Integrated Resource Plan

Appendix 6C

Electrification Potential Review

BC Hydro Electrification Potential Review Final Report

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Summary

Introduction

Significant reductions in greenhouse gas (GHG) emissions are required to reduce the risk human-induced climate change. Energy efficiency and switching between fossil fuels (i.e. coal to natural gas) can reduce greenhouse gas (GHG) emissions, but the deep cuts required to reduce the risk of climate change (~50-80% below current emissions) can only be achieved through the use of low- or zero-emissions primary energy resources (e.g., hydroelectric power, wind, solar, or coal or gas with carbon capture and storage) and energy carriers (e.g., electricity, biofuels or hydrogen). Currently, the only widely-available zero GHG energy carrier in Canada is electricity and large reductions in GHG emissions will likely require switching to electricity (i.e., "electrification") as a way to substitute zero-emissions energy for the fossil fuels that power most homes, businesses and vehicles.

British Columbia has both stringent GHG emissions targets and substantial existing and future zero-emissions electricity resources. This situation may provide great potential for GHG abatement through electrification, but it is not clear to what extent and under what conditions electricity will be used in place of fossil fuels. It is not a technical question whether low GHG emissions electricity becomes can replace fossil fuels – most of the necessary technology exists today. Rather, it is an economic question; there are many reasons we currently do not use electricity in every feasible application. The primary reason relates to the operating cost of using electricity, which is typically more than 50% higher than natural gas and other fossil fuels per unit of energy. Additionally, there are technical difficulties and higher costs surrounding electricity storage, especially on vehicles.

The status quo use of electricity and fossil fuels is less expensive for consumers than greatly increased electrification. However, this result is dependent on technologies considered, discount rates, length of time used to calculated net present values, natural gas and electricity prices, and finally GHG prices; British Columbia's carbon tax started at $10 per tonne in 2008 and is supposed to rise to $30 per tonne in 2012. These GHG prices were not established to hit a given target, and deep emissions reductions will require a much stronger policy signal. Thus, the potential for electrification will change if the strength of climate policy continues to grow in British Columbia.

A primary driver of electrification is the relative cost of electricity versus other fossil fuels. This ongoing cost, in addition to the differences in capital costs between electric and fossil fuel technologies, determines whether electricity is used rather than fossil fuels in applications where the option exists. GHG pricing applies an additional cost to fossil fuels based on their carbon content, changing the price difference relative to electricity. If electricity is produced from zero emissions sources, GHG pricing will have no effect on the electricity price and will reduce the cost premium of using electricity.

All else being equal, a GHG price will encourage different amounts of electrification in different sectors and end-uses depending on the relative efficiencies and capital costs of electric and fossil fuel combustion technologies.

While GHG pricing encourages electrification, rising electricity demand will be tempered by the cost of new electricity generation capacity. In British Columbia new demand will likely be supplied by increasingly costly hydro, wind and other renewable energy projects. As these projects are built, the average cost of electricity will rise, providing a negative feedback to the policy induced electrification. Under a given set of market and policy conditions, a specific equilibrium exists between the positive and negative drivers to electrification which in turn determines the extent of electrification.

This study has investigated the potential for electrification in British Columbia by answering the following questions:

- To what degree will consumers and firms use electrification to reduce GHG emissions between the present and 2050, and how will this fuel switching affect electricity demand?
- What sectors and technologies have the greatest potential for electrification?
- Given the impact of electrification on GHG emissions and electricity demand, how can this fuel switch be managed strategically?

Methodology

We used the CIMS energy-economy simulation model to explore the potential for GHG reductions through electrification in British Columbia. CIMS is a technologically detailed model that simulates the evolution and renewal of capital stock (buildings, cars, boilers etc.). It simulates realistic consumer and firm decision making when acquiring new capital stock, integrates energy supply and demand and accounts for macro-economic feedbacks.

A version of CIMS specific to British Columbia was used to forecast energy consumption, GHG emissions and technology market shares to 2050 in each sector for each scenario of this study. The only exception to this methodology is the exclusion of natural gas loads coming from potential production in the Horn River Basin or from liquefied natural gas (LNG) terminals in the Kitimat area. We have not included them since electrification of these facilities is the subject to other analyses being conducted in parallel with this work.

We reviewed the CIMS model to identify missing technologies and dynamics that would have a substantial impact on the potential to reduce GHG emissions by electrification. The review covered anything that could provide a significant amount of electrification abatement, could create significant new electricity demand, or could dramatically change how electricity prices would respond to increasing electricity demand.

To keep the analysis consistent and relevant to current BC Hydro planning, we aligned the economic growth and energy price assumptions of CIMS with the assumptions used in the ongoing BC Hydro Integrated Resource Plan (IRP). Using CIMS, we forecasted electrification in response to three economy-wide carbon prices (Table ES 1). For most sectors in British Columbia, electrification is mediated by the difference in electricity and natural gas prices. Therefore, we also explored the sensitivity of electrification to three natural gas price forecasts (Table ES 2) for a total of nine electrification scenarios.

Table ES 1: GHG price forecasts used in the electrification scenarios, 2005 CAD $/tCO$_2$e

GHG price scenario	2010	2020	2030	2040	2050
High, scenario D from IRP	9	69	128	236	275
Medium, scenario B from IRP	9	31	71	132	150
Low, BC Only	9	30	30	30	30

Table ES 2: Henry Hub natural gas price scenarios, 2005 CAD $/GJ

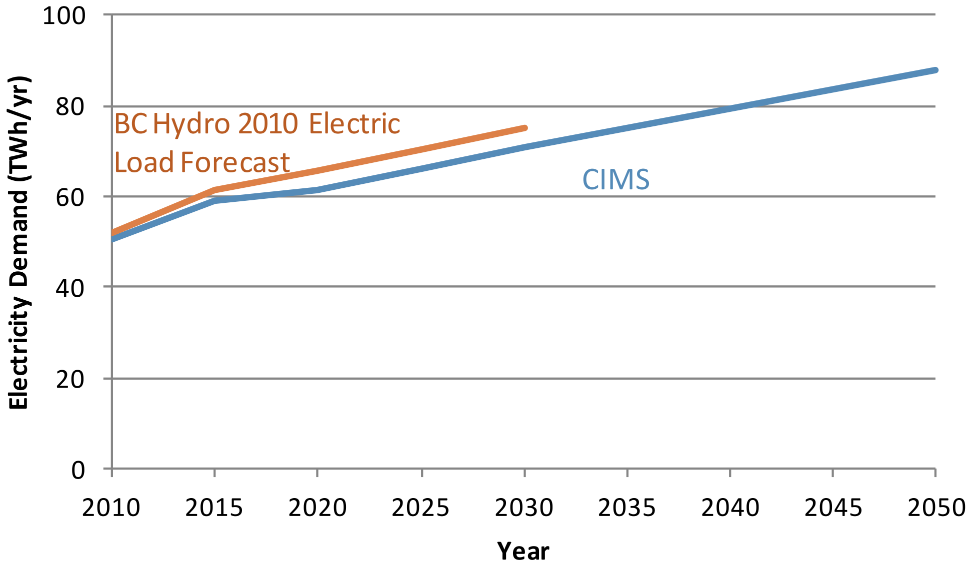
Natural gas price scenario	2010	2020	2030	2040	2050
Low	4.0	4.7	4.7	5.6	6.7
Medium	4.0	7.0	7.9	9.6	11.5
High	4.0	11.4	13.4	16.0	19.1

The electricity prices used in each scenario were based on a renewable electricity supply curve to realistically represent how the cost of new supply would constrain electrification. Results, organized by scenario and sector, include abatement by electrification, new electricity demand, and changes in the adoption of key electric technologies relative to the reference scenario.

Reference Scenario

We used the CIMS model to produce a reference forecast of energy consumption and GHG emissions in the absence of GHG pricing. The reference scenario shows steady growth in GHG emissions and electricity demand from most sectors. Emissions and new load from the natural gas sector (excluding Horn River Basin and natural gas terminals) grow rapidly to 2020 and remain significant for the duration of the forecast. The CIMS load forecast is consistent with the BC Hydro 2010 load forecast. However, a discrepancy develops between the two forecasts due to different rates of energy efficiency improvements and different assumptions about the electricity demand of new appliances and electronics in buildings (Figure ES 1).

Figure ES 1: Comparison of CIMS and BC Hydro Reference Scenario Electricity Load Forecasts

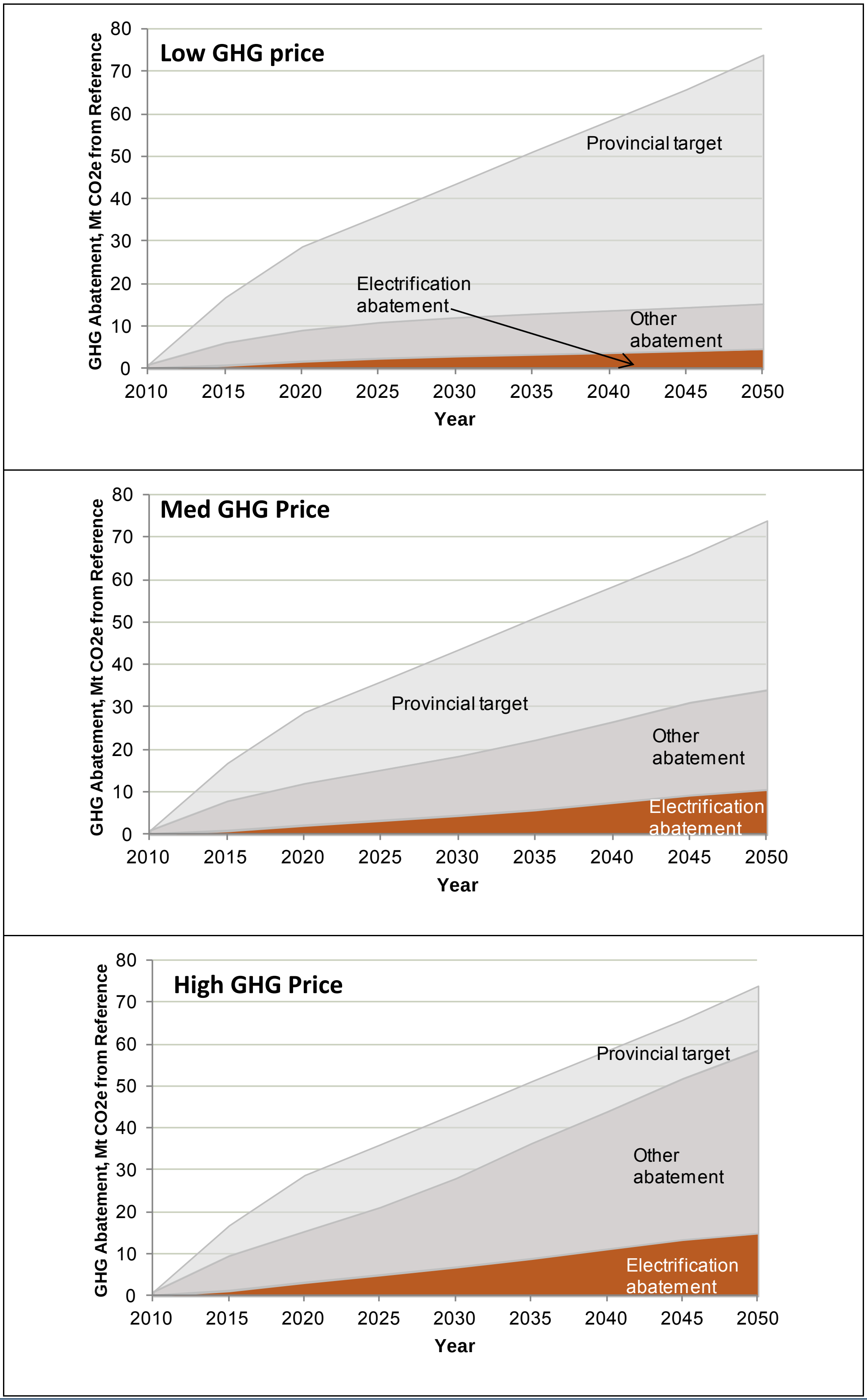


Results and Discussion

To what degree will consumers and firms use electrification to reduce GHG emissions between the present and 2050, and how will this fuel switching affect electricity demand?

Electrification can significantly reduce future GHG emissions and this abatement will account for a significant proportion of the total abatement resulting from climate policy. Electrification abatement accounts for one fifth of total abatement under current British Columbian climate policy (the low GHG price). If GHG policy is strengthened, as represented by the medium and high GHG price scenarios, electrification abatement will account for a third of total abatement. In absolute terms, by 2050, electrification may reduce emissions by up to 5 $MtCO_2e$/yr under the low GHG price, 11 $MtCO_2e$/yr under a medium GHG price, and 15 $MtCO_2e$/yr under a high GHG price (Figure ES 2).

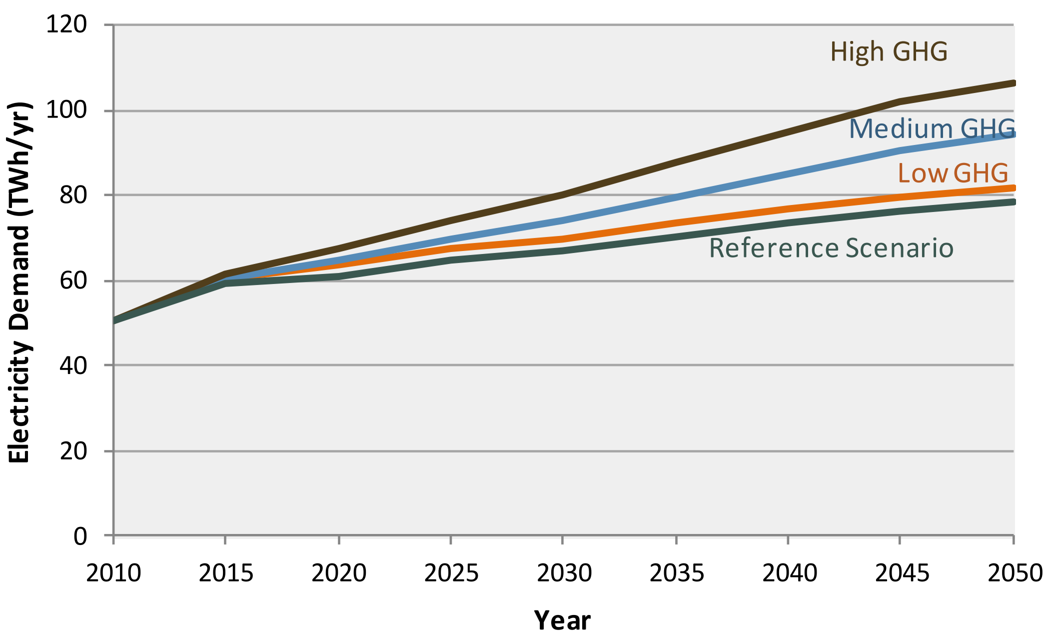
Figure ES 2: Electrification abatement in context, medium natural gas price



These GHG reductions are highly sensitive to both the strength of climate policy and the relative difference in electricity and natural gas prices. While total GHG abatement is not highly sensitive to natural gas prices, this analysis shows that the specific abatement actions used, namely electrification, may be strongly influenced by energy prices in addition to climate policy. Low natural gas prices constrain electrification abatement while high natural gas prices increase electrification abatement. Electrification is less sensitive to other fuel prices, such as liquid petroleum or bio-fuels, since the substitution between these fuels and electricity requires significantly different upfront costs (e.g., an electric vehicle battery versus an internal combustion engine).

Deep reductions of British Columbia's GHG emissions will results in substantially more electricity demand. Electricity consumption in the low GHG price scenario is only slightly above the reference scenario (approximately 3 TWh/yr). However, the medium and high GHG price scenarios result in significant additional electricity demand beyond the reference forecast. The medium GHG price increases demand by an additional 10-20 TWh/yr by 2050 (roughly 25% increase) while the high scenario see demand rise by 20-35 TWh/yr (~33% increase) relative to the reference scenario (Figure ES 3).

Figure ES 3: Electricity demand by GHG price scenario, medium natural gas price



This electrification abatement occurs even though new electricity supply comes from increasingly costly zero-emissions resources. The electricity from the small hydro and wind power resources that will dominate new electricity supply is more expensive than existing resources. Furthermore, there is a limited supply of electricity available at any given cost. When electricity demand increases relative to the reference case, so too does the electricity price. However, the potential for GHG abatement through electrification remains large (over 10 $MtCO_2e$/yr by 2050) even when electricity rates increase by two to three cent/kWh relative to the reference scenario price (Table ES 3).

