DRAFT REPORT

A Technology Roadmap to Low Greenhouse Gas Emissions in the Canadian Economy:
A sectoral and regional analysis

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Prepared for:
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Executive Summary

In 2007, the National Roundtable on the Environment and the Economy (NRTEE) published *Getting to 2050: Canada's transition to a low-emissions future*, which simulated policies that could be used to attain deep reductions in greenhouse gas emissions over the medium- and long-term.

This study expands on *Getting to 2050* to project the technological developments that occur to attain deep reductions in greenhouse gas emissions – a 20% reduction from 2006 levels by 2020 and a 65% reduction by 2050. This report also estimates the environmental and economic impacts on each sector of the economy from attaining this deep reduction. Environmental impacts include the emission of greenhouse gases and energy consumption; economic impacts include the costs of producing a good or commodity (e.g., cement), the costs of operating a sector (e.g., household) and the level of investment required by the sector to attain the emissions target for 2020 and 2050.

In order to attain a deep reduction in greenhouse gas emissions, businesses and households must reduce 780 Mt of greenhouse gas emissions (measured in carbon dioxide equivalents) from the reference case projection in 2050. To attain these emissions reductions, we simulated an economy-wide price on greenhouse gas emissions, as shown in Table ES 1. The emissions price pathways modelled in this analysis do not reflect policies *per se*; instead they capture the strength of a market-based policy signal required to achieve a given level of emissions reductions.

Table ES 1: Greenhouse gas price simulated in this report ($2005 / tonne CO_2e)

	2011-2015	*2016-2020*	*2021-2025*	*2026-2030*	*2031-2035*	*2036-2040*	*2041-2045*	*2046-2050*
Greenhouse Gas Price	$15	$115	$215	$300	$300	$300	$300	$300

Figure ES 1 illustrates how each of several key actions contributes to the total emissions reductions from the reference case projection. Of these actions, the adoption of carbon capture and storage by electric utilities, the upstream oil and gas sector and other industrial sectors is likely to be the most significant. Carbon capture and storage – represented by the orange wedge – accounts for about 40% of the emissions reductions from the reference case forecast in 2050. Fuel switching to renewable energy and to electricity accounts for 25% and 20%, respectively; and improvements in energy efficiency account for about 10 % of the emissions reductions.[1]

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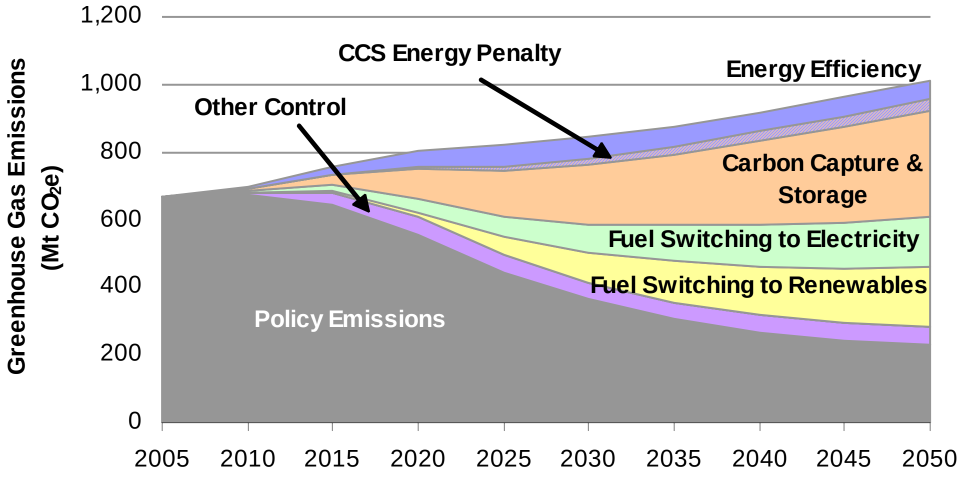
[1] Nuclear power was constrained to its current share of total primary energy, because the adoption of nuclear is more of a political decision than an economic one.

