FINAL REPORT

A Study to Assess the Impacts of Carbon Pricing in Newfoundland and Labrador

April 14, 2010

Prepared for:

Government of Newfoundland and Labrador

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Disclaimer

The following analysis uses simulated results produced from a modelling study. The strength of this analysis is that it provides an integrated picture of provincial abatement potential showing how each sector is likely to respond to carbon pricing. The simulation shows how abatement potential is affected by energy supply and demand and technological developments across the entire economy. However, consultation with each industry was not possible and the results we present are based on M. K. Jaccard and Associates' expertise in simulating the energy-economy system. This distinction is particularly important with respect to the analysis of provincial industries that have one main producing facility such as newsprint and petroleum refining.

This report was prepared by M. K. Jaccard and Associates Inc. for the Office of Climate Change, Energy Efficiency and Emissions Trading of the Government of Newfoundland and Labrador

The findings and views expressed are those of M. K. Jaccard and Associates Inc. and should not necessarily be interpreted as the policies or programs of the Government of Newfoundland and Labrador.

Executive Summary

The Government of Newfoundland and Labrador is in the process of updating its Climate Change Action Plan and producing a greenhouse gas reduction strategy. To aid this process, the Government has expressed a need to understand how the economy will evolve in response to climate policies, as well as the costs and benefits associated with those policies. The objective of this report is to provide a quantitative analysis that can assist policy makers in understanding the potential effect climate policy may have on the province.

This analysis is not intended to be a comprehensive examination of policy alternatives, and does not prescribe a policy package that Newfoundland and Labrador should implement. Rather, it provides reasonable approximations of the relative impacts of different policy options through simulations based on current information, and knowledge of currently available and emerging technologies. Given the twenty-year outlook included in this evaluation, it is expected that many economic, technological, and energy supply and demand relationships will change.

In addition, the pricing scenarios and regulations modelled in this study were selected for the purposes of examining the impact of a range of potential policies on the province's economy, and do not necessarily reflect the policy position of the Government of Newfoundland and Labrador.

In this study, the CIMS energy-economy model is used to:

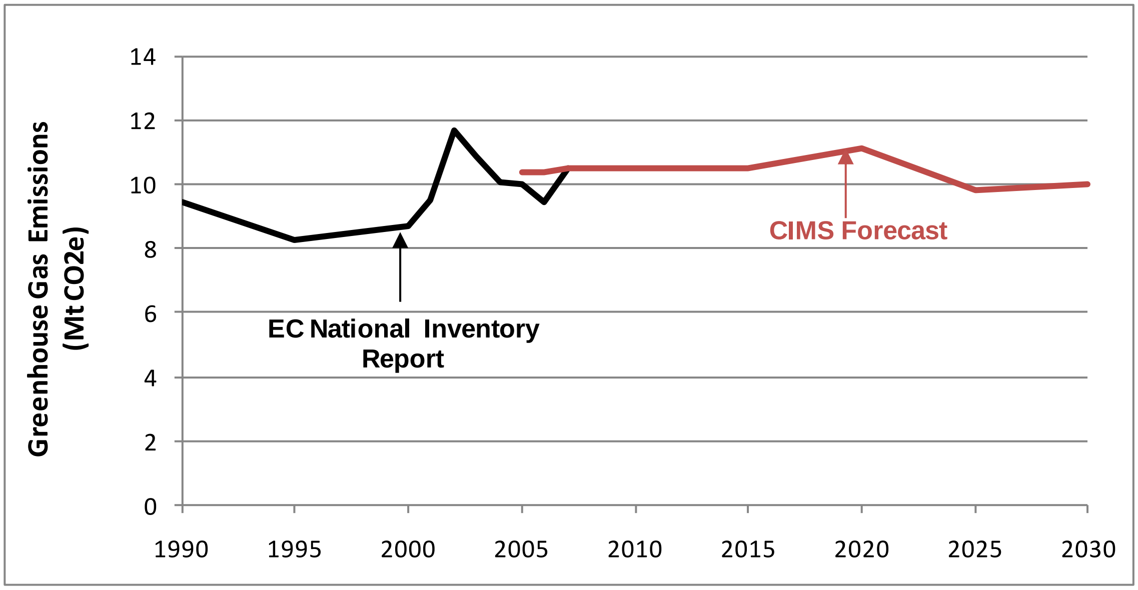
1. Forecast reference case greenhouse gas emissions in Newfoundland and Labrador to 2030.
2. Construct marginal abatement cost curves that illustrate the potential for Newfoundland and Labrador to reduce greenhouse gas emissions. Marginal abatement cost curves show the emissions reductions available at various strengths of carbon pricing and reveal the costs that businesses and consumers incur to reduce emissions.
3. Explore the magnitude of emissions reductions achieved by different trajectories of carbon pricing combined with regulatory policies. For each carbon price path, we assess changes in provincial emissions, energy consumption and key energy and economic indicators.

The marginal abatement cost curve and policy analysis were conducted with and without the construction of the Lower Churchill Falls hydroelectric project to clarify how this development may affect greenhouse gas emissions in Newfoundland and Labrador.

Reference case

- **In the absence of any additional mitigation policy (and without the development of Lower Churchill Falls), greenhouse gas emissions in Newfoundland and Labrador are projected to peak in 2020 at 11.1 Mt CO_2e, and subsequently decline to 10.0 Mt CO_2e by 2030 (Figure ES1).** Provincial emissions are heavily influenced by activity in the transportation, offshore oil and electricity sectors, which account for close to 70% of total reference case emissions in 2030. In turn, activity in the electricity sector is heavily influenced by the residential and commercial sectors.

Figure ES1: Newfoundland and Labrador's reference case greenhouse gas emissions



Marginal abatement costs

Marginal abatement cost curves show the reductions available at various prices for greenhouse gas emissions and reveal the costs that businesses and consumers incur to reduce their emissions. These figures are constructed for two development scenarios: with and without the development of Lower Churchill Falls hydroelectricity project and transmission connection to the island (Figure ES2 and Figure ES3). Each marginal abatement curve is disaggregated by key action to reduce emissions and presented in 2020 and 2030 to illustrate the reductions available over different time frames. The abatement shown is relative to reference emissions in the given year.

Key findings of the marginal abatement cost analysis include:

- **Provincial emissions reductions are sensitive to abatement activities in the electricity sector, and more abatement potential exists in the scenario with Lower Churchill Falls.** In the scenario with Lower Churchill Falls, the electricity sector will reduce its emissions substantially, regardless of the carbon price. Without the hydro development, the sector sees little abatement at carbon prices below \$125/tonne CO_2e in 2020 and \$100/tonne CO_2e in 2030. Above these prices, carbon capture and storage in the electricity sector is viable and abatement increases in the scenario without Lower Churchill Falls.
- **The construction of the Lower Churchill Falls hydroelectric project enables additional abatement outside the sector at lower carbon prices.** Because the

electricity sector is able to reduce its emissions, fuel switching to electricity becomes a significant abatement action for some industrial energy end-use as well as space and water heating in buildings.

- **Carbon capture and storage becomes an important abatement action in the scenario without Lower Churchill Falls.** This abatement action allows the sector to make deep emissions cuts while increasing its output. In this scenario, the electricity sector does not achieve significant abatement at carbon prices lower than $125/tonne CO_2e in 2020. The cost of carbon capture declines by 2030 as experience with the technology accumulates, and by 2030 a carbon price greater than $100/tonne CO_2e induces carbon capture and storage.
- **Improvements in energy efficiency yield reductions in emissions of about 5% from the reference case at an emissions price of $25/tonne CO_2e.** Higher emissions prices fail to achieve additional reductions in part because significant improvements in energy efficiency occur in the reference case.
- **Biofuel consumption becomes an increasingly important abatement action at carbon prices greater than $150/tonne CO_2e in 2020 and $100/tonne CO_2e in 2030, especially for freight and mining vehicles.** For these applications, this analysis forecasts few other abatement possibilities. Establishing biofuel production facilities and distribution networks takes time. Consequently, abatement from this action increases from 2020 to 2030. Even by 2030 with a carbon price of $300/tonne CO_2e, biofuel only accounts for half of transportation fuels.
- **Other significant abatement actions include the following:**
    a. Landfill gas recovery and flaring, which is a low cost abatement action that reaches full potential in 2020 at carbon prices greater than $50/tonne CO_2e. The gas recovery occurs at the two larger landfill sites in the province.
    b. Carbon capture and storage for capturing combustion emissions in the petroleum refining sector, which is likely to be a viable abatement action by 2030. However, this abatement action is not used in other sectors in the scenario with the Lower Churchill project, thus the small scale of the transportation and storage network (0.5 to 1.0 Mt CO_2e/yr in 2030) could make this action less viable.

Figure ES2: Cost curve for Newfoundland and Labrador with Lower Churchill Falls

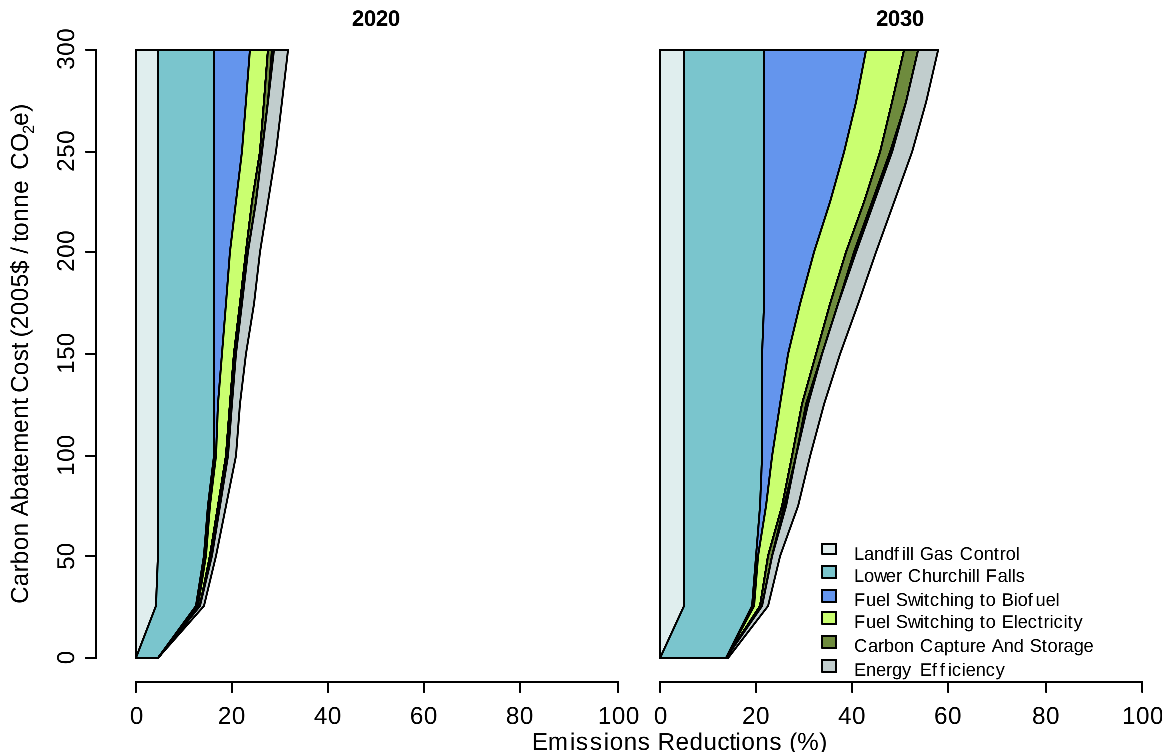
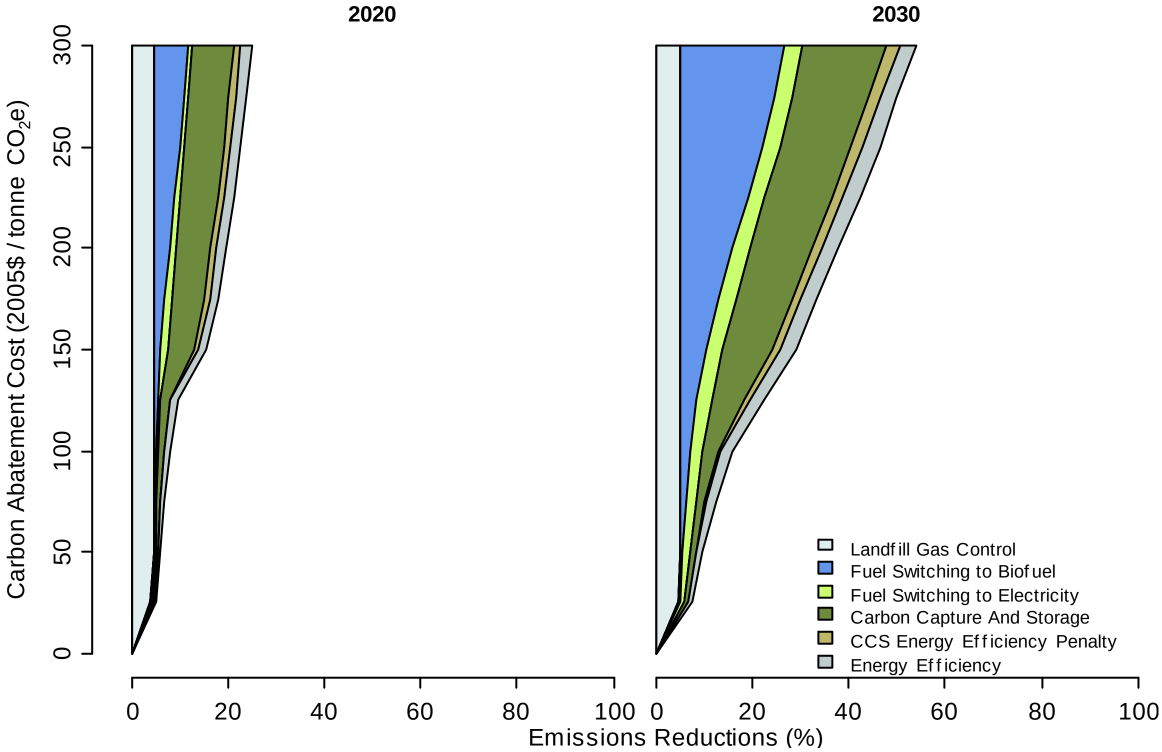


Figure ES3: Cost curve for Newfoundland and Labrador without Lower Churchill Falls



Quantitative policy analysis

The quantitative policy analysis explores the magnitude of emissions reductions achieved by a variety of carbon price pathways combined with regulatory policies. The emissions prices are roughly equivalent to the selling price of emissions permits in an emissions cap-and-trade system, or to an economy-wide tax on greenhouse gas emissions.

Carbon pricing scenarios begin in 2012 and increase over the simulation period, ending in 2030. Four carbon price pathways (low, low-medium, medium-high and high) and two development scenarios (Lower Churchill Falls ***is not*** developed and Lower Churchill Falls ***is*** developed) are modeled.

In addition, complementary policies are applied to each scenario to attain additional reductions from the buildings and transportation sectors. These policies include revisions to building codes after 2015 and the introduction of vehicle emissions standards equivalent to those of the State of California. Table ES1 summarizes the carbon prices of the policy scenarios assessed in this analysis.

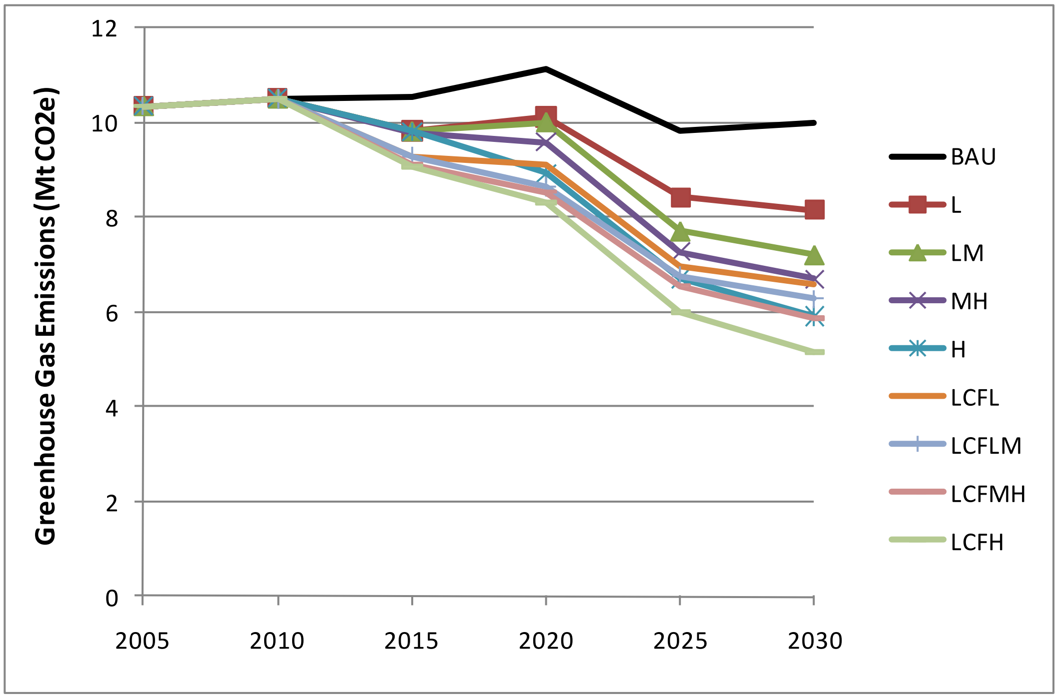
Table ES1: Carbon price paths of the policy scenarios

		2015	2020	2025	2030
Policy Scenario	*Policy Name*	*Emissions Charges 2005$ / tonne*			
No Lower Churchill Falls Development					
Low price	*L*	$15	$25	$50	$100
Low-Medium price	*LM*	$15	$35	$75	$150
Medium-High Price	*MH*	$25	$50	$100	$200
High Price	*H*	$25	$100	$200	$250
Lower Churchill Falls Development					
Low price	*LCFL*	$15	$25	$50	$100
Low-Medium price	*LCFLM*	$15	$35	$75	$150
Medium-High Price	*LCFMH*	$25	$50	$100	$200
High Price	*LCFH*	$25	$100	$200	$250

Key findings from the quantitative policy analysis include:

- **By combining an economy-wide carbon price with regulatory policies, Newfoundland and Labrador can achieve emissions reductions of about 20% to 50% relative to the reference case in 2030 (Figure ES4).** Without construction of the Lower Churchill Falls hydroelectric project, the low price path reduces emissions by 18% relative to the reference case, and the high carbon price path reduces emissions by 41%. With construction of the Lower Churchill Falls project, the same emissions prices yield reductions of 34% and 49%.

Figure ES4: Greenhouse gas emissions in each policy scenario



- **As demonstrated in the marginal abatement cost curve analysis, construction of the Lower Churchill Falls project allows either more emissions reductions for a similar carbon price, or similar emissions reductions for a lower price, relative to if the project is not developed.** An emissions price of $200/tonne CO2e in 2030 (Medium-High price) without development of Lower Churchill Falls achieves similar emissions reductions as does a price of $100/tonne (Low price) with Lower Churchill Falls.
- **Emissions reduction opportunities are likely concentrated in the electricity and transportation sectors.** In 2030, these sectors account for approximately 55% of Newfoundland and Labrador's greenhouse gas emissions in the reference case. Furthermore, they represent about 50% of total reductions in 2030 without the Lower Churchill Falls development and 70% with its development.
- **Consistent with the marginal abatement cost analysis, the scenarios without Lower Churchill Falls show that the abatement potential of the electricity sector is constrained in lower pricing scenarios.** However, in the higher pricing scenarios carbon capture and storage becomes feasible, resulting in substantial reductions from the sector.
- **Some of the carbon price paths allow the province to meet targets from current emissions reduction initiatives.** With the exception of low carbon price path (LCFL), all scenarios with Lower Churchill Falls achieve reductions that meet or exceed the equivalent targets from the federal government (17% below 2005 by 2020), the Western Climate Initiative (14% below 2005 by 2020), and

New England Governors-Eastern Canadian Premiers Forum (15% below 2005 by 2020). If the Lower Churchill is not developed, only the high carbon price path (H) achieves a reduction (14% below 2005 by 2020) similar to these targets. The other policy scenarios reduce emissions by 2-7% relative to 2005 in 2020.

Several economic and energy indicators were analyzed to assess the impact of the policy scenarios on the economy of Newfoundland and Labrador. Key points from this analysis are:

- **Changes to capital investment are quite diverse across sectors in the policy scenarios.** The electricity and residential sectors experience the most growth in capital investment, with greater investment in the electricity sector. Capital investment in the residential sector is caused by the revisions to the residential building code. Costs are less sensitive to the carbon price or the Lower Churchill Falls development scenario. Conversely, investment in the electricity sector is sensitive to the development of Lower Churchill Falls. Increases to capital investment are generally higher under stronger carbon prices in the scenarios without the Lower Churchill Falls project. Under these conditions, the sector will invest in carbon capture and storage capacity.
- **In the policy scenarios, household energy costs decline relative to the reference case primarily because the energy efficiency of building shells improves.** Energy costs decrease between 5% and 10% relative to the reference case projection in 2030 as the building code regulation ensures new building shells are more energy efficient.
- **Although vehicle fuel prices increase in response to carbon pricing and the vehicle emissions standard, average annual vehicle fuel costs decrease due to the greater adoption of more efficient and alternative-fuelled vehicles.** In the policy scenarios, average annual fuel costs decrease by almost $500 (2005$) relative to the reference case in 2030.
- **Electricity prices increase in all of the scenarios but the increase is relatively low, even in the most aggressive policy scenarios (less than 1¢/kWh (2005¢) in 2030 relative to the reference case).** Prices increase because the electricity generation sector adopts carbon capture and storage in the scenario without Lower Churchill Falls. In both development scenarios, the price of electricity rises slightly since additional electricity demand requires additional development of the transmission system.
- **Industrial unit production costs experience modest increase in response to policy.** Unit production costs increase more in scenarios with a higher carbon price as industries will invest in higher cost technology or alternative fuels to avoid paying a carbon price. Additionally, industrial production costs generally increase more in scenarios without the Lower Churchill Falls (for any given carbon price) because electricity prices are highest in these scenarios. Changes range from 0-3% depending on the sector and the scenario.

Limitations and recommendations for further research

- **Although this modelling analysis provides an integrated forecast showing how each sector is likely to respond to carbon pricing, it does not contain data obtained in consultation with individual industries**. As such, the results may not reflect abatement opportunities at specific facilities. Nonetheless, it provides an economy-wide assessment of how energy supply and demand and technological development affect abatement potential in Newfoundland and Labrador.
- **CIMS does not account for economic activity unrelated to energy consumption or greenhouse gas emissions.** The CIMS model accounts for the energy and emissions intensive portion of the economy, but does not account for other economic activity. For example, the CIMS model accounts for a household's costs related to energy consumption (e.g., light bulbs), but does not account for other household expenses. Therefore, CIMS does not estimate how a change in expenditures on energy or capital related to energy consumption might affect other household expenditures.
- **CIMS is not a general equilibrium model, and does not account for some markets likely to be affected by the implementation of climate policy.** The CIMS model also does not account for key markets such as capital or labour and cannot simulate how increased capital expenditures to abate emissions might affect interest or wage rates. Additionally, CIMS does not simulate supply and demand of all commodities, so it cannot track how gross domestic product is affected by climate policy. Furthermore, this modeling framework has not been used to investigate how different designs of climate policy (e.g., are permits in an emissions cap-and-trade system auctioned or allocated for free) can attain different policy objectives (e.g., mitigating competitiveness impacts on certain industries).

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Glossary of Terms

Baseload electricity generation	Baseload electricity generation is the portion of generation which is continuously required over time despite fluctuations in electricity demand. In this report, electricity generation and consumption is measured in kWh (thousand watt-hours), MWh (million watt-hours) and TWh (trillion, or 10^{12} watt-hours).
Building code	In this report, a building code is a regulatory policy that specifies minimum efficiency standards for building shells in the residential and commercial sectors.
Carbon capture and storage	Carbon capture and storage (CCS) is a carbon abatement action that involves capturing greenhouse gas emissions, typically from large industrial sources such as thermal electricity generation plants or steam production in the petroleum refinery, and injecting these emissions into geological formations for long-term storage.
Carbon pricing	Carbon pricing (also known as greenhouse gas or emissions pricing) represent a cost placed on the release of greenhouse gas emissions throughout the economy. Carbon pricing is analogous to the value of a carbon tax or the equilibrium permit price in a cap-and-trade system. In this analysis carbon pricing is simulated as a shadow price (defined below).
Cogeneration	Cogeneration, also known as combined heat and power (CHP), is the combined production of electricity and heat.
Downstream	With respect to energy consumption or greenhouse gas emissions, downstream refers to activities that are closer to the point of final consumption of a fuel (e.g., personal vehicles) rather than the point of fuel production (e.g., crude oil extraction).
Energy intensity	Energy intensity is the amount of energy consumed relative to output for either a sector, an activity within a sector, or the economy as a whole.
Fugitive emissions	Fugitive emissions are irregular releases of greenhouse gases that are associated with industrial activity, such as leaks and venting of methane during the production of crude oil.
Greenhouse gas	In this report, greenhouse gases include carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) from anthropogenic sources. Greenhouse gases are typically measured in tonnes (t) or millions of tonnes (Mt) of CO_2 equivalent emissions (CO_2e).

Greenhouse gas intensity	Greenhouse gas intensity is the amount of greenhouse gas emissions relative to output for either a sector, an activity within a sector, or the economy as a whole.
Marginal abatement cost curve	Marginal abatement cost curves show the emissions reductions available at various strengths of carbon pricing throughout the economy and reveal the costs that businesses and consumers incur to reduce emissions.
Peakload electricity generation	Peakload electricity generation is the portion of generation that is only required during times of maximum electricity demand, such as during a cold winter evening when heating and appliance use are at their peak. In this report, electricity generation and consumption is measured in kWh (thousand watt-hours), MWh (million watt-hours) and TWh (trillion or 10^{12} watt-hours).
Reference case	The reference case, or business-as-usual (BAU) forecast, is a description of how the Newfoundland and Labrador economy may evolve in the absence of any policies aimed at reducing greenhouse gas emissions. For the purposes of this report, the development of the Lower Churchill Falls hydroelectric project is excluded from the reference case.
Scenario	Scenarios are forecasts of how the economy may evolve based on different sets of assumptions. In addition to the reference case, this report examines several policy scenarios that include different assumptions about carbon pricing, regulatory policies, and the development of the Lower Churchill Falls hydroelectricity project.
Shadow Price	Shadow prices reveal the strength of the price policy necessary to change the result of the model. In this case the shadow price is the price on carbon that would reduce one additional unit of emissions, or the cost imposed by lowering an emissions cap by one unit. They are equivalent to the value of a tax on emissions or the equilibrium permit price in a cap-and-trade system.
Upstream	With respect to energy consumption or greenhouse gas emissions, downstream refers to activities that are closer to the point of fuel production (e.g., crude oil extraction) rather than the point of fuel consumption (e.g., personal transportation).
Vehicle emissions standard	In this report, a vehicle emissions standard is a regulatory policy that sets a limit on the allowable amount of greenhouse gas emissions per distance travelled for personal vehicles.

Introduction

The Government of Newfoundland and Labrador is in the process of updating its Climate Change Action Plan to fulfill commitments made in its 2007 Energy Plan. As part of this process, the Government is responsible for setting a greenhouse gas emission reduction target and developing a strategy to reach this target. Furthermore, it is likely that a national market-based climate policy (e.g., cap-and-trade) will be implemented in the near future. To aid its planning process, the Government of Newfoundland and Labrador needs to understand how the economy will evolve in response to such policies, as well as the costs and benefits associated with those policies.

M. K. Jaccard and Associates Inc. (MKJA) has been selected to perform a quantitative analysis that can assist policy makers in understanding the potential effect climate policy may have on the province. This study is divided into three sections:

1. First, we use the CIMS energy-economy model to forecast reference case greenhouse gas emissions in Newfoundland and Labrador without climate policy.
2. Relative to this reference case forecast, we use CIMS to explore the potential to reduce greenhouse gas emissions in the province with a study of marginal abatement cost curves. Marginal abatement cost curves show the emissions reductions available at various strengths of carbon pricing and reveal the costs that businesses and consumers incur to reduce emissions. To deepen this analysis, we produce a marginal abatement cost curve for each energy intensive economic sector and identify the key actions that reduce emissions.
3. Finally, we use CIMS to provide a quantitative policy analysis. In this analysis we explore the magnitude of future emissions reductions achieved by different possible carbon pricing scenarios combined with regulatory policy. For each carbon price scenario, we assess changes in provincial emissions, energy consumption and key energy/economic indicators. This analysis is conducted under two scenarios regarding Lower Churchill Falls. In the first scenario, the proposed Lower Churchill Falls hydroelectricity project is built and connected to the Island. In the second scenario, this project is not built. Comparison of these scenarios helps clarify how this significant uncertainty will affect greenhouse gas emissions in Newfoundland and Labrador.

Reference Case

The first section of this report presents the CIMS model reference case forecast of energy and emissions for Newfoundland and Labrador and outlines the inputs and assumptions used to generate this forecast. The reference case forecast describes how the economy may evolve in the absence of any policies aimed at reducing greenhouse gas emissions.

The reference scenario described in this report is based on external inputs and shows how Newfoundland and Labrador's economy may evolve from the present to 2030. We use credible sources to guide these inputs, but no amount of research allows perfect foresight into the future of the economy and some of the key inputs underlying our assumptions are uncertain. If economic evolution takes a different path than the one projected here, future energy consumption and emissions will also be different. Therefore, this reference scenario should be regarded as just one possible reference scenario. We consider it a reasonable "business as usual" forecast based on historic trends and research into likely future technological and economic evolution, but the uncertainty remains large.

Many of the key assumptions to the reference case have been specified by Newfoundland and Labrador's OCCEEET, as well as the Departments of Natural Resources, Environment and Conservation, and Finance. This report builds on those assumptions and provides a detailed description of how these assumptions have shaped the reference case.

Key economic drivers and assumptions

To develop the reference case forecast, CIMS requires external forecasts for the economic or physical output of each economic sector (e.g., the number of residential households or the amount of crude oil produced in the province). The external forecast assumptions used in this study were agreed upon in the initial stages of the project's development through consultation between MKJA and the Government of Newfoundland and Labrador.

Energy demand sectors

In response to projected population growth and dwelling density assumptions, the residential housing stock will grow 7% between 2010 and 2030. Forecasts indicate that the rate of population growth declines after 2015. Household formation follows a similar trend, but total floorspace continues to rise as larger homes are built.

The commercial sector is expected to experience steady growth through to 2030 – approximately 1% a year – stimulated by growth in output, as well as real income growth in the province's services sector. Based on trends in physical building footprints and projections of gross output, commercial floor space is anticipated to increase 25% between 2010 and 2030; the strongest growth experienced by the Information and Culture, and Transportation and Warehousing sub-sectors.

