indicators.

The CIMS model provides insight into:

- Greenhouse gas emissions;
- Energy consumption;
- Technological choice and technology dynamics.
- Energy expenditures

Appendix B: Detailed Modelling Inputs and Assumptions

Calibration to Historical Data

Individual sectors are calibrated to historical data over a back-casting period (2000-2014) using several sources. Energy consumption, energy intensity, GHG emissions and sector activity for the residential buildings, commercial/institutional buildings and transportation sectors are calibrated by end-use (e.g., water heating vs. lighting vs. space heating) to the Comprehensive Energy Use Database from the Office of Energy Efficiency at Natural Resources Canada.[9] Industrial sectors are calibrated using a combination of the Comprehensive Energy Use Database and publications and data from the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC). Provincial disaggregation of industrial energy use and emissions is achieved by parsing out national data according to provincial energy consumption data contained in the Report on Energy Supply and Demand by Statistics Canada. The calibration of all sectors by province is cross-checked against GHG emissions data in the National Inventory Report from Environment Canada, and in the case of this project specifically, BC's GHG Inventory.

Two additional data sources are used to calibrate the electricity sector and the oil and gas sector. Electric Power Generation, Transmission and Distribution data from Statistics Canada is used to calibrate the energy consumption and GHG emissions associated with power production in each province. These data also permit calibration of the method and efficiency of electricity generation. Historical fugitive and combustion GHG emissions associated with oil and gas extraction are calibrated against data collected by Clearstone Engineering.[10] Again, this calibration is checked against the national and provincial inventories.

Energy Prices

Figure 20 and Figure 21show the wholesale natural gas price and oil price forecasts we have used in this analysis.

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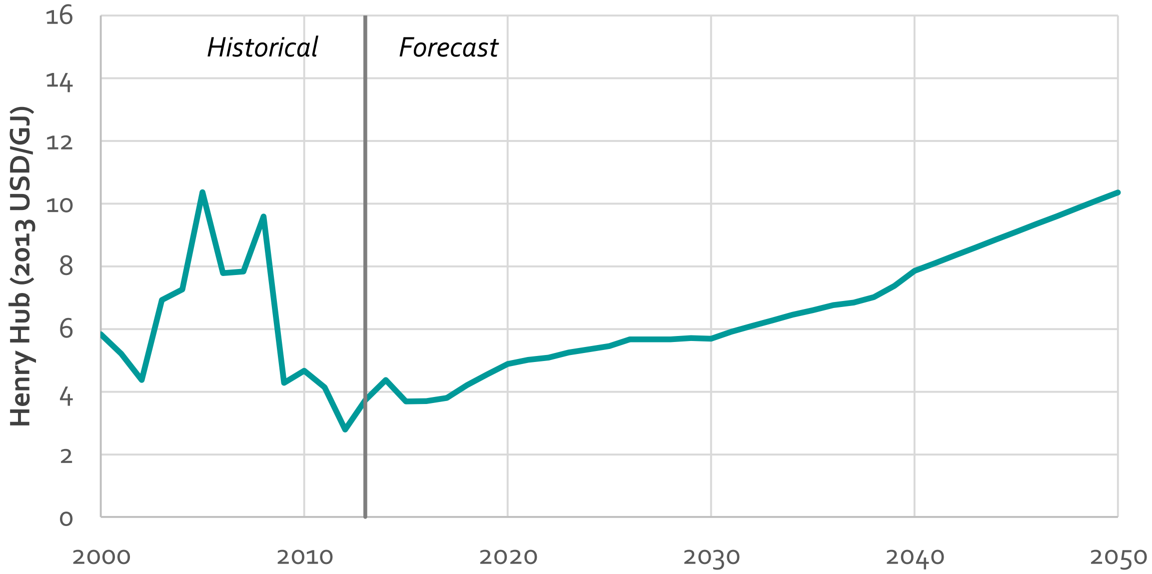
[9] http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