Table ES 3: Electricity rate impacts by scenario (2005 cent/kWh relative to reference scenario)

GHG price scenario	Natural gas price scenario	2010	2020	2030	2040	2050
Low	Low	0.0	0.1	0.0	-0.2	-0.3
	Medium	0.0	0.3	0.3	0.3	0.4
	High	0.0	0.7	1.1	1.2	1.3
Medium	Low	0.0	0.2	0.3	0.7	1.0
	Medium	0.0	0.4	0.8	1.3	1.8
	High	0.0	0.9	1.5	2.0	2.5
High	Low	0.0	0.5	1.0	1.8	2.4
	Medium	0.0	0.7	1.4	2.3	3.0
	High	0.0	1.1	2.0	2.9	3.6

The benefit of electrification in reducing GHG emissions depends on the use of this higher cost zero-GHG electricity. If electricity generation is GHG intensive, then most of the abatement from electrification would not occur. Either the carbon price would be passed through the electricity rates, reducing electricity demand, or the emissions from electricity generation would negate the electrification abatement achieved in other sectors.

What sectors and technologies have the greatest potential for electrification?

Electrification abatement comes from a broad set of energy end-uses in buildings, transportation and industry. The GHG price encourages a switch between electricity and fossil fuels for the provision of compression (natural gas production, processing, and transmission), transportation (light-duty vehicles, light freight vehicles), mining (ore and coal transportation, coal drying), manufacturing (process heat), and space and water heating (residential and commercial/institutional buildings) (Figure ES 4).

Figure ES 4: Electrification abatement by sector, medium natural gas price

The amount of electrification abatement in the transportation sector carries the most uncertainty and could be much larger than we have estimated. This uncertainty comes from unknown future battery and liquid biofuel costs. It was explored with a sensitivity analysis.

The sensitivity analysis demonstrated that electrification abatement in the transportation sector is constrained by battery costs rather than low biofuel and fuel prices. Limiting the availability of biofuels did not increase electrification abatement at a given policy strength, it only reduced total abatement. Conversely, cheaper electric vehicle batteries increased electrification abatement and load growth in the transportation sector six-fold by 2050.

Given the impact of electrification on GHG emissions and electricity demand, how can this fuel switch be managed strategically?

This research question takes the findings of this electrification potential review and draws out additional lessons to guide policy and decision making:

Use this analysis to identify the important electrification opportunities to target with further research, validation and stakeholder engagement. This analysis provides a high level description of electrification and it is limited in its ability to accurately represent the unique circumstances of any firm or consumer. Specific barriers or advantages may make electrification more or less attractive on a case-by-case basis. Practical survey work or engagement with important stakeholders (e.g., mines, municipalities, and delivery vehicle fleet managers) can identify what policies or actions can leverage advantages or overcome barriers associated with electrification abatement.

In a carbon constrained world, expect to deliver electricity to where it typically has not been used. While it is obvious that BC Hydro will need to take delivery from widely dispersed zero GHG emissions sources (e.g. wind farms, biomass cogeneration, small hydro), it is less obvious where new demand will arise. Much of the electrification abatement is contingent upon generating zero-GHG electricity and transmitting and distributing this electricity to customers that have not typically required substantial access to the BC Hydro grid. A pre-requisite to the electrification abatement potential in this analysis is sufficient transmission and distribution. Half of the electrification abatement in this forecast occurs where new or increased transmission and distribution capacity will be needed: At mine sites, natural gas wells, pipelines, and processing plants[1], manufacturing enterprises and in transportation.

Delays or uncertainty in electricity supply and transmission could result in missed GHG abatement opportunities. Some industrial projects or other investments will move forward without electric equipment, even if electrification might have been preferred.

[1] Again, this is even with the exclusion of gas production and processing in the horn river basin and liquefied natural gas terminals.

Capital investments (vehicles, machinery etc.) have long lives. If fossil fuel powered equipment is purchased rather than electric equipment, it creates a technological "lock-in" of GHG emission that can prevail for decades until the equipment is retired.

Improved transport electricity storage technologies could radically alter demand for grid electricity. This project included a review of the potential for transport electrification, but technological developments in this area are highly uncertain. "Surprises" will bias towards better battery storage technology and cheaper vehicle batteries, the key barrier to widespread transport electrification.

Introduction

Context

Significant reductions in greenhouse gas (GHG) emissions are required to reduce the risk human-induced climate change. Energy efficiency and switching between fossil fuels (i.e. coal to natural gas) can reduce greenhouse gas (GHG) emissions, but the deep cuts required to reduce the risk of climate change (~50-80% below current emissions) can only be achieved through the use of low- or zero-emissions primary energy resources (e.g., hydroelectric power, wind, solar, or coal or gas with carbon capture and storage) and energy carriers (e.g., electricity, biofuels or hydrogen). Currently, the only widely-available zero GHG energy carrier in Canada is electricity and large reductions in GHG emissions will likely require switching to electricity (i.e., "electrification") as a way to substitute zero-emissions energy for the fossil fuels that power most homes, businesses and vehicles.

British Columbia has both stringent GHG emissions targets and substantial existing and future zero-emissions electricity resources. This situation may provide great potential for GHG abatement through electrification, but it is not clear to what extent and under what conditions electricity will be used in place of fossil fuels. It is not a technical question whether low GHG emissions electricity becomes can replace fossil fuels – most of the necessary technology exists today. Rather, it is an economic question; there are many reasons we currently do not use electricity in every feasible application. The primary reason relates to the operating cost of using electricity, which is typically more than 50% higher than natural gas and other fossil fuels per unit of energy. Additionally, there are technical difficulties and higher costs surrounding electricity storage, especially on vehicles.

An analysis of most electrification options, at current electricity and natural gas prices (especially using British Columbia's conservation rate structures), will show that the status quo use of electricity and fossil fuels is less expensive for consumers than greatly increased electrification. However, this result is dependent on technologies considered, discount rates, length of time used to calculated net present values, natural gas and electricity prices, and finally GHG prices; British Columbia's carbon tax started at $10 per tonne in 2008 and is supposed to rise to $30 per tonne in 2012. These GHG prices were not established to hit a given target, and deep emissions reductions will require a much stronger policy signal. Thus, the potential for electrification will change if the strength of climate policy continues to grow in British Columbia.

What drives electrification?

A primary driver of electrification is the relative cost of electricity versus other fossil fuels. This ongoing cost, in addition to the differences in capital costs between electric and fossil fuel technologies, determines whether electricity is used rather than fossil fuels in applications where the option exists. GHG pricing applies an additional cost to fossil fuels based on their carbon content, changing the price difference relative to electricity. If electricity is produced from zero emissions sources, GHG pricing will have no effect on the electricity price and will reduce the cost premium of using electricity. All else being equal, a GHG price will encourage different amounts of electrification in different sectors and end-uses depending on the relative efficiencies and capital costs of electric and fossil fuel combustion technologies.

While GHG pricing encourages electrification, rising electricity demand will be tempered by the cost of new electricity generation capacity. In British Columbia new demand will likely be supplied by increasingly costly hydro, wind and other renewable energy projects. As these projects are built, the average cost of electricity will rise, providing a negative feedback to the policy induced electrification. Under a given set of market and policy conditions, a specific equilibrium exists between the positive and negative drivers to electrification which in turn determines the extent of electrification.

Research Questions

This study has investigated the potential for electrification in British Columbia by answering the following questions:

- To what degree will consumers and firms use electrification to reduce GHG emissions between the present and 2050, and how will this fuel switching affect electricity demand? How will this outcome vary in response to GHG pricing and natural gas prices? Are there other variables that significantly affect electrification potential?
- What sectors and technologies have the greatest potential for electrification?
- Given the impact of electrification on GHG emissions and electricity demand, how can this fuel switch be managed strategically? What subset of electrification actions are most valuable for reducing GHG emissions given the cost and constraints of supplying additional electricity, and to what degree should electrification be encouraged or discouraged by utilities or government?

Project Overview

We used a three part study to address these questions. First, we identified initial electrification opportunities through a literature review and a preliminary modelling study using the CIMS energy-economy model. This model allowed us to forecast electrification under several future GHG price and fossil fuel price scenarios. The purpose was to characterize known electrification technologies, identify electrification opportunities to incorporate into the analysis, and refine the representation of the dynamics that drive or constrain electrification in British Columbia. Second, we addressed the data and methodological gaps identified by the initial analysis. Finally, we have conducted a summary analysis that incorporates the knowledge gained throughout the project to provide a detailed understanding of electrification potential in British Columbia.

Structure of the report

This report begins with a description of the methodology used for this study, including the CIMS modelling framework used to forecast electrification potential. The CIMS reference scenario forecast of electricity demand follows the methodology. Then we forecast and discuss electrification potential under several alternate climate policy and energy price scenarios while addressing further uncertainties with sensitivity analyses. The report concludes with a discussion of the electrification potential which answers the research questions that frame the analysis. Appendices to the report include detailed quantitative results, a summary of the review of electrification opportunities and issues developed during the analysis, and a detailed description of the modelling framework used in the analysis.

Methodology

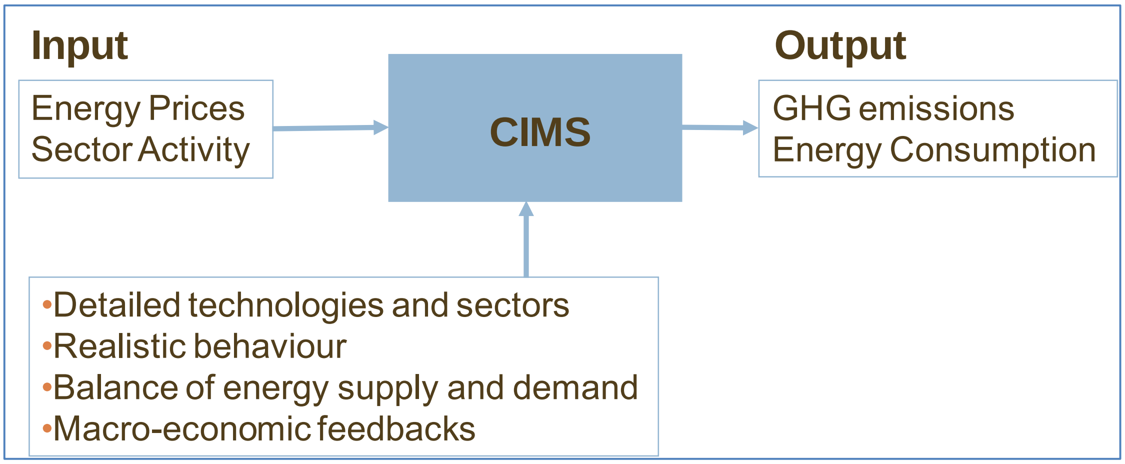
We used the CIMS energy-economy simulation model to explore the potential for GHG reductions through electrification in British Columbia. Shortcomings in the data and methodology of the model were identified and addressed with a review of key electrification opportunities. To keep the analysis consistent and relevant to current BC Hydro planning, we aligned the input assumptions of CIMS with the assumptions used in the ongoing BC Hydro Integrated Resource Plan (IRP). Using CIMS, we forecasted electrification in response to three economy-wide carbon prices. For most sectors in British Columbia, electrification is mediated by the difference in electricity and natural gas prices. Therefore, we also explored the sensitivity of electrification to three natural gas price forecasts for a total of nine electrification scenarios. The electricity prices used in each scenario were based on a renewable electricity supply curve to realistically represent how the cost of new supply would constrain electrification. Results, organized by scenario and sector, include abatement by electrification, new electricity demand, and changes in the adoption of key electric technologies relative to the reference scenario.

The CIMS modelling framework

CIMS is a technologically detailed model that simulates the evolution and renewal of capital stock (buildings, cars, boilers etc.). It simulates realistic consumer and firm decision making when acquiring new capital stock, integrates energy supply and demand and accounts for macro-economic feedbacks. A version of CIMS specific to British Columbia was used to forecast energy consumption, GHG emissions and technology market shares to 2050 in each sector for each scenario of this study. CIMS is describe briefly here and in more detail in Appendix C.

Figure 1 is a simple representation of CIMS. The primary inputs to a simulation are forecasts of future energy prices and forecasts of sector activity (e.g., number of households, demand for personal transportation, production of cement etc.).

Figure 1: Simple representation of the CIMS model



The modelling framework includes detailed sectors and technologies and describes realistic investment behaviour. For example, the residential sector is organized according to energy end-uses such as space and water heating. Each end-use may be satisfied by several technologies. Space heating may be provided with natural gas furnaces of varying efficiencies, baseboard electric heaters, or ground and air source heat pumps. Technologies are used for the duration of their operating life or may be retrofitted. When they are replaced, the choice of new technology is based on a probabilistic algorithm that accounts for non-financial costs, related preferences, perceptions of technology or investment risk, and real discounting behaviour (i.e., most consumers and firms implicitly want very fast payback on their investments).

CIMS integrates energy demand with energy supply. Therefore, an increase in electricity demand requires an increase in electricity generation. Related to energy integration is endogenous energy pricing where the cost of each fuel may be internally adjusted to reflect its changing average cost of production relative to a reference cost forecast (e.g., electricity is more expensive if it must be supplied from zero-emissions sources rather than from conventional sources).

Lastly, CIMS represents how costs affect supply and demand for goods and services. It calculates demand for all energy services based on the cost of supplying those services. If a policy or scenario assumptions changes the unit cost to supply an energy service (e.g., cost per output of wood products or cost per vehicle kilometre travelled) relative to the reference scenario, the demand for that service will also change.

Primary outputs from CIMS include GHG emissions and energy consumption by fuel. Both of these results can be disaggregated by sector and technology. Additionally, because CIMS is technologically detailed and represents energy supply and demand, results also include technology market shares, energy prices, and sector activity/output.

We reviewed the CIMS model to identify missing technologies and dynamics that would have a substantial impact on the potential to reduce GHG emissions by electrification. The review covered anything that could provide a significant amount of electrification abatement, could create significant new electricity demand, or could dramatically change how electricity prices would respond to increasing electricity demand. Included was a review of:

- The availability and timing of electricity transmission to natural gas producers
- Electric process heat for small and medium manufacturing enterprises and the role for biofuel as a heat source for wood products manufacturing
- Electric transport in mines and microwave coal drying
- The role of biomass versus electricity for zero-GHG heating in buildings
- Electric freight vehicles
- Direct to wholesale electricity purchases by industry
- The effect of GHG pricing on production and electricity demand in the natural gas sector

Appendix B summarizes the results of this review.

Reference Scenario Assumptions and Inputs

Sector Activity Forecasts

Wherever possible, the assumptions driving the CIMS outputs have been matched to those being used in the BC Hydro IRP. Table 1 shows the sector activity forecasts that are inputs to CIMS. To establish sector activity forecasts, we drew upon material in the 2010 load forecast.[2]

The only exception to this methodology is the exclusion of natural gas loads coming from potential production in the Horn River Basin or from liquefied natural gas (LNG) terminals in the Kitimat area. Electrification of these facilities is the subject to other analyses being conducted in parallel with this study. Furthermore, these facilities will require specific transmission projects to use electricity from the BC Hydro grid. Therefore, we have not included them in the reference scenario and their GHG emissions and energy consumption will not be shown in the results.

[2] Electric Load Forecast 2010/11 – 2030/31, BC Hydro 2010

Table 1: Reference scenario sector activity forecasts

	Units	2010	2020	2030	2040	2050
Demand Sectors						
Residential	*thousands of households*	1815	2195	2573	2755	2893
Commercial	*million m^2 of floor space*	103	127	149	168	184
Passenger transport	*billion passenger-km*	79	92	103	112	120
Freight transport	*billion tonne-km*	156	225	286	333	379
Chemical Products	*million tonnes* [a]	0.5	0.7	0.7	0.8	0.9
Industrial Minerals	*million tonnes* [b]	3.2	3.7	4.3	5.0	6.2
Metal Smelting	*million tonnes*	0.4	0.5	0.5	0.5	0.5
Mining	*million tonnes*	70	114	116	139	160
Pulp and Paper	*million tonnes* [c]	1.9	1.9	2.4	2.6	2.9
Other Manufacturing	*billion $2005* [d]	12.7	14.5	15.2	16.2	17.2
Supply Sectors						
Petroleum Refining	*million m^3*	2.8	5.2	6.6	8.3	10.1
Crude Oil	*thousand barrels per day*	20.0	10.0	7.5	7.1	7.1
Natural Gas						
Conventional Gas	*billion cubic feet per day*	1.7	1.7	1.7	1.6	1.5
Unconventional Gas [e]	*billion cubic feet per day*	0.6	3.5	3.5	3.3	3.1
Coal Mining	*million tonnes*	32	53	53	54	55
Biofuel Manufacturing	*PJ*	0.1	0.9	2.5	3.0	4.0

Notes: [a] chemical product output is the sum of chlor-alkali, sodium chlorate, hydrogen peroxide, ammonia, methanol, and petrochemical production

[b] industrial mineral output is the sum of cement and lime production

[c] pulp and paper output is the sum of linerboard, newsprint, coated and uncoated paper, tissue and market pulp production

[d] Other manufacturing includes wood products, food and beverage manufacturing, leather and textiles, furniture, printing, machinery, transportation equipment, and electronics

[e] Production from the Horn River Basin is not included in this analysis

For the residential sector, the household growth rate to 2030 matches the forecast used in the BC Hydro 2010 load forecast. From 2030 to 2050, we assume the annual household growth rate falls from roughly 1.4% to 0.5%.