A rise in personal income coupled with a declining unemployment rate and population growth is expected to result in greater travel demand for light duty vehicles (cars, SUV's and trucks). These trends are projected to continue, slowing somewhat in the latter half of the forecast period. In the freight transportation sector, growth is more rapid than in the passenger transportation sector.[1] Consistent with the growth of retail sales, demand for freight transportation grows 27% between 2010 and 2030.

Production in the mining sector is driven by three major companies: Vale Inco Newfoundland and Labrador Limited, Wabush Mines and the Iron Ore Company of Canada Ltd. Production at Vale Inco's Voisey's Bay mine began in 2005; production has increased significantly since. It is anticipated that Voisey's Bay will maintain this high level of production over the forecast period. Along with its mining operation, Vale Inco will start production at its new hydrometallurgical metal processing facility in 2013; this plant will process all output from the Voisey's Bay mine.

The remaining energy demand sectors in Newfoundland and Labrador include other manufacturing and newsprint. Despite dwindling demand for newsprint and plant closures, the region's remaining newsprint plant is projected to sustain current production levels over the forecast period. Continued growth will be seen in the other manufacturing sector – a conglomerate sector representing low energy and emissions intensive sectors – dominated by the food processing subsector.

Energy supply sectors

The energy supply sectors in Newfoundland and Labrador include crude oil extraction, petroleum refining and electricity generation. While the supply of biomass (wood fuels) is not explicitly modelled in this study, it is assumed that the biomass supply is sourced from regional resources.

In terms of GDP, offshore crude oil extraction is the largest energy supply sector in the region. Oil production is an integral part of Newfoundland and Labrador's economy, representing approximately 40% of GDP in 2008.[2] The crude oil production forecast has been provided by the Departments of Natural Resources and Finance.

Following a peak of 111.3 million barrels in 2005, offshore oil production is expected to gradually decline as fields are exhausted (assuming no additional production from existing or satellite fields). Over the simulation period a portion of the decline is expected to be offset by production from the Hebron field.

Newfoundland and Labrador’s projected energy demand, adjusted for expected net exports, regional capacity and physical constraints, determines the supply forecast for petroleum refining and electricity generation. In CIMS, the forecast for electricity production from the electricity sector does not include non-utility thermal and combustion electricity generation. Own production from industry, on offshore oil

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[1] The freight transportation sector includes demand for off-road transportation in the forestry, agriculture and constriction sectors.

[2] Government of Newfoundland and Labrador, The Economic Review 2009, http://www.economics.gov.nl.ca/Review2009/TheEconomicReview2009.pdf.

platforms or by Vale Inco for example, is accounted for separately in each sector. Within these sectors, it is assumed that any electricity produced is consumed within the sector thereby reducing the amount of electricity purchased from the utility.

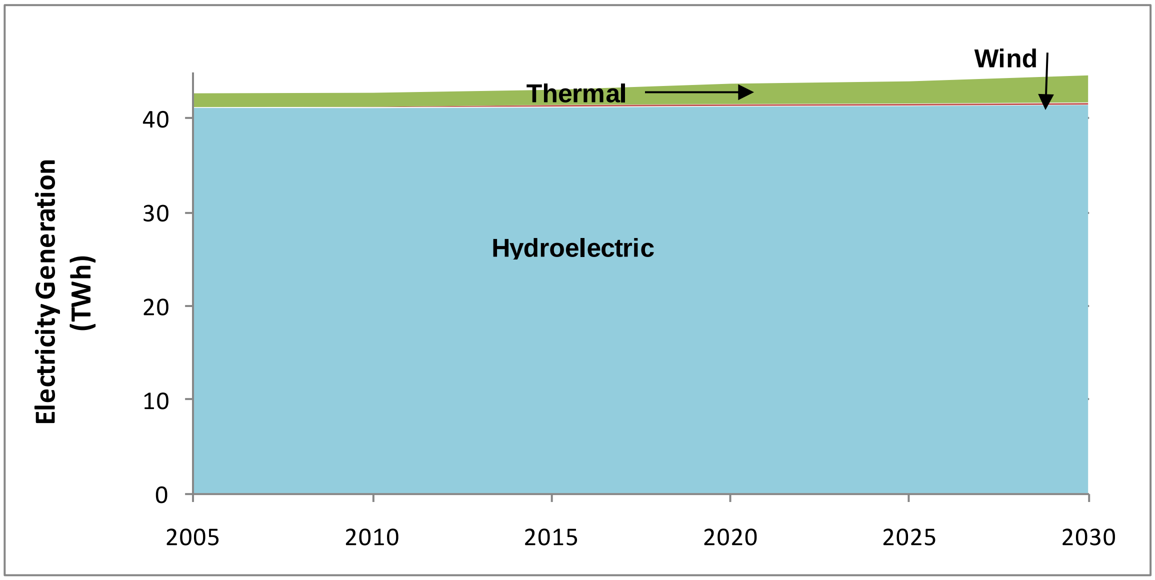
Newfoundland and Labrador has a substantial portfolio of electricity generation assets, with a significant amount of undeveloped capacity.[3] At present, the region exports approximately three quarters of the electricity it generates. Given growth in the building (commercial and residential) and industrial sectors, along with export obligations, demand for electricity increases over the simulation period. Thus, there is a need to increase regional generation. The Lower Churchill project, with two proposed generation installations at a combined capacity of 3,074 MW, is currently in the planning stages with a decision on the project sanction expected at some point in the future. Therefore, alternative supply options are considered. Figure 1 shows the reference case electricity generation by fuel type. Additional electricity demand is met with production from existing thermal and new wind and small hydro generation sources. As demand increases over the simulation period, generation requirements from these sources grow. By 2030, thermal production grows to 2.95 TWh/year – still within the capacity of the Holyrood plant. 0.21 TWh/year of wind generation and 0.40 TWh/yr of small hydro are added to the grid. While the current capacity of the Holyrood plant can accommodate this additional demand, it is possible that a new generation facility could be constructed to supplement a portion of production at the Holyrood plant. The reference case forecast for additional generation capacity is closely aligned with Nalcor's 2010 Capital Budget Plan.[4]

Generation from the Lower Churchill is not included in the reference case. Production from the Lower Churchill, with an in-feed to the island projected to begin in 2020, will be modelled in future policy scenarios. The exclusion of the Lower Churchill hydro electricity project from the reference case was a decision made to evaluate the project's impact on Newfoundland and Labrador's total greenhouse gas emissions and does not reflect any view by the Province on the project's economic viability.

[3] Government of Newfoundland and Labrador, Energy Plan: Focusing Our Energy, http://www.nr.gov.nl.ca/energyplan/EnergyReport.pdf.

[4] Newfoundland and Labrador Hydro, 2010 Capital Budget, http://n225h099.pub.nf.ca/applications/NLH2010Capital/index.htm

Figure 1: Reference case utility electricity generation by fuel type



Note: Figure 1does not include transmission and distribution losses.

All petroleum refining in the region occurs at one facility. Plans to develop a second facility or to expand the existing facility remain uncertain, thus output from the petroleum refining sector will be constrained by the capacity of the existing plant for this analysis. It is anticipated that production at the refining plant will continue at the facility's maximum capacity of 115,000 barrels per day.

Energy price forecast

CIMS also requires an external forecast for fuel prices. Similar to sectoral output, a policy can change fuel prices if it changes the cost of fuel production. Reference case prices through to 2020 are based on historical energy prices, and energy price forecast assumptions. The forecasted price of refined petroleum products reflect the long-run crude oil price used in the 2010 *Annual Energy Outlook*, which reaches a high of $112/barrel (2005$ US) by 2030.[5] Energy price forecasts for other fuels were agreed upon in the initial stages of the project's development through consultation between MKJA and the Government of Newfoundland and Labrador. Table 1 shows the refined petroleum product price forecast used in the reference case. Like the other forecasts that are used as inputs to CIMS, the fuel price forecast adopted here is uncertain, particularly in the longer term. In addition, the fuel price forecasts that we have adopted are intended to reflect long-term trends only and will not reflect short-term trends caused by temporary supply and demand imbalances.[6]

As mentioned previously, a policy may change the prices of fuels. In the Lower Churchill scenario, electricity prices are likely to increase because of capital investments related to operating and distributing electricity from these facilities.

Table 1: Reference case price forecast for refined petroleum products

	Units	*2010*	*2015*	*2020*	*2025*	*2030*
Residential						
Light Fuel Oil	*2005$ / GJ*	25.41	27.00	29.63	31.26	32.75
Commercial	*2005$ / GJ*					
Light Fuel Oil	*2005$ / GJ*	23.34	24.86	27.58	29.21	30.7
Transportation	*2005$ / GJ*					
Aviation Turbo	*2005$ / GJ*	26.91	28.34	30.89	32.53	34.01
Diesel	*2005$ / GJ*	29.76	30.86	33.22	34.86	36.34
Gasoline	*2005$ / GJ*	32.48	33.39	35.6	37.23	38.71
Heavy Fuel Oil	*2005$ / GJ*	13.32	14.21	15.78	16.69	17.51
Propane	*2005$ / GJ*	35.48	36.75	38.85	40.48	41.97
Industry	*2005$ / GJ*					
Diesel	*2005$ / GJ*	29.17	30.46	33.38	35.01	36.50
Gasoline	*2005$ / GJ*	31.81	32.94	35.77	37.4	38.89
Heavy Fuel Oil	*2005$ / GJ*	14.36	15.28	16.99	17.89	18.71
Light Fuel Oil	*2005$ / GJ*	25.61	26.97	30.00	31.63	33.12

Note: All prices in Canadian dollars. All prices are in real terms.

[5] Energy Information Administration, Annual Energy Outlook 2010, http://www.eia.doe.gov/oiaf/aeo/index.html

[6] Demand for energy can vary significantly on a daily, monthly and yearly basis, but new supply can only be brought into production on a 1-10 year investment horizon, depending on the energy form. This leads to normal short-term imbalances in supply and demand and significant short-term energy price changes in markets where energy prices are allowed to change in respond to market dynamics. CIMS is designed to represent a 5-year demand and investment horizon, a period representing a normal cycle from "boom to bust and back again".

Reference case energy and emissions outlook

Employing the economic assumptions highlighted above, we used CIMS to develop an integrated reference case forecast for energy consumption and greenhouse gas emissions through 2030. The CIMS model captures virtually all energy consumption and production in the economy.[7]

The reference case forecast for total energy consumption is shown in Table 2, while Table 3 and Table 4 show refined petroleum product and electricity consumption, respectively. The residual energy consumption of other fuel types (total minus, refined petroleum product and electricity) is not explicitly shown in this report.

Table 2: Reference case total primary and secondary energy consumption

	Units	*2010*	*2015*	*2020*	*2025*	*2030*
Primary and Secondary Energy						
Demand Sectors						
Residential	*PJ*	19.1	18.4	18.2	18.1	18.1
Commercial	*PJ*	14.4	14.8	14.3	13.9	14.0
Transportation	*PJ*	49.3	49.6	49.3	49.0	50.5
Industrial Sector^	*PJ*	36.5	38.6	38.5	37.0	36.4
Waste	*PJ*	1.6	1.6	1.5	1.5	1.5
Total Demand Sectors	***PJ***	**120.8**	**123.0**	**121.7**	**119.5**	**120.4**
Primary and Secondary Energy (including producer consumption)						
Supply Sectors						
Electricity	*PJ*	165.2	167.1	171.8	173.2	177.4
Fossil Fuel Sectors*	*PJ*	41.9	44.8	52.0	35.2	37.6
Total Supply Sectors	***PJ***	**207.1**	**211.9**	**223.8**	**208.4**	**215.0**

^ Includes consumption of hog fuel in the newsprint sector
* Fossil Fuel Sectors include petroleum refining and petroleum crude extraction.
Note: Producer consumption of energy (e.g., natural gas in the crude extraction sector or refinery gas in the petroleum refining sector) is included in these totals. Producer consumption in the petroleum refining sector does not include crude oil feedstock. Energy consumption in the electricity generation sector includes consumption of water, wind, and biomass using coefficients adopted from the International Energy Agency.[8]

[7] This excludes energy consumption in the construction, forestry and agriculture sectors that is not related to off-road transportation. CIMS also excludes non-energy fuel use.

[8] International Energy Agency, 2007, "Energy Balances of OECD Countries: 2004-2005". Renewable electricity generation is assumed to require 1 GJ of energy (e.g., wind, hydro) for each GJ of electricity generated.

Table 3: Reference case refined petroleum product consumption

	Units	*2010*	*2015*	*2020*	*2025*	*2030*
Demand Sectors						
Residential	*PJ*	3.2	1.8	1.1	0.7	0.3
Commercial	*PJ*	5.4	5.3	4.5	3.6	2.7
Transportation	*PJ*	49.2	49.5	49.1	48.7	49.6
Industrial Sectors	*PJ*	16.9	16.5	15.1	13.2	12.2
Waste	*PJ*	0.0	0.0	0.0	0.0	0.0
Supply Sectors						
Supply Sectors	*PJ*	32.9	34.5	40.0	38.5	42.8
Total	***PJ***	**107.6**	**107.5**	**109.7**	**104.6**	**107.6**

Table 4: Reference case electricity consumption

	Units	*2010*	*2015*	*2020*	*2025*	*2030*
Demand Sectors						
Residential	*PJ*	12.8	13.6	14.5	15.2	16.1
Commercial	*PJ*	8.5	8.9	9.2	9.8	10.8
Transportation	*PJ*	0.0	0.0	0.0	0.1	0.5
Industrial Sectors	*PJ*	13.8	15.6	16.4	16.3	16.2
Waste	*PJ*	0.0	0.0	0.0	0.0	0.0
Supply Sectors						
Supply Sectors	*PJ*	1.1	1.2	1.4	1.5	1.6
Total	***PJ***	**36.1**	**39.4**	**41.5**	**42.8**	**45.1**

Based on total energy consumption and process emissions in the industrial sector and supply sectors, we calculate the greenhouse gas emissions associated with the reference case forecast, as shown in Table 5 and Figure 2.

Table 5: Reference case greenhouse gas emissions

	Units	*2010*	*2015*	*2020*	*2025*	*2030*
Demand Sectors						
Residential	*Mt CO2e*	0.30	0.20	0.14	0.10	0.06
Commercial	*Mt CO2e*	0.43	0.42	0.36	0.29	0.23
Transportation	*Mt CO2e*	3.56	3.58	3.54	3.51	3.57
Industrial Sectors	*Mt CO2e*	1.53	1.57	1.52	1.43	1.37
Waste	*Mt CO2e*	0.61	0.61	0.60	0.58	0.57
Supply Sectors						
Supply Sectors	*Mt CO2e*	4.08	4.16	4.97	3.91	4.21
Total	**Mt CO2e**	**10.51**	**10.53**	**11.12**	**9.83**	**10.00**

Note: CIMS emissions do not include land use changes or consumption of halocarbon and SF_6.

Figure 2: Newfoundland and Labrador's reference case greenhouse gas emissions

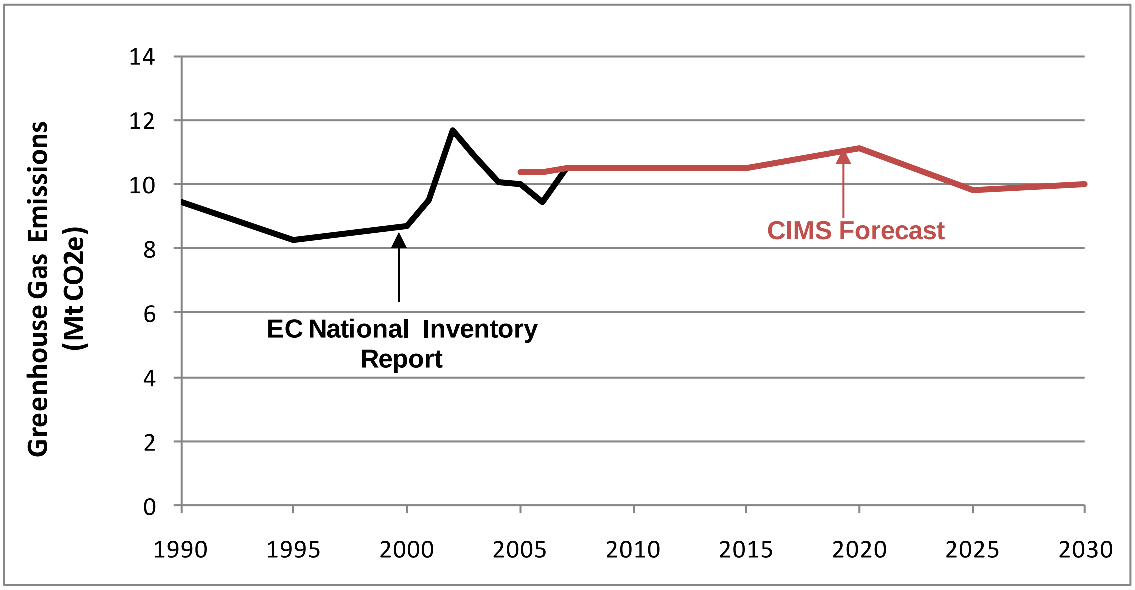


Table 5 indicates that in the absence of policies, greenhouse gas emissions will vary over time, with emissions trending upwards in the first half of the simulation period and trending downward in the latter half. The variability in the emissions forecast is largely a by-product of emissions in the crude oil extraction sector.

Emissions growth in the building sector reflects fuel switching in both the residential and commercial sectors over the simulation period. Most new buildings are built with electric space and water heating. As new buildings replace older ones, the emissions from the sector decline even though the total stock of buildings is growing.

As a result of demand trends in the personal transportation sector, growth in energy consumption slows after 2015. Between 2010 and 2030, energy intensity in the sector decreases by approximately 23% as consumers purchase more efficient vehicles in response to high oil prices. With these efficiency gains, greenhouse gas emissions in the sector start to decline after 2020. Conversely, the freight sector has fewer opportunities to improve energy efficiency, so rising demand for freight transportation causes both energy consumption and greenhouse gas emissions to grow.

In the industrial sectors (mining, metals smelting, newsprint and other manufacturing), energy consumption is projected to be fairly constant over the simulation period because of anticipated production growth and modest gains in energy efficiency. Coupled with a decrease in the consumption of refined petroleum, these efficiency gains result in a small decline in sectoral greenhouse gas emissions from 2015 to 2030.

The region's electricity sector has very low emissions intensity – 0.027 tCO_2e /MWh in 2005 – because of its extensive use of hydroelectric power. Due to increased thermal production, the emissions intensity of the sector increases over the simulation period to 0.044 tCO_2e /MWh in 2030. Output from the sector also increases, as do total greenhouse gas emissions.

In the crude oil extraction sector, energy consumption and greenhouse gas emissions are linked to the number of fields in operation and the activity in those fields. Reference case greenhouse gas emissions from the sector closely match the data provided by the Government of Newfoundland and Labrador. Greenhouse gas emissions increase with the addition of the Hebron field and subsequently decrease as fields are exhausted. Temporary venting and flaring emissions from new oil production facilities have not been included in this forecast.

Marginal Abatement Costs

This section presents marginal abatement cost curves, produced with the CIMS energy-economy model, for the emissions-intensive sectors of Newfoundland and Labrador's economy. Marginal abatement cost curves show the reductions available at a various prices for greenhouse gas emissions (carbon prices) – from \$25/tonne CO_2e to \$300/tonne CO_2e – and reveal the costs that businesses and consumers incur to reduce emissions. For example, if a consumer takes an action to reduce emissions when the price is \$25/tonne, we can infer that the consumer perceives their costs of abatement to be less than \$25/tonne. If another consumer does not take any action to reduce emissions when the price is \$25/tonne but does when the price is \$50/tonne, we can infer that the consumer perceives their costs of abatement to be between \$25/tonne and \$50/tonne. The reductions covered in this analysis do not include offsets sold between sectors or jurisdictions.

The following analysis uses simulated results produced from a modelling study. The strength of this analysis is that it provides an integrated picture of provincial abatement potential showing how each sector is likely to respond to carbon pricing. The simulation shows how abatement potential is affected by energy supply and demand and technological developments across the entire economy. However, consultation with each industry was not possible and the results we present are based on M. K. Jaccard and Associates' expertise in simulating the energy-economy system. This distinction is particularly important with respect to the analysis of provincial industries that have one main producing facility such as newsprint and petroleum refining.

This analysis provides a theoretical assessment of the effect of carbon pricing and does not include a schedule for changes to the carbon price or any regulatory policy. Therefore, the simulation of marginal abatement costs does not represent any specific policy scenario. Analysis of possible policy scenarios is contained in the Quantitative Policy Analysis section of this report.

To expand the analysis, each marginal abatement cost curve is disaggregated by the key actions that reduce emissions. These actions include improvements in energy efficiency, switching to low-carbon fuels, electrification, and directly controlling the release of greenhouse gas emissions (e.g., carbon capture and storage or the capture of landfill gas).

The marginal abatement cost curves are discussed first for the province as a whole and then for the emissions-intensive sectors. The provincial cost curve is shown for the scenarios with and without the Lower Churchill Falls hydroelectricity project and transmission in-feed to the island. The sector specific results are then discussed for the scenario where Lower Churchill Falls is built shortly before 2020, followed by sector specific results for the scenario without Lower Churchill Falls. Abatement by sector for this latter scenario only covers the sectors whose abatement curves change in the scenario without Lower Churchill Falls relative to the scenario with Lower Churchill Falls. For both scenarios, cost curves are presented in two periods – 2020 and 2030 – to give an appreciation for the reductions available at different carbon prices and time-frames. Each specific carbon price is applied from the present until 2030. Therefore, the abatement potential in 2030 is contingent on the influence of carbon pricing acting on investment decisions, research and development over close to two decades.

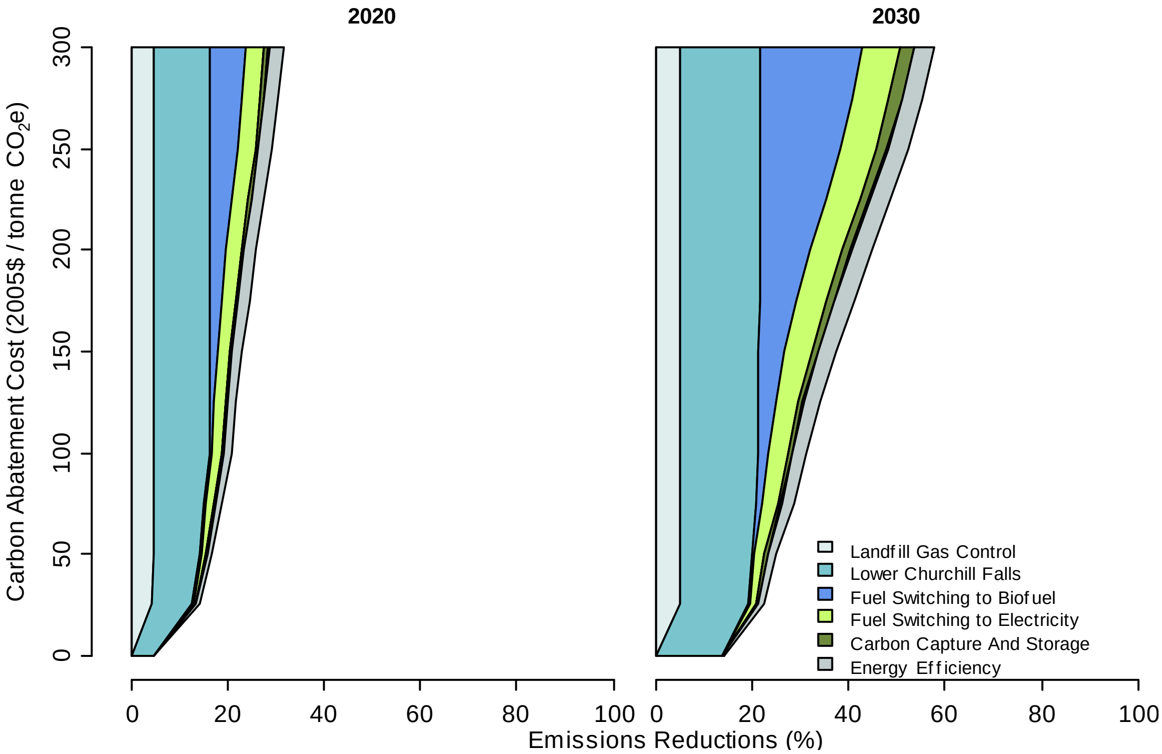
The curves only show the reduction of direct emissions produced by the sector. Indirect emissions associated with electricity consumption or the consumption of any other fuel are only shown explicitly at the point of energy production. However, the issue of indirect emissions from electricity consumption is discussed in relation to the sectors where most electricity is used or where switching to electricity is an important abatement action. Furthermore, electrification within each sector is not credited as abatement if the emissions that result from increased output in the electricity sector is not abated. This correction is negligible in the scenario with Lower Churchill Falls where most electricity is produced with hydro power. In the scenario without Lower Churchill Falls, abatement in the electricity sector relies on carbon capture and storage. Increased electricity generation can result in additional emissions, as carbon capture prevents a maximum 90% of emissions when it is used. Depending on the carbon price, some baseload and peakload capacity plants may not be equipped with carbon capture and storage. Hence increased output may increase emissions even if some carbon capture is employed.

Provincial Marginal Abatement Cost Summary With and Without Lower Churchill Falls

Figure 3 shows the abatement actions and the associated costs for Newfoundland and Labrador in 2020 and 2030 in the scenario where Lower Churchill Falls is built. In all cost curve figures in this report, the abatement potential at a given carbon price (on the vertical axis) is the total width of all the abatement wedges[9] (on the horizontal axis). Abatement is measured as a percent relative to reference case emissions in the given year. The contribution of each action to total abatement is denoted by the width of its respective wedge. For example in Figure 3, in 2030 under a carbon price of $300/tonne CO_2e total abatement is roughly 65% below the 2030 reference. Of this 65% reduction, landfill gas control accounts for 5%, switching to hydro accounts for 15%, biofuel accounts for 25%, switching to electricity accounts for 10%, carbon capture and storage accounts for less than 5%, and energy efficiency accounts for just over 5%. Again, the provincial and the sectoral marginal abatement cost curves do not include any offsets.

[9] Because CIMS does not assume that the costs and benefits of a given mitigation action are the same across the market, the quantity of each abatement action tends to rise as the carbon price rises.

Figure 3: Cost curve for Newfoundland and Labrador with Lower Churchill Falls



The key findings for abatement in Newfoundland and Labrador (scenario with Lower Churchill Falls) are:

1. The abatement potential at all carbon prices increases from 2020 to 2030. This change has several causes. First, the abatement potential is measured as a fraction of reference case emissions and these emissions fall from 11.1 Mt CO_2e in 2020 to 10 Mt CO_2e in 2030. Therefore, even if total abatement remained constant, the abatement potential would increase as a percent of 2030 reference emissions. Second, abatement in 2030 is determined assuming carbon pricing has been in effect since after 2010. A greater portion of the current capital stock has been replaced by 2030 relative to 2020. Therefore, the abatement potential is greater since carbon pricing has affected more investment decisions and has had more time to affect innovation of low emissions technologies.

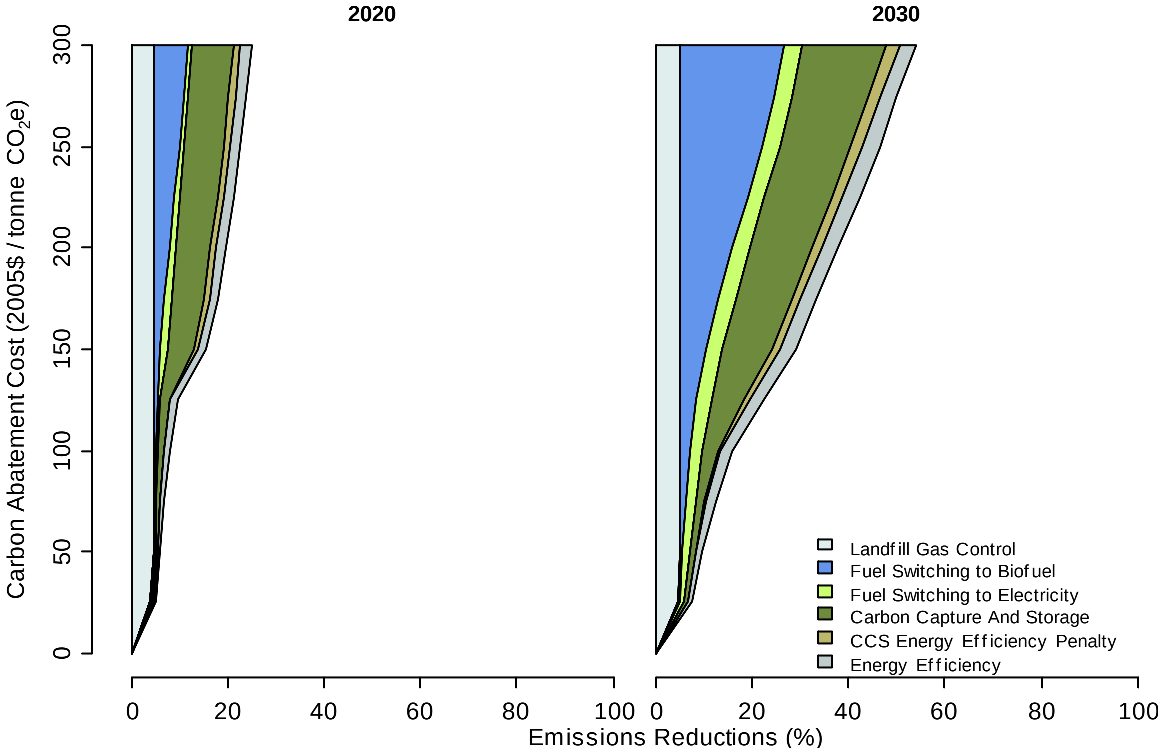
2. The construction of the Lower Churchill Falls hydroelectric project allows the electricity sector to significantly reduce its emissions. Abatement from this action is larger in 2030 than in 2020 since reference case emissions from the electricity sector are a greater share of total emissions in 2030. Because there are broader financial and economic considerations for developing Lower Churchill Falls, this abatement is generally independent of the carbon price, especially by 2030.

3. Because the electricity sector is able to reduce its emissions, fuel switching to electricity becomes a significant abatement action. Electrification in the residential and commercial sectors is accelerated somewhat and production of industrial process heat switches to electricity.
4. Biofuel consumption becomes an increasingly important abatement action at carbon prices greater than \$150/tonne CO_2e in 2020 and \$100/tonne CO_2e in 2030, especially for freight and mining vehicles. For these applications, this analysis forecasts few other abatement possibilities. Establishing biofuel production facilities and distribution networks takes time. Consequently, abatement from this action increases from 2020 to 2030. Even by 2030 with a carbon price of \$300/tonne CO_2e, biofuel only accounts for half of transportation fuels.
5. Because the majority of standing waste is concentrated in one landfill, landfill gas recovery and flaring is a low-cost abatement action that could reach full potential by 2020 at carbon prices greater than \$50/tonne CO_2e.
6. By 2030, carbon capture and storage is likely to be a viable abatement action for capturing combustion emissions in the petroleum refining sector if the carbon price is greater than \$150/tonne CO_2e. However, this abatement action is not used in other sectors, thus the small scale of the transportation and storage network (0.5 to 1.0 Mt CO_2e/yr in 2030) could raise the carbon price at which this abatement action is viable by another 10-20%.
7. Energy efficiency improvements achieve some abatement, much of which can be attributed to the increased use of hybrid and plug-in hybrid vehicles for personal transportation.