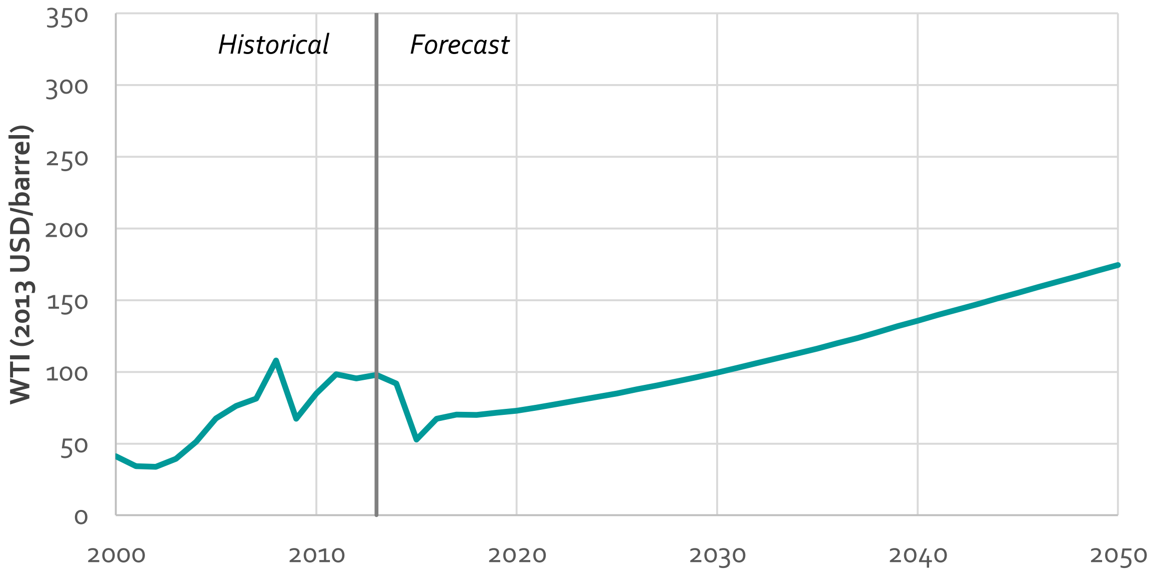
[10] [EC] Environment Canada. 2014. Technical Report on Canada’s Upstream Oil and Gas Industry prepared by Clearstone Engineering. June 2014.

Figure 20: Natural Gas Price Forecast (Henry Hub Benchmark)



Source: US Energy Information Administration, 2015 Annual Energy Outlook. Our extrapolation after 2040

Figure 21: Crude Oil Price Forecast (West Texas Intermediate Benchmark)



Source: US Energy Information Administration, 2015 Annual Energy Outlook. Our extrapolation after 2040

For natural gas, we converted wholesale benchmark prices to retail prices by including;

- The regional differential in wholesale prices from Henry Hub in British Columbia, based on the Pacific and West South Central regions of the United States in the 2015 Annual Energy Outlook by the US Energy Information Agency.

- The daily basic charge for each customer charge by FortisBC (in $/day, converted to $/GJ with an assumption for daily consumption)
- The retail margin charged by FortisBC for distributing natural gas in British Columbia, covering the cost of gas transportation, storage and delivery)

For petroleum fuels we converted the benchmark price to retail prices in by including:

- The discount in western Canadian oil relative to the WTI price, based on the Sproule Escalated Forecast, March 31 2015[11]
- Refining and marketing margins in BC, based on Kent Marketing[12]
- Provincial and Federal excise taxes as well as transit taxes which are summarized by Petro-Canada[13]

Key Technology Assumptions

Electricity Generation Technologies

Technology cost and operating parameters are based on the US Energy Information Administration NEMS model documentation, supplemented with BC Hydro's 2013 Resource Options Report Update for renewable energy (including geothermal). The costs presented here exclude carbon charges and potential costs associated with integrating intermittent resources. Tidal and wave power technologies are not included in the model. We assume no nuclear generation is built in BC.

Most of the electricity generation resources do not have a single cost. For example, many wind power opportunities would have a lower levelized cost than we have assumed, while others would have a higher cost. The CIMS model cannot accommodate this explicit variation in the cost of generation. However, CIMS assumes costs for a given technology are heterogeneous and exist on a distribution around the value listed in Table 13. Therefore, the modelling indirectly accounts for the variation in generation costs.