Figure ES 1: Wedge diagram for Canadian economy



In the following discussion, we outline the key findings for each action to reduce greenhouse gas emissions:

Carbon capture and storage (325 Mt CO_2e of reductions from reference projection in 2050)

- **Natural gas processing, ammonia production and hydrogen production are likely to be early adopters of carbon capture and storage.** In the medium-term, the first adopters of carbon capture are likely to be in the separation of formation carbon dioxide in natural gas processing, ammonia production in chemical products manufacturing and hydrogen production in oil sands upgrading. Each of these processes is uniquely suitable for carbon capture because their costs of capturing carbon dioxide are relatively low, and many plants are situated close to areas with good potential for carbon storage. These processes produce, or can be easily retrofitted to produce, relatively pure streams of carbon dioxide; therefore, they avoid the costs of separating carbon dioxide from the other flue gases. By 2030, almost all these processes employ carbon capture and storage. Table ES 2 shows the penetration of carbon capture in each of these processes that results from the policy.

Table ES 2: Penetration of carbon capture in ammonia, formation carbon dioxide separation and hydrogen production

	2020	*2030*	*2040*	*2050*
Formation Carbon Dioxide from Natural Gas Processing	100%	100%	100%	100%
Hydrogen Production from Oil Sands Upgrading	91%	98%	100%	100%
Ammonia Production from Chemical Products Manufacturing	67%	93%	98%	99%

- **Most emissions reductions from carbon capture and storage are attained in the electricity generation and oil sands extraction and upgrading sectors.** In the long-run, carbon capture is likely to play the most significant role from combustion sources in the electricity generation and oil sands extraction and upgrading sectors. These sources are forecasted to produce 167 Mt CO_2e and 172 Mt CO_2e in 2050, respectively, in the absence of any mitigation policy. The uptake of carbon capture from these sources is slower than for sources with relatively pure streams of carbon dioxide for several reasons. 1) Capture from combustion sources is more costly because it requires greater capital and energy expenditures to separate the carbon dioxide from the other flue gases. Therefore, a stronger policy signal is required to induce the investments in capture from combustion sources. Because the policy is ramped up in stringency over time, some of these investments do not occur until later. 2) Retrofitting existing facilities is also more costly. 3) The stock of electricity plants, oil sands upgraders and in-situ operators is sufficiently large that it will take many years to retrofit or retire the existing stock. 4) Many electricity plants are in locations without good potential for geological storage, and will require pipelines to transport carbon dioxide. Table ES 3 shows the penetration of carbon capture and storage from these sources as a percentage of total installed capacity. In the electricity sector, 27% of total generation employs carbon capture by 2050, and the remaining electric capacity is almost completely renewable or nuclear. Virtually all oil sands upgraders and most in-situ operations employ carbon capture by the end of the simulation period.

Table ES 3: Penetration of carbon capture from large combustion sources

	2020	*2030*	*2040*	*2050*
Utility Electricity Generation	7%	17%	23%	27%
Oil Sands Upgrading	58%	88%	96%	99%
In-situ	35%	54%	57%	55%

Fuel switching to renewable fuels (185 Mt CO_2e of reductions)

- **Emissions reductions from fuel switching to renewables are concentrated in the transportation sector.** Approximately 70% of the emissions reductions from personal and freight transportation sectors are the result of fuel switching to renewable fuels. In most modes of transportation, consumers and the freight industry begin to fuel their vehicles with biodiesel or ethanol instead of refined petroleum products (i.e., gasoline and diesel). In some situations, fuel switching requires adjustments to the engine to use biofuels (e.g., a gasoline engine must be modified to run on fuels with 85% ethanol by volume). In other situations, the biofuel may be a perfect substitute for a refined petroleum product (e.g., biodiesel may be manufactured so that it has similar performance to diesel). By 2050, 62% of the passenger vehicle stock and virtually the entire freight fleet are fuelled by renewable fuels. Table ES 4 shows the penetration of biofuel passenger vehicles and freight trucks.