The decision on the sanction of the Lower Churchill Falls hydroelectric project has not been made by the Government of Newfoundland and Labrador at this point. Therefore, this analysis also considers a scenario where Newfoundland and Labrador pursues carbon pricing but does not proceed with the hydroelectric project or an in-feed connection to the island. We assume that higher-cost wind and small hydro resources[10] are available, however, even with carbon pricing these renewable additions to capacity are not significantly larger than what occurs in the reference case**.** In the scenario without Lower Churchill Falls, carbon pricing will still mitigate emissions, but the provincial marginal abatement cost curve is very different. Figure 4 shows the abatement actions and the associated costs for Newfoundland and Labrador in 2020 and 2030 in the scenario where Lower Churchill Falls is not built.

[10] The higher costs could be associated with developing more remote sites that have less generation potential and less firm energy available, requiring greater efforts for construction and transmission per unit energy.

Figure 4: Cost curve for Newfoundland and Labrador without Lower Churchill Falls



Comparing the provincial marginal abatement cost curve with and without Lower Churchill Falls yields the following conclusions:

1. There is less abatement potential without Lower Churchill Falls in both 2020 and 2030 at any given carbon price. This difference is greater below carbon prices where carbon capture and storage is not viable. This threshold is below \$125/tonne CO_2e in 2020 and \$100/tonne CO_2e in 2030. Once low-emissions electricity from thermal power plants is possible, the difference between the abatement in the two scenarios is less pronounced.
2. Carbon capture and storage becomes an important abatement action in the scenario without Lower Churchill Falls because it is the only way the electricity sector can increase its output while making deep emissions cuts.
3. Without Lower Churchill Falls fuel switching to electricity is a less significant abatement action because carbon capture and storage is a higher cost abatement option than hydroelectricity. Therefore, electricity produced with carbon capture and storage is more expensive and switching to electricity is less desirable from the consumer's point of view. Additionally, the methodology of this study does not credit abatement from switching to electricity if the action yields additional emissions in the electricity sector. For example, if electrification involves adding additional peak load electricity generation capacity that is not equipped with

carbon capture and storage, then this would reduce the abatement from electrification.

Sector Marginal Abatement Costs – With Lower Churchill Falls

This section contains additional results and discussion of abatement actions and their associated costs at a sector level. This detailed analysis is first presented for the scenario with Lower Churchill Falls and later for the scenario without Lower Churchill Falls.

Residential

Direct emissions from the residential sector were 0.41 Mt CO_2e in 2005, equivalent to 4% of the Newfoundland and Labrador total. In the reference case, more homes switch to electricity as their primary fuel. Consequently direct emissions decrease to 0.1 Mt CO_2e by 2030. Presently, most emissions from the sector are produced by two main processes: 1) space heating, and 2) water heating where fuel oil still accounts for roughly 20% of energy consumption. Emissions from these processes are declining as most new heating equipment is powered with electricity.

Abatement response in the residential sector

Figure 5 shows the actions and associated costs of reducing direct emissions from the residential sector. Because reference case emissions are very low, abatement is limited in this sector. The key findings for the residential sector are:

1. **Abatement is achieved through the accelerated electrification of space and water heating and the associated gains in energy efficiency. However, this abatement is limited because electrification is rising and reference case emissions are decreasing.** In the absence of policy, electric space heating (e.g., electric baseboard heating, ground- and air-source heat pumps) accounts for over 80% of the market from 2020 onward, while the penetration of electric water heating equipment will be as high as 90% of the market. Penetration of electric heating increases somewhat with carbon pricing because the policy raises the price of fuel oil relative to electricity. Electricity prices do not rise significantly in response to carbon pricing because of the availability of electricity from Lower Churchill Falls. By 2030, with a carbon price of $300/tonne CO_2e, over 90% of all households use electric baseboard heating and 2% use heat pumps (both air- and ground-source) for space heating. Further abatement is somewhat constrained by the rate of house and furnace stock turnover. New oil-heating systems installed before carbon pricing takes effect can still be in service by 2020 and even 2030.
2. **Space heating with wood fuel rather than fuel oil will also achieve abatement.** In less densely inhabited areas, wood fuel provides an attractive abatement opportunity when used with modern wood furnaces. However, wood combustion does release methane and nitrous oxide, two potent greenhouse gases. By 2030 at carbon prices above $150/tonne, half of the remaining emissions from the residential sector are from these gases. Carbon pricing will not affect these

emissions since the production of these gases from any one source is small and difficult to officially track. The switch from oil to wood is somewhat less at higher carbon prices since accumulated experience with heat pumps reduces their costs. Consequently, abatement using wood diminishes while abatement from switching to electricity grows.

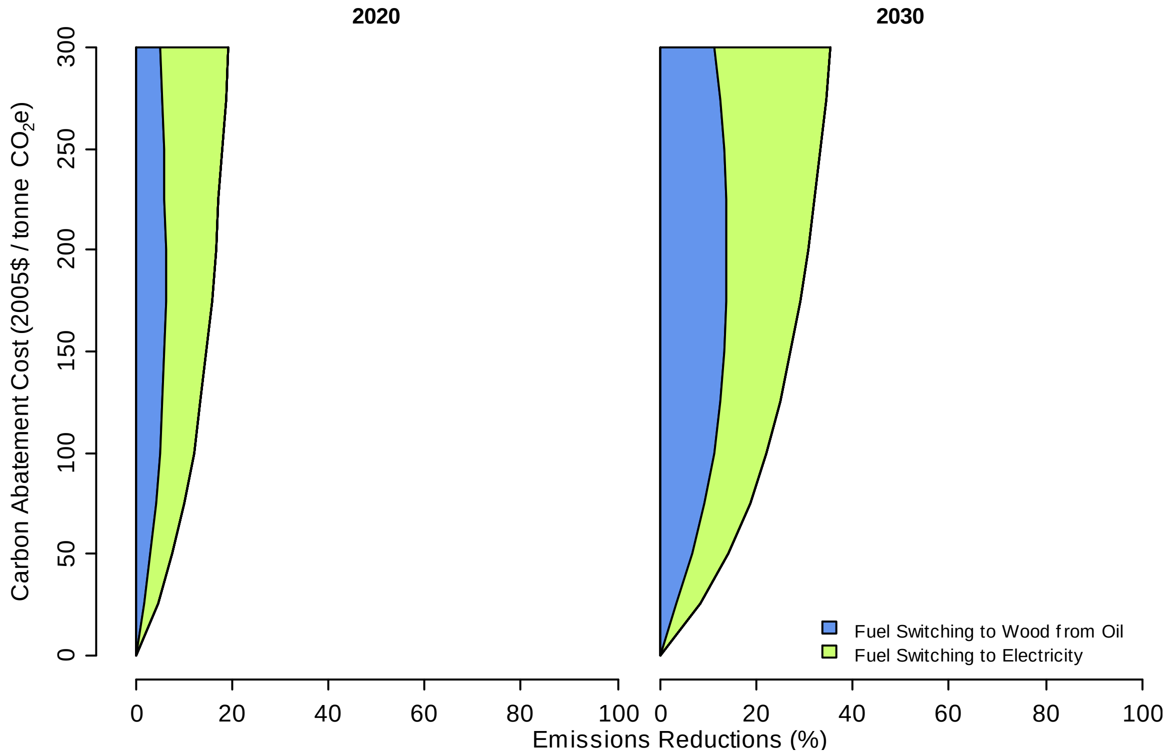
3. **Indirect emissions associated with electricity consumption also decrease in response to carbon pricing even though this consumption is rising. This decrease happens because the electricity sector achieves near zero emissions once the Lower Churchill Falls project is built.** In the reference case, the residential sector consumes roughly 35% of the electricity in 2005, rising to 37% by 2030. Since electricity from the existing Churchill Falls facility is not available, we have excluded this generation capacity from our calculation of indirect emissions. Using this correction for the reference case, the residential sector indirectly emitted about 0.5 Mt CO_2e in 2005, rising to 0.8 Mt CO_2e in 2030. In response to carbon pricing, the electricity sector reduces its emissions substantially in the scenario with the Lower Churchill Falls hydro project. In this scenario, a modest carbon price of $25/tonne CO_2e will reduce the residential sector's indirect emissions to roughly 0.1 Mt CO_2e in 2030, whereas higher prices reduce indirect emissions to zero.

4. **Improvements in shell energy efficiency (e.g., greater insulation, better windows) provide few emissions reductions relative to the reference case.** Residential shells do not improve significantly as the strength of policy increases indicating that these improvements are relatively more costly than other methods of reducing emissions. The electrification of space heating equipment reduces both the incentive and the effect of reducing emissions by improving shell efficiency. The low-cost (relative to wind or carbon capture and storage) electricity available from Lower Churchill Falls has the same effect. In other words, if heating a building already emits few greenhouse gases and incurs a small cost due to the emissions price, then upgrades to the building shell will bring small additional savings. This is not to suggest that policy makers should avoid targeting the energy efficiency of residential shells. There are additional reasons for these policies, such as reducing any principal-agent problems associated with house construction. The principal-agent problem arises when the person or business responsible for house construction does not pay for the house's energy costs. While improved energy efficiency may be in the interest of the owners and tenants, it is in the interest of developers and landlords to reduce costs. Therefore economically efficient improvements to energy efficiency may not occur because those who incur the cost do not enjoy the benefit.

5. **Improvements in appliance energy efficiency provide modest emissions reductions.** Like building shells, the energy efficiency of home appliances such as fridges, freezers or dishwashers, does not improve significantly above the reference case indicating that these changes are more costly than other abatement methods. Similar to residential shells, the low emissions of the electricity sector

reduce the incentive to decrease electricity consumption in response to a carbon price. Again, this result does not mean policy makers should not require greater energy efficiency from household appliances. Rather, regulatory policies that narrow the market to more efficient models might reduce problems associated with poor consumer information when purchasing appliances. A regulation may also reduce principal-agent problems when landlords/developers purchase appliances that are used by tenants/owners.

Figure 5: Cost curve for the residential sector with Lower Churchill Falls



Commercial

In 2005 the commercial sector produced 0.44 Mt CO_2e of direct emissions, roughly 4% of the provincial total, and is forecast to fall to 0.23 Mt CO_2e by 2030 in the absence of policy. Like the residential sector, new building stock is built with electric heating equipment. Similarly, the direct emissions that remain are produced from fuel oil combustion for space and water heating.

Abatement response in the commercial sector

Figure 6 shows the marginal abatement costs and actions to reduce greenhouse gas emissions in the commercial sector. The main findings for the commercial sector are:

1. **Using electricity for space heating and water heating is forecast to be the primary abatement method in 2020 and 2030.** Like the residential sector, reference case emissions decline over the forecast period thus limiting abatement

options. Baseboard electric heating and electric water heaters are widely adopted in most new buildings in the reference case forecast. Additionally some new building stock uses ground-source heat pumps. At carbon prices greater than \$50/tonne CO_2e, the small number of new buildings that would have used fuel oil heating switch to electricity. Where possible, major renovations of buildings would also install electric heating equipment rather than replacing fossil fuel based equipment. New electric heating equipment is more energy efficient, so a portion of the abatement from this fuel switching is attributed to energy efficiency.

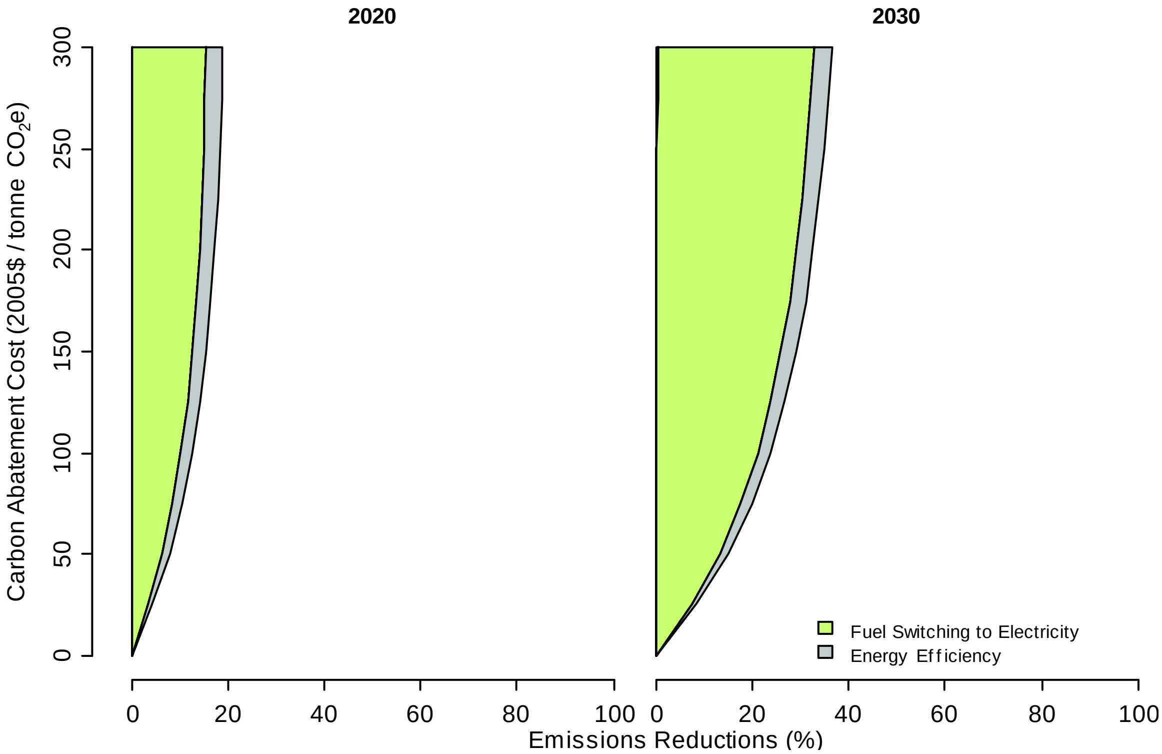
2. **Greater abatement in the sector is constrained by the rate of building stock turnover.** Recently installed fossil fuel based heating systems are likely to remain in service by 2020 and even 2030. Very stringent carbon pricing would be required to force a retrofit of these heating systems before the end of their useful life.

3. **Like the residential sector, indirect emissions from the commercial sector decrease in response to policy.** Even though the sector consumes more electricity at higher carbon prices, the abatement in the electricity sector reduces the amount of indirect emissions associated with this consumption. In 2005, the commercial sector consumed over 20% of all electricity. Again, by correcting for the unavailable Lower Churchill Falls energy, indirect emissions in 2005 were 0.28 $MtCO_2$e, rising to 0.6 $MtCO_2$e by 2030. In this scenario, carbon pricing reduces the commercial sector's indirect emissions to near-zero by 2030.

4. **Improvements in shell energy efficiency do not contribute significantly to emissions reductions.** Similar to the residential sector, the reduced emissions and increased efficiency of space heating that comes with the adoption of electric heating reduces both the incentive and the effect of high efficiency building shells.

5. **Improvement to the energy efficiency of auxiliary equipment provides little abatement.** This equipment consumes mostly electricity, thus efficiency improvements provide no direct abatement. The energy efficiency of the equipment that does consume fossil fuels increases in the reference case and emissions pricing does not result in significantly greater efficiency.

Figure 6: Cost curve for the commercial sector with Lower Churchill Falls



Personal transportation

Direct emissions from the personal transportation sector were 1.5 Mt CO_2e in 2005, accounting for 15% of Newfoundland and Labrador's emissions. This sector includes light-duty vehicles, transit and passenger air travel. Emissions will decrease to just over 1.2 Mt CO_2e in 2030 even though the sector is forecasted to grow by 10% over this period. The reference case energy efficiency of the sector improves in response to high long-term oil prices and this change results in decreasing emissions in spite of rising output. Emissions from this sector come primarily from personal vehicles and air travel, but also include transit travel and intercity buses. Domestic air travel emissions remain steady at 0.4 Mt in the absence of policy.

Abatement response for personal transportation

Figure 7 shows the marginal abatement curve and associated actions for personal transportation. The acronym "SVHOMT" (smaller vehicles, higher occupancy, mass transit) indicates reduced energy consumption per person kilometre travelled due to consumers purchasing smaller vehicles, higher occupancy of passenger vehicles and increasing use of public transit. "PHEV" indicates a switch to plug-in hybrid electric vehicles. Key findings for the personal transportation sector are:

1. **Most reductions in the near term (2020) are the result of purchasing smaller vehicles, higher occupancy and increased mass transit use (SVHOTM).**

These options are currently available, whereas other opportunities, such as plug-in hybrid vehicles and increased use of biofuels, may not be cost competitive or widely available within a decade. Furthermore, the rate of replacement of vehicles also constrains the total market penetration of these technologies by 2020. Switching to hybrid vehicles provides some additional abatement, but the potential is limited since high oil prices already induced a significant uptake of these vehicles in the reference case. Overall, these actions do not significantly reduce emissions from the transportation sector in the near-term (i.e., 2020). A policy that imposes costs of \$300/tonne CO_2e would only reduce emissions by about 20% below the reference case. As a result, deep reductions in emissions will require a long-term price signal to induce innovation in the sector and ensure that emissions fall as the vehicle stock is replaced.

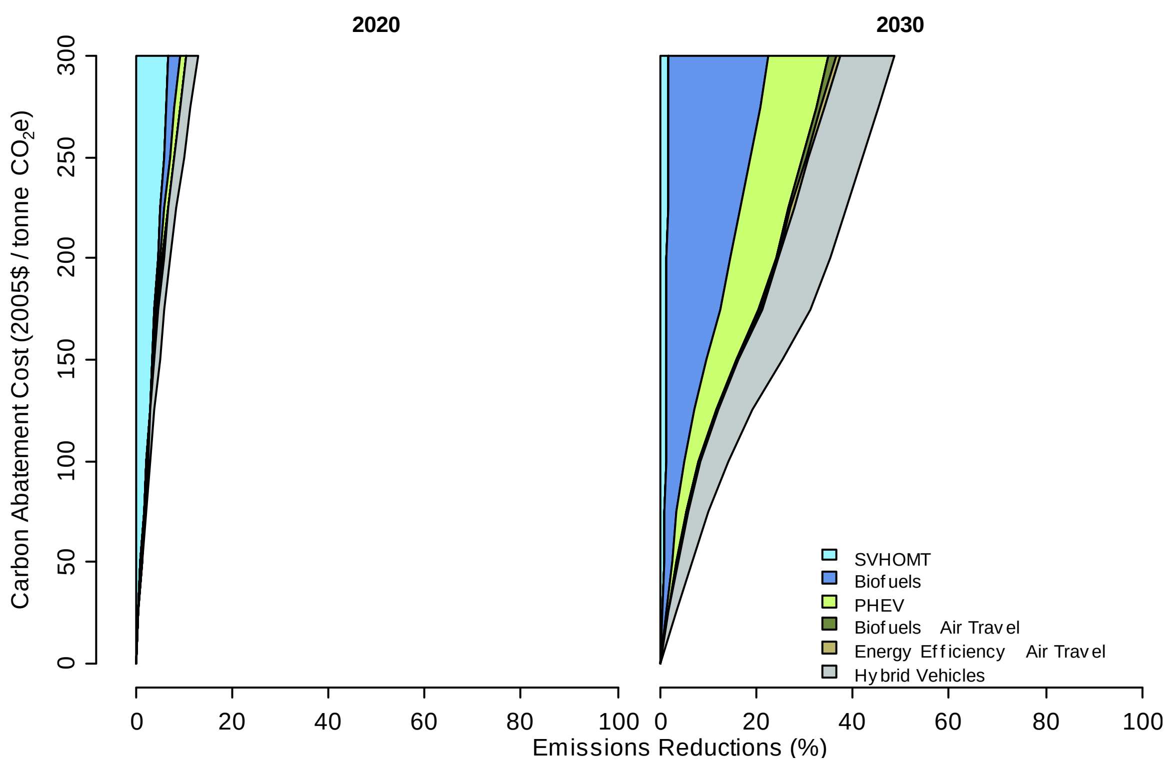
2. **By 2030, the maturation of plug-in hybrid vehicles that consume biofuels may significantly reduce emissions from personal transportation.** The cost of plug-in hybrid vehicles, which prevent their widespread adoption in the near-term, is likely to decline as manufacturers accumulate experience. The decline in costs is contingent on strong policy acting over many years that increases the demand for low-emissions vehicles and provides an incentive for continued research and development in plug-in and electric vehicles. Likewise, strong climate policy will also encourage innovations in biofuel production, such as cellulosic ethanol, that will contribute to emissions reductions.
3. **The penetration of plug-in vehicles does not result in indirect emissions from this sector.** By 2030, the electricity sector produces close to zero emissions at carbon prices where plug-in vehicles are adopted. Therefore adding new electricity demand from the transportation sector does not increase the indirect emissions of the sector.
4. **Widespread biofuel use for transportation requires innovation in biofuels manufacturing.** The analysis shows that between 2020 and 2030, most biofuel consumption in passenger transportation is ethanol produced from cellulose, sourced from forestry and agricultural waste, or purpose-grown cellulosic material. This method of producing ethanol uses the non-edible portion of plants and does not compete with food production. Further, cellulosic ethanol production is less energy intensive than corn-based ethanol, and would become cost competitive if its capital costs decline as producers accumulate experience with the technology.[11]
5. **In the long-term, consumers may revert to purchasing larger vehicles and reducing transit use as passenger vehicles become less greenhouse gas intensive.** The decoupling of greenhouse gas emissions from energy use by 2030 allows consumers to satisfy their apparent preferences towards larger personal vehicles while avoiding greenhouse gas emissions.

[11] Farrell et al, 2006, "Ethanol can contribute to energy and environmental goals", *Science*, 311.

6. **There are very few abatement options for air travel in 2020, and emissions reductions from this mode of travel remain small in 2030.** At a carbon price of $300/tonne in 2030, 0.4 Mt CO_2e (roughly two thirds) of the remaining transportation emissions are from air travel. Therefore, attaining deep reductions in transportation emissions will require additional innovation that has not been foreseen in this analysis. Options for reducing emissions from air travel include fuel switching to biofuels and possibly hydrogen as well as energy efficiency.

7. **Future innovation in passenger transportation is highly uncertain.** Our analysis illustrates the significant reductions achieved with biofuels and plug-in hybrids. However, other technologies that are currently under development may play more important roles than recognized in this analysis. For example, a barrier to full electric vehicles is that current prototypes cannot be quickly refuelled and therefore are not conducive to long-distance travel. A breakthrough in electric vehicle refuelling or the establishment of battery exchanges along travel routes may allow for the adoption of electric vehicles. Similarly for fuel cell vehicles, a breakthrough in fuel cell or hydrogen injection technology may move the sector in a different direction than what we assume here. Increased market penetration of these types of vehicles would reduce dependence on biofuels and potentially eliminate fossil fuel consumption. An additional challenge with biofuels is that ethanol must currently be blended with gasoline. However, advances in biofuels may allow 100% biofuel content in transportation fuels.

Figure 7: Cost curve for personal transportation with Lower Churchill Falls



Freight transportation

The freight transportation sector emitted 1.9 Mt CO_2e in 2005, accounting for 18% of provincial emissions. The sector is forecast to emit roughly 2.4 Mt CO_2e by 2030 without greenhouse gas mitigation policy. Direct emissions in this sector are produced by freight trucks, marine vehicles and off-road vehicles. Off-road vehicles include vehicles used in the forestry, agriculture and construction sectors. Emissions from off-road vehicles used in the industrial sector are allocated to the sectors that produce them.[12]

Abatement response for freight transportation

Figure 8 shows the marginal abatement costs and associated actions for freight transportation. Key findings for the freight transportation sector are:

1. **The switch from diesel fuel to biodiesel is responsible for most reductions from the sector.** Similar to passenger transportation, emissions can be reduced by blending biofuels into the fuel, since biofuels does not produce net emissions at the point of energy consumption. Biodiesel is the primary biofuel used in the freight sector, and throughout the simulation, we have used a price forecast that is roughly 40% greater than the reference case price of diesel. By 2020, biodiesel is used to reduce emissions if the carbon price is above \$150/tonne CO_2e, and abatement could be as high as 30% under a price of \$300/tonne CO_2e. Since establishing biodiesel production facilities and distribution networks takes time, the abatement potential increases during the simulation. By 2030, with a carbon price of \$300/tonne CO_2e applied over two decades, biodiesel accounts for 60% of the sector's energy consumption and emissions are also reduced by 60%.
2. **The policy does not induce significant improvements in the energy efficiency of freight trucks or marine vehicles.** Only minor energy efficiency improvements are undertaken in the absence of policy, in part explaining the rapid growth of freight emissions relative to passenger emissions. The carbon price does not induce many efficiency improvements beyond the reference case. For trucks, hybrid technology using electric motors and regenerative braking is available in the freight sector. However, these motors achieve the greatest efficiency gains where the output of the battery component is maximized, typically for shorter trips and at lower speeds. Current designs are for medium-duty trucks which are a minor component of total freight emissions.[13] Because most freight transportation occurs at high speeds over long distances, biofuel consumption is a more cost-effective abatement action while efficiency improvements from hybrid motors are limited.

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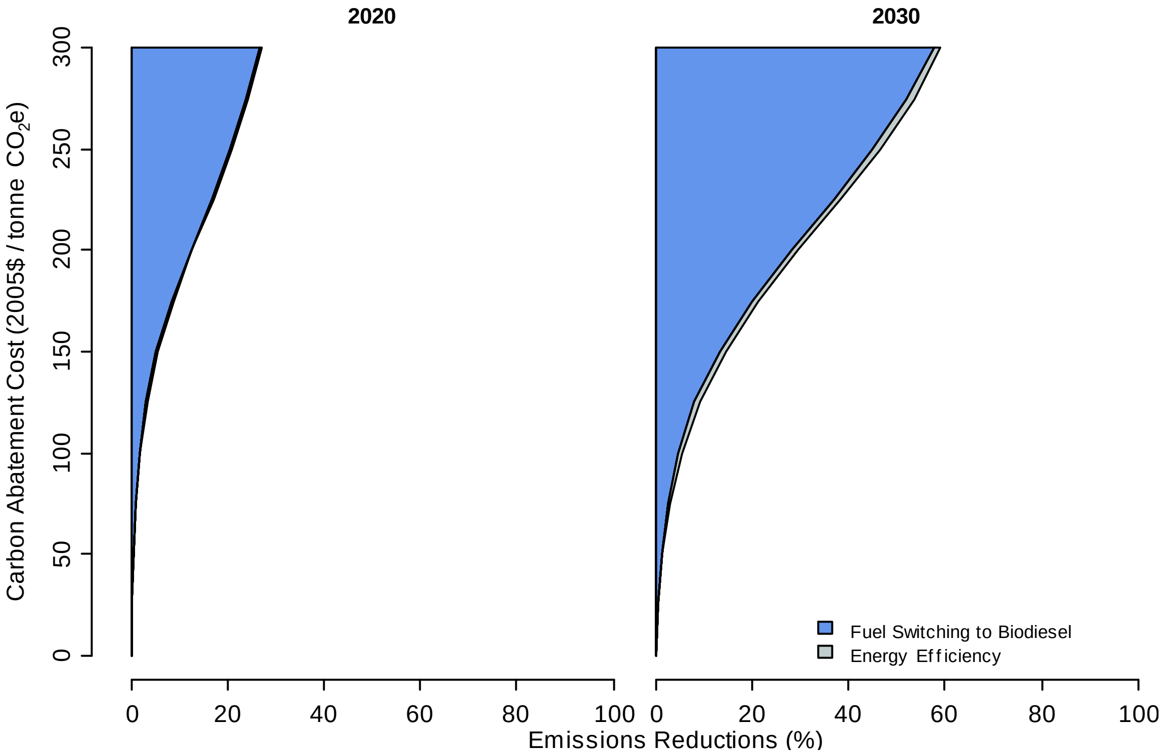
[12] CIMS does not account for stationary sources of combustion in the forestry, construction and agriculture sectors.

[13] For example freightliner, www.freightlinertrucks.com/trucks/find-by-model/m2e-hybrid/

3. **Widespread biodiesel use for freight transportation requires innovation in biofuels manufacturing.** Given the scale of biodiesel consumption in the carbon pricing forecasts, biodiesel production will likely need to use non-agricultural crops or algae. This would avoid the potential land-use emissions that could occur if vegetated land is converted to farmland for fuel production.
4. **Other abatement options may be used, but the current analysis indicates they are less likely to be viable compared to biodiesel consumption.** Similar to passenger transportation, there are uncertainties around the development of biofuel production, fuel cell technology and battery technology. If there is a breakthrough in battery or fuel cell production then biodiesel consumption will be less than we have forecasted.

Figure 8: Cost curve for freight transportation with Lower Churchill Falls



Newsprint

In 2005, emissions from this sector were 0.13 Mt CO_2e, accounting for 1% of provincial emissions. Currently, production has decreased and annual emissions are roughly 0.08 Mt CO_2e. Emissions will decline slightly and energy efficiency will increase as some equipment is retired and replaced. Most direct emissions from newsprint manufacturing come from the production of process heat required for pulp production and paper drying. This heat is produced by fuel oil combustion, co-fired with biomass.