Solar Photovoltaic power is subject to a steep declining cost. By 2050, its levelized cost is 70 $/MWh with the poor to moderate solar resource in BC.[14] Because our

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[11] http://www.sproule.com/forecasts/archives

[12] http://kentreports.com/wpps.aspx

[13] http://retail.petro-canada.ca/en/fuelsavings/2139.aspx

modelling framework does not simulate short term electricity supply and demand, we cannot fully represent how low-cost solar electricity would integrate into the grid. On one hand, it becomes the cheapest source of electricity. On the other hand, it will not produce during the annual peak load in BC which typically occurs during winter evenings. As such we have constrained it so that it may not account for more than 20% of new electricity generation. Solar can be built at the both the utility scale and distributed scale. Without any specific policy to change consumers' investment behaviour, we assume they make the decision to invest in building integrated solar generation using an implicit discount rate of 20-30%. In other words, they have a preference for rapid payback on investment which constrains distributed solar generation.

While we have used the BC Hydro estimate for the cost of geothermal power, we have not constrained its ultimate capacity. Recent analysis by the Canadian Geothermal Association suggests that geothermal generation could provide upwards of 12 TWh/yr of electricity at less than 100$/MWh.[15]

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[14] IEA, 2014, Technology Roadmap: Solar Photovoltaic Energy

[15] Canadian Geothermal Energy Association, 2014, Geothermal Energy: The Renewable and Cost Effective Alternative to Site C

Table 13: Current Electricity Generation Costs for New Facilities

	Average Levelized Cost ($2014 CAD/MWh)
Renewable Energy	
Large Hydro	112
Run-of-River Hydro	116
Wind	115
Solar PV	314
Geothermal	112
Biomass Combustion	95
Fossil Fuel Technologies	
Diesel	359
Single Cycle Gas Turbine	53
Combined Cycle Gas Turbine	62
Combined Cycle Gas Turbine with carbon capture and storage	102

Notes: Assumes 2015 energy prices as described above; capital costs are amortized with a 10% discount rate over a period of 30 years; and a capacity factor of 85% for conventional resources. Carbon costs are not included in the levelized cost of energy.

Vehicle Hybridization and Electrification

Table 14 shows the associated costs for various archetypes of personal and light/medium freight vehicles included in CIMS. A declining capital cost function in the model endogenously determines the cost decline as a function of cumulative production. The lowest cost for electric vehicles is based on a battery cost of 150 $/kWh, down from a starting cost (pre-2010) of 1000$/kWh.

Table 14 Overview of incremental transport vehicle motor capital costs relative to high efficiency internal combustion reference

Technology archetype	Starting cost (2012$)	Lowest cost (2012$)
Passenger vehicles		
Electric (150km)	29,158	3,930
Hybrid-electric	2,899	1,398
Plug-in hybrid (30km)	11,926	3,517
Plug-in hybrid (60km)	18,580	4,765
Light/medium freight trucks		
Hybrid	8,617	1,616
Electric	56,105	10,520
Plug-in hybrid	13,755	2,579

Low Energy and Emission Homes and Buildings

Table 15 through Table 19 present our assumptions for the cost and energy performance of low energy and emissions building and home technologies.

Table 15: Heating energy intensity (GJ useful energy per m^2) by detached home archetype

Province	2000-2010 Vintage	Current codes (~enerGuide 78)	Net-Zero Ready (Thin Wall)
British Columbia	0.20	0.10	0.07

Table 16: Incremental cost of net-zero ready homes relative to current codes (2010 $CAD)

Archetype	$/m^2	$ per home (313m^2)
Single stud (thin wall) net-zero ready	22	6,882

Table 17: Cost and energy efficiency of home heating equipment

	Cost (2010 $CAD)	Efficiency (% over year)
Gas Furnace	3,922	90%
Air source heat pump	5,375	150-250%
Cold climate air source heat pump	9,300	210-260%
Ground Source Heat Pump	21,000	320%