Table ES 4: Penetration of vehicles that consume biofuels

	Renewable fuel share (% of total fuel)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Passenger Vehicles	7%	51%	62%	62%	7%	50%	60%	59%
Freight Trucks	20%	72%	96%	97%	20%	72%	96%	97%

- **The increases in ethanol and biodiesel consumption require a substantial increase in the production of biofuels.** In order to meet the demand for biofuels, the production of biofuels is forecasted to expand from negligible levels in 2005 to over 2,000 PJ by 2050. The sector must also reduce its greenhouse gas intensity and produce biofuels in a manner that does not put politically unsustainable pressure on agroecosystems or food prices. In the modeling, the greenhouse gas intensity of biofuel production declines due to the production of cellulosic ethanol instead of corn ethanol – which requires greater energy inputs – and from the adoption of carbon capture at biofuel manufacturing plants.

- **The expansion of electricity generated from renewables reduces greenhouse gas emissions at the point of electricity consumption.** The analysis shows a considerable increase in electricity generated from renewable sources, but it does not show significant emissions reductions in the electricity sector from switching to renewables. Most of the new capacity to generate electricity from renewables is added in provinces where generation is already dependent on renewables, and does not have a significant impact on emissions at the point of electric generation. However, the expansion of generation from renewables in these provinces enables other sectors, such as the residential and commercial sectors, to increase electricity consumption and reduce their consumption of fossil fuels.

Fuel switching to electricity (155 Mt CO_2e of reductions)

- **Many sectors throughout the economy increase electricity consumption to reduce their direct greenhouse gas emissions.** Many energy end-uses can be met with electricity instead of fossil fuels, and the policy increases the electrification of the economy. In the residential and commercial sectors, the policy causes an increase in the uptake of ground source heat pumps or electric baseboards for space heating; in the transportation sector, the share of plug-in hybrid vehicles among passenger vehicles expands considerably; and in the manufacturing sectors, electricity can be used to produce heat, steam and hot water in the manufacturing sectors. Table ES 5 shows the share of electricity among total energy consumption from each of the key sectors that reduce emissions by switching to electricity.

Table ES 5: Electricity share of total energy consumption

	Electricity fuel share (%)				*Increase in electricity share due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Residential	68%	87%	94%	97%	20%	35%	36%	32%
Commercial	57%	69%	77%	79%	12%	24%	33%	35%
Passenger Transportation	3%	18%	23%	23%	3%	15%	19%	19%
Other Manufacturing	48%	65%	75%	78%	21%	38%	47%	50%

- **The increase in electricity demand requires a significant expansion of the electricity sector.** Similar to the biofuels, the increased demand for electricity requires a considerable expansion of electric capacity and a reduction in the greenhouse gas intensity of the sector. In 2050, electricity generation in the policy scenario is 1,700 TWh – 50% greater than the reference projection.

Reducing the greenhouse gas intensity of the electricity sector presents unique challenges to each province. Provinces without significant hydroelectric potential – particularly Alberta and Saskatchewan – show an expansion of electricity generated using carbon capture and storage. Provinces with better hydroelectric potential enjoy considerable expansions of hydroelectric generation. Table ES 6 illustrates electric generation by different systems, and the increase above the reference case projection.

Table ES 6: Electric generation in the policy scenario

	Electric Generation (TWh)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Renewable	544	703	860	1,013	20%	36%	42%	43%
Nuclear	124	168	204	232	25%	54%	64%	57%
Coal	112	86	43	5	4%	-30%	-71%	-98%
Natural Gas	26	15	9	6	-29%	-65%	-81%	-89%
Carbon Capture & Storage	62	193	328	456	NA	NA	NA	NA

Note: There is minimal penetration of carbon capture and storage in the reference case, so we do not show an increase over the reference case.