The physical output forecast for the commercial sector is based on the implicit rate of growth derived from the BC Hydro load forecast and anticipated changes in energy intensity in the sector to 2030. The activity forecast for the industrial and energy supply sectors were also set according to this methodology. We assumed continuing trends to 2050.

The forecast for unconventional natural gas production was taken directly from the 2010 load forecast, but has had an estimate of production in the Horn River Basin removed from the forecast. From 2030 to 2050, we assumed unconventional natural gas production declined slowly at 0.6% annually, equivalent to the long-term change in output from a typical shale gas well.

Energy Price Forecasts

Like the sector activity forecasts, the energy price forecasts were aligned with inputs used with the IRP. The reference natural gas price in this analysis is the same as the reference price used in the IRP, and is described in greater detail in a coming section.

Electricity prices follow the schedule of rate changes outlined in the 2010 rate forecast. That forecast runs to 2030, after which we assume continued investments in existing facilities and the continued rising cost of new generation capacity results in a continued increase in electricity rates by 0.9% annually. Table 2 shows the percent electricity rate change we have applied to each customer type in CIMS. The rate of change is for real costs meaning they do not include inflation rates.

Table 2: Reference scenario electricity rate forecast

	2010	2020	2030	2040	2050	
Annual % rate change, real value[a]	5.50%	5.50%	0.90%	0.90%	0.90%	0.90%

[a] Real value means the forecast does not include inflation

The cost for petroleum products, primarily gasoline and diesel, is based on an 85 $/bbl (2005 CAD) long-run price of oil from 2020 onward. Table 3 shows the gasoline and diesel price that correspond to this oil price forecast. Again, these prices are real values and do not account for inflation. Note that prices in 2010 represent a five year average and will not be the same as the fuel price in 2010 itself. Many oil price forecasts are currently higher, but electrification potential was not highly sensitive to the price of oil, hence this assumption is not very significant. 2005 dollars are used throughout this analysis since this is units used in the CIMS model.

Table 3: Petroleum product price forecasts (2005 CAD $/L, real dollars)

	2010	2020	2030	2040	2050
Gasoline	105.0	98.2	94.8	94.8	94.8
Diesel	98.2	89.2	86.1	86.1	86.1

Electrification Scenario Assumptions and Inputs

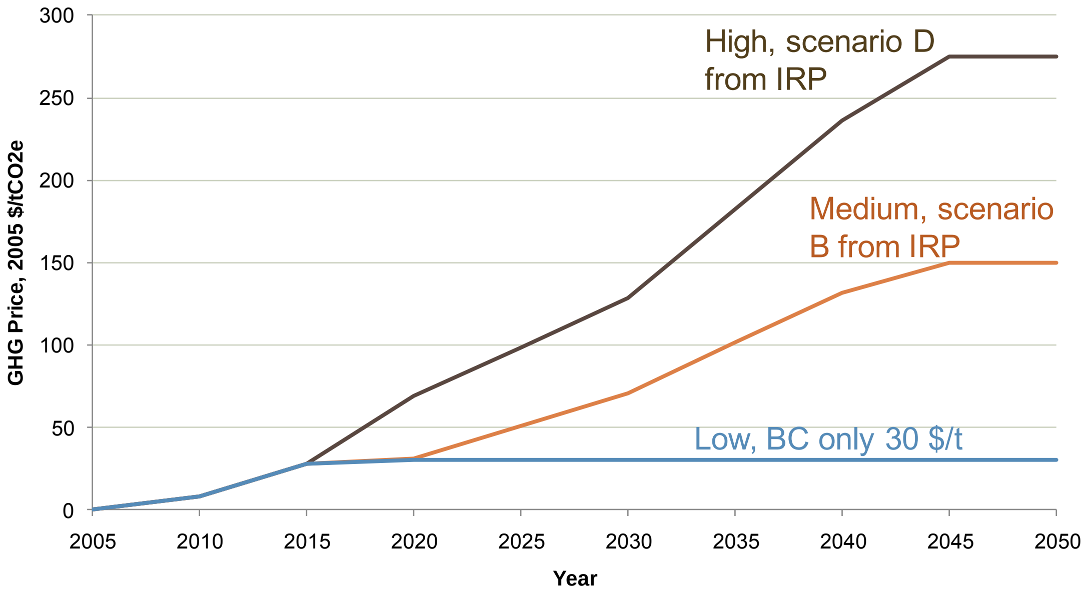
Greenhouse Gas Price Scenarios

Three GHG price forecasts were used to test the sensitivity of electrification to carbon pricing. This analysis used a low price, a medium price, and a high GHG price scenario (Figure 2, Table 4). The low price scenario assumed no other jurisdiction will enact climate policy. In this case we assumed the BC carbon tax remains but will not increase. The medium and high price scenarios were aligned with forecasts taken from a study of the market price for GHG emissions in North America, produced by Black and Veatch for the IRP.[3] The medium scenario is based on the scenario B price which assumes the

[3] Greenhouse Gas (GHG) Price Forecast , 2011 IRP Technical Advisory Committee Summary Brief

Western Climate Initiative takes the lead on enacting policy, with Canadian and US federal policy following by 2020. The high price scenario is based on scenario D which assumes a delayed policies and stifled international cooperation requires higher GHG prices to reach regional emissions targets. The GHG prices in this analysis were applied economy-wide and to all GHG emissions.

Figure 2: GHG price forecasts used in the electrification scenarios



Note: CIMS solves in five year time steps so GHG prices for past and announced years are shown as five year averages.

Table 4: GHG price forecasts used in the electrification scenarios, 2005 CAD $/t$CO_2$e

GHG price scenario	2010	2020	2030	2040	2050
High, scenario D from IRP	9	69	128	236	275
Medium, scenario B from IRP	9	31	71	132	150
Low, BC Only	9	30	30	30	30

Natural Gas Price Scenarios

Three natural gas price forecasts were also used to further test the sensitivity of electrification. These price scenarios were also drawn from analyses that inform the 2011 BC Hydro IRP.[4] These forecasts extend to 2030, after which we have assumed a continued 1.8% annual price increase for all three price scenarios, consistent with trends to 2030. The low price forecast represents a future where low oil prices, additional renewable electricity capacity, and large scale shale gas development across North America keep the continental gas price relatively low. The medium price scenario

[4] Natural Gas Price Forecast , 2011 IRP Technical Advisory Committee Summary Brief

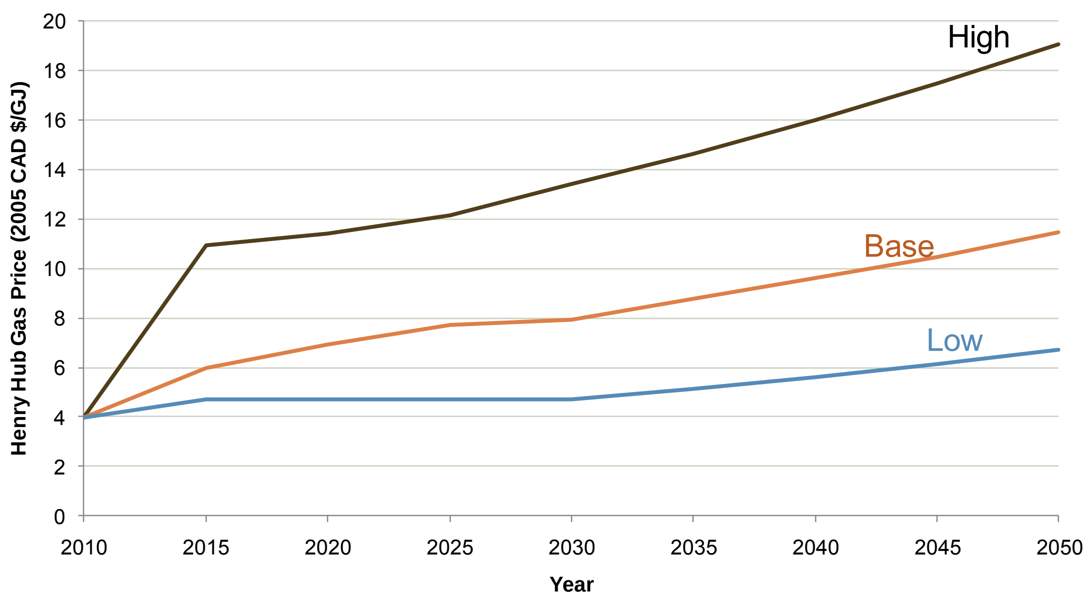
represents a similar scenario, but one with less renewable electricity capacity development, hence more demand for natural gas for electricity generation, and slightly constrained shale gas development due to technical challenges and environmental issues. The high price scenario sees little shale gas development across North America due to environmental concerns.

Table 5 and Figure 3 show the Henry Hub wholesale gas prices used in each scenario. The natural gas prices paid by residential, commercial and industrial customers are the inputs to the model. These retail prices are set relative to the wholesale price based on the historic difference in the two prices.[5] We assume the retail prices are higher than the Henry Hub price by 5.5 $/GJ for residential customers, 4.2 $/GJ for commercial customers and 2.4$/GJ for industrial customers.

Table 5: Henry Hub natural gas price scenarios, 2005 CAD $/GJ

Natural gas price scenario	2010	2020	2030	2040	2050
Low	4.0	4.7	4.7	5.6	6.7
Medium	4.0	7.0	7.9	9.6	11.5
High	4.0	11.4	13.4	16.0	19.1

Figure 3: Wholesale natural gas price forecasts used in the electrification analysis



Electricity Prices in the Scenarios

Even though this analysis explicitly uses one electricity price, we capture the important price dynamics that will affect electrification: The "spark spread" and the cost of new

[5] Derived from Statistics Canada data

zero-emissions electricity supply. Variation in the "spark spread", the relative difference between the price of natural gas and electricity per unit of energy, was created by using several natural gas price scenarios. Given that the relative cost of the fuels is as important as the absolute cost, it was not necessary to use multiple electricity prices with multiple natural gas prices. Furthermore, in each scenario, we used an electricity supply curve to adjust the electricity prices for each scenario based on the change in electricity demand relative to the reference forecast.

Characterization of the Electricity Supply Curve

The electricity price in each scenario was based on estimates of the cost and quantity of renewable electricity capacity in British Columbia. To accurately represent the electricity demand/price relationship that exists in British Columbia, the electricity prices for each scenario were determined using a representative renewable energy supply curve based on BC Hydro data. The supply curve used in this analysis is based on a renewable energy portfolio that:

- Includes only certain resources that are primarily small hydro, wind energy and the site C project.
- Excludes uncertain resources such as geothermal and tidal power.
- Uses pumped storage for peak power supply.
- Assumes average cost electricity is sold to all customer classes.

The purpose of this electricity supply curve was not to prescribe a portfolio of supply options, but instead show how the increasing cost of electricity supply affects electrification. Some of the assumptions above were deliberately simplified to make this a tractable analysis. Specifically, to the cost of peak power may be less than we have portrayed by assuming pumped storage. Furthermore, pumped storage may not be available until after 2020, but this is when the majority of additional load growth occurs in the scenarios.

Given these assumptions, the electricity prices used in the scenarios are conservative in that they will show the largest plausible changes in electricity prices as the demand increases. Furthermore, since the electricity system will emit no additional GHG emissions, the electrification abatement reported will not be reduced by electricity supply emissions.

Other assumptions would portray a different supply curve and this supply curve would produce a slightly different estimation of electrification potential. The assumptions used to create this supply curve are uncertain. However, the upward trend in the cost of new supply means electrification provides a negative feedback to itself. In other words, more electrification raises the price which constrains further electrification. This negative feedback will mitigate the differences between alternative supply curves.

Representation of New Natural Gas Sector Loads

This analysis only accounts for the impact of the LNG terminals and gas production in the Horn River Basin on the electricity rates of other customers. Because of the sale of electricity to these developments will require the construction of specific transmission line and will be done with a specific pricing scheme, they were omitted from our forecast of the potential for GHG abatement through electrification.

Our assumption is that these projects use electricity priced at the marginal cost of electricity supply. It is impossible to make no assumption regarding their electricity use. Completely removing them from the analysis is the same as assuming these developments do not happen or they do not use electricity from the BC Hydro Grid. We have assumed these projects use marginal cost pricing (i.e., all extra capital, operating and fuel costs are recovered from the new load), approximately removing a 20 TWh block of supply from the supply curve used to calculate the electricity prices for other sectors. Exactly which block of supply is removed is based on the relative timing and magnitude of demand from these projects and other sectors.

Sensitivity Analyses

Two sensitivity analyses help address other uncertainties in the analysis. The first sensitivity analysis explores how electrification is affected by either reduced biofuel availability or lower cost electric vehicles batteries. The second explores how controls on electric resistance heating in buildings will impact electrification in all sectors.

Other Policies Included in the Electrification Scenarios

The scenarios also include the current and announced provincial and federal climate policies. Many of these policies are similar to those included in the 2007 modelling analysis described in the appendix to the Climate Action Plan. [6] The policies in this analysis are:

- Changes to the residential and commercial building code
- The BC LiveSmart Incentives
- Minimum energy performance standard for equipment (e.g., water heaters)
- The low carbon fuel standard (modelled as a renewable fuel requirement)
- The federal light-duty vehicle emissions standard
- Improvements to public transit
- Landfill gas regulation

Finally, the renewable supply curve that determines the electricity prices in this analysis implicitly complies with the Clean Energy Act. Specifically, this means the generation of

[6] Climate Action Plan, Government of British Columbia, 2008

electricity produces no net GHG emissions, and electrification abatement from the electricity demand sectors results in no upstream GHG emissions.

Results Indicators

The analysis uses three indicators to explore the results of the electrification scenarios. These indicators are abatement of GHG emissions by electrification, new electricity demand, and the change in electricity rates relative to the reference scenario. Fourth indicator, the market share of specific electric technologies, is used to help explain the results.

Electrification Abatement

GHG abatement by electrification is the sum of GHG abatement achieved by switching to electricity and any associated improvement in energy efficiency. This change in GHG emissions is measured relative to the reference scenario for each sector and scenario.

Abatement by switching to electricity occurs when a given sector increases its share of electricity consumption while decreasing its share of fossil fuel consumption relative to a reference scenario**.** For example, for a given sector in the reference scenario, electricity may represent 30% of sectoral energy consumption while natural gas may represent 70%. Abatement by switching to electricity occurs if the share of electricity rises above 30% and the share of natural gas falls below 70%. The magnitude of the abatement depends on the change in fuel shares and the total amount of energy consumed.

The energy efficiency gains associated with electrification occur because electric technologies may be fundamentally different, and more efficient, than the combustion technologies they replace. For example, the theoretical maximum efficiency of a natural gas furnace is less than 100%; no more energy can be provided for space heating than is contained in the natural gas used for that purpose. However, an electric heat pump uses a small amount of energy to transfer ambient heat from a source (e.g., ground, air or water) to a sink (a building) and can be 200-400% efficient. This increase in energy efficiency also results in GHG abatement and is included as electrification abatement. Significant energy efficiency improvements also occur when switching from internal combustion engines to electric or plug-in hybrid electric engines in the transportation sector. However, if plug-in vehicles were not used, hybrid vehicles are a logical low-emissions alternative. Therefore, the efficiency improvement in the transportation sector is measured relative to a hybrid vehicle rather than a standard vehicle.

This definition of electrification abatement assumes no upstream emissions from electricity generation. In a worst case scenario, these upstream emissions can be larger than the avoided emissions in the energy demand sectors. However, compliance with the Clean Energy Act in British Columbia ensure that upstream emissions are negligible.

New Electricity Demand

Changes in demand relative to the reference scenario provide insight into the implications of electrification on generation, transmission and distribution. Like electrification abatement, new electricity demand for each electrification scenario is measured relative to the reference scenario for each sector. Because the reference scenario uses the base natural gas price, it is possible that the electrification scenarios using the low natural gas price could show a reduction in electricity consumption from the reference forecast.

Change in Electricity Price from the Reference Scenario

The electricity price for each scenario is quantified as a difference from the reference scenario price forecast. While this output indicates how energy cost in each scenario may change, the purpose of this result is not to forecast electricity rates in the electrification scenarios. Instead, this result provides a reality check of how new demand will affect rates and in turn constrain further electrification.

Technology Market Shares

Results also include the market shares of the key technologies that permit abatement by electrification. In other words, an increase in their market share will reduce the direct GHG emissions in a given sector. These results are used throughout the report to explain the broader trends in the analysis.

In the residential and commercial/institutional sector, we track market shares for electric resistance and heat pump space and water heating. In the transportation sector, we track the adoption of plug-in hybrid and full electric light-duty and light freight vehicles. In the mining sectors sector we track the market share of trolley-assisted mining trucks, mining-pit electric conveyors and microwave coal drying. In the natural gas sector, we track the market share of electric shaft drive that powers compressors and pumps. Finally, in the other manufacturing sector (includes wood products, food manufacturing, machinery etc.) we track the use of electric resistance heater and boilers and industrial heat pumps.