Table 18: Summary of net-zero ready building requirements

	Unit	Model National Energy Code for Buildings 1997	Net-zero ready Envelope with High Heat Pump
Window U value	W/m²°C	3.2	0.94
Window S value	shading coefficient	0.74	0.31
Wall RSI	m²°C/W	1.82	5
Roof RSI	m²°C/W	2.13	5.5
Heating Efficiency	%	80%	300%
Demand control ventilation	Type, % floor area covered	none	CO2 sensor, 100%
Heat recovery ventilation	% of heat	0%	80%
cooling COP		3.8	5
Hot water Efficiency	%	80%	85%
service water reduction	%	0%	70%
heating plant	type	on/off	Modulating/ Condensing
Lighting power density	W/m^2, based on T8 lights	18	6
Lighting controls	Type and % floor area covered	none	daylight and occupancy, 50%

Table 19: Cost premium for the net-zero ready building archetype

Component	Description	$/m2 floor area
Wall and roof insulation	plus one RSI unit for wall and roof	4
Windows	Double to triple glaze ~20% premium per window	10
CO2 sensor	One sensor per 100 m2	7
Heat plant	Heat Pump rather than boiler	4
Total		**25**

Natural Gas Liquefaction

Our representation of natural gas liquefaction includes gas-fired direct drive technologies, with single cycle and combined cycle efficiencies, producing their own ancillary power or drawing that power from the grid. We also include an archetype of grid powered electric drive. For all gas liquefaction, we include process emissions of CO_2 removed and vented from the natural gas stream prior to liquefaction. Assuming 1% CO_2 in pipeline gas, this produces process emissions of 0.028 $tCO_2e/tLNG$. We assume these process emissions can be mitigated if they are removed and stored upstream of LNG facility. This process could occur at a processing plant, in the same way that the CO_2 content of field gas may be removed and sequestered in order to reach pipeline specifications.

Table 20: LNG Technology Archetype GHG Intensities, $tCO_2e/tLNG$

	Combustion GHG, Single Cycle	Combustion GHG, Combined Cycle	Process GHG, no CCS	Process GHG, with CCS
Direct Drive	0.184	0.130	0.028	-
Direct Drive, ancillary load from grid	0.147	0.104	0.028	-
Electric Drive, grid powered	-	-	0.028	-

Appendix C: Carbon Tax Revenues

Table 21 shows the revenue from the carbon tax in the deep GHG reduction scenario. The revenue is based on the carbon price multiplied by the covered emissions, those being combustion emissions. The values exclude process emissions such fugitive emissions from natural gas operations or cement production.

Table 21: Carbon Tax Revenues, million 2015 CAD

	2020	2025	2030	2035	2040	2045	2050
Revenue in given year	2,211	2,780	2,291	1,900	1,318	987	758
Cumulative, over five year period ending the given year	8,324	12,885	12,434	10,283	7,755	5,596	4,246

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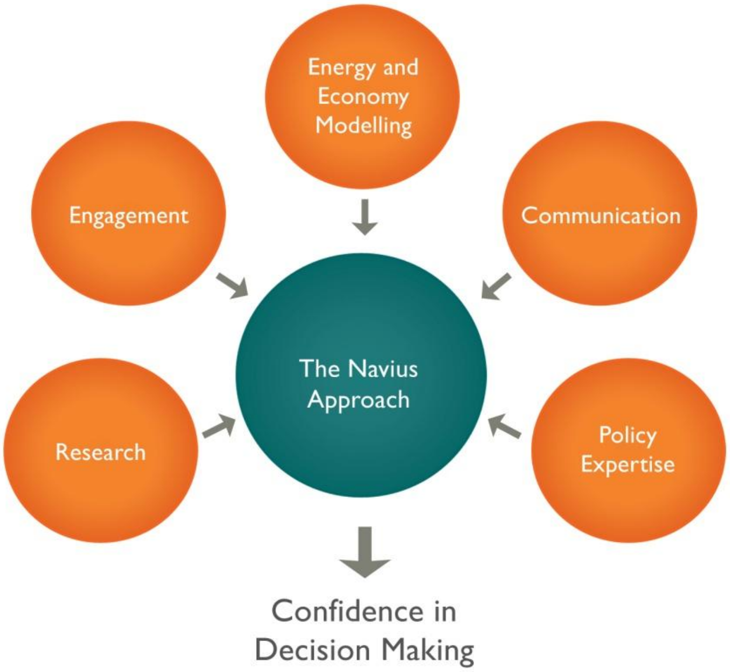

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