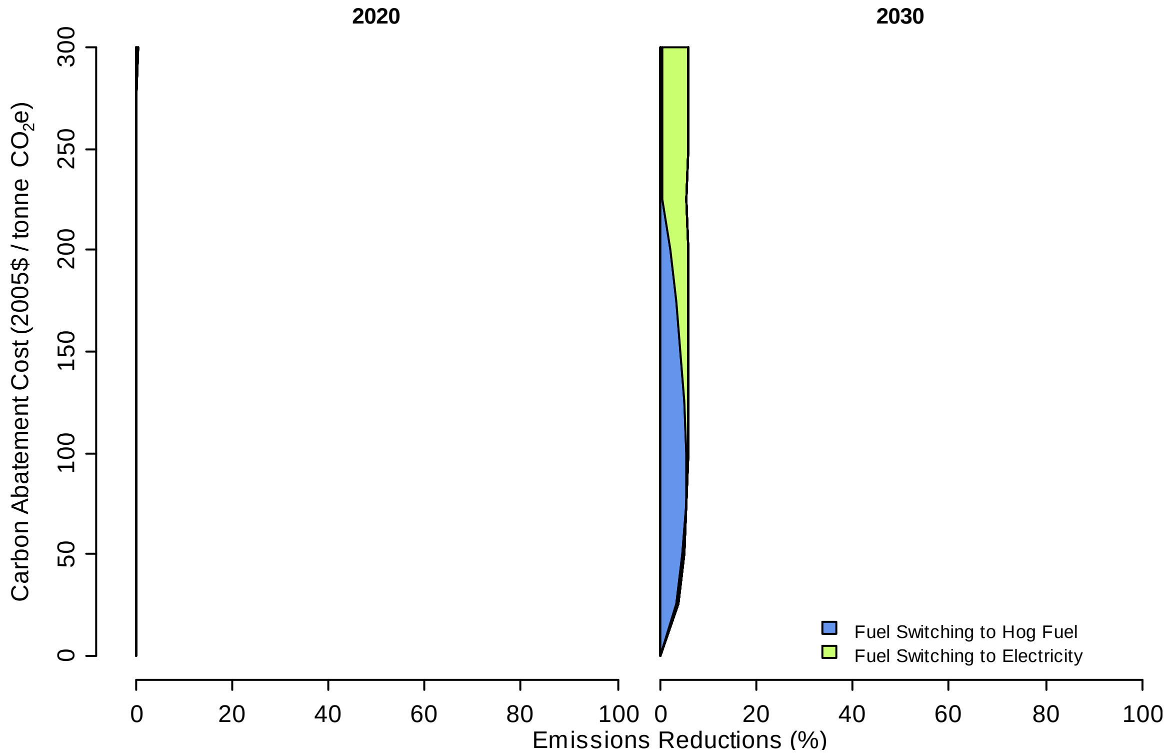
Abatement response for newsprint

Figure 9 shows the actions and the associated costs to reduce emissions from newsprint manufacturing. The key findings for this sector are:

1. **A lack of investment in the newsprint sector creates few opportunities to install new equipment that can reduce emissions.** Since we have assumed that production will remain constant, new equipment is only added as old equipment is retired. By 2020, this assumption results in almost no possibility for abatement, although by 2030 there are some small opportunities. In the short-term, further biomass co-firing opportunities, such as adding peat to the fuel-mix, have already been explored.[14] This analysis assumes no further abatement is possible by switching to renewable fuels until future boiler and co-generator upgrades occur.
2. **Further switching to biomass fuels achieves some additional reductions by 2030.** However, the biomass is still being co-fired with fossil fuels and this abatement action is less desirable at carbon prices above $150/tonne CO_2e.
3. **Above $150/tonne CO_2e, using electric boilers to produce process heat is employed as an abatement action.** However, total abatement is still constrained by the lack of new investment.
4. **Indirect Emissions associated with electricity consumption also decrease in response to carbon pricing even though the amount of electricity used by the sector increases.** In the reference case, indirect emissions from the newsprint sector were larger than direct emissions. Excluding cogeneration, indirect emissions are currently 0.1 Mt CO_2e and may rise slightly by 2030. Under carbon pricing, the electricity sector significantly reduces its emissions, thus indirect emissions also trend towards zero.

[14] The Western Star, 2007, www.thewesternstar.com/index.cfm?sid=47175&sc=23

Figure 9: Cost curve for newsprint manufacturing with Lower Churchill Falls



Other manufacturing

The other manufacturing sector includes a variety of facilities producing goods ranging from machinery to wood products, prepared foods and paint. This sector emitted less than 0.1 Mt CO_2e (>1% of provincial total) in 2005. Production of process heat and steam is the largest source of direct emissions. In the absence of policy the sector's emissions are forecast to decline somewhat as manufacturing facilities switch from oil to electricity for space and process heating.

Abatement response for other manufacturing

Figure 10 shows the abatement actions and their associated costs in this sector. The key findings in the other manufacturing sector are:

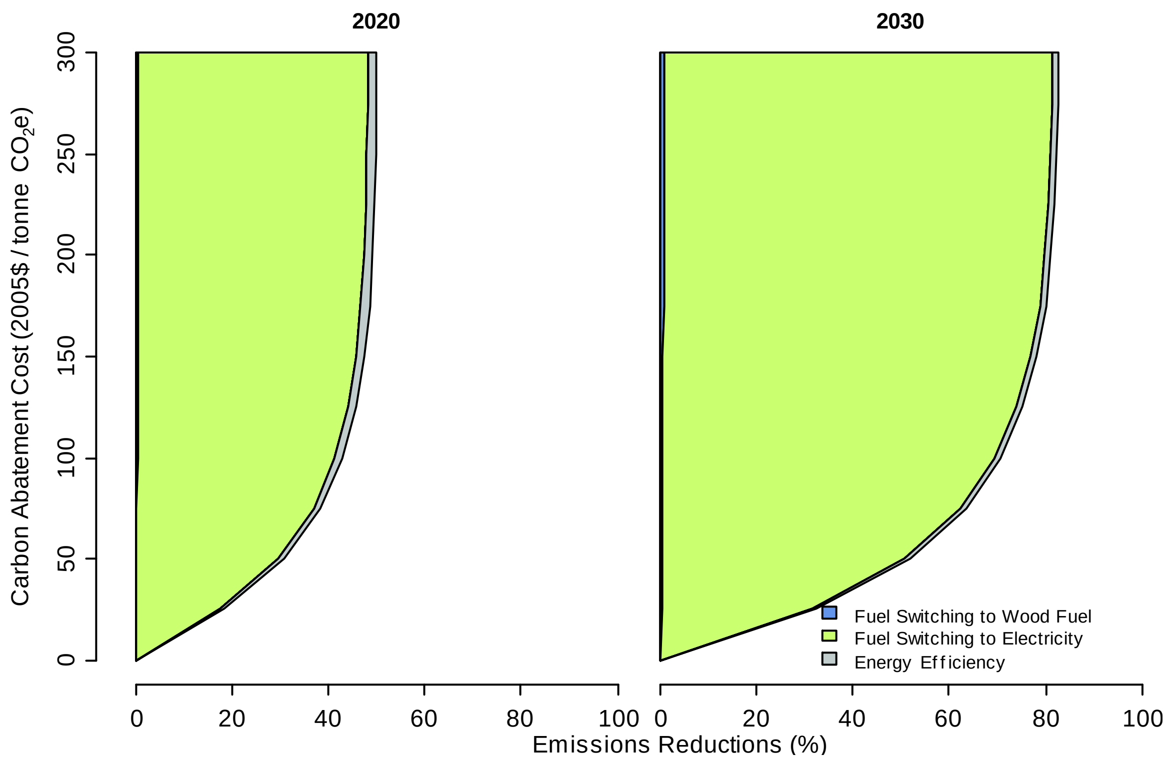
1. **Increased use of electricity for the production of heat contributes to most direct reductions.** Electric boilers reduce the amount of fossil fuels consumed, decreasing direct emissions. The low-cost electricity from Lower Churchill Falls permits a carbon price as low as $50/tonne CO_2e to achieve a 30% reduction in emissions by 2020 and a 60% reduction in emissions by 2030.
2. **Using wood fuel for the production of direct heat is a minor abatement action.** Like electricity, wood-fuelled furnaces displace fossil fuel consumption and reduce direct emissions from the sector. However, issues such the

availability of a cheap and reliable fuel supply may limit the abatement potential of this action.

3. **Most of the improvements to energy efficiency occur regardless of the policy.** The energy efficiency of the sector improves over time and carbon pricing only induces small additional improvements.

4. **Indirect emissions associated with electricity production decline in response to the carbon pricing.** Indirect emissions remain less than 0.1 Mt CO_2e in the reference case. Once the electricity is sourced from Lower Churchill Falls, indirect emissions fall to zero.

Figure 10: Cost curve for other manufacturing with Lower Churchill Falls



Metallurgy

The only facility in this sector is the Voisey Bay Hydromet facility. It is a new installation using hydrometallurgical processing. Production of process heat for metal leaching is the source of emissions which will remain lower than 0.1 $MtCO_2e$ for the duration of the simulation. Indirect emissions associated with electricity production will also be around 0.1 $MtCO_2e$. Given the age of the facility, this modelling study does not forecast any abatement. However, the sector would achieve zero emissions if all process heat were generated with electric or biomass boilers. If electric boilers were used, indirect emissions would decline since the electricity sector would be switching to hydroelectricity.

Mining

Mining for ore produced 1.27 Mt CO_2e in 2005, equivalent to 12% of Newfoundland and Labrador's emissions in 2005. The sector produces primarily nickel and iron ore. Other production includes copper, gold and other metals. Two processes account for most of the sector's greenhouse gas emissions: 1) The combustion of fuel oil, coke and coal to pellet iron ore in preparation for smelting, and 2) the combustion of diesel in vehicles that extract and transport the ore. Reference case emissions will decline slightly to 1.19 Mt CO_2e in 2030 as some fuel oil pellet kilns are replaced with more efficient kilns and microwave kilns.

Abatement response for mining

The abatement actions for the mining sector and their associated costs are shown in Figure 11. Conclusions for this sector are:

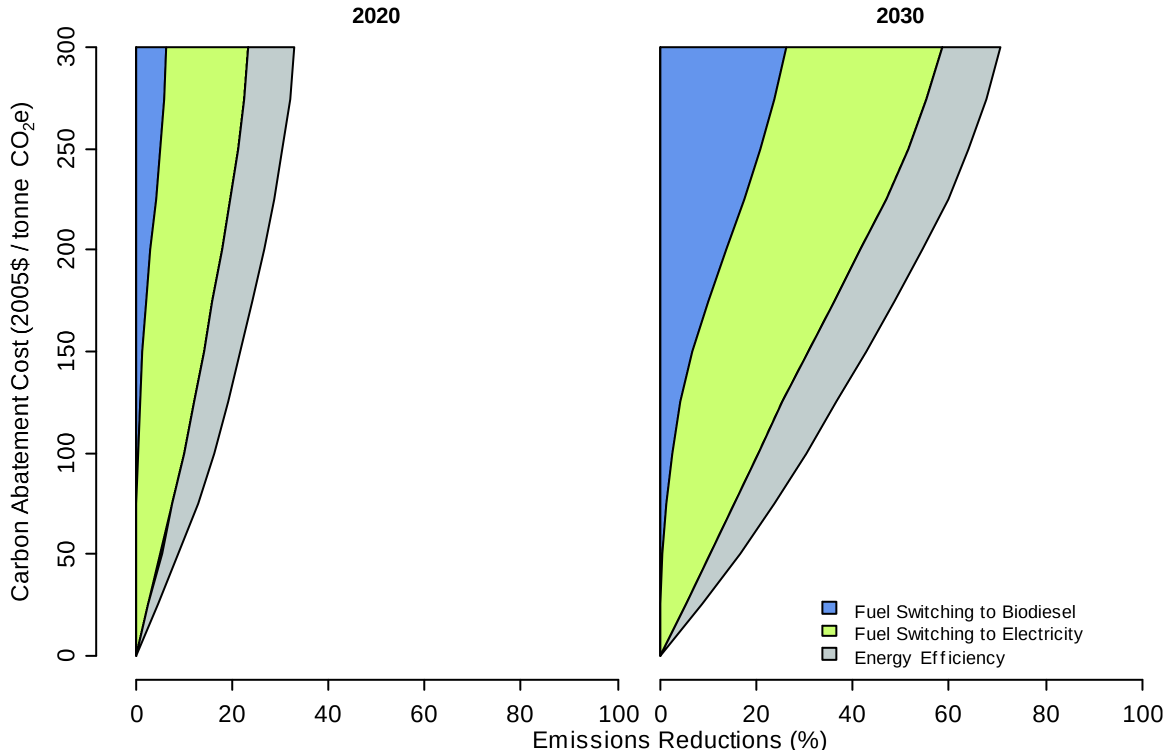
1. **Pelleting of iron can be fuelled by electricity instead of fossil fuels.** Currently, most iron pellet kilns are fuelled with oil, coke and coal. However, carbon pricing may accelerate a switch to electric heat for this end use. For the appropriate iron ore types, microwave pelleting is also possible.[15] This technology also yields abatement through energy efficiency since the energy required for a microwave kiln is less than what is required for a coke or oil kiln. For carbon prices over $100/tonne CO_2e, most pellet kilns may be fuelled with electricity by 2030.
2. **Increased use of electric equipment for extracting and transporting mineral ores reduces fossil fuel consumption and increases energy efficiency.** Mines currently use both diesel trucks and electric conveyors to move ore. Under higher carbon prices more conveyance is expected, reducing emissions from the sector. Electric motors are more efficient than combustion motors, so this switch also yields abatement through energy efficiency. However, the analysis shows the abatement potential of this action is limited. For example, some aspects of a mining operation (e.g., some transportation needs) cannot be easily carried out with electric equipment and some mines may not be near an electric grid connection.
3. **Fuel switching to biodiesel is an important mitigation action for extraction and transportation where electric equipment is not practical.** A higher carbon price results in more biodiesel consumption and greater abatement from the extraction and transportation operations. The abatement available from this action will be limited in 2020 since the biofuel industry will still be immature. By 2030 with carbon prices higher than $150/tonne, biodiesel becomes an important component of the liquid fuel used in the mining sector. Similar to the freight

[15] For example One Pro technology: www.orepro.com.au/index.html

sector, innovations in battery or fuel cell technologies could reduce the importance of abatement using biodiesel.

4. **While indirect emissions associated with electricity production are significant in the reference case, they decline once Lower Churchill Falls is developed.** In 2005, indirect emissions were 0.4 Mt CO_2e rising to 0.5 Mt CO_2e by 2030. Simply by developing the Lower Churchill Falls project, indirect emissions fall to 0.1 Mt CO_2e. With carbon pricing, indirect emissions are reduced to near-zero in this scenario.

Figure 11: Cost curve for mining with Lower Churchill Falls



Landfills

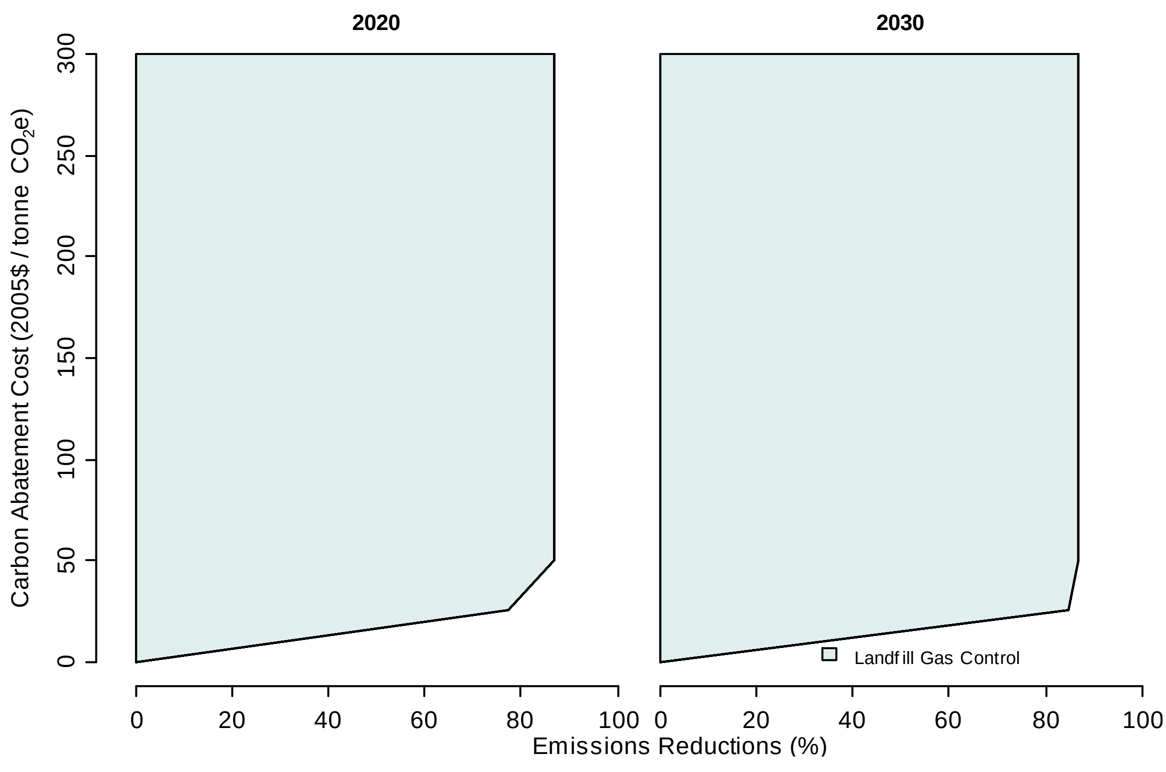
Emissions from landfills were 0.62 Mt CO_2e in 2005 and will decrease slightly after the completion of the Robin Hood Bay methane capture facility. Emissions are primarily from landfill gas (methane) that is released during the anaerobic decomposition of organic matter. Total emissions are correlated with the mass of landfilled waste. Most of this waste is at the Robin Hood Bay landfill and the Wild Cove site near Corner Brook. Historically, other smaller sources of waste were burned rather than landfilled, so they are not producing methane. In the future, much of the organic matter will be separated from the waste stream before landfilling, so methane emissions are unlikely to rise.

Abatement response for landfills

Capturing and flaring the methane emissions is the primary abatement action. Figure 12 shows the abatement costs associated with this action. Key findings for the landfill sector are:

1. **Capturing and flaring landfill gas is a relatively low cost abatement action.** Given our knowledge of the waste sector in Newfoundland and Labrador, we estimate that this action is likely to cost less than $50/tonne CO_2e and reduce virtually all the emissions from the sector. This is roughly analogous to installing full methane capture at the current landfills which can reduce over 90% of future methane emissions.[16] Furthermore, this action is likely to be an early opportunity for greenhouse gas abatement because the methane capture equipment is already a commercialized technology.
2. **The abatement is limited to roughly 80% of sector emissions because methane combustion produces CO_2 and not all methane is captured.** This analysis does not foresee any possibility of reducing these emissions.

Figure 12: Cost curve for landfills with Lower Churchill Falls



[16] Bogner, J., M. Abdelrafie Ahmed, C. Diaz, A. Faaij, Q. Gao, S. Hashimoto, K. Mareckova, R. Pipatti, T. Zhang, Waste Management, In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Electricity

The electricity sector was a significant emitter in 2005, producing roughly 1.17 MtCO_2e, or 11% of Newfoundland and Labrador's emissions. Current emissions from this sector are primarily from the Holyrood thermal electricity generation plant. In the absence of any policy, some new wind and small hydro capacity is added. However, fuel oil fired thermal generation remains a growing source of electricity and emissions for the province. Again, the reference case scenario assumes the Lower Churchill Falls hydroelectric project and in-feed to the island are not built. By 2030, emissions from this sector are projected to rise to 1.7 MtCO_2e.

Carbon pricing induces a significant amount of electrification. At a price of $300/tonne CO_2e, demand for electricity within Newfoundland and Labrador is forecast to rise by 10% in 2020 and by 20% in 2030 relative to the reference case. Consequently, the ability of this sector to increase its output without increasing its emissions is imperative to reducing provincial emissions. In this analysis of marginal abatement costs, the Lower Churchill Falls project and the transmission in-feed to the island are built thus encouraging electrification while reducing emissions from electricity generation.

Abatement response in the electricity sector

Figure 13 shows the abatement actions and associated marginal cost in the electricity sector. Conclusions for this sector are:

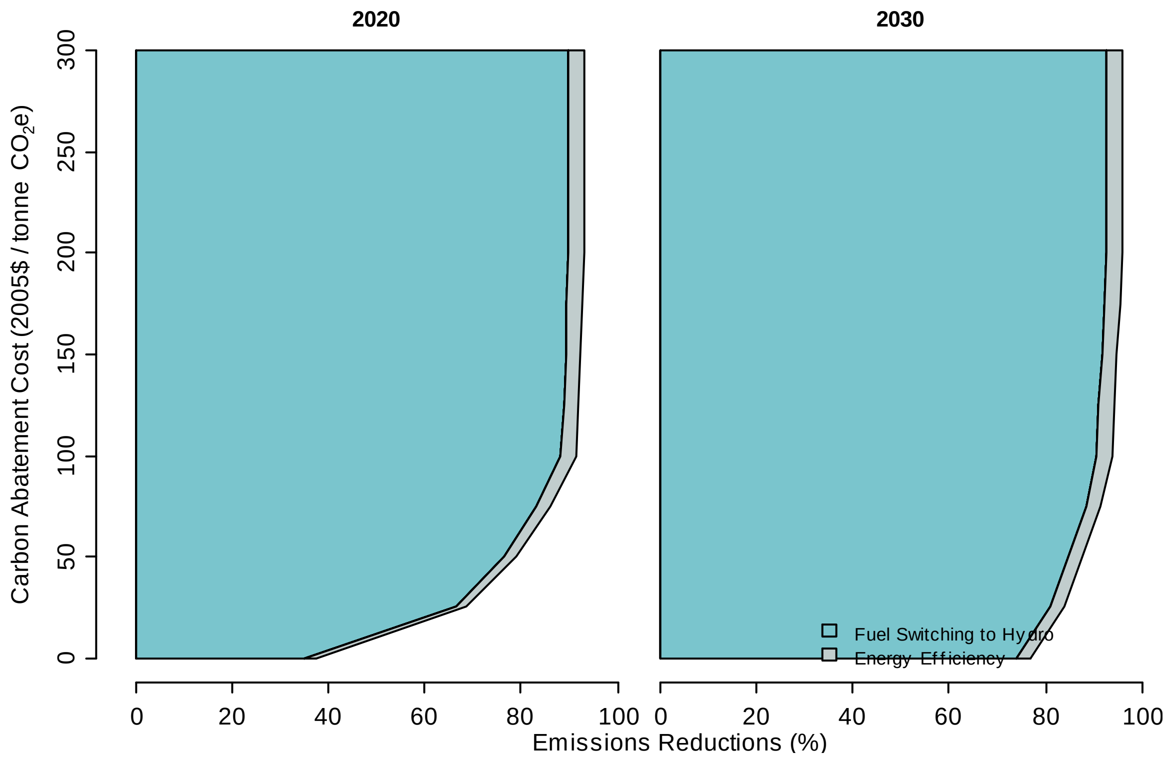
1. **Holyrood and other thermal capacity that would have developed in the reference simulation are replaced with capacity from Lower Churchill Falls.** There are broader financial and economic considerations for developing Lower Churchill Falls beyond reducing greenhouse gas emissions. As such, no carbon pricing is needed to ensure new capacity is from hydroelectricity rather than from new thermal plants. To simulate how Lower Churchill Falls would replace the Holyrood plant, the model was given the possibility of retiring the Holyrood plant if its operation cost (per unit of electricity) was higher than the total unit cost of the hydroelectricity plant. Thus, the strength of carbon price does affect the rate at which the Holyrood plant is retired and the emissions forecast, notably in 2020. By 2030 a carbon price above $50/tonne CO_2e ensures total retirement of the Holyrood plant. Actual decisions regarding Holyrood may differ from this representation and the abatement from Lower Churchill Falls may not depend on the carbon price.

2. **Generating electricity with hydro power is more energy efficient than with a thermal plant**. Because generating electricity from hydro is measured as 100% efficient in CIMS, a portion of the abatement is tracked as energy efficiency relative to thermal electricity production.

3. **The Lower Churchill Falls project allows the electricity sector to reduce its emissions earlier and at lower carbon prices than would otherwise be possible.** The emissions intensity of electricity production would still decrease in response to carbon pricing, but the sector would have to rely on higher cost

projects including thermal generation with carbon capture and storage, small hydro, and additions of wind energy with the associated integration/storage costs.

Figure 13: Cost curve for the electricity sector with Lower Churchill Falls



Petroleum refining

The petroleum refining sector produced 1.14 Mt CO_2e in 2005, or 11% of total provincial emissions. Emissions are forecast to rise to 1.17 Mt by 2030 in the absence of any new greenhouse gas mitigation policies. Petroleum refineries transform crude oil into petroleum products such as gasoline and diesel. The demand for refining is therefore strongly linked to demand for fuels from transportation. If transportation becomes more energy efficient, or if substitutes for petroleum products become widely used, demand for petroleum products will fall. However, in this analysis we examine the abatement potential assuming refinery production maintains its reference case output.

Petroleum refining requires significant amounts of process heat and the majority of this sector's greenhouse gas emissions are from the combustion of fossil fuels to provide this process heat. Some processes may require hydrogen production which emits CO_2 as a by-product.

Abatement response for petroleum refining

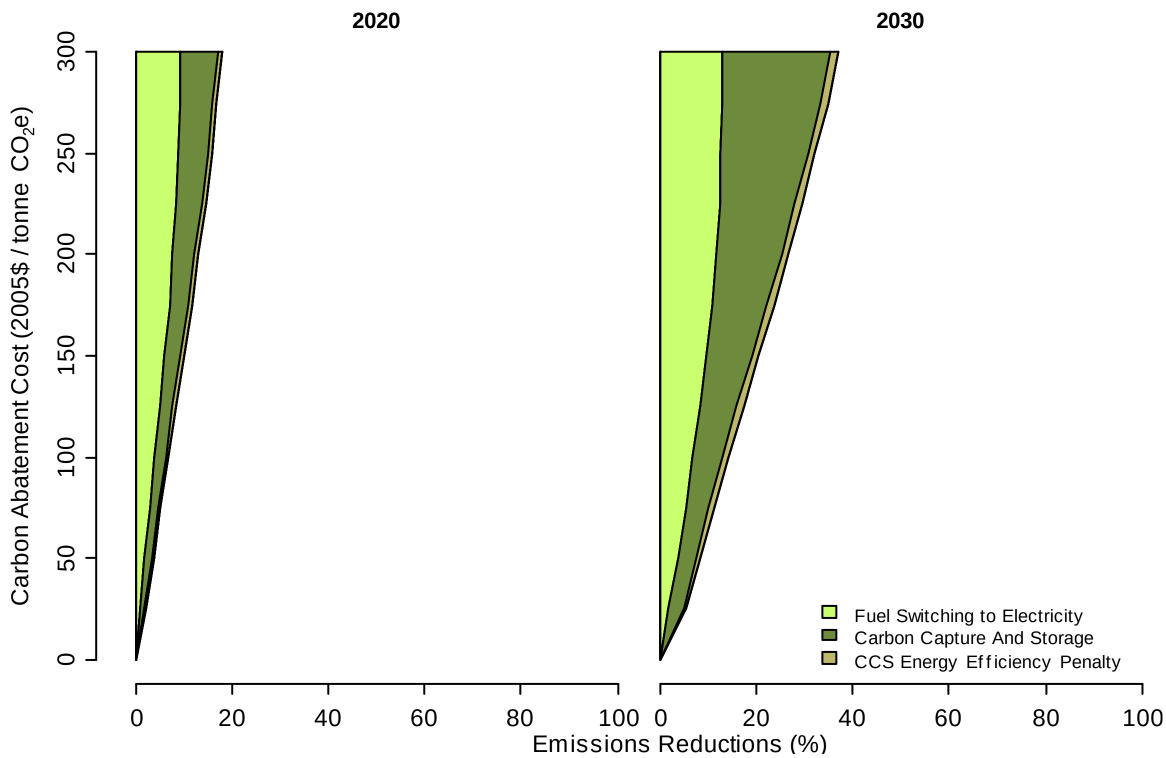
Figure 14 shows the actions and the associated costs for reducing emissions from the petroleum refining sector in Newfoundland and Labrador. The key findings for this sector are:

1. **Capturing the carbon dioxide from hydrogen production is likely to have low costs.** Hydrogen is production emits a pure stream of carbon dioxide that can be captured at low cost. Carbon capture from hydrogen production will be stimulated by an emissions price starting at \$50/tonne CO_2e. We have assumed that hydrogen production is a minor process in Newfoundland and Labrador so this abatement action has a limited effect.[17]
2. **Carbon capture and storage of combustion emissions is a high cost abatement action, but it offers the largest opportunity to reduce emissions in the long-term.** Carbon capture can be used with heat and steam production, but requires a carbon price of \$150/tonne by 2030 before the technology achieves significant uptake in this sector. Even at higher carbon prices the use of carbon capture and storage is constrained by the rate at which equipment is replaced. Furthermore, if only one facility is capturing carbon, then the cost of developing a transportation and storage network may be prohibitive on a per tonne CO_2e basis. This would increase the carbon price at which carbon capture and storage is viable in this sector. However, if this abatement action is not used in other sectors, the small scale of the transportation and storage network (0.5 to 1.0 Mt CO_2e/yr in 2030) could raise the carbon price at which this abatement action is viable by another 10-20%.[18]
3. **Electricity can be used to produce process heat in the refining sector.** In response to carbon pricing some heat will be produced with electricity. However, the cost of electricity relative to fossil fuels for this energy end-use limits abatement from electrification.
4. **Indirect emissions are insignificant in the reference case and decline in response to carbon pricing.** The refining sector is not a major electricity consumer in the reference case and indirect emissions associated with this consumption remain less than 0.1 Mt CO_2e. Carbon pricing causes emissions to decline in the electricity sector further reducing indirect emissions in the refining sector.

[17] Hydrogen production is included under "Other and Undifferentiated Production" in the Environment Canada National Inventory Report. This document indicates that CO_2 emissions from hydrogen production range at most from roughly 30 to 90 kt annually.

[18] Coleman, D., Davison, J., Hendriks, C., Kaarstad, O., Ozaki, M., Transport of CO_2 in IPCC Special Report on Carbon Dioxide Capture and Storage, Intergovernmental Panel on Climate Change, 2005.

Figure 14: Cost curve for petroleum refining with Lower Churchill Falls



Petroleum crude extraction

In 2005, emissions from the petroleum crude sector were roughly 1.72 Mt CO_2e, accounting for 17% of provincial emissions. The emissions from this sector are produced by fuel combustion for heat, motive power and electricity generation. Fugitive emissions also result from methane leaks and venting that occur during production. Emissions from associated natural gas flaring are significant during the first years of an oil field. However, these temporary emissions have been excluded from this analysis since the natural gas is re-injected into dedicated wells during normal operation. By 2030, reference case emissions decline to roughly 1 Mt CO_2e as oil production declines, although the sector remains one of largest greenhouse gas emitters.