Energy efficiency improvements (60 Mt CO_2e of reductions)

- **Improvements in energy efficiency are concentrated within the transportation sector.** Approximately 75% of the emissions reductions from improvements in energy efficiency are from the transportation sector. In the personal transportation sector, passengers have several options for improving their energy efficiency, of which purchasing hybrid and plug-in hybrid vehicles are the most significant. Table ES 7 shows that hybrid and plug-in hybrid vehicles enjoy close to a full penetration in the market for passenger vehicles. Mode switching to public transit and purchasing smaller vehicles contribute to the improvement in energy efficiency to a lesser extent. Improvements in freight transportation occur as a result of the adoption of hybrid trucks as well as mode shifts to rail transport.

Table ES 7: Penetration of hybrid and plug-in hybrid vehicles

	Technology Penetration (% of total Stock)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Passenger Hybrid	3%	6%	11%	12%	2%	3%	-14%	-29%
Passenger Plug-in Hybrid	13%	69%	83%	83%	12%	60%	67%	65%
Freight Hybrid	3%	32%	59%	62%	2%	26%	15%	0%

- **The residential and commercial sectors contribute to most of the remaining emissions reductions through improvements in energy efficiency.** Most energy efficiency improvements in the commercial and residential sectors are from investments in ground source heat pumps. Table ES 8 shows the penetration of source heat pumps in the commercial and residential sectors.

Table ES 8: Penetration of ground source heat pumps

	Technology Penetration (% of installed stock)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Residential	0%	6%	22%	33%	0%	6%	21%	29%
Commercial	16%	33%	52%	61%	10%	24%	41%	50%

- **The energy efficiency improvements in the industrial and energy supply sectors are offset due to the adoption of carbon capture and storage.** Carbon capture requires more energy than an equivalent facility without, so most of the sectors which abate their emissions using carbon capture and storage show increases in energy intensity. The wedge labelled “CCS Energy Penalty” is an estimate of decline in energy efficiency associated with carbon capture.

Controls of fugitive and landfill gas emissions (50 Mt CO_2e of reductions)

- **Capturing and flaring landfill gas is likely to be an early opportunity to reduce greenhouse gas emissions.** The cost of capping and flaring landfill gas is relatively low and the policy is likely to induce all landfills to capture and flare landfill gas by 2020. In 2020, the waste sector reduces emissions by 25 Mt CO_2e from the reference case projection, and by 2050 the reduction reaches 30 Mt CO_2e.
- **Reduced and managed well venting, testing, and leak detection and repair programs can reduce fugitive emissions from the natural gas and crude oil extraction sectors.** These programs detect and fix leaks in natural gas and crude oil pipelines and wells. By 2050, these actions account for approximately 19 Mt CO_2e of emissions reductions from the reference projection.

Capital expenditures required to meet deep reductions

In order to attain a 65% reduction in greenhouse gas emissions from 2006 levels by 2050, the level of capital expenditure rises by 5% from the reference case projection in the medium-term, and by 3% in the long-term (see Table ES 9). Most additional capital expenditures occur in the electricity and biofuels manufacturing sectors, which expand considerably in the policy scenario. The expenditures on carbon capture and storage equipment, and retrofitting existing electricity and oil sands upgraders also contributes to the rise in expenditures.

Table ES 9: Increase in capital expenditures caused by policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	6,345	5,993
Increase in Capital Expenditures (% above the reference case)	5%	3%

Summary of actions to reduce greenhouse gas emissions

Table ES 10 summarizes the emissions reductions from key actions to reduce direct greenhouse gas emissions.