Reference Scenario Results

We used the CIMS model to produce a reference forecast of energy consumption and GHG emissions in the absence of GHG pricing. The reference scenario shows steady growth in GHG emissions and electricity demand from most sectors. Emissions and new load from the natural gas sector grows rapidly to 2020 and remain significant for the duration of the forecast. The CIMS load forecast matches the BC Hydro 2010 load forecast. However, a discrepancy develops between the two forecasts due to different rates of energy efficiency improvements and different assumptions about the electricity demand of new appliances and electronics in buildings.

GHG Emissions by Sector

Table 6 shows the reference scenario GHG emissions. Emissions from most sectors grow steadily over the simulation. Emissions from freight transportation and natural gas extraction increase substantially due to high growth in sector output.

Table 6: British Columbia GHG Emissions forecast by sector, $MtCO_2e$ per year

	2010	*2020*	*2030*	*2040*	*2050*
Demand Sectors					
Residential	4.2	4.3	5.0	5.5	5.7
Commercial	4.0	4.7	5.3	5.7	6.0
Transportation Personal	11.1	11.2	10.5	10.9	11.6
Transportation Freight	14.2	19.6	24.3	27.9	31.6
Chemical Products	0.1	0.1	0.1	0.2	0.2
Industrial Minerals	2.6	3.1	3.6	4.3	5.3
Metal Smelting	1.2	0.9	0.7	0.6	0.5
Mineral Mining	0.6	0.8	0.7	0.9	1.1
Paper Manufacturing	0.8	0.6	0.3	0.3	0.3
Other Manufacturing	2.8	2.2	1.9	2.0	2.0
Agriculture	3.3	3.5	3.8	4.0	4.2
Solid Waste	3.6	3.5	3.3	3.2	3.0
Supply Sectors					
Electricity [a]	0.7	0.7	0.5	0.5	0.5
Petroleum Refining	0.6	1.2	1.6	2.1	2.6
Petroleum Crude Extraction	0.4	0.2	0.1	0.1	0.1
Natural Gas Production [b]	7.8	12.2	11.8	10.7	9.7
Coal Mining	1.6	2.5	2.4	2.3	2.2
Total	**59.6**	**71.3**	**76.1**	**81.1**	**86.7**

[a] The Clean Energy Act applies to electricity generation in the reference scenario

[b] Emissions from associated with potential liquefied natural gas terminals and with gas production in the Horn River Basin are not included

Electricity Consumption by Sector

Table 7 shows the reference electricity consumption forecast. Cogeneration and generation using landfill gas have not been netted out from these results. The electricity consumed by the Kitimat Aluminum smelter, representing most of the demand from the metal smelting sector, is produced by private generation and has been removed from this forecast.

Table 7: British Columbia electricity consumption forecast by sector, TWh per year

	2010	*2020*	*2030*	*2040*	*2050*
Demand Sectors					
Residential	18.5	20.8	24.3	25.9	28.4
Commercial	15.4	19.1	22.5	25.9	29.2
Transportation Personal	0.2	0.3	1.3	1.5	1.2
Transportation Freight	0.0	0.1	0.2	0.3	0.4
Chemical Products	1.5	1.8	1.9	2.1	2.3
Industrial Minerals	0.4	0.5	0.5	0.6	0.7
Metal Smelting	0.5	0.6	0.6	0.6	0.6
Mineral Mining	2.4	4.7	4.9	5.7	6.4
Paper Manufacturing [a]	6.0	5.7	8.1	8.3	9.3
Other Manufacturing	4.2	4.4	3.7	3.8	4.2
Agriculture	0.4	0.5	0.5	0.5	0.5
Supply Sectors					
Petroleum Refining	0.1	0.1	0.1	0.1	0.2
Petroleum Crude Extraction	0.1	0.1	0.0	0.0	0.0
Natural Gas Production [b]	0.1	1.3	1.7	1.9	2.2
Coal Mining	0.4	1.3	1.6	2.2	2.4
Total	**50.5**	**61.2**	**71.7**	**79.4**	**88.1**

[a] Net of electricity produced using black liquor combined cycle gasification for cogeneration of heat and power

[b] Electricity consumption by potential liquefied natural gas terminals and from gas production in the Horn River Basin are not included

Comparison to the BC Hydro 2010 Load Forecast

Figure 4 and Table 8 compare the BC hydro load forecast with the CIMS load forecast. The BC Hydro forecast is BC Hydro 2 which includes rate impacts and accounts for overlap of codes and standards. Added to this forecast are electricity sales to British Columbian regions outside of the BC Hydro service area. The CIMS load forecast does not include electricity consumed for aluminum smelting and it is net of new advanced cogeneration in the pulp and paper sector (black liquor combined cycle gasification), or generation in the solid waste sector.

Figure 4: Comparison of CIMS and BC Hydro Electricity Load Forecasts

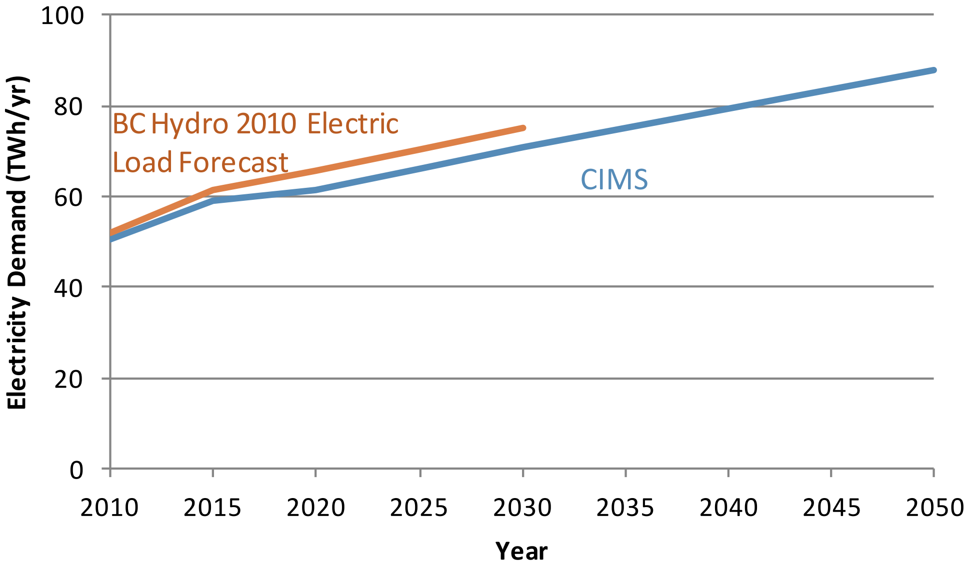


Table 8: Comparison of CIMS and BC Hydro Electricity Load Forecasts, TWh

	2010	*2020*	*2030*	*2040*	*2050*
CIMS load forecast	50.5	61.2	70.8	79.4	88.1
BC Hydro Load Forecast	51.7	65.6	75.2		

By 2030, there is a 4.4 TWh difference between the two forecasts. Approximately three quarters of this difference comes from the residential and commercial load forecasts. Both forecasts have the same assumptions for growth in households and market penetration of baseboard electric heating. A greater rate of energy efficiency improvements in the CIMS forecast and perhaps a greater increase in appliance and electronics energy consumption in the BC Hydro forecast is the cause of the discrepancy. The remainder of the discrepancy is from the industrial sector where more improvement in energy efficiency in the CIMS forecast is likely responsible for the difference.

Electrification Scenario Results and Discussion

This section presents the results of the electrification scenarios, starting with total GHG emissions, electrification abatement, and electricity price impacts by scenario. Following these results is a discussion of electrification abatement by sector and the technologies that drive this abatement. Additional electricity demand by scenario and sector are also presented.

The results show that electrification can significantly reduce GHG emissions even though new electricity supply comes from increasingly costly zero-emissions resources. Deep reductions of British Columbia's GHG emissions will results in substantially more electricity demand. This electrification abatement, and the associated load growth, comes from a broad set of energy end-uses in buildings, transportation and industry. However, this result is highly sensitive to both the GHG price and the relative difference between natural gas and electricity prices. Finally, much of the electrification abatement is contingent upon generating zero-GHG electricity and transmitting and distributing this electricity to customers and places that have not typically required substantial access to the BC Hydro grid.

Further sensitivity analyses reveal that:

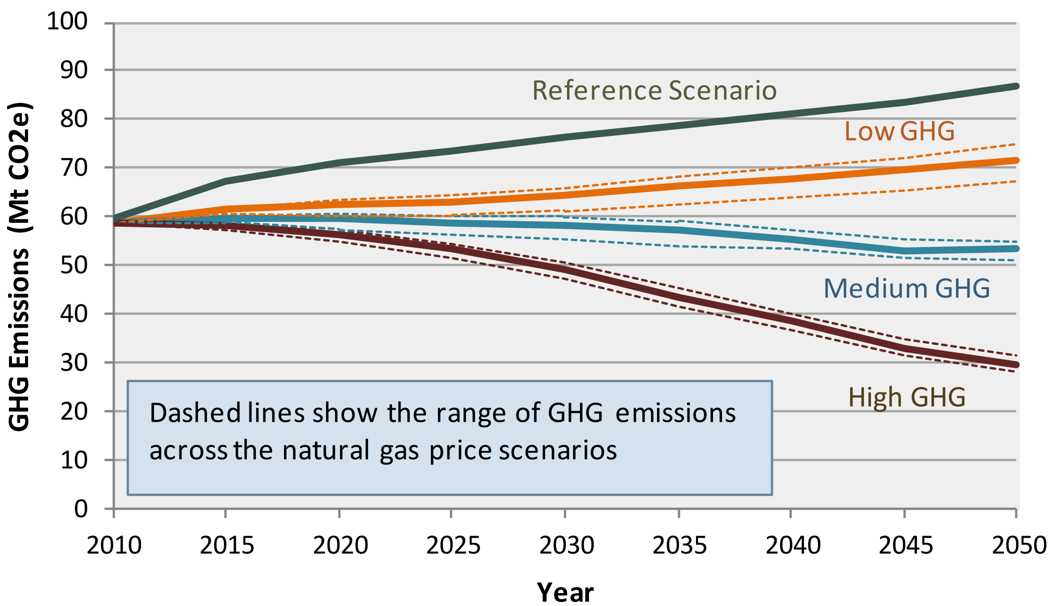
- Electrification in the transportation sector is constrained by high battery costs more so than cheap or widely available biofuels.
- Controlling the use of electric resistance heating technologies will reduce the electricity rate impacts and load growth associated with electrification abatement. However, if all electricity comes from zero-GHG sources, such a policy can also reduce total GHG abatement potential.

GHG Emissions Abatement

Figure 5 shows provincial GHG emissions for the electrification scenarios relative to the reference scenario. There are nine scenarios in total: three GHG price scenarios each with three natural gas price scenarios. For each GHG price scenario shown in the figure, the solid line represents emissions under the medium natural gas price, while the dotted lines represent the upper and lower bounds created by the low and high natural gas price forecasts. The high natural gas price forecast results in a greater reduction in emissions at a given GHG price, while the low natural gas price scenario results in less abatement.[7]

Total abatement is very sensitive to the GHG price scenario, but less sensitive to the natural gas price scenarios. While the GHG prices significantly change the trend of GHG emissions, the relative difference between electricity prices and natural gas prices, or "spark spread", created by the natural gas price scenarios, has less of an effect.

Figure 5: Total GHG emissions by scenario



However, the GHG reductions achieved by electrification are highly sensitive to both the GHG price and the spark spread. Figure 6 and Table 9 show abatement by electrification for each scenario (greater values indicate more reduction in GHG emissions). Again, the solid lines represent the abatement for each GHG price scenario with the medium natural gas price and the dotted lines show the upper and lower bounds created by the low and high natural gas prices. Because this figure shows abatement rather than total emissions, the upper bound (more abatement) corresponds with the high natural gas price scenario while the lower bound (less abatement) corresponds with the low gas price scenario. The abatement in these scenarios overlaps significantly throughout the forecast indicating that the spark spread affects electrification potential as much as the GHG price.

[7] Note that the GHG price scenarios were not chosen to meet the British Columbian emissions targets for 2020 and 2050. Rather, these price scenarios are representative of the abatement costs and targets for the regions that comprise the Western Interconnection Grid (British Columbia's electricity trading partners): Greenhouse Gas (GHG) Price Forecast , 2011 IRP Technical Advisory Committee Summary Brief

Figure 6: Electrification abatement by scenario

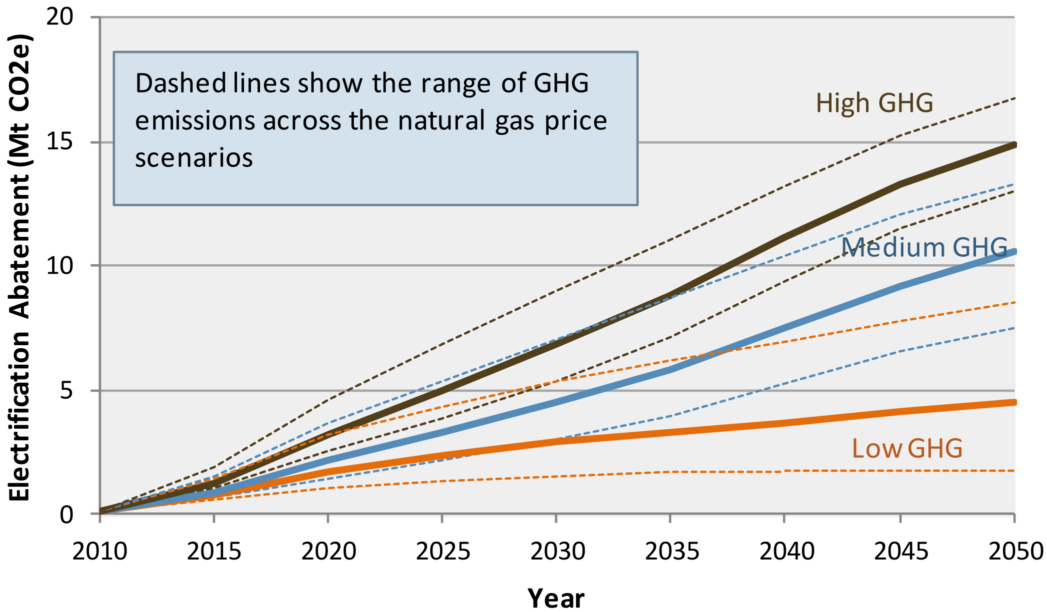


Table 9: Electrification Abatement by Scenario, $MtCO_2e$ relative to the reference scenario

GHG price scenario	Natural gas price scenario	2010	2020	2030	2040	2050
Low	Low	0	1	2	2	2
	Medium	0	2	3	4	5
	High	0	3	5	7	9
Medium	Low	0	1	3	5	8
	Medium	0	2	4	8	11
	High	0	4	7	10	13
High	Low	0	3	5	9	13
	Medium	0	3	7	11	15
	High	0	5	9	13	17

Electrification can significantly reduce GHG emissions even though new electricity supply comes from increasingly costly zero-emissions resources. The electricity from the small hydro and wind power resources that will dominate new electricity supply is more expensive than existing resources. Furthermore, there is a limited supply of electricity available at any given cost. When electricity demand increases relative to the reference case, so too does the electricity price. However, the potential for GHG abatement through electrification remains large (10+ $MtCO_2e$/yr) even when electricity rates increase by two to three cent/kWh relative to the reference scenario price (Table 10).