Abatement response for petroleum crude extraction

Figure 15 shows the cost curve for conventional oil production. The conclusions from this sector are:

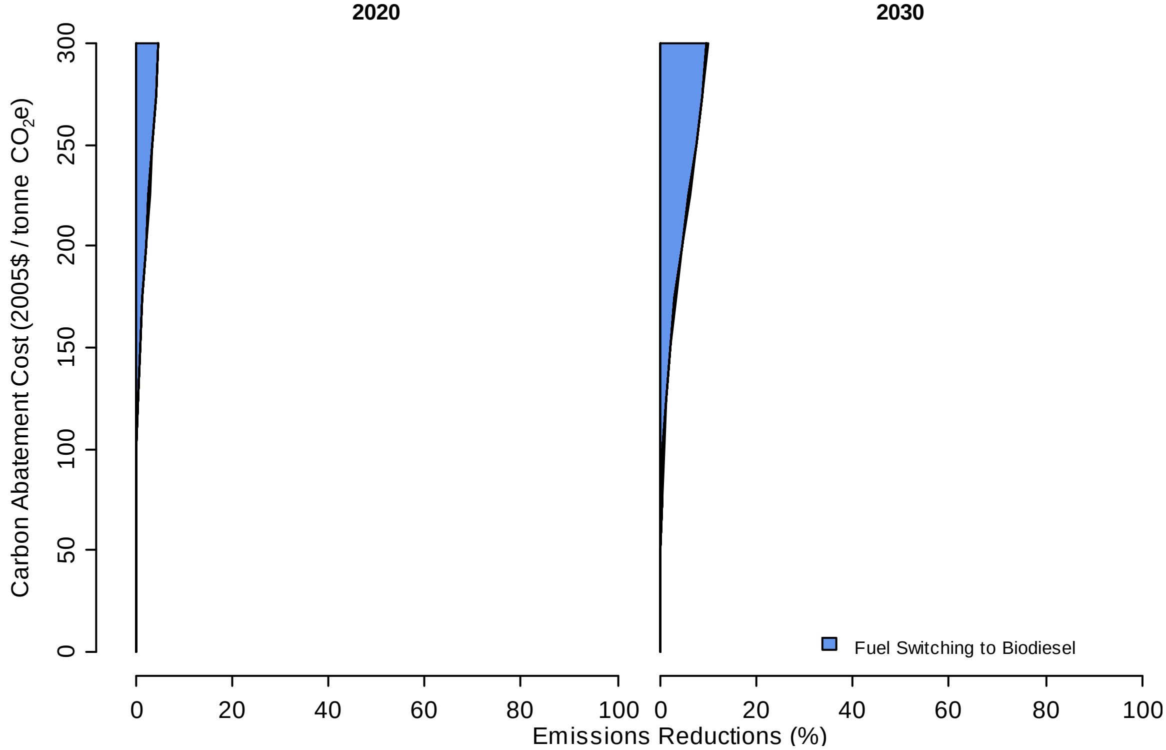
1. **Biodiesel consumption for heat, motive power, and electricity generation provides limited abatement at higher carbon prices.** This abatement action is constrained because liquid fuels are only used as a back-up to natural gas as an energy source. This latter fuel is extracted with the crude oil and must either be burned or re-injected. Furthermore, natural gas is the least carbon intensive fossil fuel, reducing the incentive to switch to biodiesel. Therefore, by 2030, at carbon

prices greater than \$150/tonne CO_2e, biodiesel, like diesel in the reference case, is only used when natural gas is not available. At most, abatement will be less than 10% of the sector's emissions.

2. **Carbon capture and storage of combustion emissions was not considered in this analysis due to unknown costs and platforms with lifecycles reflecting a non-renewable resource base.** The Sleipner gas platform in Norway is a precedent for offshore carbon capture and storage, although this project stores the pure stream of carbon dioxide produced during natural gas processing.[19] Since the Sleipner project does not separate CO_2 from combustion gases, its cost for carbon capture and storage is quite low. Even though the proximity of the oil fields offers a convenient storage site, capturing CO_2 from combustion emissions is significantly more expensive than capturing formation CO_2. Given that most of the oil platforms will be near the end of their planned operation once carbon capture is commercially available, the benefit of storing carbon would be small relative to the high cost of the necessary retrofits. Furthermore, the potential benefit storing CO_2 in the oil-bearing formations for enhanced oil recovery has not been considered.
3. **Carbon pricing is unlikely to reduce fugitive emissions.** Roughly 20% of reference case emissions are fugitives. Fugitive emission intensity (per unit oil produced) for offshore oil is low, even in the reference case. Enhanced leak detection and repair can reduce these emissions but platforms with lifecycles reflecting a non-renewable resource base and the low emissions intensities provide very little incentive or opportunity for these upgrades.

[19] Statoil, 2008, www.statoil.com/AnnualReport2008/en/Sustainability

Figure 15: Cost curve for conventional oil production with Lower Churchill Falls



Sector Marginal Abatement Costs – Without Lower Churchill Falls

This section contains the analysis of marginal abatement costs at a sector level for the scenario without Lower Churchill Falls. The two main distinctions between this scenario and the scenario with Lower Churchill Falls are, 1) sectors generally achieve less abatement from switching to electricity, and 2) the electricity sector uses carbon capture and storage rather than hydroelectricity to reduce its emissions. The reduced abatement from switching to electricity is especially noticeable in 2020 before a significant amount of carbon capture and storage capacity has been developed in the electricity sector. With the exception of the aforementioned comments, the conclusions from the scenario with Lower Churchill Falls remain valid. Likewise, the qualifications of the preceding marginal abatement cost analysis also remain valid. This analysis only explores the effect of carbon pricing and does not simulate specific carbon price paths or regulatory policies. The abatement potential of a sector does not include the sale of offsets between sectors and jurisdictions. Finally, this project did not include consultation with specific industries or facility operators.

The following discussion focuses only on the sectors where the Lower Churchill Falls scenario noticeably affects the marginal abatement cost curves and it only highlights the resulting differences. These sectors include the electricity sector because the development scenario directly affects the available abatement actions. It also includes the residential, commercial and mining sectors since these three sectors account for approximately 80% of electricity consumption in the reference case and carbon pricing scenarios. These sectors also account for much of the abatement from electrification, providing clear examples of how this abatement action differs between the Lower Churchill scenarios.

Electricity

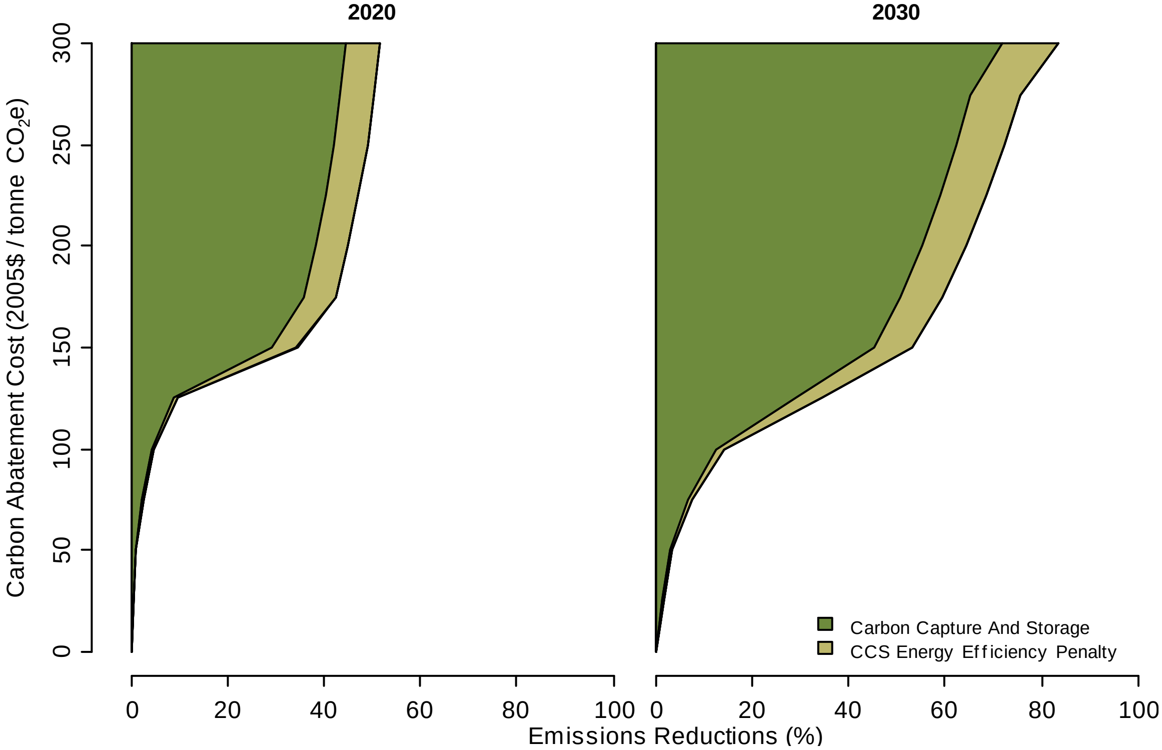
If the Lower Churchill project does not go ahead, the province continues to rely on thermal generation to meet its electricity demand, even under carbon pricing. Figure 16 shows the abatement actions and associated marginal costs in the electricity sector for the scenario without Lower Churchill Falls. Conclusions for this sector are:

1. **Carbon capture and storage allows the electricity sector to reduce its emissions, but the abatement occurs at a much higher carbon price than with the Lower Churchill Falls project.** In this scenario, the electricity sector does not achieve significant abatement unless carbon pricing makes carbon capture and storage viable. This threshold is at \$125/tonne CO_2e in 2020, although the cost of carbon capture declines by 2030 as experience with the technology accumulates. By 2030, a carbon price greater than \$100/tonne CO_2e induces carbon capture and storage. Transportation of CO_2 is a minor component of this total cost. By 2030, if carbon capture is adopted, this sector could capture 2-2.5 Mt CO_2 per year. Estimates for the transportation cost component for this quantity range from \$6-12/tonne CO_2 for a 500 km long onshore pipeline.[20] Offshore pipeline costs would be higher; however an estimate is unavailable for the specific circumstances in Newfoundland.
2. **Carbon capture for baseload generation is viable at lower costs than for peakload generation.** The capital cost of a carbon capture unit is constant, but the total emissions captured from a baseload generation unit are greater than from a peakload unit. Therefore, the marginal abatement cost for this technology is less for a baseload unit than a peakload unit. As the carbon price rises, carbon capture and storage is used to achieve more abatement from non-baseload generation. By 2030, above \$275/tonne CO_2e, this analysis indicates that most thermal generation would be equipped with carbon capture technology.
3. **Carbon capture and storage has additional energy requirements which results in greater fuel consumption per unit electricity produced.** Because carbon capture removes only 90% of the greenhouse gas emissions in the flue gas, extra fuel consumption yields additional emissions. These emissions reduce total abatement by an amount equal to the width of the wedge labelled “CCS energy efficiency penalty”.

[20] Coleman, D., Davison, J., Hendriks, C., Kaarstad, O., Ozaki, M., Transport of CO_2 in IPCC Special Report on Carbon Dioxide Capture and Storage, Intergovernmental Panel on Climate Change, 2005.

4. **New wind energy and small hydroelectric capacity does not grow significantly in response to carbon pricing.** The cost of wind and small hydro projects is determined by the location, quantity, and variability of these renewable resources. The carbon pricing simulations include wind and small hydro power at several different estimated costs. Generation from these sources increases in the reference case forecast as the lower cost sites are developed. This analysis indicates that it is cheaper to develop thermal generation with carbon capture and storage than to develop the higher-cost renewable resources. A full inventory of the cost and capacity of potential renewable electricity projects on the island would clarify the trade-off between these projects relative to using carbon capture and storage. However, to fully replace all reference case thermal electricity generation, the capacity from renewable these renewable projects would have to be over ten times what is currently outlined in the public utility capital budget document.
5. **Emissions in the sector and in the province as a whole are sensitive to the cost of carbon capture and storage.** The electricity sector is a major emitter in the province. Furthermore, switching to electricity is a common abatement action in other sectors. Therefore, the abatement in this sector has a significant influence on total provincial abatement. If the cost of carbon capture and storage is lower than assumed in this study, provincial emissions would be less at a given price. If the cost is higher than assumed in this study, the opposite would be true or additional higher cost renewable energy may be used.

Figure 16: Cost curve for the electricity sector without Lower Churchill Falls



Residential

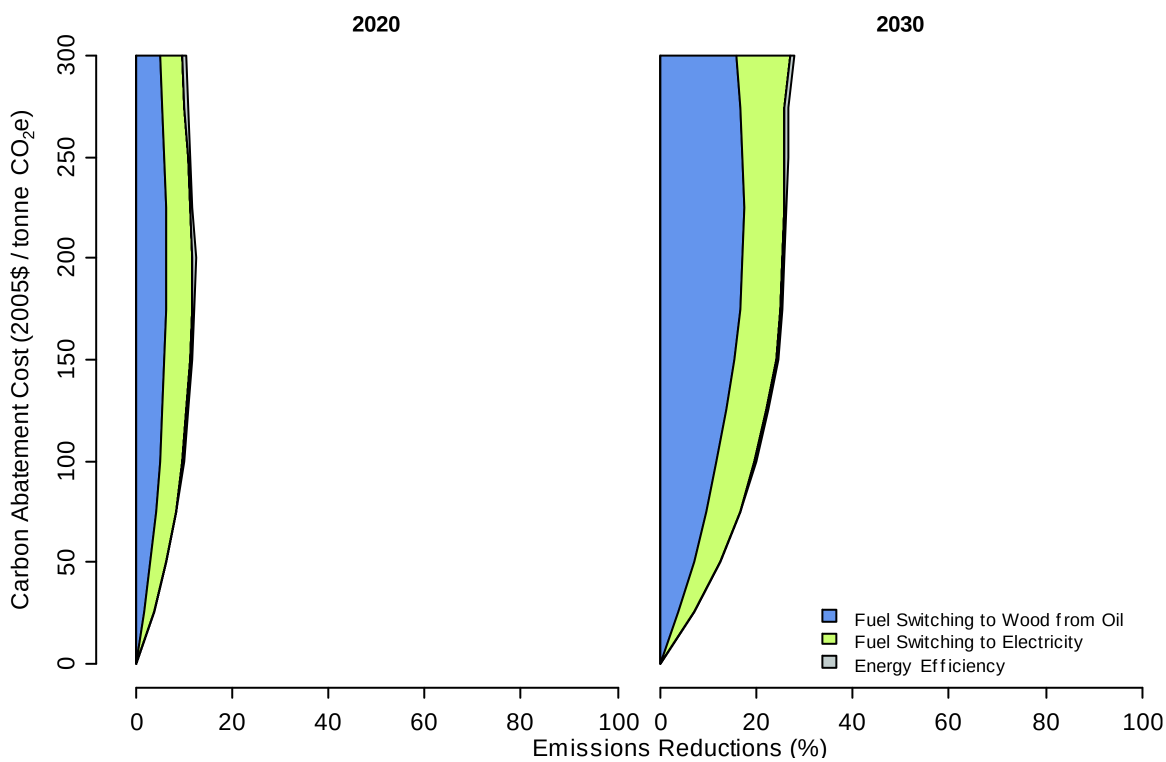
Figure 17 shows the actions and associated costs of reducing direct emissions from the residential sector if Lower Churchill Falls is not built. Again, reference case emissions are very low, so abatement is limited in this sector. The key findings for the residential sector without Lower Churchill Falls are:

1. **Less abatement is achieved through the accelerated electrification of space and water heating.** Without Lower Churchill Falls, the cost and availability of low-emissions electricity make abatement through electrification less attractive to consumers. However, this constraint encourages greater use of space and water heating with heat pumps which represent a slightly larger share of heating equipment relative to the scenario with Lower Churchill Falls.
2. **Spacing heating with wood fuel achieves more abatement relative to the scenario with Lower Churchill Falls.** This heat source does compete against electricity in some instances. More wood heating will be used if electric heating is less financially attractive, although in this analysis, the difference is slight.
3. **Indirect emissions associated with electricity consumption also decrease in response to carbon pricing.** However, they do not decrease as much as in the scenario with Lower Churchill Falls. In the reference case, indirect emissions rise to 0.83 $MtCO_2e$ by 2030. With a carbon price of \$300/tonne CO_2e, indirect

emissions are close to zero in 2030 when lower Churchill Falls is built, whereas they are 0.22 $MtCO_2e$ if the project is not built.

4. **Improvements in building shell energy efficiency still provide few emissions reductions (direct or indirect emissions) relative to the reference case.** Even without the Lower Churchill Falls development, these improvements are relatively more costly than other methods of reducing emissions. Again, this result is not showing that abatement is not possible by improving shell energy efficiency. It is demonstrating that carbon pricing is more likely to change the fuels and heating equipment used in homes rather than the homes themselves. Abatement in the electricity sector and the installation of heat pumps reduce both the incentive and the effect of improving shell efficiency.
5. **This analysis does not simulate how a carbon price might change urban form.** Higher density housing and district heating systems using combined heat and power or renewable energy could further reduce emissions. Determining this abatement potential requires a spatial analysis of population centres and has not been considered in this project.

Figure 17: Cost curve for the residential sector without Lower Churchill Falls

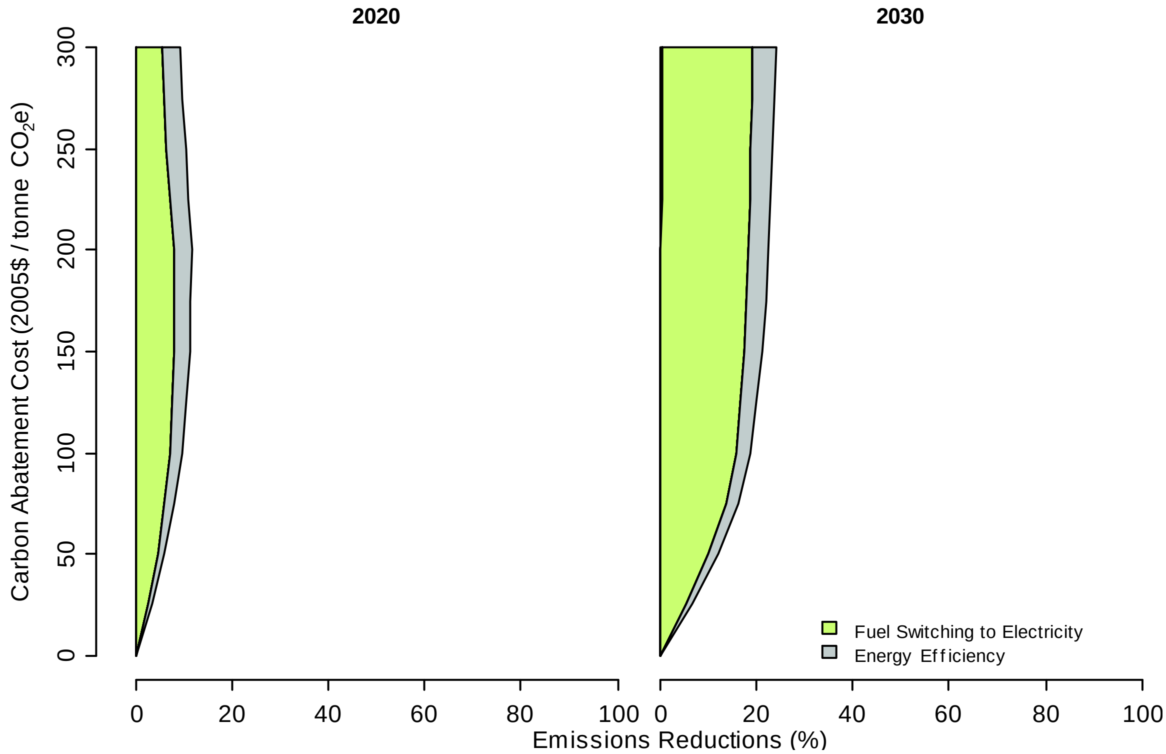


Commercial

Figure 18 shows the marginal abatement costs in the commercial sector for the scenario without Lower Churchill Falls. The main findings for the commercial sector without Lower Churchill Falls are:

1. **Using electricity for space heating and water heating are still forecasted to be the primary abatement method in 2020 and 2030.** However, abatement due to electrification is somewhat less than the in the scenario with Lower Churchill Falls. Additionally, in this scenario, abatement due to energy efficiency of heating equipment is larger. Heat pumps achieve a greater market penetration in response to higher cost electricity from thermal plants equipped with carbon capture and storage.
2. **Abatement by switching to electricity could decrease in response to high carbon prices in 2020.** The methodology used for this analysis only credits abatement from electrification in each sector if this action does not produce additional emissions in the electricity sector. Therefore, we see abatement from electrification in the commercial sector decrease at high prices in 2020. This indicates that in the short-term, a rapid rise in electricity demand could be temporarily greater than the supply of low-emissions electricity.
3. **Like the residential sector, indirect emissions from the commercial sector are greater in the scenario without Lower Churchill Falls.** In this scenario, with a carbon price of \$300/tonne CO_2e, indirect emissions fall to 0.15 $MtCO_2e$ in 2030 from 0.56 $MtCO_2e$ in the reference case. With the Lower Churchill Falls project, indirect emissions are close to zero in 2030 with the same carbon price.
4. **Improvements in shell energy efficiency achieve minor reductions in emissions (direct and indirect).** The scenario without Lower Churchill Falls makes building shells somewhat more responsive to carbon pricing. However, given that the electricity sector can reduce its emissions using carbon capture and storage, switching to electricity and installing heat pumps are still more competitive abatement actions. Carbon prices that are too low to induce carbon capture and storage also do not encourage improvements in shell energy efficiency relative to the reference case.

Figure 18: Cost curve for the commercial sector without Lower Churchill Falls

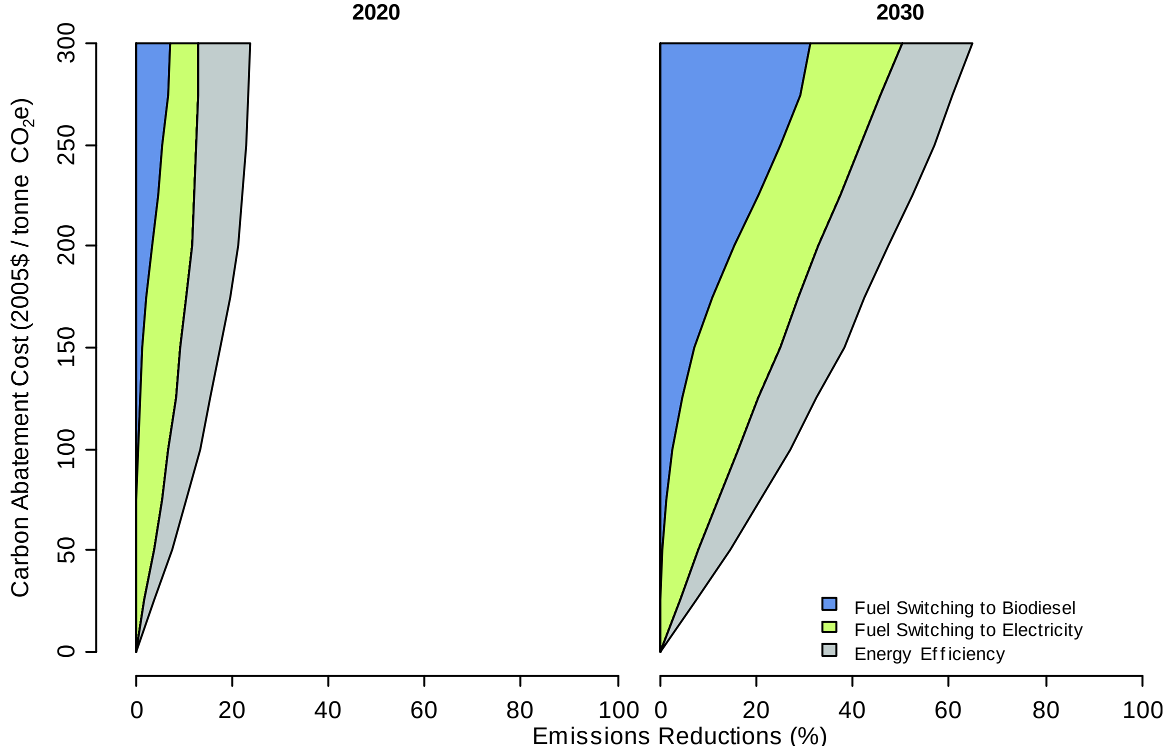


Mining

Figure 19 shows the abatement actions and their associated costs for the mining sector if Lower Churchill Falls is not built. Conclusions for this sector are:

1. **In both 2020 and 2030, carbon pricing induces less electrification for mineral extraction and transportation relative to the scenario with Lower Churchill Falls.** Biodiesel consumption is greater than in the other development scenario (at prices above \$150/tonne CO_2e) as are improvements to energy efficiency in mining equipment. These abatement actions partially compensate for the reduced abatement through electrification.
2. **Abatement through electrification also declines for iron ore pellet production at all carbon prices.** Similar to transportation and extraction, increased energy efficiency compensates for reduced abatement through electrification.
3. **In both 2020 and 2030, there is less abatement at any given carbon price in the scenario without Lower Churchill Falls**. Increased energy efficiency and biodiesel consumption do not completely compensate for reduced abatement from electrification. In general, the abatement potential from this sector for most carbon prices is roughly 10% lower than it would be if the Lower Churchill Falls project is built.

Figure 19: Cost curve for mining without Lower Churchill Falls



Quantitative Policy Analysis

The following analysis explores the magnitude of emissions reductions achieved by carbon price scenarios combined with regulatory policies. The carbon price scenarios modelled in this analysis simulate provincial emissions under a given strength of a market-based policy. The emissions prices modelled here are roughly equivalent to the selling price of emissions permits in an emissions cap-and-trade system, or to an economy-wide tax on greenhouse gas emissions. While this study does simulate the impact of carbon prices, it does not address issues related to system design, such as permit allocation and offset allowances. Again, because the development of the Lower Churchill Falls hydroelectricity project is uncertain, each policy scenario is simulated with and without the hydro development.

This section begins with an introduction to the general CIMS methodology and a discussion on the specific methodology and the major assumptions used in this study. Following this discussion, we present the results from the quantitative analysis, describing how policy scenarios affect provincial and sector emissions. In this analysis, wedge diagrams are used to identify the key abatement actions taken in each policy scenario. Next, we discuss how the policy scenarios affect key energy and economic indicators. These indicators include changes to energy intensity and greenhouse gas emissions by sector and changes to emissions from the electricity sector. The economic indicators include changes to capital investment by sector, household energy costs, transportation energy costs, fuel prices, and industrial production costs.

Methodology

The CIMS model

The analysis uses the CIMS energy-economy model to estimate the impacts of carbon pricing and regulatory policies on Newfoundland and Labrador. The CIMS model is a technologically explicit energy-economy model, which captures equilibrium feedbacks for the supply and demand of energy. As mentioned in the reference case section, CIMS requires external inputs - forecasted demand for products, services and energy prices. CIMS uses these drivers to determine the processes, technologies and energy required to meet demand enabling CIMS to produce provincial and sector emissions forecasts.

The CIMS model is well suited for this analysis because of its disaggregated sector structure and technologically explicit framework. CIMS models all the major energy supply and demand sectors in the economy as well as the main processes within those sectors (where demand for each process is satisfied by current and emerging technologies). The model captures virtually all emissions, energy consumption and energy production in the economy; thus, it is well positioned to provide a realistic forecast of abatement opportunities in the province.[21] The following discussion highlights the strengths and limitations of the CIMS model. A more detailed description of the model is provided as an appendix to this report (Appendix B).

The main advantages of CIMS over other modelling approaches are:

- **CIMS accounts for non-linearities in emissions abatement.** Many models simulate abatement using elasticities of substitution or linear functions that represent how firms can change their inputs while maintaining a given level of production. For example, computable general equilibrium models use elasticities to show how firms may switch from refined petroleum products to electricity, or how they can increase capital consumption to reduce energy consumption. The result is that the abatement from these models is relatively linear as a function of an emissions price. Rather than using elasticities or linear functions to represent abatement, CIMS simulates a competition between technologies (e.g., an oil furnace vs. a ground source heat pump) that provide the same service (e.g., space heating). The result is that some abatement technologies may be uncompetitive until an emissions price reaches a specific threshold (e.g., plug-in electric vehicles), at which point the sector undertakes a significant amount of abatement. As seen in the marginal abatement cost analysis, the abatement curves representing some sectors are not linear in CIMS.
- **The technological detail of CIMS.** Every sector requires several services and processes to function. For example, oil refining can require a combination of distillation, cracking, hydrotreating, and reforming among other processes to

[21] This excludes non-vehicle energy consumption and emissions in the construction, forestry and agriculture sectors as well as energy commodities used as refinery or chemical feedstock.

produce refined petroleum products. For each service and process required, CIMS competes a suite of technologies to fulfil the particular service or process needs of the sector. For example, low efficiency diesel, high efficiency diesel and biodiesel trucks may compete to provide freight trucking services to the freight transportation sector. CIMS represents each of the major processes/services and associated technologies, whereas the other modelling approaches represent the sector as a single production unit.

- **The detail of the policy impacts produced by CIMS.** Because of the level of detail in the CIMS model it is possible to separate the impacts of policies on each sector. For example, CIMS describes the changes in energy intensity of space heating in the commercial sector (GJ / m2 floorspace), or the changes in average vehicle fuel price (2005¢ / L gasoline eq.) that are produced when policies are implemented.

The limitations of using CIMS are:

- **CIMS does not account for economic activity unrelated to energy consumption or greenhouse gas emissions.** The CIMS model accounts for the energy and emissions intensive portion of the economy, but does not account for other economic activity. For example, the CIMS model accounts for a household's costs related to energy consumption (e.g., light bulbs), but does not account for other household expenses. Therefore, CIMS does not estimate how a change in expenditures on energy or capital related to energy consumption might affect other household expenditures.
- **CIMS is not a general equilibrium model, and does not account for some markets likely to be affected by the implementation of climate policy.** The CIMS model does not account for key markets such as capital or labour, and cannot simulate how increased capital expenditures to abate emissions might affect interest or wage rates. Additionally, while CIMS does balance supply and demand of key energy commodities, such as electricity and refined petroleum products, it does not ensure this balance for commodities such as iron or newsprint. The result of these omissions is that CIMS cannot be used to estimate a policy's impact on gross domestic product.
- **This modelling analysis provides an integrated forecast showing how each sector is likely to respond to carbon pricing, but it does not contain data obtained from consultation with individual industries**. As such, the results may not reflect abatement opportunities at specific facilities.

Modelling scenarios

The goal of this study is to examine how various strengths of carbon pricing and regulatory policies will reduce emissions and impact consumers and firms in Newfoundland and Labrador. This analysis explores a variety of potential carbon price paths and two future development scenarios, and examines how these two development scenarios interact with climate policy.

The carbon pricing scenarios selected for this study were determined through consultation with the Government of Newfoundland and Labrador; however, they do not reflect the Government's policy position on the subject matter. Carbon pricing scenarios begin in 2012 and increase over the simulation period, ending in 2030. Four carbon price pathways (low, low-medium, medium-high and high) and two development scenarios (development of Lower Churchill Falls and no development of Lower Churchill Falls) are modelled (Table 6). Exploring several carbon pricing and development scenarios reveals the range of emissions reductions that can be achieved as the strength of climate policy changes.

Table 6: Carbon price paths of the policy scenarios

		2015	*2020*	*2025*	*2030*
Policy Scenario	*Policy Name*	*Emissions Charges 2005$ / tonne*			
Lower Churchill Falls is not Developed					
Low price	*L*	$15	$25	$50	$100
Low-Medium price	*LM*	$15	$35	$75	$150
Medium-High Price	*MH*	$25	$50	$100	$200
High Price	*H*	$25	$100	$200	$250
Lower Churchill Falls is Developed					
Low price	*LCFL*	$15	$25	$50	$100
Low-Medium price	*LCFLM*	$15	$35	$75	$150
Medium-High Price	*LCFMH*	$25	$50	$100	$200
High Price	*LCFH*	$25	$100	$200	$250

In addition to the carbon pricing policy, the following complementary policies are applied to attain additional reductions from the buildings and transportation sectors:

Building Sector Policies

- **Revision to the residential building code.** After 2015, all new residential buildings must be approximately 50% more energy efficient than current standard practices. (Note: This regulation will not apply to existing buildings; therefore, it will only impact new housing stock.)
- **Revision to the commercial building code.** All new commercial buildings must be approximately 45% more energy efficient than buildings built to the current specifications of the Model National Energy Code of Canada for Buildings. (Note: This regulation will not apply to existing buildings; therefore, it will only impact new housing stock.)