Table ES 10: Summary of actions to reduce direct greenhouse gas emissions (Mt CO_2e)

	2020	2030	2040	2050
Carbon Capture and Storage	**94**	**183**	**260**	**325**
Formation Carbon Dioxide from Natural Gas Processing	6	6	5	5
Hydrogen Production from Oil Sands Upgrading	11	13	14	15
Ammonia Production from Chemical Products Manufacturing	2	3	4	4
Utility Electricity Generation	28	75	115	155
Oil Sands Upgrading	33	53	70	76
In-situ Bitumen Extraction	8	16	22	29
Other Carbon Capture and Storage	5	17	30	41
Energy Efficiency & Carbon Capture Overlap	**11**	**20**	**29**	**37**
Fuel Switching to Renewables	**16**	**91**	**154**	**184**
Passenger Vehicles	2	23	35	39
Freight Trucks	11	51	89	108
Other Fuel Switching to Renewables	4	17	29	38
Fuel Switching to Electricity	**38**	**91**	**130**	**154**
Residential Electric Space and Water Heating	13	26	30	32
Commercial Electric Space and Water Heating	8	17	27	33
Passenger Plug-in Hybrid Vehicles	3	17	23	25
Other Manufacturing Electric Process and Water Heating	8	17	27	34
Other Fuel Switching to Electricity	7	14	23	29
Energy Efficiency	**50**	**71**	**60**	**60**
Passenger Hybrid & Plug-in Hybrid Vehicles [1]	12	26	22	19
Freight Hybrid Trucks [1]	16	15	9	10
Residential Ground Source Heat Pumps [1]	2	4	4	3
Commercial Ground Source Heat Pumps [1]	3	6	9	11
Other Improvements to Energy Efficiency [1]	17	19	16	17
Other Controls on Greenhouse Gas Emissions	**53**	**55**	**54**	**53**
Landfill Gas Cap and Flare	26	27	28	29
Leak Detection and Repair at Oil and Gas Wells and Pipelines	23	23	21	19
Other Controls	4	5	5	5
Changes in Sector Output	**-14**	**-31**	**-37**	**-33**
Electricity Generation	-34	-56	-60	-55
Other Sectors	20	25	22	22
Total Reductions in Greenhouse Gas Emissions from all Actions	**249**	**479**	**649**	**780**

[1] Values for the emissions reductions from improvements in energy efficiency are approximate.

Table ES 10 shows the reductions in greenhouse gases at the point of emission. As discussed above, the expansion of biofuels and electricity production in some provinces does not significantly reduce emissions at the point of greenhouse gas emissions, but it enables emissions reductions at the point of energy consumption (e.g., an increase in the production of hydroelectricity in Québec enables the residential to reduce natural gas consumption). Table ES 11 shows the emissions reductions enabled by the expansion of different methods for producing electricity and renewable fuels.

Table ES 11: Emissions reductions enabled by the expansion of the electricity and biofuels sectors (Mt CO_2e)

	2020	*2030*	*2040*	*2050*
Clean Electricity Generation	**38**	**91**	**130**	**154**
Renewable Generation	20	40	52	57
Nuclear Generation	6	12	16	16
Carbon Capture and Storage Generation	13	39	62	81
Biofuel Production	**15**	**88**	**147**	**174**
Cellulosic Ethanol Production	8	51	63	55
Carbon Capture and Storage Production	3	19	47	73
Other Production Methods [1]	5	18	37	47

[1] Includes production methods that use electricity or renewable fuels to produce the heat necessary for biofuel production.

Table of Contents

List of Figures

List of Tables

Introduction

In *Getting to 2050: Canada's transition to a low emissions future*, the National Round Table on the Environment and the Economy (NRTEE) estimated the strength of policy that would be necessary to attain deep reductions in greenhouse gas emissions by 2050 (a 65% reduction from 2006 levels by 2050). The NRTEE retained J & C Nyboer and Associates to expand on the previous study to 1) assess the sectoral and regional implications of attaining deep reductions in greenhouse gas emissions, and 2) forecast the technological developments that must occur in order to attain these reductions.

J & C Nyboer and Associates uses a detailed energy-economy model called CIMS to evaluate energy and climate change policies and to determine the cost of reducing greenhouse gas emissions. In this project, we use the CIMS model to estimate the technological developments that occur in response to a charge on greenhouse gas emissions that attains the deep reduction in greenhouse gas emissions described in *Getting to 2050*. We estimate these developments at a sectoral and provincial level in order to forecast how each sector and region will be affected by the policy. As part of the analysis, we highlight the sectors of the economy which contribute most significantly to the emission or abatement of greenhouse gas emissions. The report is accompanied with an appendix and spreadsheet that show most of the data used to develop the report.