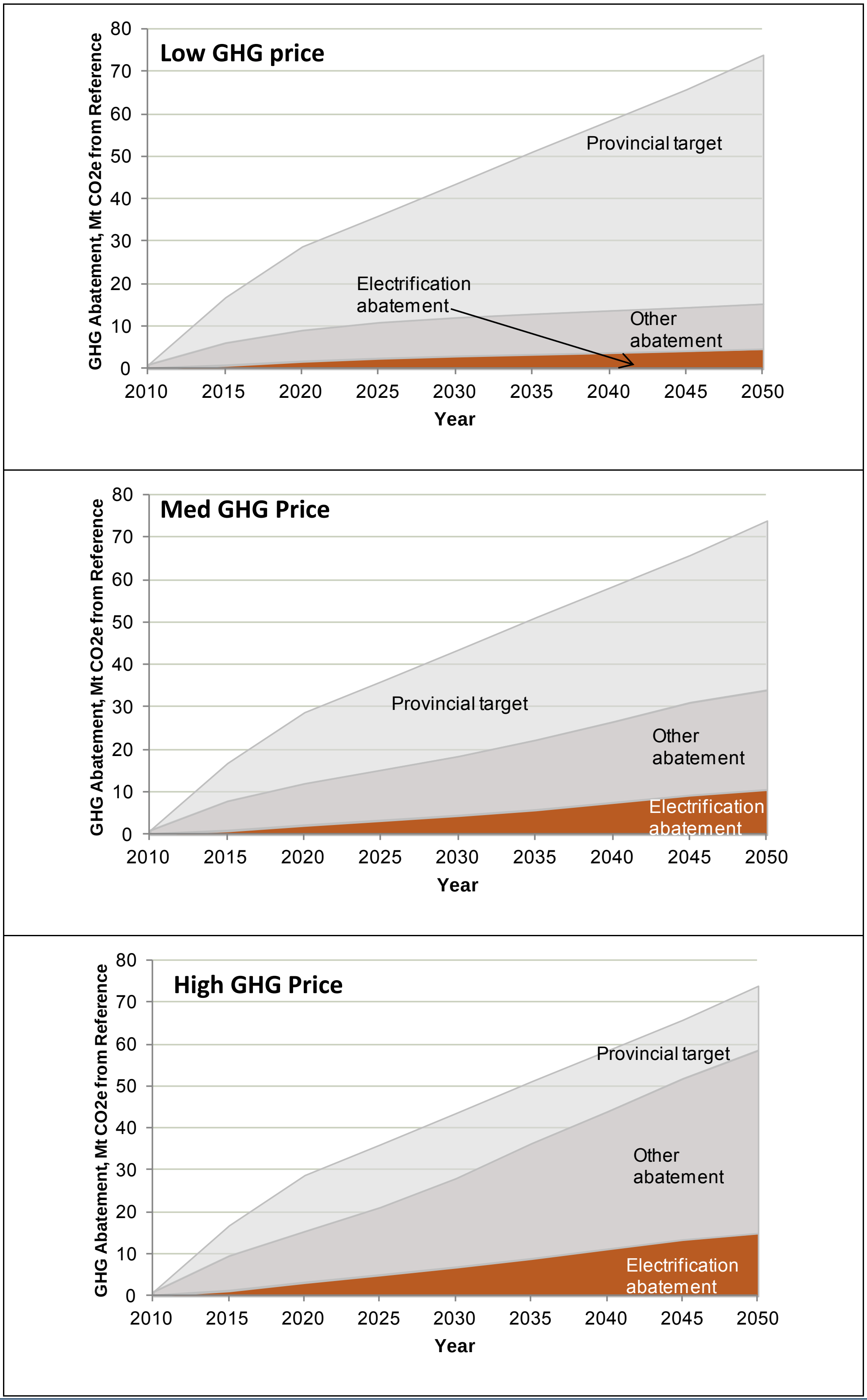
Table 10: Electricity rate impacts by scenario (2005 cent/kWh relative to reference scenario)

GHG price scenario	Natural gas price scenario	2010	2020	2030	2040	2050
Low	Low	0.0	0.1	0.0	-0.2	-0.3
	Medium	0.0	0.3	0.3	0.3	0.4
	High	0.0	0.7	1.1	1.2	1.3
Medium	Low	0.0	0.2	0.3	0.7	1.0
	Medium	0.0	0.4	0.8	1.3	1.8
	High	0.0	0.9	1.5	2.0	2.5
High	Low	0.0	0.5	1.0	1.8	2.4
	Medium	0.0	0.7	1.4	2.3	3.0
	High	0.0	1.1	2.0	2.9	3.6

The benefit of electrification abatement depends on the use of this higher cost zero-GHG electricity. If electricity generation produces GHG emissions, then most of the abatement from electrification would not occur. The carbon price would be passed through the electricity rates, raising the electricity price and reducing electrification. If electricity prices were regulated and the carbon price was not included in the electricity rates, then emissions from electricity generation would negate the electrification abatement achieved in other sectors. Generally, only electrification actions that resulted in large improvements in energy efficiency would reduce GHG emissions.

Electrification abatement accounts for a significant proportion of total abatement in all scenarios. Figure 7 shows electrification abatement in context with other GHG abatement, assuming the medium natural gas price applies. The figure also shows the provincial GHG emissions targets for 2020 and 2050 (interim values are extrapolated). Electrification abatement accounts for one fifth of total abatement under a low GHG price, and roughly one third of total abatement under a medium or high GHG price. In absolute terms, by 2050, electrification may reduce emissions by up to 5 $MtCO_2e$/yr under a low GHG price, 11 $MtCO_2e$/yr under a medium GHG price, and 15 $MtCO_2e$/yr under a high GHG price.

Figure 7: Electrification abatement in context, medium natural gas price



Electrification Abatement by Sector

Figure 8 shows electrification by sector (wedges in colour: natural gas, manufacturing and mining, transportation, commercial and residential buildings) compared with other abatement actions (wedges in grey). Other abatement actions include methane control at landfills, energy efficiency from vehicles and building shells, carbon capture and storage (CCS) associated with natural gas processing, and liquid biofuels used for transportation. Note that the vertical scale, showing GHG abatement, is <u>not</u> the same for each scenario shown in Figure 8. Figure 8 indicates that:

Electrification abatement comes from a broad set of energy end-uses in buildings, transportation and industry. The GHG price encourages a switch between electricity and fossil fuels for the provision of compression (natural gas production, processing, and transmission), transportation (light-duty vehicles, light freight vehicles, and mining vehicles), drying and process heat (coal drying and manufacturing), and space and water heating (residential and commercial/institutional buildings).

Electrification is an important abatement action, but other abatement actions are required to reduce GHG emissions. In some cases, abatement actions may compete, meaning the use of one abatement action reduces the incentive to use another. However, it is also possible that abatement actions act together to further reduce emissions. For example, a plug-in hybrid engine can be fuelled with biofuels to power a zero-GHG vehicle. In this case, one abatement action complements another and if they were not both used, total emissions would be higher.

Our assumptions show biofuels to be a lower cost abatement action than electrification, specifically for freight transportation. Electricity, hydrogen and biofuel technologies are included in the analysis, but biofuel is the most cost competitive zero-GHG fuels for transportation. Biofuel consumption is an important action given the assumed cost of biofuels and the low capital expenditures required to use them (versus the large upfront cost of a vehicle battery).

However, the relative of abatement of transportation GHG emissions using biofuels versus electrification is uncertain due to imperfect foresight of biofuel and vehicle battery costs. We assume the long-run cost of biofuels is around 1.30 to 1.50 $/L diesel equivalent. There are several uncertainties in our estimate for the cost and supply of biofuels. If the constraints on agricultural land, the emissions intensity of biofuel production or the cost of "second-generation" biofuel (e.g., cellulosic ethanol, algal biodiesel) are greater than we have assumed, the cost of biofuel will also be greater than we have assumed. Similarly, the future cost of vehicle batteries is also uncertain. Another breakthrough in battery chemistry, which is unlikely prior to 2020,[8] would improve the case for electrification. A sensitivity analysis further explores these uncertainties later in this report.

[8] Boston Consulting Group, 2010, Batteries for Electric Cars: Challenges, Opportunities, and the Outlook for 2020

Figure 8: Electrification abatement by sector in context, medium natural gas price

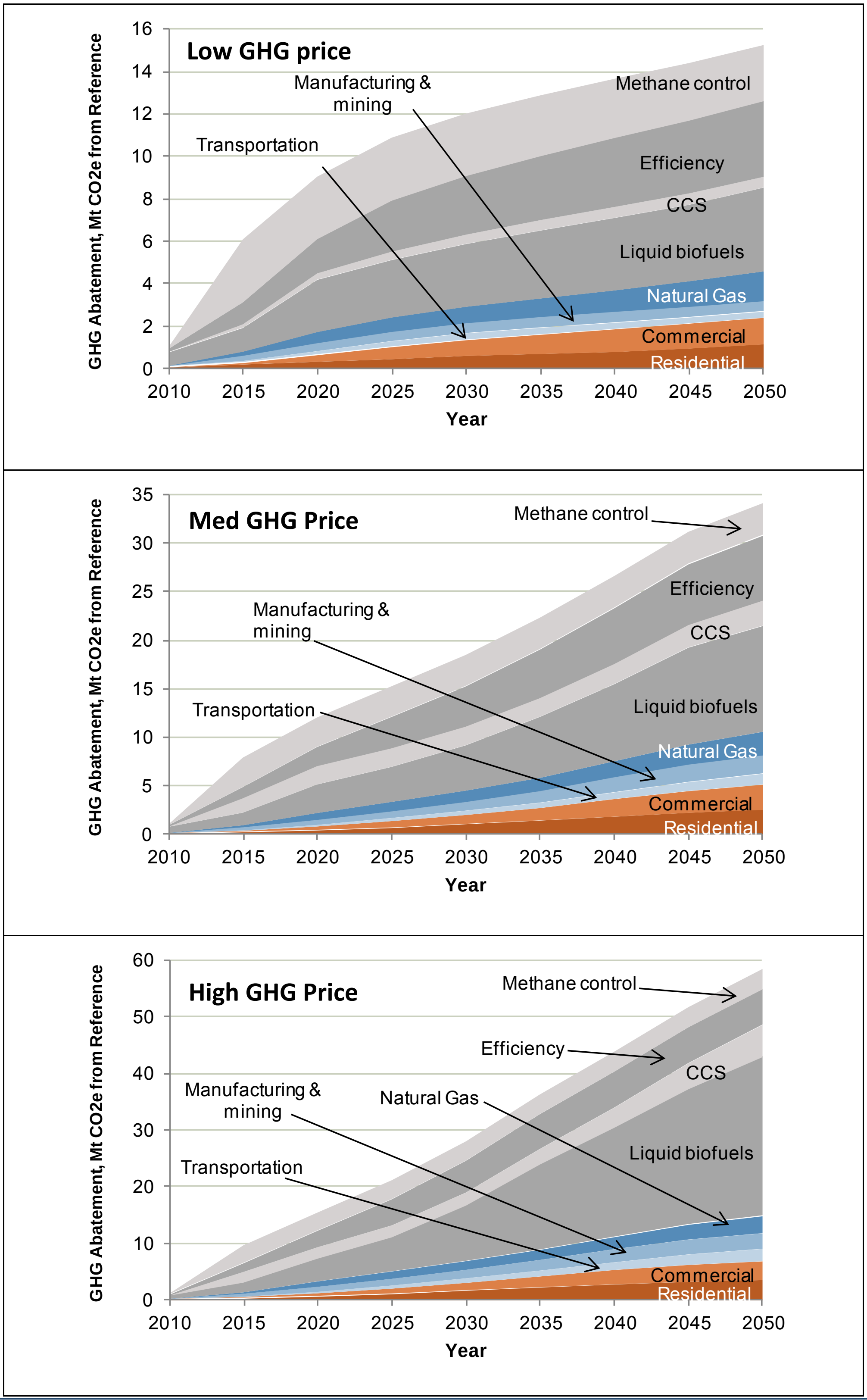


Figure 9 shows electrification abatement by sector in greater detail. To allow a comparison between the GHG price scenarios, the vertical scale showing abatement is constant throughout figure. Results from this analysis of abatement by sector indicate that:

Electrification abatement in the natural gas sector involves a switch from natural gas to electric powered compressors and pumps for gas extraction, processing and transmission. Electric compressors use roughly three times less energy than gas-fired compressors. The increased efficiency reduces the operating cost premium associated with using electricity rather than natural gas; hence electric compressors are an attractive option where electricity is available. Presently, very few natural gas operations use electric equipment and the forecast indicates these technologies will account for only 10-20% of the market in the reference scenario. However, under the medium GHG price, the market share increases to 75% by 2050.

Even with the exclusion of LNG terminals and production in the Horn River Basin, there is substantial potential for low-cost electrification abatement in the natural gas sector. Abatement is constrained by the lack of electricity transmission capacity prior to 2015. Increased transmission capacity, particularly in the Dawson Creek and Chetwynd area, eases this constraint after 2015. Consequently, electrification abatement reduces emissions by 2.5 $MtCO_2e$ in 2050 (Figure 9), even under the medium GHG price scenario. This result is contingent upon timely transmission of electricity. Delays or uncertainty in this transmission could result in projects moving forward with gas-fired equipment, resulting in a technological "lock-in" of GHG emissions from this sector.

Electrification of ore and coal transportation in the mining sectors can occur with the use of trolley-assisted mining trucks and conveyors. Trolley-assisted mining trucks use a diesel-electric drive that connects to overhead wires during specific portions of their route, typically when travelling uphill and sometimes downhill. This technology typically reduces diesel consumption for ore and coal transportation by 50%. Electric conveyors can also be used to move material. Conveyors are highly energy efficient and cheap to operate, but their infrastructure has higher initial costs and is less flexible compared with trucks. Under lower GHG prices, the trolley assisted trucks gain substantial market share, while in response to the high GHG price, there is more use of conveyance in conjunction with trucks as the benefits of low operating costs begin to outweigh the benefit of mine-plan flexibility.

Drying coal using microwaves rather than coal combustion further reduces emissions in the coal mining sector. The moisture content of coal is reduced prior to shipment and the heat for this process typically comes from fossil fuels. However, a newly commercialized technology uses microwaves to remove water from coal.

Electrification in the mining sectors can reduce GHG emissions substantially and accounts for half of the electrification abatement in "manufacturing and mining". Electrification abatement from the mining sector ranges from 0.3 $MtCO_2e/yr$ in the low GHG scenario to almost 1.5 $MtCO_2e/yr$ in the high GHG scenario (Figure 9). However, most mines are in remote areas. As with the natural gas sector, a pre-requisite to this abatement potential is sufficient transmission of electricity to areas that are currently not well connected to the grid.

Electrification abatement in manufacturing can occur with the production of heat using industrial heat pumps rather than natural gas or other fossil fuels. Heat in this sector is used in a variety of small and medium enterprises for manufacturing foods and beverages, furniture, printed material, machinery, textiles, leather, transportation equipment, and electronics.[9] Some of this heat can be produced using an industrial heat pump given that their electricity consumption is only 20-50% of their heat output. This technology is currently cost competitive where output temperatures are near or below 100 C and annual operating hours are high. Under less favourable operating conditions, only a strong policy signal results in the use of an industrial heat pump. Furthermore, some processes may require operating temperatures that are higher than a heat pump can supply, therefore we have constrained this market share to less than 20% of the heat demand for manufacturing (approximates the heat demand for food manufacturing where most heat pump applications exist).

Electrification abatement in manufacturing can also occur with the use of direct or indirect electric heating in response to higher GHG prices. Direct and indirect electric heating is a higher cost abatement action than heat pumps since there is little gain in energy efficiency relative to using fossil fuels. In other words, each unit of natural gas must be replaced by approximately one unit of electricity which increases energy costs substantially. By 2050, electric heating accounts for 40-60% of manufacturing heat supply in the high GHG price scenario, but only 20% and 5% under a medium and low GHG price. Direct and indirect electric heating, combined with industrial heat pumps, reduces emissions by 0.7 $MtCO_2e$ by 2050 under the medium GHG price, and 1.1 $MtCO_2e$ under the high GHG price (Figure 9).

There is significant variation in the specific circumstances of any mine or manufacturing facility meaning the abatement cost and electrification potential will also vary considerably. For example, deeper open-pit mines will favour trolley-assisted trucks, while mines where the mine plan does not evolve rapidly may favour conveyors. If neither of these conditions applies and electricity is not available, mine operators will favour standard equipment. Because individual facilities were not represented in this analysis, the exact electrification potential of all sectors, especially manufacturing and mining, is uncertain.

The federal light-duty vehicle emissions standard is the initial driver of electrification in the transportation sector but a strong GHG price is needed to encourage substantial electrification of personal and freight transportation by 2050. In 2020, only a 5-9% of light-duty vehicles are plug-in hybrids. The market share does not increase under the

[9] Manufacturing of wood products is not included in this list since this sector does not rely on electrification to reduce GHG emissions given its supply of wood fuel.

low GHG price and rises somewhat in response to the medium GHG price. In the high GHG price scenario, the market share of electric light-duty vehicles surpasses 60% by 2050, while the market share of electric light freight vehicles is just over 21%. Electrification abatement in the high GHG price scenario is 2.2 $MtCO_2e$ by 2050 (Figure 9), with personal transportation accounting for two thirds of this reduction. Electrification of heavy duty vehicles was not considered in this analysis.

Electric vehicle batteries are very expensive, and although the cost will decline with increased production, consumers and firms will use plug-in hybrid electric motors to minimize their exposure to battery cost. Batteries account for a significant proportion of an electric vehicle's cost. Currently, the battery for a light freight truck costs $80,000 to $100,000[10], making an electric truck two to three times more expensive than a standard truck. With sufficient production and use, we assume battery costs fall by a factor of two in the forecast. Nonetheless, the cost of premium of a full-electric vehicle remains large. Consequently, consumers and firms use plug-in hybrid vehicles, with smaller and less expensive batteries, at the expense of some GHG abatement, rather than full-electric vehicles. Furthermore, the auxiliary energy source of hybrid vehicles improves the short range and long charging times of full electric vehicles.