Transportation Policies

- **All new vehicles sold meet the California greenhouse gas emissions standards starting in 2011**, with expectation of a gradually tightening standard trending towards zero emissions beyond the horizon of this analysis (Table 7). The 2015 target requires roughly 25% fewer emissions from new vehicles, while the 2030 target requires a 50% decline.

Table 7: Vehicle Emissions Standards Targets

	2015	2020	2025	2030
g CO_2/km	172	139	129	119

Modelling assumptions

The analysis is carried out under several key assumptions, including:

- The sectors modelled in this study are representative of the economy of Newfoundland and Labrador. This study identifies potential abatement opportunities in the economy, and may not reflect current or projected abatement activity at the facility level. While we strive for accuracy, a model of an archetypical sector can never be as accurate as an assessment of the abatement potential at a specific facility.
- Carbon pricing scenarios are simulated by applying ‘shadow prices’ to all technology choice decisions in the CIMS model. Shadow prices are equivalent to the value of the carbon tax or the equilibrium permit price in a cap-and-trade system. A shadow price reveals the strength of the carbon price policy necessary to reach a given level of emissions.
- The analysis in this report is aimed at understanding the potential for reducing Newfoundland and Labrador’s greenhouse gas emissions. As a result, we restrict the analysis to domestic greenhouse gas reductions. We assume other provinces have implemented similar policy signals and we allow no purchases of carbon offsets between sectors and provinces or internationally.
- For both Lower Churchill Falls development scenarios, the simulations assume wind and small hydro power are available at several different estimated cost points because the costs of these projects are generally determined by the location, quantity, and variability of these renewable resources.
- All of the carbon price policies simulated here are revenue neutral from a fiscal perspective, meaning that any revenue attained from the carbon charge is returned to the sector that paid it. As a result, a sector as a whole does not incur any net costs associated with paying an emissions tax, but only incurs the investment costs associated with abating its emissions. Individual facilities may incur costs associated with the carbon pricing,
- The analysis excludes natural gas commodity production (for export). This decision is based on the current lack of transportation and distribution/processing infrastructure for natural gas in the province. Given the 20 year time period of the forecast, it is assumed that there are no conditions that could generate incentives to build such a market in the province, baring a large scale effort initiated by factors beyond the market price of natural gas.
- Due to unknown costs and oil platform with lifecycles reflecting a non-renewable resource base, this analysis does not include carbon capture and storage technologies for offshore oil production.

- Carbon pricing does not change the world price for crude oil (Canada is assumed to be a price taker), nor does it impact the output and production life of the offshore fields in Newfoundland and Labrador.

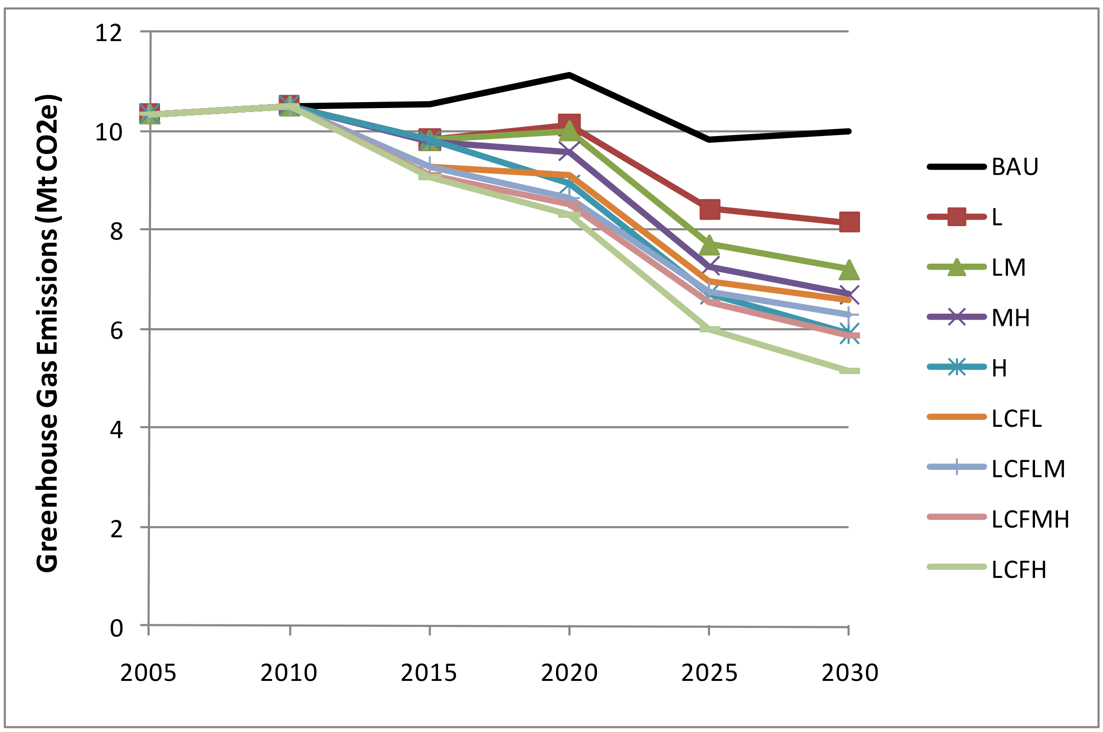
Quantitative analysis of carbon pricing scenarios

This section contains the quantitative analysis of eight carbon pricing scenarios, showing how they affect Newfoundland and Labrador's emissions. The analysis identifies the specific impacts policies have on each sector in the economy, namely how carbon pricing changes the energy intensity and emissions of each sector and how it changes energy related costs for households, transportation, electricity production and industrial production.

Effect of carbon pricing on provincial emissions

In total, eight policy scenarios – two sets of carbon pricing scenarios under two different development scenarios – are modelled in CIMS. Figure 20 shows the forecasted greenhouse gas emissions for each policy scenario. As mentioned previously, policy scenarios do not consider the purchase of offsets. Emissions reductions in these policy scenarios range from 18% to 49% relative to the reference case in 2030. Reductions are greater for the policy scenarios that include Lower Churchill Falls. Thus, this analysis reveals that the abatement potential of the province is greater under the assumption that Lower Churchill Falls is developed.

Figure 20: Greenhouse gas emissions in each policy scenario



Note: In this graph and those that follow, the reference case scenario will be referred to as BAU. All policy labels refer to the strength of the carbon price, L (low), LM (low-medium), MH (medium-high), and H (high), and development scenario, Lower Churchill Falls (LCF). Please refer to Table 6 for more detail on each policy scenarios.

Table 8 shows the changes in emissions by sector for the eight policy scenarios. The majority of reductions are concentrated in the electricity and transportation sectors. In

2030, these sectors account for approximately 55% of Newfoundland and Labrador's greenhouse gas emissions in the reference case. Furthermore, they represent approximately 50% of total reductions in 2030 without the Lower Churchill Falls development and 70% with its development.

Emissions reductions are concentrated in these sectors in all carbon pricing scenarios. Consistent with the marginal abatement cost analysis, the scenarios without Lower Churchill Falls show that the abatement potential of the electricity sector is constrained in lower pricing scenarios. However, in the higher pricing scenarios abatement is less constrained as carbon capture and storage becomes feasible, resulting in substantial reductions. In the scenarios that include the development of the Lower Churchill, emissions reductions from the electricity sector have a greater impact on total reductions in the province.

Table 8: Greenhouse gas emissions reductions, by sector in 2030

	No LCF			
	L	*LM*	*LM*	*H*
Demand Sectors				
Residential	0.00	0.00	0.01	0.01
Commercial	0.05	0.05	0.06	0.07
Transportation Personal	0.51	0.55	0.58	0.62
Transportation Freight	0.07	0.17	0.36	0.72
Industrial Sectors	0.28	0.38	0.49	0.66
Waste	0.49	0.49	0.49	0.49
Total Demand Sectors	*1.39*	*1.65*	*1.99*	*2.58*
Supply Sectors				
Total Supply Sectors	*0.45*	*1.13*	*1.31*	*1.51*
Total Province	**1.84**	**2.77**	**3.30**	**4.09**

	LCF			
	LCFL	*LCFLM*	*LCFMH*	*LCFH*
Demand Sectors				
Residential	0.00	0.00	0.01	0.01
Commercial	0.05	0.05	0.06	0.07
Transportation Personal	0.51	0.55	0.58	0.63
Transportation Freight	0.07	0.17	0.36	0.73
Industrial Sectors	0.28	0.39	0.50	0.66
Waste	0.49	0.49	0.49	0.49
Total Demand Sectors	*1.39*	*1.65*	*2.00*	*2.59*
Supply Sectors				
Total Supply Sectors	*2.01*	*2.06*	*2.12*	*2.26*
Total Province	**3.40**	**3.71**	**4.11**	**4.86**

Greenhouse gas reduction "wedge" diagrams

A wedge diagram is a graphical representation of the relative contribution of different actions towards reducing total greenhouse gas emissions from their business as usual trend.

Wedge diagrams differ from marginal abatement cost curves in two distinct ways:

1. Wedge diagrams reflect the abatement actions that result from the implementation of policies, such as a cap-and trade system, rather than showing theoretical abatement potential;
2. Wedge diagrams are dynamic, reflecting abatement activity over time, not just in one year.

The wedge diagrams generated with CIMS estimate the response of firms and individuals to each of the policy scenarios that are modelled. Because CIMS is an integrated model in which firm and consumer behaviour has an empirical basis, the results account for preferences and behaviour, the relative cost of different actions, and the interaction of actions (i.e. overlap of policy is explicitly accounted for and one action cannot be double counted for abatement).

Figure 21 illustrates a standard wedge diagram and shows abatement from the LCFH scenario. The top of the stack of wedges reflects the reference case greenhouse gas emissions. Each wedge below corresponds to reductions of greenhouse gas emissions that result from abatement activity in the economy, with the exception of the policy emissions wedge. The policy emissions wedge represents the emissions that remain after the policies are implemented. In CIMS, all abatement activity is classified into six main categories: fuel switching, energy efficiency, output (output reductions), carbon capture and storage (CCS), CCS/energy efficiency overlap, and other greenhouse gas control.[22] In this analysis, other greenhouse gas control refers to methane capture from landfills.

[22] The fuel switching wedge corresponds to emissions reductions from replacing emissions intensive fuels like light fuel oil and diesel, with lower and zero emissions sources of energy like electricity, biodiesel, and hydro.

Figure 21: Wedge diagram for LCFH

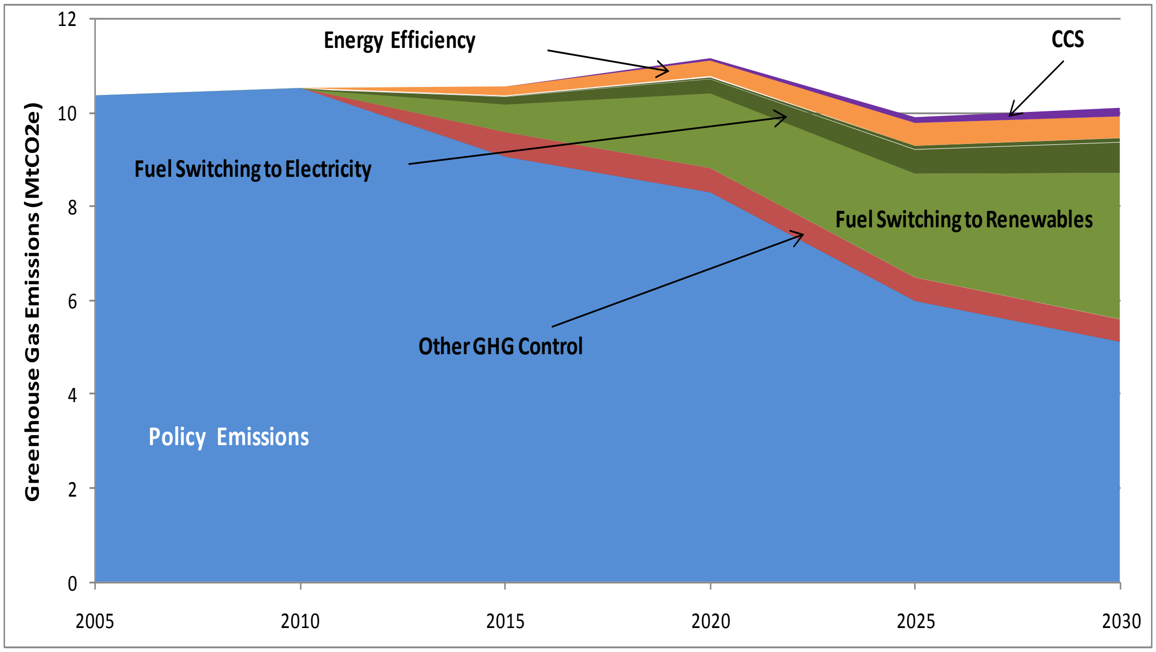
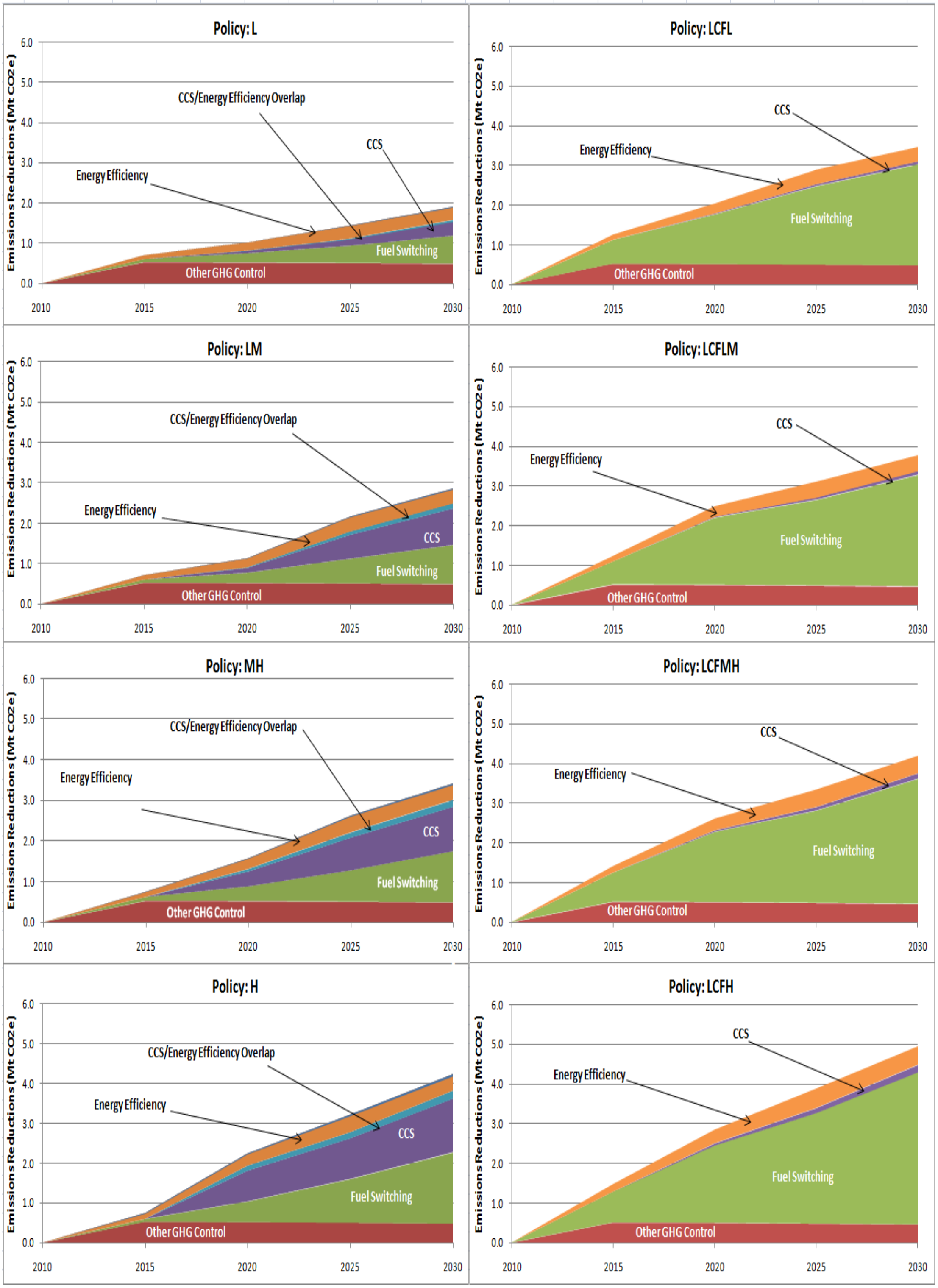


Figure 22 shows wedge diagrams for all policy scenarios. Figure 22 illustrates the wedges corresponding only to abatement actions in each policy scenario and omits the final greenhouse gas emissions after the policy has been applied (policy emissions wedge). The size of each wedge reflects the amount of abatement achieved in each scenario, which is a function of the policy strength and the Lower Churchill development assumption. For each policy, the wedge diagrams show more abatement if the Lower Churchill is developed. Fuel switching to hydro power in the electricity sector is the main driver of this additional abatement.

Figure 22: Greenhouse gas reduction wedge diagrams for all policy scenarios



Effect of carbon pricing on energy and emissions indicators

The marginal abatement cost analysis demonstrated that in each sector a variety of actions can be taken to reduce emissions. Consumers and firms will make different decisions depending on the carbon price they face. Likewise, in this quantitative policy analysis, varying abatement actions will be used in response to each policy scenario. The effect of the policy scenarios can be further understood by exploring how they change key energy and emissions indicators. Specifically, this section highlights how the policy scenarios change the energy and emissions intensity of residential space heating, commercial space heating, personal vehicles, and freight travel. This section also covers the industrial and electricity sectors. However, because of the diverse nature of these sectors, we only discuss changes to total energy consumption and emissions rather than changes to intensities.

Residential and commercial

In the residential and commercial sectors, space heating technologies account for over 50% of total energy consumption. Thus, changes to the energy and greenhouse gas emissions intensities of space heating are likely to have a big impact on total sector energy consumption and emissions.

Figure 23 and Figure 24 compare the energy and emissions intensity of space heating in the residential sector from the present to 2030 for all policy scenarios. By 2030, energy intensity (measured as GJ/m^2 floorspace per year) decreases approximately 15% from the reference case in all policy scenarios. The marginal abatement cost analysis demonstrated that the energy efficiency of the residential sector was not sensitive to carbon pricing. Furthermore, the change in energy intensity is constant across policy scenarios. Therefore, the residential building code regulation is driving this change.

Figure 24 shows that the emissions intensity of residential space heating is not sensitive to the regulation or to carbon pricing. In the reference case, the emissions intensity of the sector decreases so much that changes in energy consumption have little impact on emissions. As well, further decreases in emissions are also difficult to achieve.

Even with high carbon price signals, a small proportion of Newfoundland and Labrador's population continue to consume fuel oil for space heating in 2030, either because they have no other option (limited grid connection or wood fuel supply) or because they have not yet had to replace their furnaces.

Figure 23: Energy intensity of residential space heating

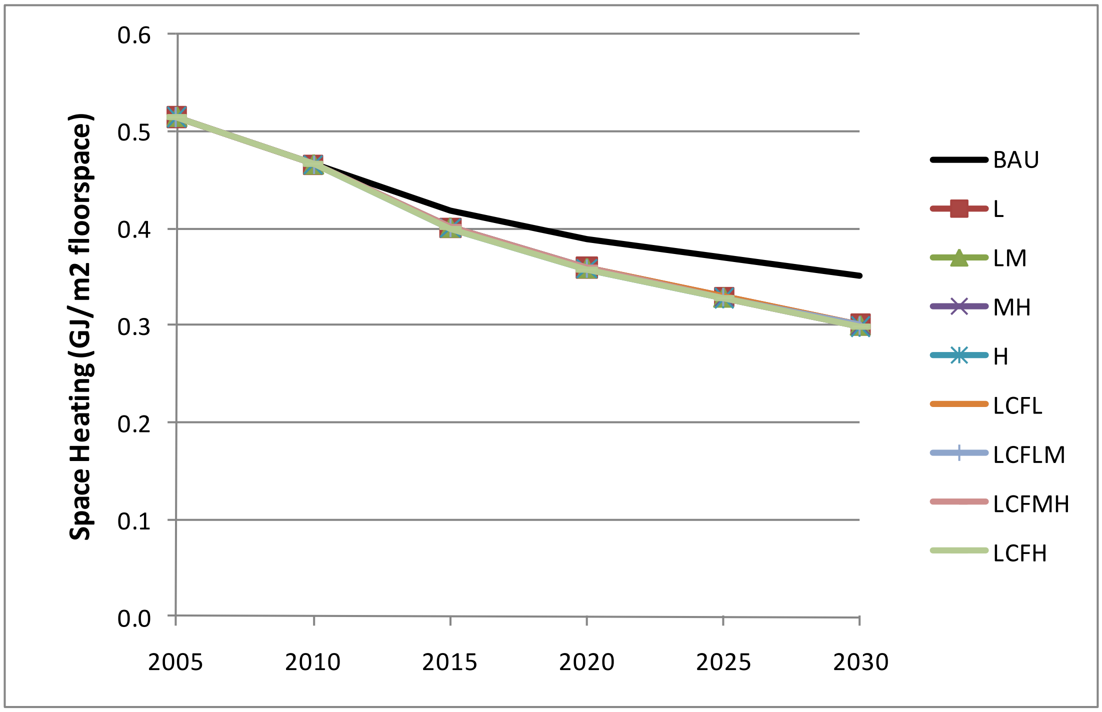


Figure 24: Greenhouse gas intensity of residential space heating

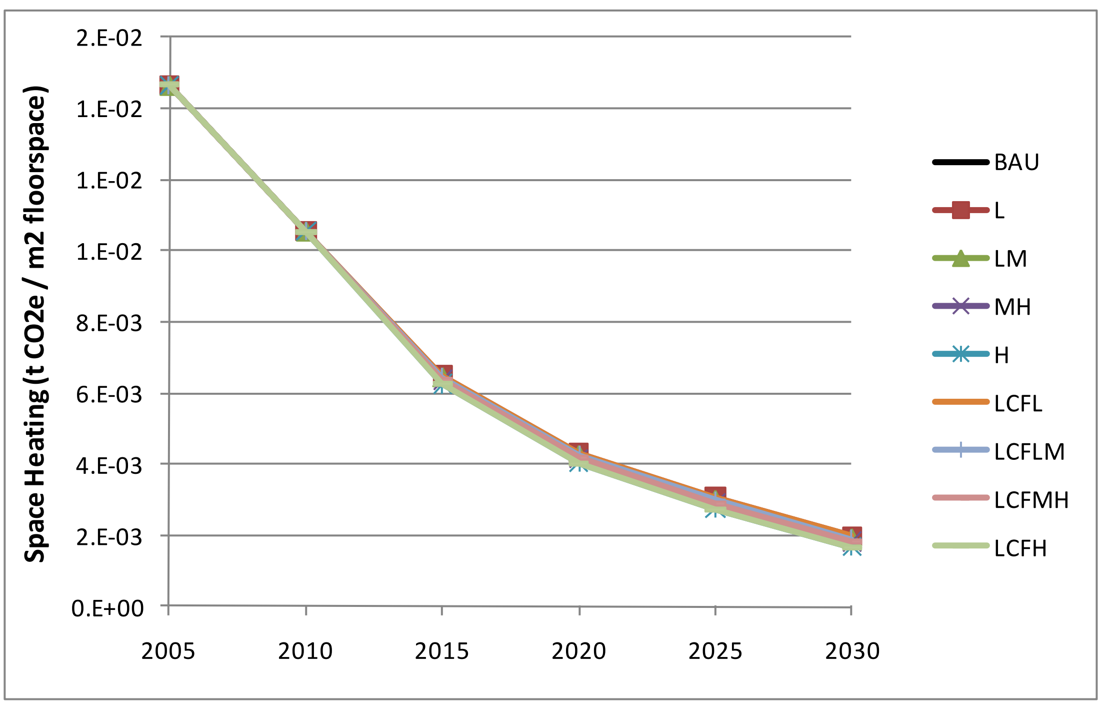


Figure 25 and Figure 26 compare the energy and emissions intensity of space heating in the commercial sector for all scenarios. In the reference case, the energy and emissions intensity of the sector decline over the simulation period due to increased adoption of electric space heating systems and improved shell energy efficiency. Both energy and emissions intensity decrease when polices are implemented. For example, by 2030 in the LM scenario, energy intensity and emissions intensity decrease 17% and 30%, respectively, from the reference case. The primary driver of change in energy intensity and emissions intensity is the commercial building code. However, a small amount additional reduction in emissions intensity, induced by carbon pricing, is achieved as commercial enterprises switch from combustion based heating systems to standard electric or electric heat pump systems. Both the energy and emissions intensity of the sector are insensitive to development scenario assumptions; the changes within the commercial sector in each pricing scenario are similar regardless of whether or not Lower Churchill Falls is built.

Figure 25: Energy intensity of commercial space heating

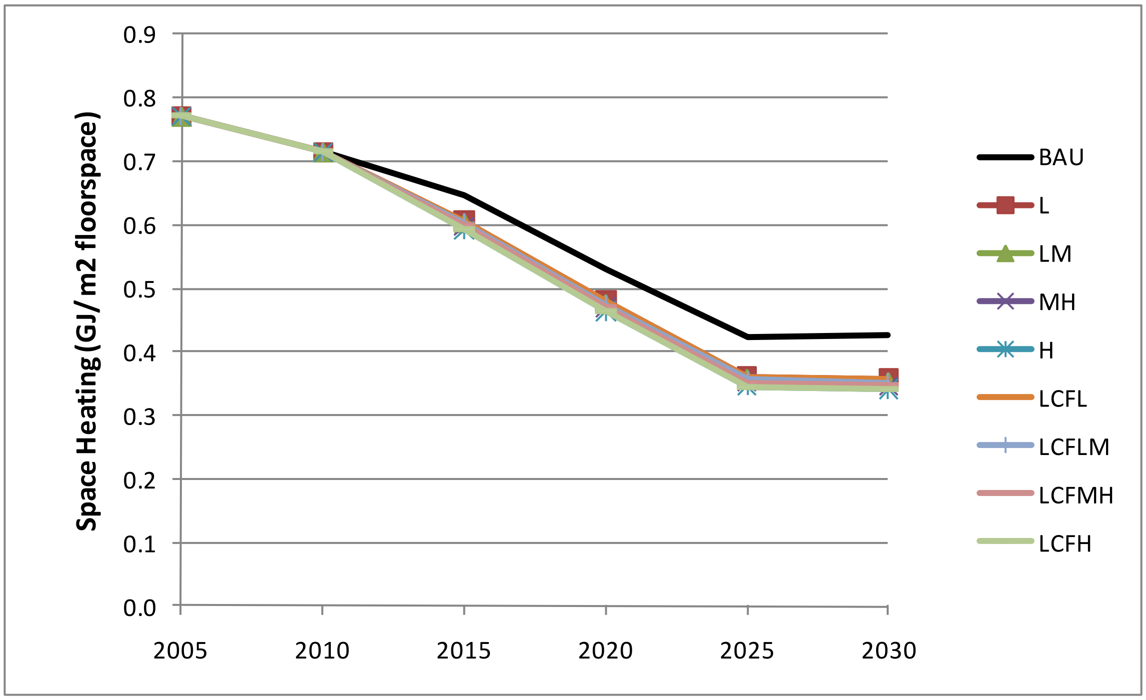
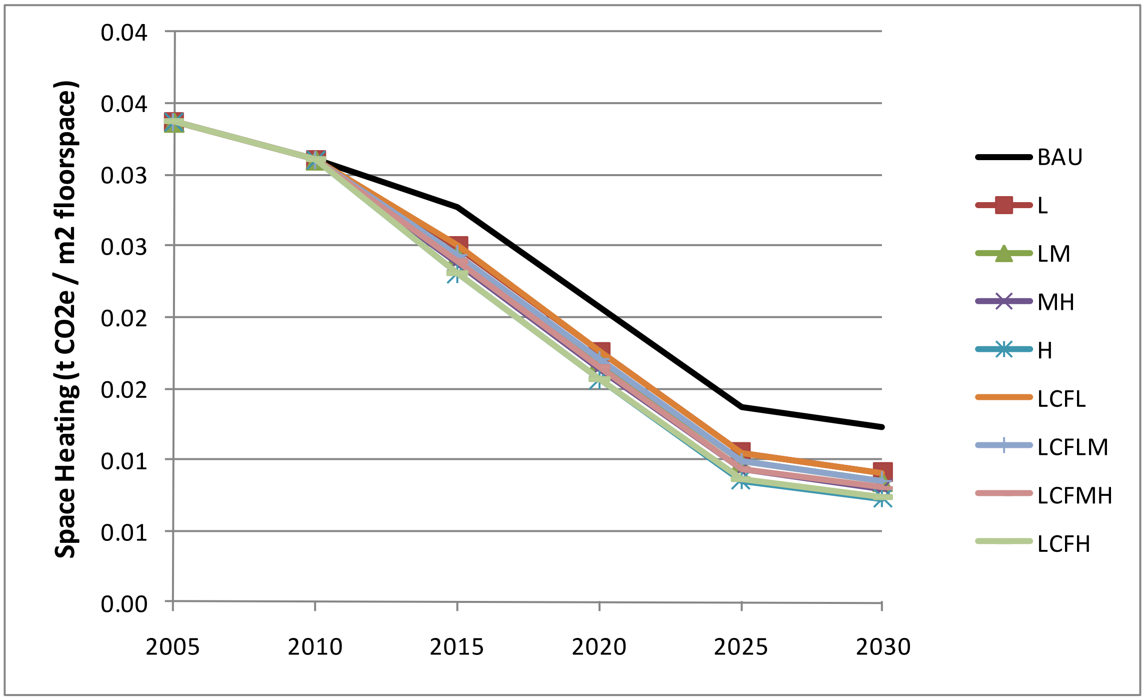


Figure 26: Greenhouse gas intensity of commercial space heating



Transportation

Figure 27 and Figure 28 compare the energy and greenhouse gas emissions intensity of passenger vehicles. In the reference case, both the energy and emissions intensity of passenger vehicles decrease over time as older vehicles are replaced with more efficient gasoline and hybrid vehicles. The high oil price forecast used in the reference case scenario is a significant driver of this change; carbon pricing and the vehicle emissions standard accelerate this trend. In the initial simulation periods, the impact of emissions price and vehicle emissions standard are low relative to the impact of high fuel prices and do not induce much additional abatement from the reference case. As the strength of carbon pricing and regulatory policy increase, the energy and emissions intensity of the sector decline more rapidly between 2020 and 2030 than in the previous decade.