Structure of this report

We begin this report with an overview of the methodology used to produce the quantitative results, including a general description of the CIMS model that was used for the analysis. We then discuss the assumptions and inputs that were used to develop the reference case forecast that was produced for this report, and present the reference case forecast in detail. The following section presents the sectoral and regional implications of deep reductions in greenhouse gas emissions, and it discusses the technological developments that must occur to attain these reductions.

Methodology

The primary objective of this study is to forecast the technological developments that must occur in order for Canada to attain deep reductions in greenhouse gas emissions by 2050. A deep reduction in greenhouse gas emissions is defined as a 65% reduction from 2006 levels. To conduct the analysis, the CIMS energy-economy model was updated to reflect recent national data and trends, and used to forecast the developments that occur in response to a charge on greenhouse gas emissions. The model is described very briefly here; a somewhat more comprehensive description of the model is provided in the Appendix.

The CIMS model

The CIMS model, developed by the Energy and Materials Research Group at Simon Fraser University and by J & C Nyboer and Associates, simulates the technological evolution of fixed capital stocks (such as buildings, vehicles, and equipment) and the resulting effect on costs, energy use, emissions, and other material flows. The stock of capital is tracked in terms of energy service provided (m^2 of lighting or space heating) or units of physical product (metric tons of market pulp or steel). New capital stocks are acquired as a result of time-dependent retirement of existing stocks and growth in stock demand. Market shares of technologies competing to meet new stock demands are determined by standard financial factors as well as behavioral parameters from empirical research on consumer and business technology preferences. CIMS has three modules — energy supply, energy demand, and macro-economy — which can be simulated as an integrated model or individually. A model simulation comprises the following basic steps.

1. A base-case macroeconomic forecast initiates model runs. The macroeconomic forecast is at a sectoral or sub-sectoral level (for example, it estimates the growth in total passenger travel demand, or in airline passenger travel demand). The macroeconomic forecast adopted for this study is described in detail in the following section.
2. In each time period, some portion of existing capital stock is retired according to stock lifespan data. Retirement is time-dependent, but sectoral decline can also trigger retirement of some stocks before the end of their natural lifespans. The output of the remaining capital stocks is subtracted from the forecast energy service or product demand to determine the demand for new stocks in each time period.
3. Prospective technologies compete for new capital stock requirements based on financial considerations (capital cost, operating cost), technological considerations (fuel consumption, lifespan), and consumer preferences (perception of risk, status, comfort), as revealed by behavioral-preference research. The model allows both firms and individuals to project future energy and carbon prices with imperfect foresight when choosing between new technologies (somewhere between total

myopia and perfect foresight about the future). Market shares are a probabilistic consequence of these various attributes.

4. A competition also occurs to determine whether technologies will be retrofitted or prematurely retired. This is based on the same type of considerations as the competition for new technologies.
5. The model iterates between the macro-economy, energy supply and energy demand modules in each time period until equilibrium is attained, meaning that energy prices, energy demand and product demand are no longer adjusting to changes in each other. Once the final stocks are determined, the model sums energy use, changes in costs, emissions, capital stocks and other relevant outputs.

The key market-share competition in CIMS can be modified by various features depending on the evidence about factors that influence technology choices. Technologies can be included or excluded at different time periods. Minimum and maximum market shares can be set. The financial costs of new technologies can decline as a function of market penetration, reflecting economies of learning and economies of scale. Intangible factors in consumer preferences for new technologies can change to reflect growing familiarity and lower risks as a function of market penetration. Output levels of technologies can be linked to reflect complementarities.