The maximum potential for electrification of light freight vehicles is much larger than what occurs in the scenarios. The market share of electric freight vehicles hits a maximum of 20% by 2050 in the high GHG price scenario. Most abatement from freight vehicles is achieved by using biofuels. However, with different assumptions for biofuel and battery costs, this abatement, and any biofuel abatement in the personal transportations sector, could also be achieved with electrification. A sensitivity analysis later in the report delves into the implication of the biofuel and battery costs assumptions in the main analysis.

Electrification of space and water heating in residential and commercial/institutional buildings accounts for roughly half of all electrification abatement in any scenario. Electrification abatement in buildings occurs when electric resistance, heat pump, or electric solar assisted heating equipment is used instead of fossil fuels. It accounts for most GHG reductions from buildings relative to the reference scenario. Electrification abatement from buildings reaches 2.4 $MtCO_2e$ in 2050 in the low GHG price scenario,

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[10] This cost is for a truck with an 80 kWh battery pack, such as the Navistar E-Star or Smith Electric, with batteries costing $1000-$1200/kWh:

Transport Canada, 2012, Evaluation of performance and energy consumption of Electric trucks, http://www.tc.gc.ca/eng/programs/environment-ecofreight-road-evaluation-performance-energy-consumption-electric-trucks-2763.htm

Boston Consulting Group, 2010, Batteries for Electric Cars: Challenges, Opportunities, and the Outlook for 2020 and 5.1 and 6.9 $MtCO_2e$ by 2050 in medium and high GHG price scenarios, respectively (Figure 9).

Residential buildings use electric resistance heating and air-source heat-pumps while the scale of commercial/institutional buildings allows ground-source heat pumps to gain market share. Baseboard electric heaters are used in roughly 35% of homes in the reference scenario. The market share of baseboard electric heating increases in response to carbon pricing as consumers seek to avoid the carbon cost associated with natural gas combustion. However, the rising electricity prices in the electrification scenarios constrain the use of baseboard heaters such that they are not used in more than 40-45% of homes. In the residential sector there is some early adoption of air-source heat pumps which increases through time in response to and rising GHG prices as homes are renovated and replaced. Ground source heat pumps are not widely used in homes. By 2050, 20-25% of homes may use heat pumps if GHG prices continue to increase. Electrification abatement in the commercial and institutional buildings is driven primarily by ground-source heat pumps. In the high GHG price scenario, 60% of total heating for these buildings comes from heat pumps by 2050. In all buildings, the rate at which electrification occurs is constrained by the rate at which buildings are renovated and replaced.

Wood and other biomass fuel can reduce the role of electricity in supplying zero-GHG heating to buildings, but the potential for this fuel is uncertain.

The scale of advanced wood heat technologies and their air-emissions controls mean they can be used only for larger buildings or campuses. Therefore, we constrained wood heat so it would supply no more than 10% of the heating in the commercial/institutional sector. This constraint is equivalent to half the floorspace in large institutional buildings such as universities, hospitals and government buildings. This analysis shows a modest adoption of biomass heating even without GHG pricing, but under strong policy signals, our assumptions constrain further adoption. Uncertainties include the cost of wood, public acceptance of advanced wood heating, and the role district energy may play in allowing greater use of wood for space and water heating in residential and commercial buildings.

Figure 9: Electrification abatement by sector, medium natural gas price

Electricity Demand

Figure 10 shows the electricity demand forecast for the GHG price scenarios relative to the reference scenario. For clarity, the upper and lower bounds created by the natural gas price scenarios have been omitted. Table 11 shows the forecast for all scenarios.

Figure 10: Electricity demand by GHG price scenario, medium natural gas price

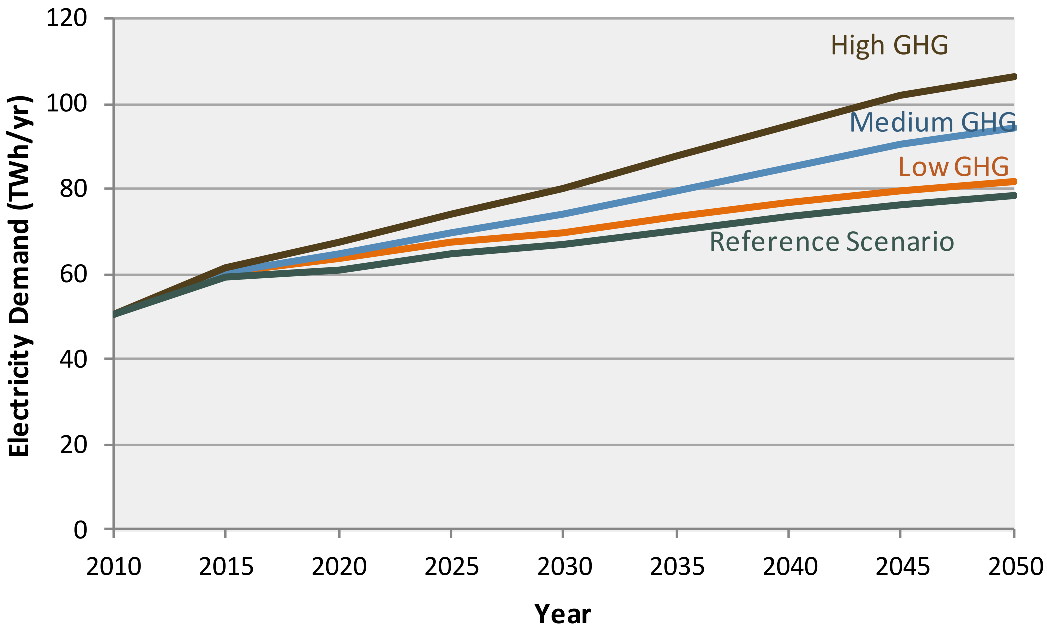


Table 11: Electricity Demand by Scenario, TWh/yr

GHG price scenario	Natural gas price scenario	2010	2020	2030	2040	2050
Low	Low	51	62	67	72	76
	Medium	51	64	70	77	82
	High	51	68	77	84	91
Medium	Low	51	63	70	80	88
	Medium	51	65	74	85	95
	High	51	69	80	92	102
High	Low	51	65	76	90	101
	Medium	51	67	80	95	106
	High	51	71	86	101	112
Reference		50	61	67	73	78

Deep reductions of British Columbia's GHG emissions will results in substantially more electricity demand. Electricity consumption in the low GHG price scenario is only slightly above the reference scenario (approximately 3 TWh/yr). However, the medium and high GHG price scenarios result in significant additional electricity demand beyond the reference forecast. The medium GHG price increases demand by an additional 10-20 TWh by 2050 while the high scenario see demand rise by 20-35 TWh relative to the reference scenario.

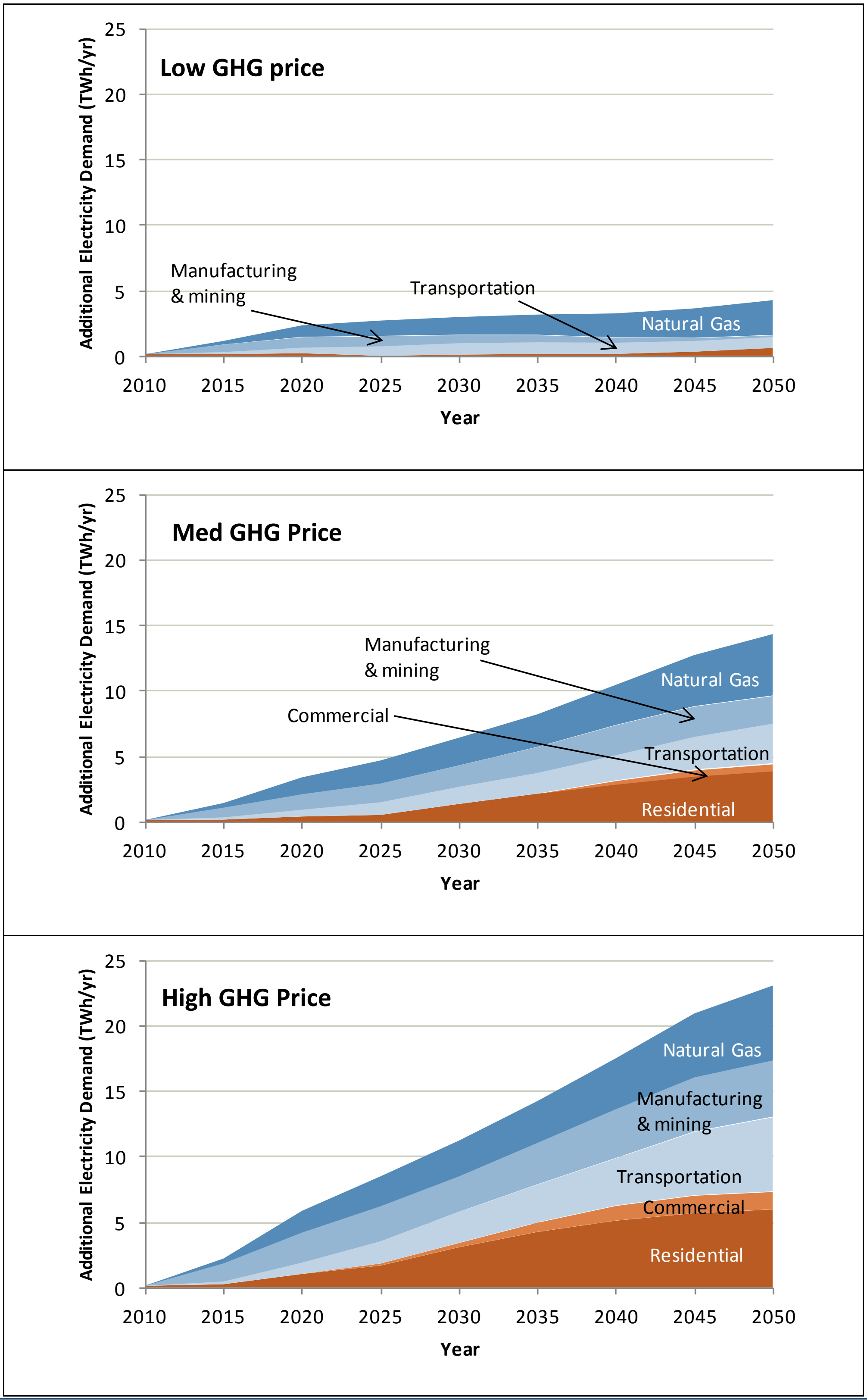
Additional Electricity Demand by Sector

Electrification abatement does not result in the same proportional increase in electricity demand for all sectors. Figure 11 shows the additional electricity demand by sector relative to the reference scenario for each GHG price (medium natural gas price forecast). The additional electricity demand does not follow the same trend as the electrification abatement described above. Differences in the trends occur because some abatement actions makes very efficient use of electricity, consuming much less electricity than the amount of fossil energy that is displaced (e.g., heat pumps or electric vehicles). As well, increased demand for electricity raises electricity rates relative to the reference scenario. Consequently, consumers and firms will invest in more efficient equipment for processes that already use electricity (e.g. ventilation and lighting in buildings, crushing and milling of ore in the mining sector).

Much like electrification abatement, new demand comes from the entire economy including buildings, transportation and industry. The exception to this statement is the commercial/institutional sector. In all scenarios, this sector shows very little new load growth relative to the amount of electrification abatement it yields. This ratio of abatement to new load occurs because electrification occurs with the installation of highly efficient ground-source heat pumps. Furthermore, the sector achieves numerous other efficiency gains in ventilation and air-conditioning that offset new demand. On the other hand, the new demand from the residential sector is much greater even though electrification abatement is similar. This is because less efficient air-source heat pumps and resistance electricity are used to reduce GHG emissions in residential buildings.

New load from mining and manufacturing is offset by numerous improvements in electrical efficiency and additional cogeneration of electricity. The additional electricity demand from the industrial sectors would be between two and five TWh/yr higher if it were not offset by energy efficiency improvements and additional cogeneration. Improvements include more efficient crushing and milling of ore in the mining sector. The additional cogeneration occurs primarily in the pulp and paper sector as cogeneration units are run with lower heat to power ratios (more electricity output) and with better utilization of spent pulping liquor as a fuel for the cogeneration units.

Figure 11: Additional electricity demand, medium natural gas price



Sensitivity Analysis

These sensitivity analyses explore the impact of two key uncertain determinates of future electricity demand in BC: The limits on biofuel availability and the cost of electric vehicle batteries in the transport sector; and the impact of banning baseboard electric heaters in buildings. All sensitivity analyses have been performed using the medium natural gas price and medium greenhouse gas price scenario. The sensitivity results from this scenario are representative of the results from the other electrification scenarios.

Biofuel and Electric Vehicle Battery Costs and Availability

The main analysis indicates that the availability of liquid biofuel may reduce the potential for electrification abatement from vehicles. Our assumptions are that biofuel will be widely available with a long-run cost of whose long-run cost of $1.30/L diesel equivalent, compared with diesel at roughly $1/L. However, neither the cost or availability of biofuels nor the cost of electric vehicle batteries is certain. If biofuels prove to be unviable at scale or if battery technology improves, could the electrification abatement and new load required be very different from the initial results?

Two alternate scenarios explore this question. In the first, biofuel is not viable at a large scale and can account for little more than the current renewable fuel content, roughly 10-15% of liquid fuels. The base assumption for the cost of batteries applies where initial costs are roughly 1000$/kWh storage capacity, falling to 500$/kWh. In the second scenario, biofuel is available as in the main analysis, but greater improvements are possible for batteries. In this scenario the lowest cost is 250$/kWh representing commercialization of metal-air or ionic-liquid batteries to replace current lithium-ion batteries.

Limited availability of biofuels does not increase electrification abatement at a given policy strength, it just reduces total abatement. Electrification abatement is almost identical in the base scenario and the limited biofuel scenario (Table 12)**.** Instead, total abatement from the transportation sectors is reduced by 1 $MtCO_2e$ by 2030 and almost 5 $MtCO_2e$ by 2050 (Table 13). This indicates that abatement by electrification and biofuel may act together, as in the case of a plug-in hybrid vehicle running on a biofuel rather petroleum fuel, rather than exclusively of one another.

Cheaper electric vehicle batteries increase electrification abatement and load growth six-fold by 2050. Electrification abatement from vehicles rises to 6 $MtCO_2e$ by 2050, an increase of 4.9 Mt, requiring an additional 18 TWh/yr relative to the reference scenario (Table 12, Table 14). This result indicates that electrification abatement in the transportation sector is constrained by battery costs rather than low biofuel and fuel prices.

Table 12: Electrification abatement ($MtCO_2e$) from transportation under different assumptions for the cost of biofuels and electric vehicle batteries

GHG/NG price scenario	Biofuel and battery scenario	2010	2020	2030	2040	2050
Medium	Base assumptions	0.0	0.2	0.4	0.7	1.1
	Limited biofuel, base battery	0.0	0.2	0.5	0.7	1.1
	Improved battery, base biofuel	0.0	0.2	2.2	4.5	6.0

Table 13: Total abatement ($MtCO_2e$) from transportation under different assumptions for the cost of biofuels and electric vehicle batteries

GHG/NG price scenario	Biofuel and battery scenario	2010	2020	2030	2040	2050
Medium	Base assumptions	0.0	3.8	6.9	11.2	15.4
	Limited biofuel, base battery	0.0	3.7	5.9	8.1	10.7
	Improved battery, base biofuel	0.0	3.9	9.2	14.7	20.9

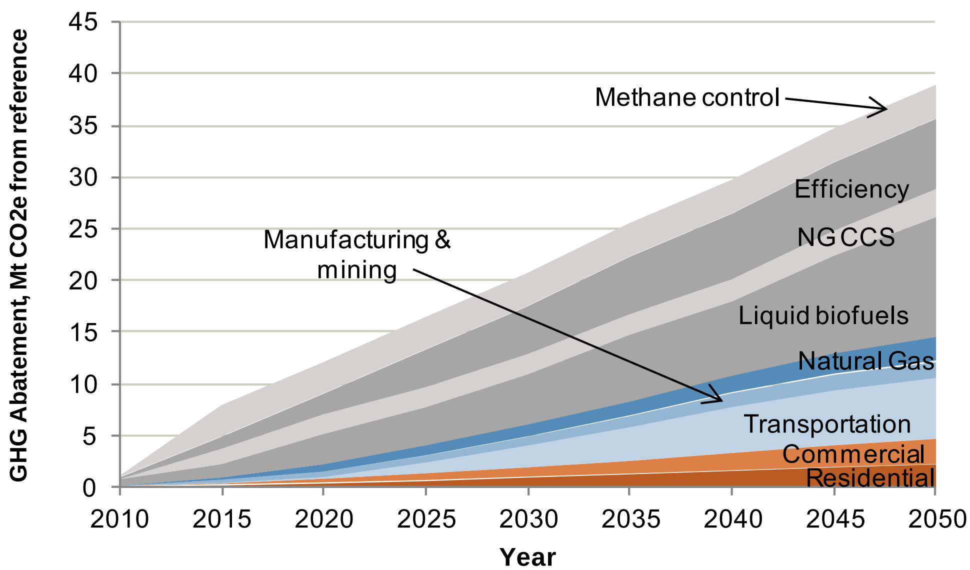
Table 14: Electricity load growth (TWh/yr) from transportation under different assumptions for the cost of biofuels and electric vehicle batteries

GHG/NG price scenario	Biofuel and battery scenario	2010	2020	2030	2040	2050
Medium	Base assumptions	0.0	0.5	1.3	2.0	3.1
	Limited biofuel, base battery	0.0	0.5	1.3	2.0	3.0
	Improved battery, base biofuel	0.0	0.4	3.6	12.0	18.2

The improved battery scenario represents the upper limit for electrification of vehicles since heavy-duty vehicles are unlikely to be fuelled by batteries. Even with low cost batteries, switching to biofuels is still an important abatement action. In the medium GHG price scenario with improved batteries (Figure 12), biofuel consumption still reduces emissions by more than 10 $MtCO_2e$ in 2050. This result indicates that improving the potential for batteries does not remove the need for an energy dense fuel that can be easily stored.