By 2030, all policy scenarios reduce energy intensity by a minimum of 26% and emissions intensity by a minimum of 70% from the reference case. Reductions in energy intensity appear to be driven by the vehicle emissions standard, as there is only a 4% range in emissions reduction between the lowest price and the highest price scenario; 26% and 30% for the lowest and highest price scenarios, respectively). Reductions in emissions intensity are driven by both the vehicle emissions standard and emissions prices. In 2030, the emissions intensity in the lowest price scenario is approximately 50% greater than the highest pricing scenario, indicating that abatement in the lower pricing scenarios is produced by the vehicle emissions standard, and that incremental abatement in the higher price scenarios is produced by the carbon price. Both the energy and emissions intensity of the sector are insensitive to the Lower Churchill Falls development scenario.

Across all scenarios, energy efficiency (hybrid vehicles) and fuel switching to biofuel and electricity are the abatement actions used in the personal transportation sector. The abatement these actions achieve is significant; however, as the marginal abatement cost analysis indicated, total personal transportation sector emissions remain significant due to the difficulty of reducing air travel emissions.

Figure 27: Personal vehicle energy intensity

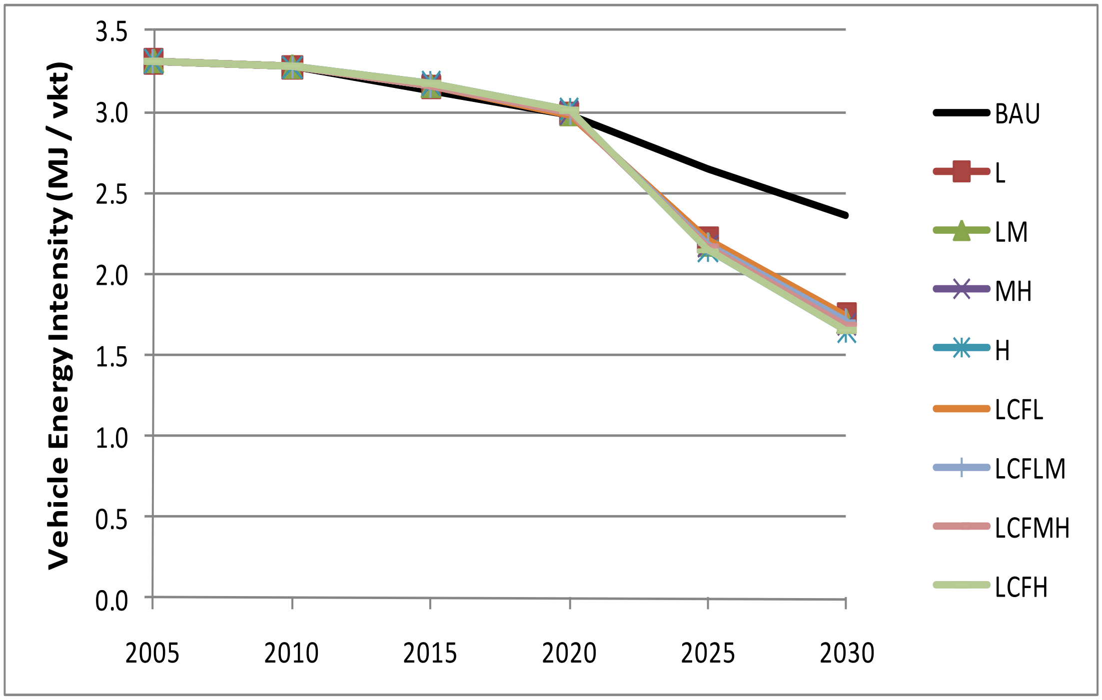


Figure 28: Personal vehicle greenhouse gas intensity

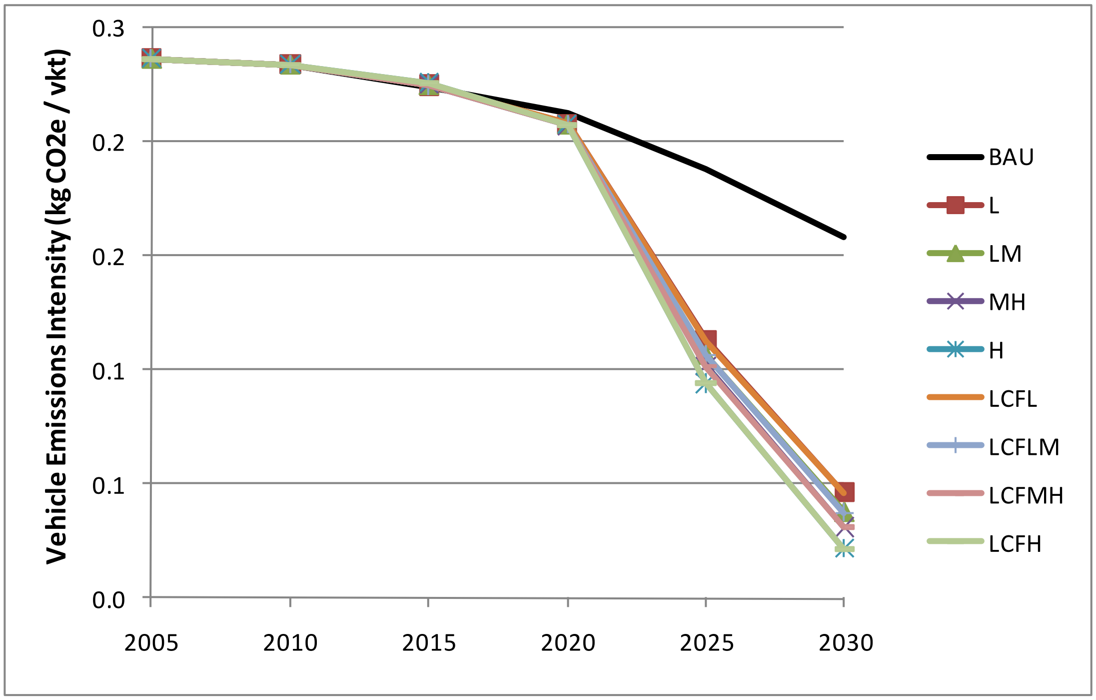


Figure 29 and Figure 30 show the energy and emissions intensity of the freight sector. While these intensities decline in response to the policy scenarios, the magnitude of the decline is less than in the personal transportation sector. The absence of a vehicle emissions standard and a lack of emerging abatement options are the reasons for this difference. Consistent with the marginal abatement cost analysis, Figure 29 shows that carbon pricing induces few gains in energy efficiency relative to the reference case.

Conversely, Figure 30 shows that emissions intensity is more sensitive to carbon pricing. The change in emissions intensity shows the potential for fuel switching between diesel and biodiesel. The marginal abatement cost analysis indicates that this abatement action is most viable after 2020 and with higher carbon prices. Figure 30 confirms this conclusion, and by 2030, the highest carbon price scenarios see significant consumption of biodiesel. Like personal transportation, the energy and emissions intensity of the sector are insensitive to the development scenario.

Figure 29: Freight energy intensity

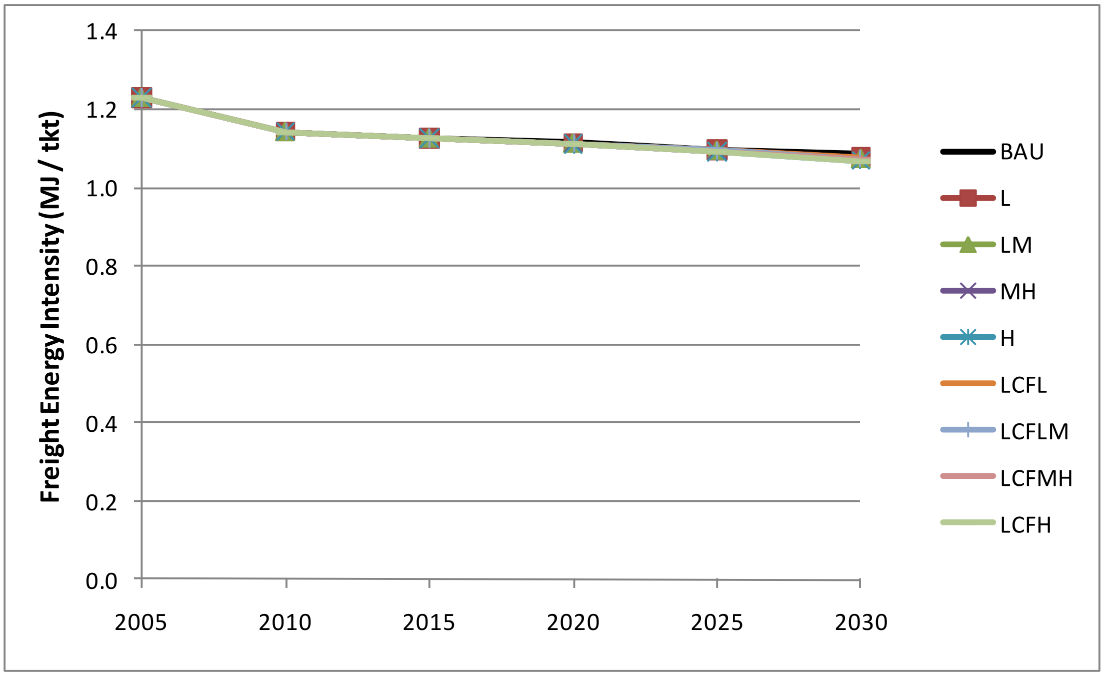
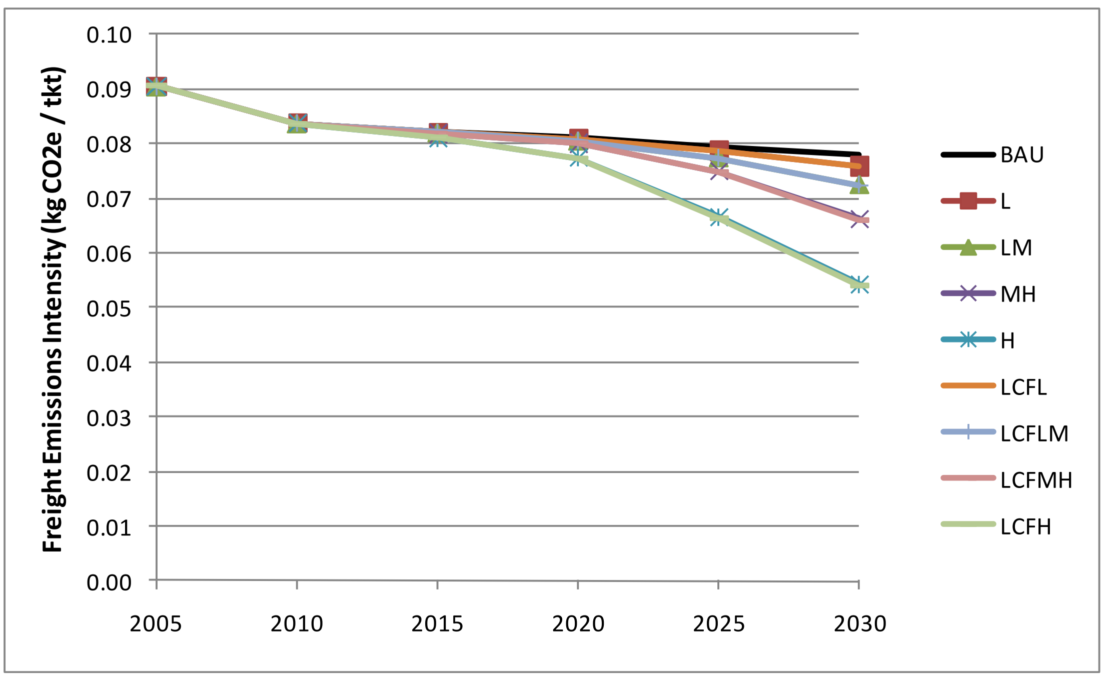


Figure 30: Freight greenhouse gas intensity



Industry

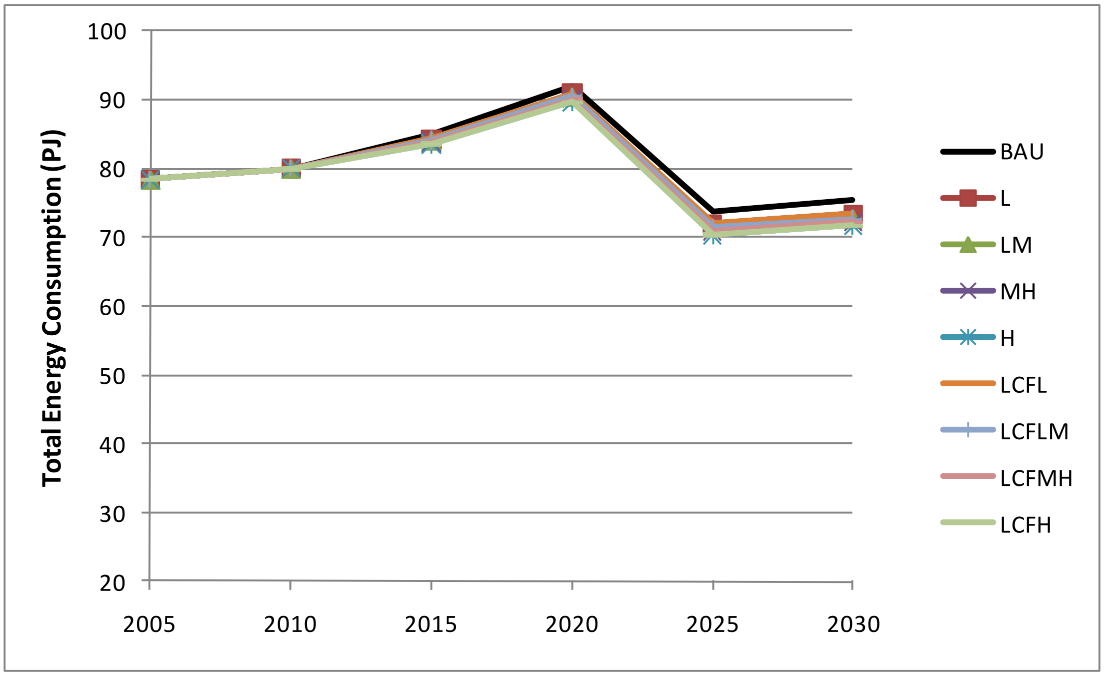
Figure 31 and Figure 32 show the energy consumption and greenhouse gas emissions of the industrial sectors (inclusive of petroleum refining, waste and crude oil extraction).

Both Figure 31 and Figure 32 are strongly influenced by the emissions from the petroleum refining and crude oil extraction sectors, which account for half of reference case industrial greenhouse gas emissions in 2030. In the reference case, energy and emissions in the industrial sector decrease slightly over the simulation period, although this is largely due to fewer operating oil platforms. When policies are applied, this decline is more pronounced. By 2030, industrial energy consumption declines from 3% in the L scenario to 5% in LCFH scenario. Over that same period, industrial emissions decline from 21% in the L scenario to 36% in the LCFH scenario.

The change in energy consumption is less than the change in emissions since much of the abatement in the industrial sector comes from using alternative fuels or controlling the emissions of greenhouse gases. The marginal abatement cost analysis demonstrated that most industrial abatement should occur by switching to electricity for process heat and biodiesel for transportation in the mining sector, by controlling landfill gas in the waste sector, and under high carbon prices, by using carbon and capture and storage in the refining sector.

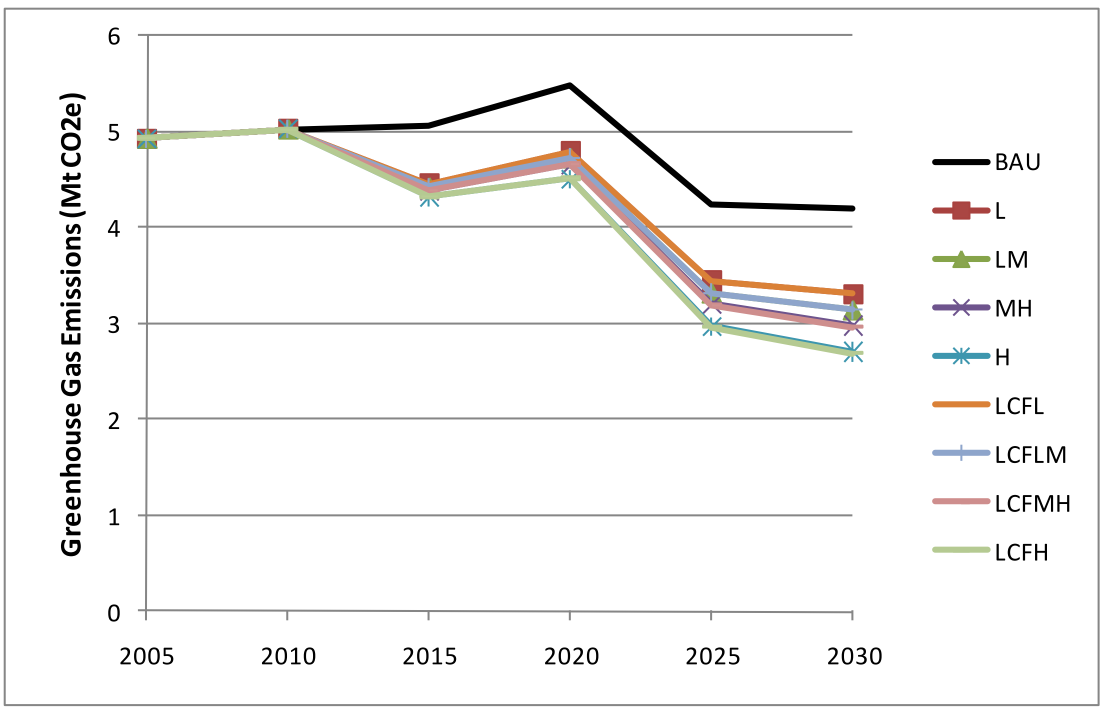
Without Lower Churchill Falls, electricity is more expensive since generation requires carbon capture and storage. However, this price change is small and where it does reduce fuel switching to electricity, other actions such as biodiesel consumption increase somewhat. Overall, the Lower Churchill Falls assumption has a minimal (<0.1 Mt CO_2e) effect on industrial emissions under all carbon price scenarios.

Figure 31: Industrial energy consumption



Note: Includes energy consumption from the mining, metallurgy, newsprint, other manufacturing, waste, petroleum refining, and petroleum crude extraction sectors. The electricity sector is not included.

Figure 32: Industrial greenhouse gas emissions



Note: Includes greenhouse gas emissions from the mining, metallurgy, newsprint, other manufacturing, waste, petroleum refining, and petroleum crude extraction sectors. The electricity sector is not included.

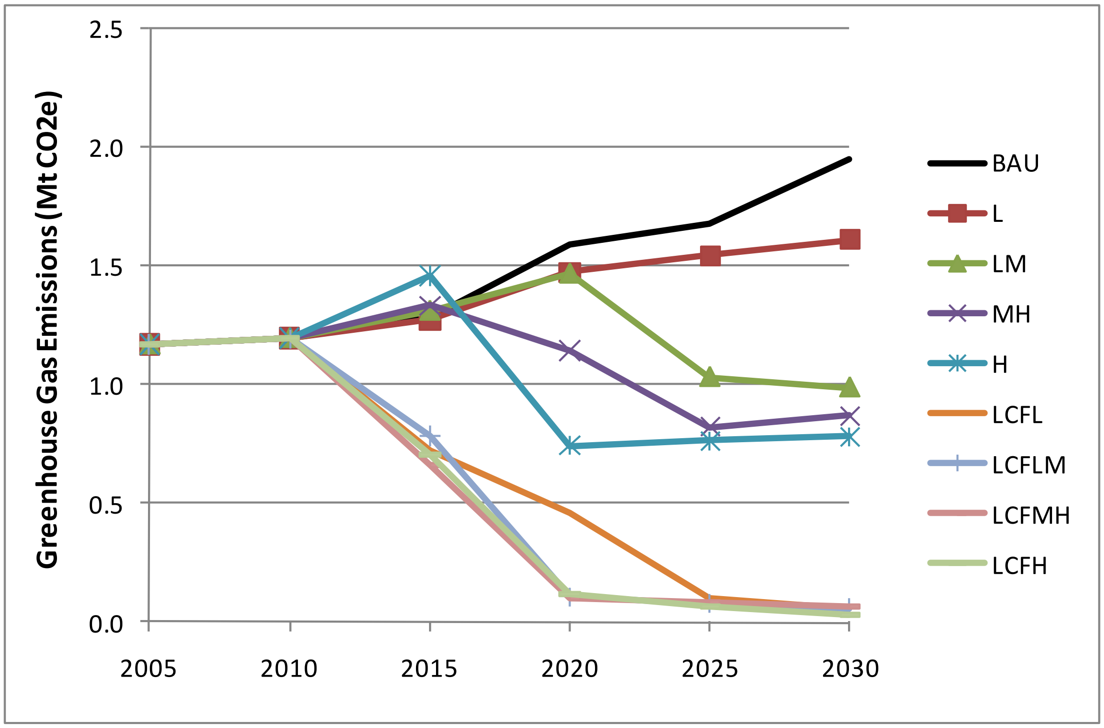
Electricity

Figure 33 shows greenhouse gas emissions in the electricity sector. The eight scenarios result in a broad range of emissions abatement. In 2030, reductions range from 0.3 Mt CO_2e in the L scenario to 1.9 CO_2e in LCFH scenario. For each carbon price scenario, emissions are lower with Lower Churchill Falls because this development replaces most thermal generation. In the alternative development scenario, only carbon capture and storage allows the sector to achieve deep emissions reductions while increasing its output. In the marginal abatement cost analysis, we show that this technology becomes viable at carbon prices greater than $100-125/tonne CO_2e. The high and medium-high carbon prices can stimulate carbon capture by 2020. The medium price scenario does not rise quickly enough to make carbon capture and storage viable before 2025, while the low price scenario does not induce this abatement until 2030.

The cost of carbon capture and storage is a fundamental reason why total provincial emissions are lower for all scenarios with Lower Churchill Falls, especially under lower carbon prices. Again, this analysis indicates that without the Lower Churchill project, carbon capture and storage is necessary given the viability and cost of incorporating an additional 3-4 TWh/yr of wind and small hydro capacity. This is the capacity required to fully replace most thermal generation in the province by 2030 even with the building code regulations ensuring greater efficiency of electricity use in buildings. However, the difference between the development scenarios could be smaller if new small hydro developments or advances in wind energy storage make these sources of electricity viable at lower carbon prices.

In Figure 33, a distinct spike in the electricity sector's emissions is evident in 2015 for most scenarios that assume Lower Churchill Falls is not built. In 2015, CIMS shows that consumers and firms purchase more electrical equipment in anticipation of higher carbon prices without full knowledge of how electricity prices could change. However, carbon capture and storage technologies are not available until 2020. Consequently, we see a spike in emissions in the H, MH, and LM scenario as additional demand for electricity is met with thermal generation. After 2020, carbon capture and storage technologies become available and emission decline. In 2030, all three scenarios achieve substantial emissions reductions (50%-60% from the reference case). While the spike in emissions is an artefact of a model that solves in five year periods, it does indicate that carbon pricing is likely to raise electricity consumption. In the short-term, this could increase emissions from the electricity sector, although the long-term trend will be towards lower sectoral and provincial emissions.

Figure 33: Electricity sector greenhouse gas emissions



Incremental policy impact analysis

Some overlap exists between what is accomplished by the carbon prices and by the sector-specific regulations in the eight policy scenarios. In this section, we examine the incremental effect of the regulations (the residential and commercial building codes and the vehicle emissions standard) on each policy scenario. Table 9 shows how removing these regulations from each policy scenario (carbon pricing and regulations) impacts emissions in 2030, revealing the incremental impact of each regulation beyond what the carbon price achieves. For example, the incremental effect of the revisions to the commercial building codes is .04 Mt CO_2e in 2030 in scenario MH.

In general, the incremental effect is greater for the lower price scenarios than for the higher price scenarios. In the higher price scenarios, the carbon price is able to induce similar abatement actions as the regulations. The incremental effect of the regulations is limited in all scenarios because the regulations only affect new stock. Thus, the regulations have greater impact on emissions reductions over longer times.

Residential and commercial building codes

Revisions to the residential and commercial building codes have little effect on downstream greenhouse gas emissions because the regulations affect space heating demand, which is generally supplied with electricity. Therefore, the incremental effect of these regulations depends on the emissions intensity of the electricity sector.

The revisions to the residential building code produce an additional reduction of 0.18 Mt CO_2e by 2030 in scenario L; the electricity sector has the highest emissions intensity in this scenario. As the carbon price rises, in scenarios where Lower Churchill is not built, the incremental effect falls to 0.06 Mt CO_2e. In scenarios where Lower Churchill Falls is built, the emissions intensity of the electricity sector is close to zero by 2030. Consequently, the residential building code regulation has no incremental effect on provincial emissions.

Likewise, in scenarios where Lower Churchill is not built, the revision to the commercial building code achieves an additional 0.08 Mt CO_2e reduction under the L scenario, falling to 0.03 Mt CO_2e in the H scenario. In scenarios where the Lower Churchill is developed, this regulation also has little incremental effect.

Vehicle emissions standard

The incremental effect of the vehicle emissions standard ranges from 0.18 Mt CO_2e (scenario H) to 0.36 Mt CO_2e (scenario L, LM, and LCFL). The reason for the smaller difference in the higher price scenarios is that the higher carbon price induces similar actions to the emissions standard – such as purchasing more fuel efficient vehicles and switching to renewable fuels. The incremental effect of the vehicle emissions standard is somewhat smaller if Lower Churchill Falls is built. This is likely because electricity is somewhat cheaper in this development scenario making plug-in electric vehicles more competitive. The additional abatement from this regulation is mostly from the personal transportation sector rather than from upstream energy supply sectors.

Table 9: Incremental emissions reductions from regulatory policies for all policy scenarios in 2030 (Mt CO_2e)

	No LCF			*LCF*		
Greenhouse Gas Emissions (Mt CO2e)	**Res**	**Com**	**Ves**	**Res**	**Com**	**Ves**
Low (L)	0.18	0.08	0.36	0.00	0.01	0.36
Low Medium (LM)	0.10	0.05	0.36	0.00	0.01	0.32
Medium High (MH)	0.08	0.04	0.26	0.00	0.01	0.25
High (H)	0.06	0.03	0.18	0.00	0.00	0.16

Note: Res refers to the residential building code, Com refers to the commercial building code, and Ves refers to the vehicle emissions standard.

Economic analysis

In this section we discuss the economic impact of the policy and the development scenarios. As noted above, the economic analysis covers only the energy and greenhouse gas intensive portions of the economy. Because CIMS is not a full equilibrium model, we are unable to forecast how climate policy might affect GDP, economic structure, employment, net exports, savings and investment. The economic indicators generated by CIMS are as follows:

- **Changes to capital investment by sector**, which shows how capital investments change in response to policy and development scenarios.
- **Changes to household energy costs**, which shows how household energy costs (i.e., heating cost) change in response to policy and development scenarios.
- **Changes to transportation energy costs**, which shows how annual vehicle fuel costs and average vehicle fuel prices change in response to policy and development scenarios.
- **Changes to energy prices**, which shows how electricity and refined petroleum product prices change in response to policy and development scenarios.
- **Changes to industrial production cost**, which shows how production costs in the industrial sector change in response to policy and development scenarios.

Changes to capital investment by sector

Table 10 presents the projected cumulative change in capital investment for each sector from 2010 to 2030, relative to the reference case. In CIMS, capital investment includes the cost of new or retrofit equipment which is based on archetypal technologies for each sector. As such, these values do not relate to firm-specific investments in the region.

In response to the policy scenarios, changes in capital investment are expected to range from $1.4 to $4.9 billion (2005$) between 2010 and 2030. Capital investment generally increases in response to higher carbon prices, and is highest in the high price scenarios without the Lower Churchill Falls project.

In all scenarios, the electricity, residential and commercial sectors are projected to experience the greatest increase in capital investment. Investment in the residential sector is about $1.1 billion (2005$), and does not vary significantly with between policy scenarios because the residential building code requires similar investment across all scenarios. Investment in the commercial sector is roughly $0.25 billion (2005$) in all scenarios. Like the residential sector, the building code regulation is driving the changes in investment which do not vary significantly between scenarios.

Investment in the electricity generation sector ranges from $0.8 to $4.5 billion (2005$). Unlike investment in the residential and commercial sectors, investment in the electricity sector varies significantly depending on the carbon price and whether or not the Lower Churchill Falls project is developed. At lower carbon prices, investment in the electricity sector is greater in scenarios where the Lower Churchill Falls is built because a new development is replacing the existing Holyrood thermal electricity generation plant. However, at higher carbon prices the reverse is true because of the high cost of carbon capture and storage. In all scenarios, electricity generation accounts for the majority of additional investment in the energy supply sectors, as the policies stimulate minimal capital investment in the petroleum refining and crude oil extraction sectors.

Conversely, some sectors experience a decline in capital investment. The largest reduction occurs in the personal transportation sector, as consumers shift to smaller and higher occupancy vehicles and transit.