Personal mobility provides an example of CIMS' operation. The future demand for personal mobility is forecast for a simulation of, say, 30 years and provided to the energy demand module. After the first five years, existing stocks of personal vehicles are retired because of age. The difference between forecast demand for personal mobility and the remaining vehicle stocks to provide it determines the need for new stocks. Competition among alternative vehicle types (high and low efficiency gasoline, natural gas, electric, gasoline-electric hybrid, and eventually hydrogen fuel-cell) and even among alternative mobility modes (single occupancy vehicle, high occupancy vehicle, public transit, cycling and walking) determines technology market shares. The results from personal mobility and all other energy services determine the demand for fuels. Simulation of the energy supply module, in a similar manner, determines new energy prices, which are sent back to the energy demand module. The new prices may cause significant changes in the technology competitions. The models iterate until quantity and price changes are minimal, and then pass this information to the macro-economic module. A change from energy supply and demand in the cost of providing personal mobility may change the demand for personal mobility. This information will be passed back to the energy demand module, replacing the initial forecast for personal mobility demand. Only when the model has achieved minimal changes in quantities and prices does it stop iterating, and then move on to the next five-year time period.

Model limitations and uncertainties

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

- **Technological detail and dynamics –** CIMS contains a considerable level of technological detail in each of its sectoral sub-models. This detail enables CIMS to show accelerated market penetration of alternative technologies in response to an energy or climate change policy and to ensure that reference and policy scenarios are grounded in technological and economic reality. While care has been taken in representing the engineering and economic parameters of the many technologies in CIMS, uncertainty exists (particularly in industrial sectors) as to the appropriate cost and operating parameters of specific technologies.

  This uncertainty becomes larger over time. While CIMS contains a representation of dynamic technological change that depicts how the costs of new technologies can be reduced through economies of scale and production experience based on historical experience, there is no guarantee that these relationships will hold in the future. In addition, CIMS only contains technological options that are known today (including those that are not yet commercialized). By definition, CIMS does not contain a depiction of new technologies that have not yet been invented. As a result, CIMS could miss technological substitution options in later years of the forecast.

- **Behavioural realism** – The technology choice algorithm of CIMS takes into account implicit discount rates revealed by real-world technology acquisition behavior, intangible costs that reflect consumer and business preferences, and heterogeneity in the marketplace. Incorporating behavioral realism is critical in order to predict realistic consumer and firm response to policies, however, incorporating preferences at a detailed level into a model that is technologically explicit is challenging. In addition to the sheer volume of the data requirements, the non-financial preferences of consumers and firms are difficult to estimate, and can change over time. The complexities associated with estimating behavioral parameters, combined with the fact that information cannot be collected for all the technology competitions in CIMS, result in a high degree of uncertainty associated with these parameters overall. The potential for preference change is also a key uncertainty.

- **Equilibrium feedbacks -** Unlike most computable general equilibrium models (which do not contain technological detail), the current version of CIMS does not equilibrate government budgets and the markets for employment and investment. Also, its representation of the economy's inputs and outputs is skewed toward energy supply, energy intensive industries, and key energy end-uses in the residential, commercial/institutional, and transportation sectors. As a result, it is likely to underestimate the full structural response of the economy to energy and climate change policies.

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

Modelling scenario

In order to determine the greenhouse gas abatement opportunities in Canada, we use the concept of a reference scenario and a policy scenario. The reference scenario shows how the Canadian economy might evolve in the absence of specific new policies to reduce greenhouse gas emissions. The policy scenario shows how the economy might evolve under a given policy. The difference between the two scenarios is due to the effect of the policy.

In this report, we use an economy-wide emissions price to simulate deep reductions in greenhouse gas emissions – a 20% reduction from 2006 levels by 2020, and a 65% reduction by 2050. The emissions price pathway modelled in this analysis does not reflect policies *per se*; instead it captures the strength of a market-based policy signal required to achieve a given level of emissions reductions. Table 1 illustrates the price on greenhouse gas emissions that attains the deep reduction in greenhouse gas emissions.