Much of this biofuel is consumed by heavy-duty vehicles whose requirements for energy make batteries impractical. A typical fuel tank on a tractor-trailer can hold 1000L of diesel or 38,500 MJ. If an electric motor is three times as efficient as an internal combustion engine, then an electric truck would need to store 3500 kWh to carry an equivalent amount of useful energy. If the capacity cost of batteries were $50/kWh, equivalent to the cost of a lead-acid battery, the battery alone for one truck would cost $175,000 which is more than the cost of a standard truck. Even with a very optimistic price for batteries, reducing GHG emissions from heavy trucks will likely require biofuels or another zero-GHG fuel.

Figure 12: Electrification abatement by sector in context, improved battery scenario, medium natural gas and GHG price. ***Note the large biofuel wedge in this improved battery scenario: Improving the potential for batteries does not remove the need for an energy dense fuel that can be easily stored.***



Electrification abatement labelled by sector, shown in colour, other abatement labelled by action shown in greyscale

Controls on Baseboard Electric Heating

The value of electric resistance heating for reducing GHG emissions is debatable. Electric resistance heating uses a high quality fuel, electricity, to produce low quality energy, such as heat at room temperature. It does not provide the energy efficiency gains that a heat-pump can achieve relative to heating with combustion. Therefore, resistance heating tends to have high operating costs due to the high cost of electricity relative to fuels such as natural gas. Although widespread adoption of electric baseboard heating would reduce GHG emissions in British Columbia, it would drive up electricity rates which may constrain electrification abatement elsewhere. Furthermore, the additional electricity demand will increase the upstream impact the electricity system (e.g., more small hydro projects, more transmission lines).

The advantages of electric resistance heating are a low upfront cost, simple equipment, and an extensive distribution system. Consequently, many British Columbian homes are heated with electric resistance baseboard heaters. They are cheap in the short term and they offer a simple method to avoid using fossil fuels in buildings. Using them in energy efficient buildings with low heating requirements would mitigate their impact on electricity demand.

Some proposed climate policies include a ban on baseboard electric heaters in order to save electricity for more valuable abatement opportunities. Such a policy may have positive impacts, such as reduced GHG emissions, lower electricity rates and less development of new generation capacity. Additionally, this policy would prevent technology "lock-in" to a heating system that may not have been chosen with perfect foresight of future electricity rates.

On the other hand, banning baseboard electric heaters may not have a significant effect on GHG emissions, electricity rates or demand. If combustion heating is still allowed while baseboard electric heating is banned, the ban could lead to a lock-in to fossil fuel combustion technologies, increasing GHG emissions.

To clarify this debate, we have explored the consequences of such a ban by comparing the main analysis with scenario where baseboard electric heating is banned from 2015 onward. The ban applies to residential, commercial and institutional buildings.

Banning baseboard electric heaters significantly reduces the number of buildings in which they are used. In the main analysis, electric baseboard heaters were used for 35 to 45% of residential floorspace, depending on the natural gas and GHG price scenario. The higher electricity prices of the electrification scenarios kept the market share of baseboard electric heating within 5 to 10% of the reference scenario forecast (Table 15). If baseboard electric heaters are banned, the market share falls from 32% currently to 10% in 2050. The market share of resistance electric heating in commercial and institutional buildings is low in all scenarios.

Table 15: Market Share of baseboard electric heat in residential buildings (%) under different assumptions for the use of this technology

GHG/NG price scenario	Resistance heating scenario	2010	2020	2030	2040	2050
Medium	Base assumption	32%	34%	35%	37%	37%
	No baseboard elec.	32%	23%	16%	13%	10%

Banning baseboard electric heaters reduces electrification abatement, resulting in slightly more GHG emissions. The ban results in roughly 0.2 to 0.3 MtCO2e more GHG emissions throughout the forecast (Table 16), indicating there is some lock-in to fossil fuel technologies that persist for several decades. Any reduction in electricity rates and increase in electrification abatement that may occur in other sectors does not entirely offset the increased GHG emissions from buildings.

Table 16: Electrification abatement ($MtCO_2e$) under different assumptions for the use of baseboard electric heating

GHG/NG price scenario	Resistance heating scenario	2010	2020	2030	2040	2050
Medium	Base assumption	0.0	2.2	4.5	7.5	10.5
	No baseboard elec.	0.0	2.0	4.2	7.2	10.2

Banning baseboard electric heating reduces additional electricity demand and results in lower electricity rates. The ban reduces electricity demand by 2 TWh by 2050 (Table 17). To put this reduction in context, it is equivalent to roughly 40% of the annual electricity production from the proposed site C dam. Because less new capacity is required, electricity rates are lower by 0.2 cent/kWh in 2050 (Table 18).

Table 17: Additional load growth (TWh/yr relative to reference scenario) under different assumptions for the use of baseboard electric heating

GHG/NG price scenario	Resistance heating scenario	2010	2020	2030	2040	2050
Medium	Base assumption	0	4	7	12	16
	No baseboard elec.	0	3	6	10	14

Table 18: Electricity rate impacts (2005 cent/kWh relative to reference scenario) under different assumptions for the use of baseboard electric heating

GHG/NG price scenario	Resistance heating scenario	2010	2020	2030	2040	2050
Medium	Base assumption	0.0	0.4	0.8	1.3	1.8
	No baseboard elec.	0.0	0.3	0.6	1.1	1.6

Allowing baseboard electric heating will only reduce emissions if electricity generation produces no GHG emissions. The ban reduces electricity demand by 2 TWh in 2050. Even If this electricity were produced by a thermal power plant using carbon capture and storage, the upstream emissions could be equal to the total downstream abatement that occurs without the ban. For example, if emissions intensity of the power plant were 125 kt/TWh (e.g., coal with carbon capture), then upstream emissions would be roughly 0.3 Mt, equal to the additional abatement in the scenario where baseboard electric heaters are allowed.

Conclusions

This study has investigated the potential for electrification in British Columbia by answering the following broad questions:

To what degree will consumers and firms use electrification to reduce GHG emissions between the present and 2050, and how will this fuel switching affect electricity demand?

Electrification can significantly reduce future GHG emissions and this abatement will account for a significant proportion of the total abatement resulting from climate policy. Electrification abatement accounts for one fifth of total abatement under current British Columbian climate policy (the low GHG price). If GHG policy is strengthened, as represented by the medium and high GHG price scenarios, electrification abatement will account for a third of total abatement. In absolute terms, by 2050, electrification may reduce emissions by up to 5 $MtCO_2e$/yr under the low GHG price, 11 $MtCO_2e$/yr under a medium GHG price, and 15 $MtCO_2e$/yr under a high GHG price.

These GHG reductions are highly sensitive to both the strength of climate policy and the relative difference in electricity and natural gas prices. While total GHG abatement is not highly sensitive to natural gas prices, this analysis shows that the specific abatement actions used, namely electrification, may be strongly influenced by energy prices in addition to climate policy. Low natural gas prices constrain electrification abatement while high natural gas prices increase electrification abatement. Electrification is less sensitive to other fuel prices, such as liquid petroleum or bio-fuels, since the substitution between these fuels and electricity requires significantly different upfront costs (e.g., an electric vehicle battery versus an internal combustion engine).

Deep reductions of British Columbia's GHG emissions will results in substantially more electricity demand. Electricity consumption in the low GHG price scenario is only slightly above the reference scenario (approximately 3 TWh/yr). However, the medium and high GHG price scenarios result in significant additional electricity demand beyond the reference forecast. The medium GHG price increases demand by an additional 10-20 TWh/yr by 2050 (roughly 25% increase) while the high scenario see demand rise by 20-35 TWh/yr (~33% increase) relative to the reference scenario.

This electrification abatement occurs even though new electricity supply comes from increasingly costly zero-emissions resources. The electricity from the small hydro and wind power resources that will dominate new electricity supply is more expensive than existing resources. Furthermore, there is a limited supply of electricity available at any given cost. When electricity demand increases relative to the reference case, so too does the electricity price. However, the potential for GHG abatement through electrification remains large (over 10 $MtCO_2e$/yr by 2050) even when electricity rates increase by two to three cent/kWh relative to the reference scenario price.

The benefit of electrification in reducing GHG emissions depends on the use of this higher cost zero-GHG electricity. If electricity generation is GHG intensive, then most of the abatement from electrification would not occur. Either the carbon price would be passed through the electricity rates, reducing electricity demand, or the emissions from electricity generation would negate the electrification abatement achieved in other sectors.

What sectors and technologies have the greatest potential for electrification?

Electrification abatement comes from a broad set of energy end-uses in buildings, transportation and industry. The GHG price encourages a switch between electricity and fossil fuels for the provision of compression (natural gas production, processing, and transmission), transportation (light-duty vehicles, light freight vehicles, and mining vehicles), drying and process heat (coal drying and manufacturing), and space and water heating (residential and commercial/institutional buildings).

The amount of electrification abatement in the transportation sector carries the most uncertainty and could be much larger than we have estimated. This uncertainty comes from unknown future battery and liquid biofuel costs. It was explored with a sensitivity analysis.

The sensitivity analysis demonstrated that electrification abatement in the transportation sector is constrained by battery costs rather than low biofuel and fuel prices. Limiting the availability of biofuels did not increase electrification abatement at a given policy strength, it only reduced total abatement. Conversely, cheaper electric vehicle batteries increased electrification abatement and load growth in the transportation sector six-fold by 2050.

Given the impact of electrification on GHG emissions and electricity demand, how can this fuel switch be managed strategically?

This research question takes the findings of this electrification potential review and draws out additional lessons to guide policy and decision making:

Use this analysis to identify the important electrification opportunities to target with further research, validation and stakeholder engagement. This analysis provides a high level description of electrification and it is limited in its ability to accurately represent the unique circumstances of any firm or consumer. Specific barriers or advantages may make electrification more or less attractive on a case-by-case basis. Practical survey work or engagement with important stakeholders (e.g., mines, municipalities, and delivery vehicle fleet managers) can identify what policies or actions can leverage advantages or overcome barriers associated with electrification abatement.

In a carbon constrained world, expect to deliver electricity to where it typically has not been used. While it is obvious that BC Hydro will need to take delivery from widely dispersed zero GHG emissions sources (e.g. wind farms, biomass cogeneration, small hydro), it is less obvious where new demand will arise. Much of the electrification abatement is contingent upon generating zero-GHG electricity and transmitting and distributing this electricity to customers that have not typically required substantial access to the BC Hydro grid. A pre-requisite to the electrification abatement potential in this analysis is sufficient transmission and distribution. Half of the electrification abatement in this forecast occurs where new or increased transmission and distribution capacity will be needed: At mine sites, natural gas wells, pipelines, and processing plants[11], manufacturing enterprises and in transportation.

Delays or uncertainty in electricity supply and transmission could result in missed GHG abatement opportunities. Some industrial projects or other investments will move forward without electric equipment, even if electrification might have been preferred. Capital investments (vehicles, machinery etc.) have long lives. If fossil fuel powered equipment is purchased rather than electric equipment, it creates a technological "lock-in" of GHG emission that can prevail for decades until the equipment is retired.

Improved transport electricity storage technologies could radically alter demand for grid electricity. This project included a review of the potential for transport electrification, but technological developments in this area are highly uncertain. "Surprises" will bias towards better battery storage technology and cheaper vehicle batteries, the key barrier to widespread transport electrification.

[11] Again, this is even with the exclusion of gas production and processing in the horn river basin and liquefied natural gas terminals.

Appendix A: Detailed Quantitative Results

The accompanying spreadsheet "BC Hydro Electrification Potential Review_Final_Detailed Quantitative Results.xlsx" contains the quantitative results of this analysis in detail. Table 19 describes the data contained accessed with each tab in the spreadsheet.

Table 19: Description of detailed quantitative results organized by spreadsheet tab

Tab	*Description*
Technology Market Shares	Summarizes the market share of key technologies in each major sector for each scenario to 2050
Electrification Abatement	Contains total GHG emissions and electrification abatement by scenario in British Columbia. Contains electrification abatement disaggregated by sector for each scenario.
Change in Electricity Demand	Contains total electricity demand by scenario in British Columbia. Contains additional electricity demand disaggregated by sector for each scenario.
Abatement in Context	Contains the electrification abatement relative to other abatement and the abatement required to reach British Columbia's GHG emission targets.

Appendix B: Summary of the Review of Electrification Opportunities

This summary documents the review of key electrification opportunities and data gaps identified and researched during the initial phase of this project. The information summarized below was incorporated into the methodology to refine our portrayal of electrification. Included is a review of:

- The availability and timing of electricity transmission to natural gas producers.
- Electric process heat for small and medium manufacturing enterprises and the role for biofuel as a heat source for wood products manufacturing.
- Electric transport in mines and microwave coal drying.
- The role of biomass versus electricity for zero-GHG heating in buildings
- Electric freight vehicles
- Direct to wholesale electricity purchases by industry
- The effect of GHG pricing on production and electricity demand in the natural gas sector

Electricity Transmission Constraints to the Natural Gas Sector

- Near term constraints were put on electrification based on the schedule for the Dawson Creek/Chetwynd area transmission upgrade. No incremental load growth relative to the reference scenario was permitted before 2015. After 2015, no constraints were applied to electrification.
- The short-term constraint delays electrification abatement, and results in a lock-in of gas-fired equipment prior to 2015.
- A limitation of this review is the assumption that after 2015, the market will determine the amount of electricity available to natural gas producers and the electricity will be sold based on the provincial average cost. Non-market factors may delay or prevent transmission developments, and the electricity price may not be based on the average cost of supply. Given the scale of electrification in the natural gas sector, the effect of this uncertainty on GHG emissions and electricity demand could be large.

The Role of Heat Pumps and Biomass Fuel in Other Manufacturing

- The other manufacturing sector was reviewed to better understand the potential for producing process heat with electricity.

- The goal of the review was to better understand how the manufacturing sector in British Columbia uses heat and to increase our knowledge of how electricity could be used to provide process heat.
- A large fraction of the heat in the other manufacturing sector is used to dry lumber and wood products. Wood waste can fuel all of this heat production, limiting the role or need for electrification abatement in this segment of the manufacturing sector. This revision reduces the potential for electrification abatement in the manufacturing sectors since a substantial amount of heat can be produced with wood waste which produces no net GHG emissions.
- For the rest of the manufacturing sector, we found that process heat can be produce directly or indirectly with electricity (e.g., resistance) and with industrial heat pumps. The latter technology was not represented in the analysis so industrial heat pump archetype was added to the model. This increased the potential for electrification abatement. But the energy efficiency of the heat pump allowed this potential to be realized with less growth in electricity demand.
- A limitation of this review is the uncertainty in our representation of heat pumps. Heat pumps can be used for many applications requiring a large range of temperature lifts. Consequently, the energy consumption and cost of the technology can also vary significantly. In some applications, heat pumps may be the most cost effective way to provide heat, while in others they may be more costly than other technologies. Therefore, an archetypical representation of this technology in a model of the entire economy will not be accurate for all situations.

Electrification of Coal and Metal Mining

- Significant electrification abatement is possible in the coal and metal mining sectors through the use of trolley-assisted mining trucks (able to use grid electricity when connected to overhead wires), and in-pit crushing and conveyance of ore and coal. Additionally, coal must be dried prior to shipment. This process is often fuelled with coal, but it can be done using microwaves.
- Electrification an important abatement action available to these sectors. Abatement could be several MtCO2e in British Columbia by 2050 in response to the high GHG price. Therefore, availability of electricity to mines will be important for large emissions reductions from these sectors.
- Although electrification is a key abatement action, some electrification may occur in the reference scenario since in some instances, electrification can lower mining costs even in the absence of GHG pricing. This statement is contingent upon a reasonable cost to transmit electricity to the mine.