Table 10: Cumulative changes to capital investment by sector, relative to the reference case (2010-2030)

	No LCF			
Capital Costs (2005$ Millions)	***L***	***LM***	***MH***	***H***
Demand Sectors				
Residential	1,087	1,090	1,093	1,099
Commercial	225	227	229	233
Transportation	-794	-878	-982	-1,126
Industrial Sectors	13	19	23	28
Waste	33	35	38	41
Supply Sectors				
Supply Sectors	866	2,764	3,470	4,619
Total Province	**1,430**	**3,257**	**3,872**	**4,894**
	LCFL			
Capital Costs (2005$ Millions)	***LCFL***	***LCFLM***	***LCFMH***	***LCFH***
Demand Sectors				
Residential	1,086	1,088	1,090	1,095
Commercial	225	227	229	232
Transportation	-791	-873	-976	-1,119
Industrial Sectors	13	18	22	27
Waste	33	35	38	40
Supply Sectors				
Supply Sectors[a]	1,665	2,165	2,684	3,740
Total Province	**2,231**	**2,660**	**3,087**	**4,016**

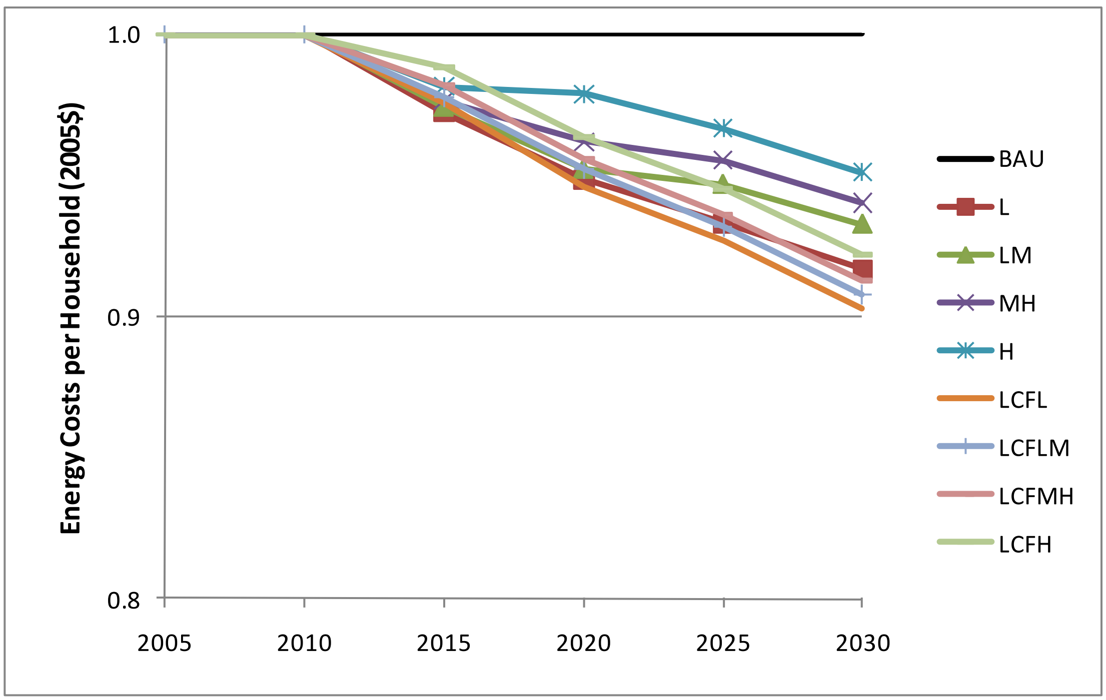
[a]CIMS only accounts for the fraction of the Lower Churchill Falls construction costs that are associated with electricity consumed within the province. For example, if 10% of the energy from the project is consumed in the province, then the change in capital investment only includes 10% of the project cost.
Note: The capital costs used in this analysis reflect the investment costs associated with archetypical sectors and do not reflect the investment cost of any specific facility in the region.

Changes to household energy costs

Figure 34 depicts the change in household energy costs over the simulation period. Because carbon pricing revenues are recycled back into the economy, this figure, and other figures showing energy costs in this report, do not include carbon prices paid on the fuel. While an individual or company may pay more for fuel, the revenue recycling compensates consumers and firms so that aggregate energy costs do not change.

In the reference case, energy costs increase as energy prices increase. The residential building code regulation ensures that energy costs decrease by 2030. Additionally, in the policy scenarios, energy costs decline with an accelerated shift from fuel oil to electricity and greater adoption of heat pump technologies. Across all policies, energy costs decrease between 5% and 10%, with greater reductions in scenarios with Lower Churchill Falls. In these scenarios, electricity is generally cheaper than in the scenarios without the hydroelectricity project. Furthermore, relative energy costs are slightly lower with low emission prices (i.e., scenario L achieves a reduction of 8%, whereas scenario H achieves a reduction of only 5% relative to the reference case).

Figure 34: Household energy costs



Changes to transportation energy costs

Figure 35 and Figure 36 show how average vehicle fuel prices and annual vehicle fuel costs change in response to policy over the simulation period. Again, the changes in cost relate to a changing fuel mix (ex: more ethanol vs. gasoline) and changing production costs (ex: using electric process heating for petroleum refining). The carbon cost is not included here because the carbon pricing is modelled as revenue neutral.

In all policy and development scenarios, the average fuel price rises, increasing incrementally with higher carbon prices. This increase in the average fuel price occurs as higher priced biofuels replace gasoline and diesel. The largest increase in average fuel price of 9% by 2030 occurs in the H scenario where there is the greatest switch to biofuels.

Despite this increase in the price of fuel, average annual fuel costs actually decrease. In the reference case, annual fuel costs are projected to decline in 2020 with the increased adoption of high efficiency and hybrid vehicles. In the policy scenarios, carbon pricing and vehicle emissions standards cause an increase in the market penetration of more efficient and alternative-fuelled vehicles over the reference case. This increase in penetration causes fuel costs to decline even further.

Figure 35: Average vehicle fuel prices

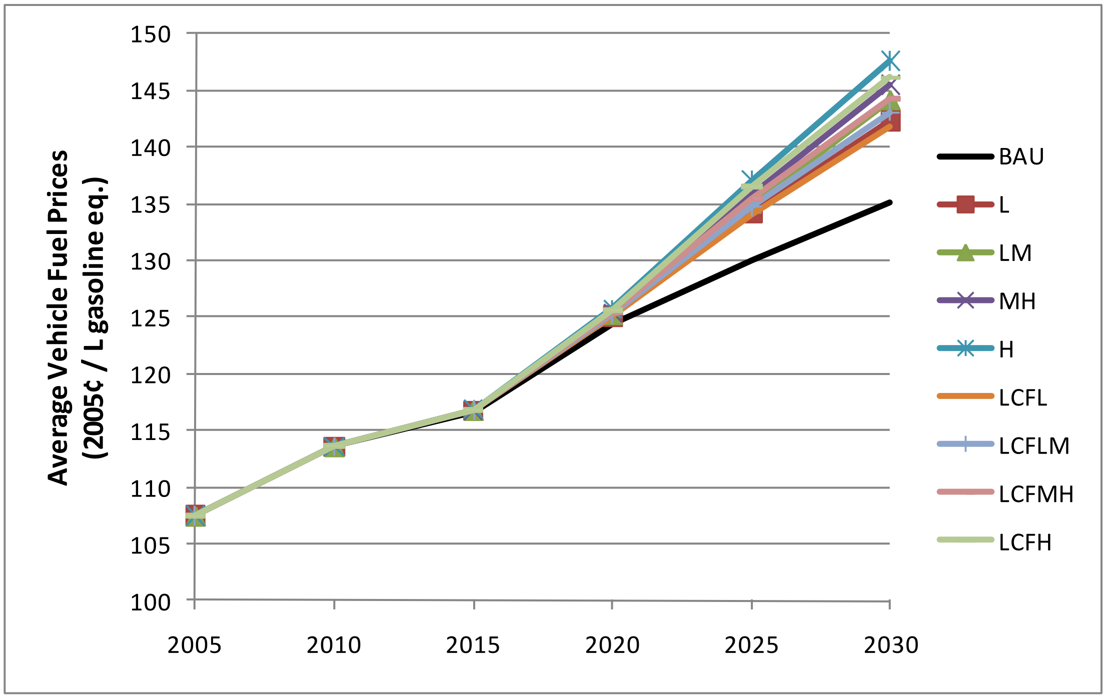
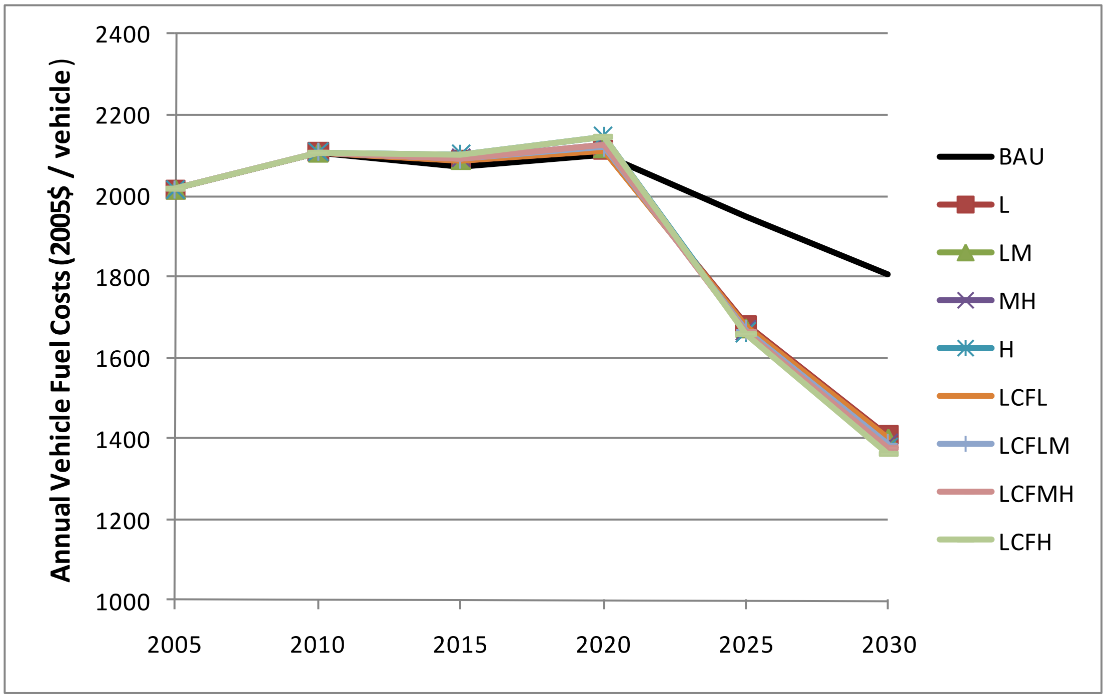


Figure 36: Annual vehicle fuel costs



Changes to energy prices

Figure 37 shows the forecasted increase in retail electricity prices for each carbon price scenario. These price changes do not include any carbon cost since policy revenues are recycled back into the economy. Prices increase in both development scenarios as the sector responds to policies by adopting abatement technologies and adding additional capacity to the grid. In the LCF scenario, electricity prices increase because new transmission infrastructure is built to support additional electricity demand.[23] In the scenario without LCF, electricity prices increase because carbon capture and storage units are purchased. Under the policy scenarios, electricity price adjustments range from 0 to 0.9 2005¢ / kWh in 2030. With the exception of the lowest price path (scenario L), electricity price adjustments for policy scenarios that do not include Lower Churchill Falls are considerably higher than the scenarios that do. The greatest price increase is in the H scenario, where a high carbon price stimulates a large amount of carbon capture and storage capacity. While the electricity price adjustments are quite diverse across scenarios, these changes are relatively small (< 1.0 2005¢) since existing hydro capacity still generates a significant amount of electricity. The largest price adjustment, in scenario H, is a 7% increase relative to the reference case.

[23] CIMS only simulates the portion of transmission infrastructure costs that is required to meet provincial demand.

Figure 37: Electricity price adjustment

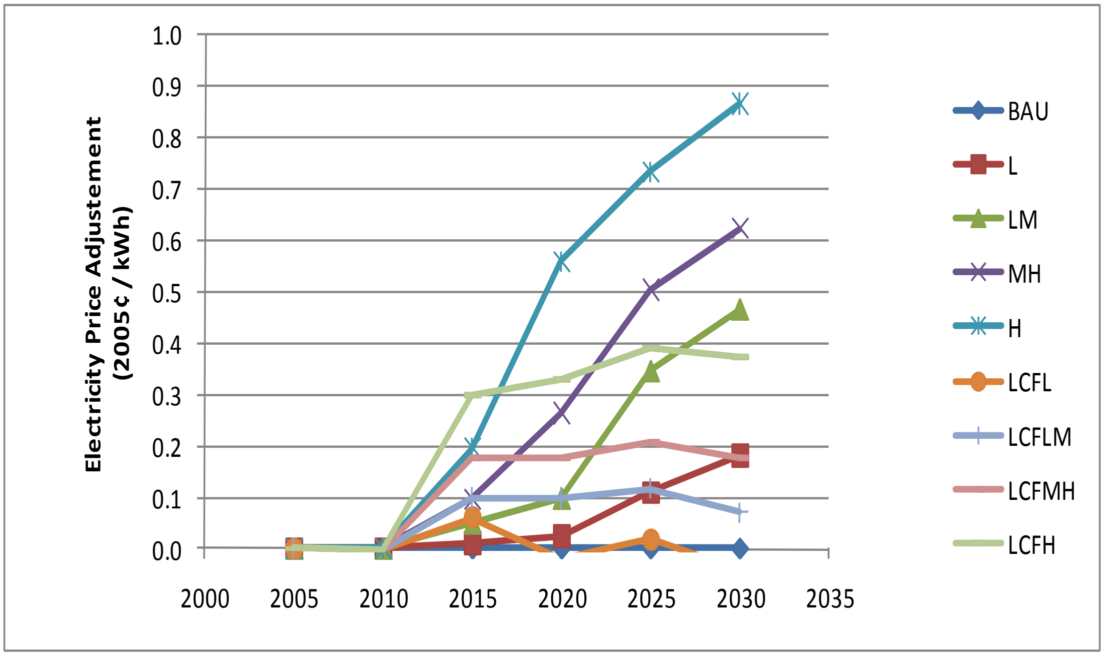
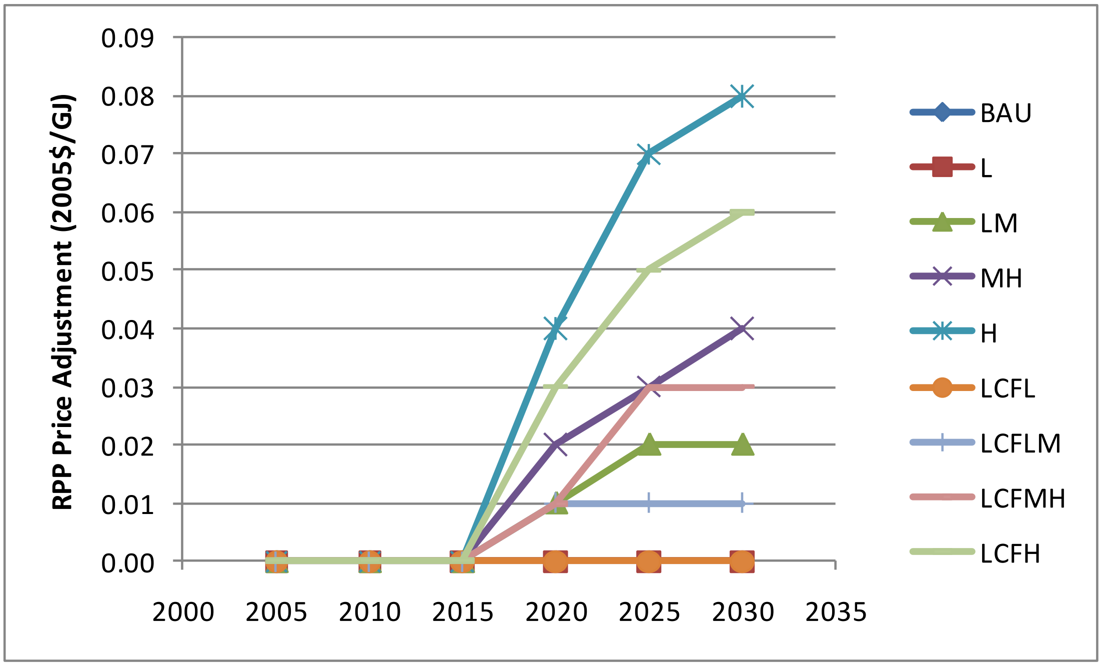


Figure 38 shows that the forecasted change in the price of refined petroleum products is very small for each policy scenario. This figure does not include the cost of carbon pricing if this were levied on the fuel itself or passed to consumers from an upstream cap-and-trade policy since all carbon price revenues are recycled back into the economy.[24] Thus, this price change occurs because the capital costs and energy costs of the sector increase in response to carbon pricing. However, because the crude oil feedstock is the main expense for the sector these changes result in less than a 0.1% increase in production costs. Again, this analysis assumes that carbon pricing does not change the world oil price. The differences in the price adjustments between the Lower Churchill Falls development scenarios relate to the relative amount of electrification versus abatement through carbon capture and storage.

[24] For illustrative purposes, a carbon price of $300/tonne levied directly on gasoline would raise the price by roughly 70% in 2030 based on the reference case fuel price forecast we have used.

Figure 38: Refined petroleum product price adjustment



Changes industrial production costs

Figure 39 shows the change in industrial unit production costs (from the metallurgy, mineral mining, newsprint manufacturing and other manufacturing sectors) relative to the reference case in 2030. Unit production costs represent the sum of annualized capital, energy and operating and maintenance cost in a specific year per unit of production. As mentioned previously, these calculations are based on cost assumptions of an archetypical sector. Additionally, as CIMS is not a general equilibrium model, it only simulates changes to the costs associated with energy consumption. For example, this analysis does not show how interest rates or wages rates may change in response to climate policy so it cannot show how these changes affect production costs.

In general, unit production costs increase more in scenarios with a higher carbon price as industries will invest in higher cost technology or alternative fuels to avoid paying a carbon price. Additionally, industrial production costs generally increase more in scenarios without the Lower Churchill Falls (for any given carbon price) because electricity prices are highest in these scenarios. This increase is most apparent in sectors where electricity is a large component of sectoral energy consumption, such as the metallurgy sector. Carbon costs are not included here since the revenue from the carbon price policy is recycled back into the economy.

Figure 39: Increase in industrial unit production costs relative to the reference case in 2030

	No LCH				LCH			
	L	*LM*	*MH*	*H*	*LCFL*	*LCFLM*	*LCFMH*	*LCFH*
Metallurgy (2005$ / tonne)	1%	2%	2%	3%	0%	0%	1%	2%
Mineral Mining (2005$ / tonne)	0%	0%	0%	1%	0%	0%	0%	0%
Newsprint (2005$ / tonne)	1%	1%	1%	1%	1%	1%	1%	1%
Other Manufacturing (2005$ / million $ GDP)	0%	0%	0%	1%	0%	0%	0%	0%

Conclusion

The Government of Newfoundland and Labrador selected M. K. Jaccard and Associates (MKJA) to perform a quantitative analysis on the effect of climate policy in the province. The purpose of this analysis is to help policy makers in setting an appropriate emissions reduction target. In developing this target, the Government needs to understand how its economy is likely to evolve in response to climate policies, as well as the potential costs and benefits associated with those policies. To achieve these objectives, MKJA has used the CIMS energy-economy model to forecast provincial reference case emissions. Against this reference case, MKJA has forecasted how carbon pricing and regulatory policy will affect provincial greenhouse gas emissions and key energy and economic indicators. The analysis was conducted with and without the construction of the Lower Churchill Falls hydroelectric project to clarify how this development will affect greenhouse gas emissions in Newfoundland and Labrador.

In the absence of policies (and without the development of the Lower Churchill), emissions in Newfoundland and Labrador are projected to peak in 2020 at 11 Mt CO_2e. Between 2020 and 2030, emissions are projected to decline to 10 Mt CO_2e. The increase and subsequent decrease in emissions is largely due to the crude oil extraction sector. Furthermore, several sectors such as the personal transportation and industrial sectors experience declining emissions in the latter half of the simulation period.

Marginal abatement cost curves show which abatement actions are available relative to this reference case. Various prices for greenhouse gas emissions were tested ranging from $25/tonne CO_2e to $300/tonne CO_2e. These carbon price simulations reveal the costs that businesses and consumers incur to reduce emissions. The marginal abatement analysis reveals that there is less abatement potential without Lower Churchill Falls than with Lower Churchill Falls, assuming the same carbon price signal. This difference is greatest at carbon prices below $125/tonne CO_2e in 2020 and $100/tonne CO_2e in 2030. Above these prices, carbon capture and storage in the electricity sector is viable and the difference between the two scenarios is less pronounced. This indicates that provincial emissions reductions are most sensitive to abatement activities in the electricity sector. Other key conclusions from the marginal abatement cost analysis include:

1. Abatement in the electricity sector influences the total abatement potential of the province. If Lower Churchill Falls is built, then total abatement is greater in response to any given carbon price relative to the scenario where the project does not go ahead. Without the Lower Churchill project, the electricity sector must use carbon capture and storage to reduce emissions.
2. Fuel switching to electricity is a significant abatement action, especially when Lower Churchill Falls is developed. In the scenarios with no Lower Churchill Falls development, fuel switching to electricity is a less significant abatement action. This is because carbon capture and storage is a higher cost abatement option than hydroelectricity, and does not prevent 100% of the sector's emissions. Therefore electricity produced with carbon capture and storage is more expensive

and switching to electricity is less desirable from the consumer and firm's point of view. Furthermore, not all electrification results in province-wide abatement.

3. Biofuel consumption becomes an increasingly important abatement action at carbon prices greater than \$150/tonne CO_2e, especially for freight and mining vehicles. However, the establishment of biofuel production, distribution and consumption infrastructures takes time. Consequently, even under a price of \$300/tonne CO_2e in 2030, gasoline and diesel still account for half of all transportation fuels.
4. Landfill gas recovery and flaring is a low cost abatement action that reaches full potential in 2020 at carbon prices greater than \$50/tonne CO_2e.
5. By 2030, carbon capture and storage is likely to be a viable abatement action for capturing combustion emissions in the petroleum refining sector if the carbon price is greater than \$150/tonne CO_2e. However, this abatement action is not used in other sectors, thus the small scale of the transportation and storage network (0.5 to 1.0 Mt CO_2e/yr in 2030) could raise the carbon price at which this abatement action is viable by another 10-20%.
6. Energy efficiency improvements achieve some abatement. Much of this abatement is due to the increased use of hybrid and plug-in hybrid vehicles for personal transportation.

The policy analysis in this report uses carbon pricing scenarios and regulations to examine the relationship between policy strength and emissions reductions. Similar to the marginal abatement cost curve analysis, the policy analysis reveals that regional abatement potential is significantly higher with the development of Lower Churchill Falls. Furthermore, if the project does not go ahead and carbon prices are below \$100/tonne CO_2e in 2020 (L, LM and MH) total abatement by 2020 is projected to be small (2-7% below 2005). In the H scenario, when carbon prices are \$100/tonne CO_2e in 2020, carbon capture and storage becomes viable and the emissions reductions increase to 14% below 2005. In 2020, if Lower Churchill Falls is built, emissions reductions in the LCF scenarios range from 12% to 20% below 2005 (Table 11). With the exception of LCFL, all scenarios with Lower Churchill Falls achieve reductions that meet or exceed the equivalent targets from existing policies and initiatives listed in Table 11.

Table 11: Comparison of study results to other targets

	Equivalent Target/ Reductions
Existing Targets	
New England Governors-Eastern Canadian Premiers Forum	14% below 2005 by 2020
Western Climate Initiative	15% below 2005 by 2020
Government of Canada	17% below 2005 by 2020
No LCF	
L	2 % below 2005 by 2020
LM	3 % below 2005 by 2020
MH	7 % below 2005 by 2020
H	14 % below 2005 by 2020
LCF	
LCFL	12 % below 2005 by 2020
LCFLM	16 % below 2005 by 2020
LCFMH	17 % below 2005 by 2020
LCFH	20 % below 2005 by 2020

The economic analysis in this report examines the how the policy scenarios impact certain elements in Newfoundland and Labrador's economy. Specifically, it explores the impact policy has on capital investment, household energy costs, transportation costs, energy costs and unit production costs.

The residential and electricity sectors experience the largest increase in capital investment under the policy scenarios. Capital investment in the residential sector is driven by the building code regulation, while investment in the electricity sector is due to the development of Lower Churchill Falls or the addition of new thermal generation capacity with carbon capture and storage.

While capital investment increases in the residential sector, household energy costs actually decline. In response to carbon prices and the building code regulation, household energy costs drop between 5 and 10% since new buildings must meet a minimum level of energy efficiency.

Policy impacts on transportation costs are measured as changes to vehicle fuel prices and fuel costs. While the policy scenarios cause an increase in the average vehicle fuel price, average annual vehicle fuel costs are actually lower than in the reference case since vehicles are more energy efficient.

Policy scenarios also impact the price of electricity and refined petroleum products. Increases in electricity prices are produced by sector abatement activity: the addition of new grid capacity to meet new electricity demands and, if Lower Churchill Falls is not built, the adoption of carbon capture and storage technologies. In scenarios that do not include Lower Churchill Falls the price of electricity is higher as carbon capture and storage has a higher cost per output than hydroelectricity. The greatest increase in the price of electricity is 0.9 2005¢ / kWh, which occurs under the H scenario. The price of refined petroleum products increases slightly in response to carbon pricing if the price signal is large enough to induce electrification or carbon capture for process heat production.

The impact that policy has on industrial unit production costs is the final indicator analyzed. Unit production costs represent the sum of annualized capital, energy and operating and maintenance cost in a specific year. Production costs rise between 0-3%, with larger changes associated with higher carbon prices. Additionally, industrial unit production costs generally increase more in scenarios without the Lower Churchill Falls (for any given carbon price) because electricity prices are highest in these scenarios.

Appendix A: Sources for Reference Case Output

Sectors	Sources: Base-year Data (2005)	Growth Forecast (2010-2030)
Residential*	Natural Resources Canada	Government of Newfoundland and Labrador (Population) Informetrica (dwelling density)
Commercial	Natural Resources Canada	Government of Newfoundland and Labrador (Gross Output)
Transportation		
Passenger	Natural Resources Canada	Government of Newfoundland and Labrador (population) MKJA (household/transportation ratio)
Freight	Natural Resources Canada	Government of Newfoundland and Labrador (Retail Sales)
Mining	CIMS Atlantic Government of Newfoundland and Labrador	Government of Newfoundland and Labrador (Volume of Shipments)
Metallurgy	N/A	Vale Inco's Environmental Impact Statement
Newsprint	Government of Newfoundland and Labrador	Government of Newfoundland and Labrador
Other Manufacturing	Government of Newfoundland and Labrador	Government of Newfoundland and Labrador (Gross Output)
Electricity Generation	Government of Newfoundland and Labrador	Government of Newfoundland and Labrador
Petroleum Refining	Government of Newfoundland and Labrador	Government of Newfoundland and Labrador
Crude Oil	Government of Newfoundland and Labrador	Government of Newfoundland and Labrador

Note: The Government of Newfoundland and Labrador refers to the Department of Finance, the Department of Natural Resources, and the Office of Climate Change, Energy Efficiency, and Emissions Trading

* The growth forecast for the residential sector is based on the population forecast of the Department of Finance and the household density assumptions of Informetrica.

Appendix B: The CIMS Model

The CIMS Model

CIMS has a detailed representation of technologies that produce goods and services throughout the economy and attempts to simulate capital stock turnover and choice between these technologies realistically. It also includes a representation of equilibrium feedbacks, such that supply and demand for energy to reflect policy.

CIMS simulations reflect the energy, economic and physical output, greenhouse gas emissions from its sub-models as shown in Table 12. CIMS does not include adipic and nitric acid, solvents or hydrofluorocarbon (HFC) emissions.

Table 12: Sector Sub-models in CIMS

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

* Metallurgy includes Aluminium. Natural includes extraction and transmission.

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. The model calculates energy costs (and emissions) for each energy service in the economy, such as heated commercial floor space or person kilometres travelled. 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, and then the subsequent interplay of energy supply-demand with the macroeconomic module. A model simulation iterates between energy supply-demand and the macroeconomic module until energy price changes fall below a threshold value, and repeats this convergence procedure in each subsequent five-year period of a complete run.

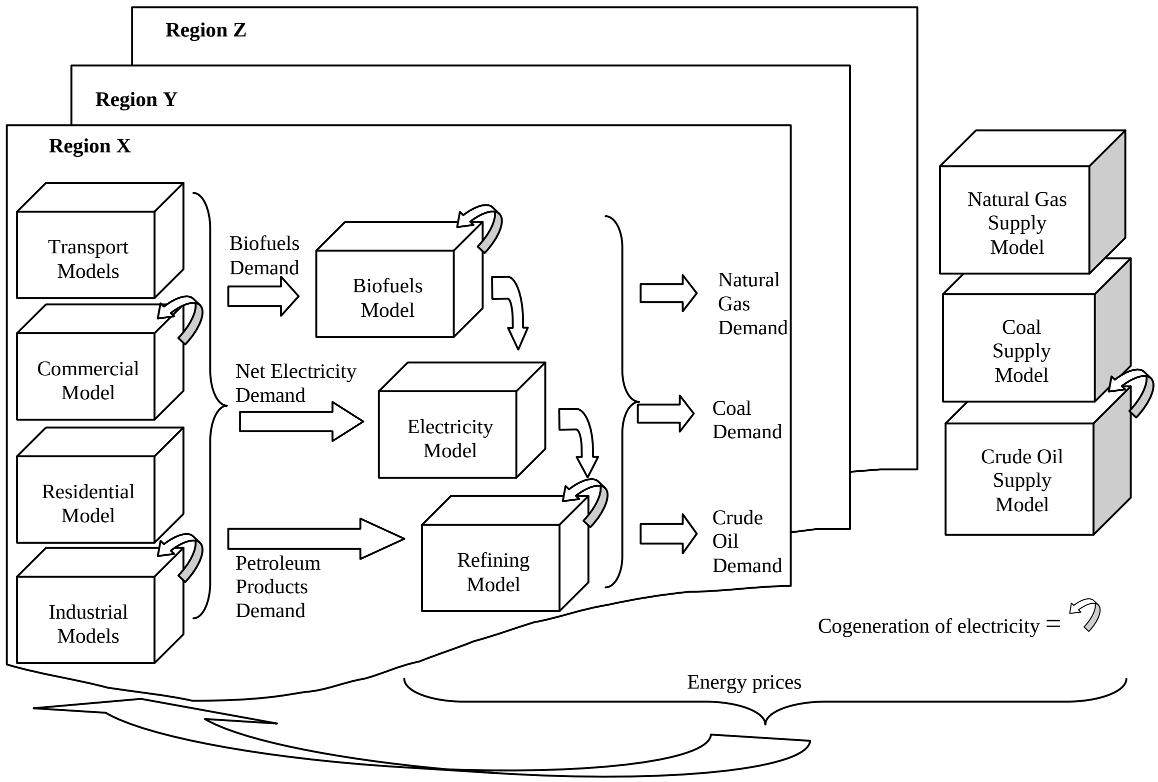
CIMS simulates the competition of technologies at each energy service node in the economy based on a comparison of their life cycle cost (LCC) and some technology-specific controls, such as a maximum market share limit in the cases where a technology is constrained by physical, technical or regulatory means from capturing all of a market. 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 that of bottom-up analysis by including intangible costs that reflect consumer and business preferences and the implicit discount rates revealed by real-world technology acquisition behaviour.

Equilibrium feedbacks in CIMS

CIMS is an integrated, energy-economy equilibrium model that simulates the interaction of energy supply-demand of key sectors of the economy. 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 iterative 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. In the second phase, 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 40 provides a schematic of this process. For this project, endogenous pricing was used only for electricity and refined petroleum products; crude remained at exogenously forecast since Canada is assumed to be a price-taker for these fuels.

Figure 40: CIMS energy supply and demand flow model



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 greenhouse gas emissions are calculated directly from CIMS' estimates of fuel consumption and the greenhouse gas coefficient of the fuel type. Process-based greenhouse gas emissions are estimated based on technological performance or chemical stoichiometric proportions. CIMS tracks the emissions of all types of greenhouse gases, and reports these emissions in terms of carbon dioxide equivalents.[25]

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

[25] 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.