- The choice to use electric mining transportation technologies represents a substitution between ongoing energy costs for standard diesel technologies and the higher upfront costs and reduced flexibility of electric technologies. Electric technologies have higher upfront costs since they require more infrastructure (conveyors, overhead wires, electricity transmission and distribution)
- The use of these technologies is less sensitive to electricity price since the electricity use per unit of output (e.g., tonnes moves) is relatively low. Instead, it is more sensitive to the amount of diesel fuel saved (relates primarily to mine depth) and to the value of flexibility in the mine plan which is reduced by the installation of fixed electric equipment (e.g., a conveyor) or electricity distribution infrastructure.
- Since microwave coal drying does not result in a large energy savings, the choice to use this technology depends on the relative energy costs of electricity versus fossil fuels. However, microwave dried coal is typically drier and has improve qualities for steelmaking. The uncertainty here is the extent to which coal buyers are willing to pay a premium for the unique properties and energy density of microwave dried coal. If this willingness turns out to be high, the microwave technology may be used even in the reference scenario.
- The greatest uncertainty in this review of the mining sectors is the variability in mine circumstances. Electrification is more attractive for deep mines where significant amounts of material must be moved to access the coal or ore. Likewise for microwave coal drying, if the moisture content of the coal must be reduced to less than 8-10%, the microwave drying technology will be favoured.
- Given this reality of varied incentives for electrification, these abatement actions will not be used in response to a single carbon price. Instead, as the policy signal increases, so too will the instances where the benefits of using electric mining technologies are larger than the costs.

Advanced Biomass Heating in the Building Sector

- We explored the use of advanced biomass combustion for space heating in commercial and institutional buildings and added a biomass technology archetype to the model. The scale of the technology and its air-emissions controls indicate it must be used at larger scales, so the technology was constrained to supply a maximum of 10% of the heating in the sector (equivalent to roughly half the heating required for large institutional buildings).
- Biomass heating reduces the role of electricity in supplying zero-GHG heating in this sector. Therefore, increased biomass use reduces the potential for electrification abatement and reduces the amount of electricity needed by the sector in the electrification scenarios.

- The limitations of this review are numerous and include the cost of biomass fuel, public acceptance of biomass heating, and the role district energy may play in allowing greater use of biomass for space and water heating. This analysis portrays modest adoption of biomass heating that is plausible given current interest in the technology. However, development of district energy systems could increase the scale of biomass consumption to a point where it significantly reduces the role of electrification in zero-GHG buildings.

Electrification of Light/Medium Freight Trucks

- A battery and plug-in hybrid truck archetype were added to the light/medium freight truck technologies (i.e., commercial and delivery vehicles). Many of these trucks are fleet vehicles and travel over known routes, eliminating the challenges of reduced range associated with battery vehicle.
- Electrification abatement of freight vehicles could be even more significant than the electrification of light-duty vehicles. However, the large energy storage requirements of freight trucks mean the batteries for these vehicles account for a larger fraction of total vehicle cost than for personal vehicles, thus increasing the barrier to adoption.
- Even though economies of scale and learning decrease the initial costs of batteries, the cost remains prohibitive keeping the market share of electric trucks smaller than the market share of electric light-duty vehicles.
- The uncertainty with this result comes from imperfect knowledge of how biofuel or battery costs will evolve in the latter half of the forecast period (post-2025). If the cost and emissions intensity of producing biofuel can be reduced, there will likely be less electrification than shown in this analysis. If new battery chemistry reduces the battery cost, or if new battery ownership models evolve, there could be more electrification than we have forecast.

Review of Other High Level Issues

Two additional high level issues relevant to electrification were reviewed qualitatively:

- Large electricity customers may choose to buy electricity directly from the wholesale market outside of British Columbia if BC Hydro prices remain consistently above the wholesale price. This situation would change electricity demand and prices, thus affecting our estimation of electrification potential. However, the electrification scenarios assume that higher GHG prices are adopted only if they apply across many jurisdictions, introducing a carbon cost to wholesale electricity. Therefore, if direct to wholesale purchases are not expected in the reference scenario, then they will also be unlikely to occur in the electrification scenarios.

- Natural gas production determines the upper bounds for electrification abatement and new electricity demand from the natural gas extraction sector. Consequently, the production forecast is significant to total electrification potential. Natural gas production was fixed in this analysis and there was concern that the GHG prices would reduce the output of the sector and change the estimated electrification potential. A literature review of this topic indicated that natural gas demand will remain strong across North America with the application of a GHG price. Specifically, natural gas demand by electric utilities in the United States will grow if climate policies are applied. Therefore, the fixed natural gas production forecast is a reasonable assumption.

Appendix C: Detailed Description of the CIMS model

The CIMS Model

CIMS has a detailed representation of technologies that produce goods and services throughout the economy and attempts to realistically simulate capital stock turnover and choice between these technologies. It also includes a representation of equilibrium feedbacks, such that supply and demand for energy intensive goods and services adjusts to reflect policy. Using external forecasts of energy prices and economic and physical output, CIMS forecasts the technologies used to provide energy services (e.g., heated commercial floor space or person kilometres travelled). Hence, CIMS forecasts the reference greenhouse gas emissions and energy consumption in each sector sub-models (shown by region in Table 20). Relative to this reference case, CIMS forecasts the effect of policies on the energy consumption, economic and physical output, GHG emissions (energy and non-energy GHG emissions), and most local air pollution emissions from its sub-models.

Table 20: Sector Sub-models in CIMS

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

* Metal smelting includes Aluminium.

Model structure and simulation of capital stock turnover

As a technology vintage model, CIMS tracks the evolution of capital stocks over time through retirements, retrofits, and new purchases, in which consumers and businesses make sequential acquisitions with limited foresight about the future. This is particularly important for understanding the implications of alternative time paths for emissions reductions. In each time period, capital stocks are retired according to an age-dependent function (although retrofit of un-retired stocks is possible if warranted by changing economic conditions), and demand for new stocks grows or declines depending on the initial exogenous forecast of economic output adjusted by the interplay of energy supply-demand with the macroeconomic module. New stock is aquired if the supply of an energy service, net of retired stock, is less than total demand.

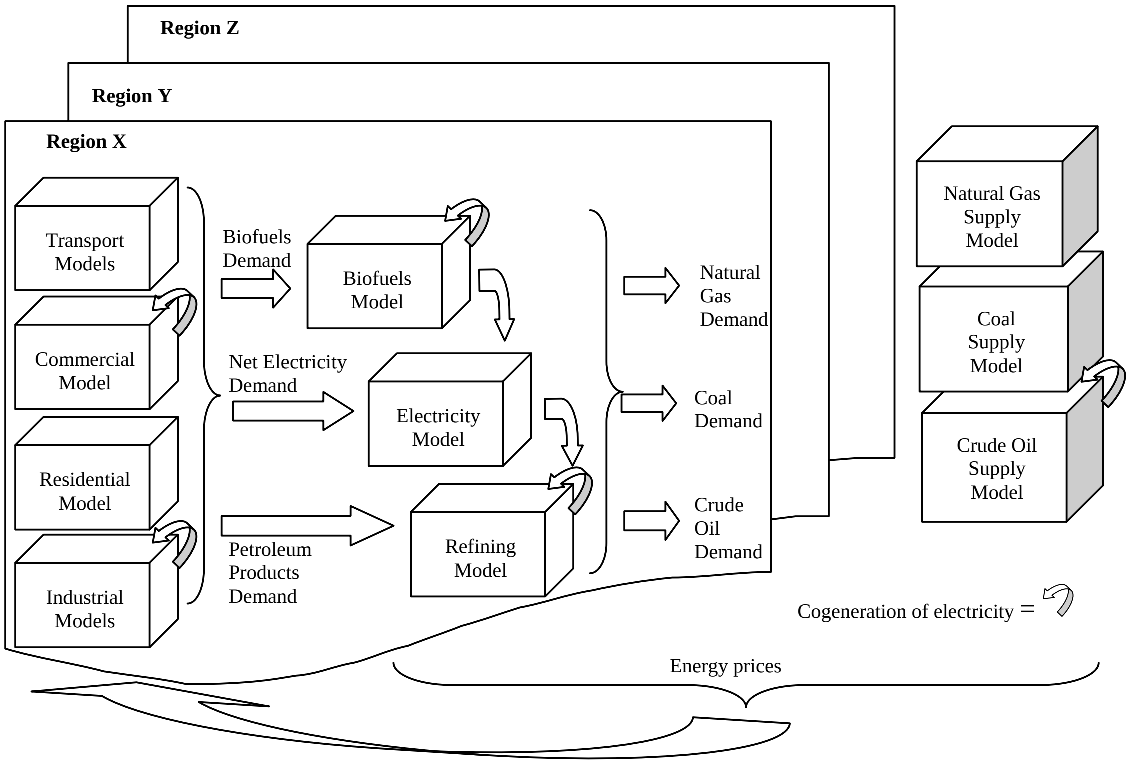
CIMS simulates the competition of technologies at each energy service node in the economy based on a comparison of their life cycle cost (LCC) and some technology-specific controls, such as a maximum market share limit in the cases where a technology is constrained by physical, technical or regulatory means from capturing all of a market. The LCC of each tecnology accounts for capital, operating, energy and emissions costs. Instead of basing its simulation of technology choices only on financial costs and social discount rates, CIMS applies a definition of LCC that differs from simple technology models. It includes intangible costs that reflect consumer and business preferences and the implicit discount rates revealed by real-world technology acquisition behaviour. Additionally, CIMS assumes a heterogeneous market where the LCC of each technology exists in a distribution rather than a single point cost. A policy scenario is developed by applying policies that change the LCC's or constraints on technologies relative to the reference scenario.

Equilibrium feedbacks in CIMS

CIMS is an integrated, energy-economy equilibrium model that simulates the interaction of energy supply-demand and the macroeconomic performance of key sectors of the economy, including trade effects. Unlike most computable general equilibrium models, however, the current version of CIMS does not equilibrate government budgets and the markets for employment and investment. Also, its representation of the economy's inputs and outputs is skewed toward energy supply, energy intensive industries, and key energy end-uses in the residential, commercial/institutional and transportation sectors.

CIMS estimates the effect of a policy by comparing a business-as-usual forecast to one where the policy is added to the simulation. The model solves for the policy effect in two phases in each run period. In the first phase, an energy policy (e.g., ranging from a national emissions price to a technology specific constraint or subsidy, or some combination thereof) is first applied to the final goods and services production side of the economy, where goods and services producers and consumers choose capital stocks based on CIMS' technological choice functions. Based on this initial run, the model then calculates the demand for electricity, refined petroleum products and primary energy commodities, and calculates their cost of production. If the price of any of these commodities has changed by a threshold amount from the business-as-usual case, then supply and demand are considered to be out of equilibrium, and the model is re-run based on prices calculated from the new costs of production. The model will re-run until a new equilibrium set of energy prices and demands is reached. Figure 13 provides a schematic of this process. For this project, while the quantities produced of all energy commodities were set endogenously using demand and supply balancing, endogenous pricing was used only for electricity, biofuels and refined petroleum products; natural gas, crude oil and coal prices remained at exogenously forecast levels, since Canada is assumed to be a price-taker for these fuels.

Figure 13: CIMS energy supply and demand flow model



In the second phase, once a new set of energy prices and demands under policy has been found, the model measures how the cost of producing energy services and traded goods has changed given the new energy prices and other effects of the policy. For internationally traded goods, such as lumber and passenger vehicles, CIMS adjusts demand using price elasticities that provide a long-run demand response that blends domestic and international demand for these goods (the “Armington” specification).[12] Freight transportation is driven by changes in the combined value added of the industrial sectors, while personal transportation is adjusted using a personal kilometres-travelled elasticity (-0.02). Residential and commercial floor space is adjusted by a sequential substitution of home energy consumption vs. other goods (0.5), consumption vs. savings (1.29) and goods vs. leisure (0.82). If demand for any good or service has shifted more than a threshold amount, supply and demand are considered to be out of balance and the model re-runs using these new demands. The model continues re-

[12] CIMS’ Armington elasticities are econometrically estimated from 1960-1990 data. If price changes fall outside of these historic ranges, the elasticities offer less certainty.

running until both energy and goods and services supply and demand come into balance, and repeats this balancing procedure in each subsequent five-year period of a complete run.

Empirical basis of parameter values

Technical and market literature provide the conventional bottom-up data on the costs and energy efficiency of new technologies. Because there are few detailed surveys of the annual energy consumption of the individual capital stocks tracked by the model (especially smaller units), these must be estimated from surveys at different levels of technological detail and by calibrating the model's simulated energy consumption to real-world aggregate data for a base year.

Fuel-based GHGs emissions are calculated directly from CIMS' estimates of fuel consumption and the GHG coefficient of the fuel type. Process-based GHGs emissions are estimated based on technological performance or chemical stoichiometric proportions. CIMS tracks the emissions of all types of GHGs, and reports these emissions in terms of carbon dioxide equivalents.[13]

Both process-based and fuel-based CAC emissions are estimated in CIMS. Emissions factors come from the US Environmental Protection Agency's FIRE 6.23 and AP-42 databases, the MOBIL 6 database, calculations based on Canada's National Pollutant Release Inventory, emissions data from Transport Canada, and the California Air Resources Board.

Estimation of behavioural parameters is through a combination of literature review and judgment, supplemented with the use of discrete choice surveys for estimating models whose parameters can be transposed into CIMS behavioural parameters.

Simulating endogenous technological change with CIMS

CIMS includes two functions for simulating endogenous change in individual technologies' characteristics in response to policy: a declining capital cost function and a declining intangible cost function. The declining capital cost function links a technology's financial cost in future periods to its cumulative production, reflecting economies-of-learning and scale (e.g., the observed decline in the cost of wind turbines as their global cumulative production has risen). The declining capital cost function is composed of two additive components: one that captures Canadian cumulative production and one that captures global cumulative production. The declining intangible cost function links the intangible costs of a technology in a given period with its market share in the previous period, reflecting improved availability of information and decreased perceptions of risk as new technologies become increasingly integrated into the wider economy (e.g., the "champion effect" in markets for new technologies); if

[13] CIMS uses the 2001 100-year global warming potential estimates from Intergovernmental Panel on Climate Change, 2001, "Climate Change 2001: The Scientific Basis", Cambridge, UK, Cambridge University Press.

a popular and well respected community member adopts a new technology, the rest of the community becomes more likely to adopt the technology.

Model limitations and uncertainties

Like all models, CIMS is a representation of the real world, and so does not represent it perfectly. Even though CIMS is very detailed compared to other models that are used for similar purposes, its broad scope (it represents all energy consumption throughout the economy) requires many simplifying assumptions. The main uncertainties and limitations in the model are:

- **Technological detail and dynamics –** CIMS contains a considerable level of technological detail in each of its sectoral sub-models. This detail enables CIMS to show accelerated market penetration of alternative technologies in response to an energy or climate change policy and to ensure that reference and policy scenarios are grounded in technological and economic reality. While care has been taken in representing the engineering and economic parameters of the many technologies in CIMS, uncertainty exists (particularly in industrial sectors) as to the appropriate cost and operating parameters of specific technologies.
- This uncertainty becomes larger over time. While CIMS contains a representation of dynamic technological change that depicts how the costs of new technologies can be reduced through economies of scale and production experience based on historical experience, there is no guarantee that these relationships will hold in the future. In addition, CIMS only contains technological options that are known today (including those that are not yet commercialized). By definition, CIMS does not contain a depiction of new technologies that have not yet been invented. As a result, CIMS could miss technological substitution options in later years of the forecast.
- **Behavioural realism** – The technology choice algorithm of CIMS takes into account implicit discount rates revealed by real-world technology acquisition behavior, intangible costs that reflect consumer and business preferences, and heterogeneity in the marketplace. Incorporating behavioral realism is critical in order to predict realistic consumer and firm response to policies, however, incorporating preferences at a detailed level into a model that is technologically explicit is challenging. In addition to the sheer volume of the data requirements, the non-financial preferences of consumers and firms are difficult to estimate, and can change over time. The complexities associated with estimating behavioral parameters, combined with the fact that information cannot be collected for all the technology competitions in CIMS, result in a degree of uncertainty associated with these parameters overall. The potential for preference change is also a key uncertainty.
- **Equilibrium feedbacks -** Unlike most computable general equilibrium models (which do not contain technological detail), the current version of CIMS does

not equilibrate government budgets and the markets for employment and investment. Also, its representation of the economy's inputs and outputs is skewed toward energy supply, energy intensive industries, and key energy end-uses in the residential, commercial/institutional, and transportation sectors. As a result, it is likely to underestimate the full structural response of the economy to energy and climate change policies.

- **External inputs** – CIMS requires external forecasts of macroeconomic activity in each subsector, population growth forecasts, and fuel price forecasts on which to base the analysis. These forecasts are uncertain and could affect the results of the simulations. In addition, since no individual forecast is available to provide all key inputs over the period of interest in this analysis, we have adopted inputs from several different sources. We have used respected sources, and attempted to ensure consistency between various sources, but it is likely that the various inputs we use are not perfectly consistent with one another.