Table 1: Greenhouse gas price ($2005 / tonne CO_2e)

	2011-2015	*2016-2020*	*2021-2025*	*2026-2030*	*2031-2035*	*2036-2040*	*2041-2045*	*2046-2050*
Greenhouse Gas Price	$15	$115	$215	$300	$300	$300	$300	$300

The reference scenario

The reference scenario described in this report is based on several external inputs showing how the economy will evolve over the coming 42 years to 2050. Many key inputs underlying the reference scenario are highly uncertain, and if the economy evolves differently than as shown in this reference scenario, energy consumption and emissions will also differ from what we show here. We have used credible sources to guide key inputs wherever possible, but no amount of research allows perfect foresight into the future of the economy. As a result, the scenario described here should be considered just one possible reference scenario. We consider it a good "business as usual" forecast, based on historic trends and research into likely future technological and economic evolution, but the uncertainty remains large. We begin by highlighting our key assumptions, and follow by showing the results of our forecast.

Key economic drivers and assumptions

CIMS uses an external forecast for the economic or physical output of each economic sector to develop the business as usual forecast. For example, CIMS requires an external forecast for the number of residential households, and another for the amount of cement produced in the province. These forecasts can be internally adjusted when a policy is applied. We discuss the forecasts adopted for both the energy supply sectors and the energy demand sectors.

Energy demand sectors

For all energy demand sectors, the external forecast through 2020 is based on the same data used by Natural Resources Canada to develop the national energy outlook in 2006.[2] For years beyond 2020, the forecast for demand sectors is based on a long-run economic forecast of gross domestic product, population, and labour force participation prepared by Informetrica for the federal government, which is depicted in Table 2.[3] The population forecast used here is based on the medium growth scenario developed by Statistics Canada in a recent demographic forecast.[4]

Table 2: Canada's economic and demographic forecast

	Units	*2010*	*2020*	*2030*	*2040*	*2050*
Population	*Thousands*	33,639	36,344	38,812	40,644	41,896
Gross Domestic Product	*billion 2005$* [a]	1,460	1,827	2,194	2,652	3,153

Note: [a] Gross domestic product is presented in basic prices

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[2] Natural Resources Canada, 2006, "Canada's Energy Outlook: The Reference Case 2006", Analysis and Modelling Division, Natural Resources Canada.

[3] Infometrica, 2007, "Infometrica's Long-run Reference Population and Productivity Forecast". Natural Resources Canada also bases its forecast on Infometrica's macroeconomic and demographic projections.

[4] Statistics Canada, 2006, "Population Projections for Canada, Provinces, and Territories: 2005-2031", Demography Division, Statistics Canada.

The residential sector is anticipated to grow rapidly because of continued population growth. The rate of both population growth and household formation are expected to slow later in the forecast, when Canada's population is anticipated to be about 25% larger than the current level.

The commercial sector is expected to undergo rapid expansion, driven by expanding economic output. By the end of the forecast period, the commercial sector is expected to be more than double its current size (based on physical building footprint).

Travel demand in the passenger transportation sector is increasing quickly in Canada, fuelled by growth in population as well as income. These trends are expected to continue in general, but slow throughout the forecast period. In the freight transportation sector, growth is based on gross domestic product and expansion of industrial output, which expand rapidly in the reference case.

Like other demand sectors, output is expected to grow in the industrial manufacturing sector. The output from the other manufacturing sector grows the most rapidly, while growth in other sectors is more muted.

Energy supply sectors

The main energy supply sectors in CIMS include crude oil extraction, natural gas extraction and processing, petroleum refining, electricity generation, coal mining and biofuels manufacturing. For crude oil and natural gas, we rely on external forecasts of production, because a large percentage of Canada's production is exported to other regions. For petroleum refining, electricity generation, and coal mining, we base the supply forecast on Canada's projected energy demand and add in an external forecast of net exports of each commodity to calculate total production.

Canada's crude oil production forecast is shown in Figure 1 and is based on the moderate growth case of the Canadian Association of Petroleum Producers 2007 report.[5] Between 2025 and 2050, the output of conventional crude oil (light/medium and heavy) is projected to continue to decline due to existing reserve depletion. By 2050, conventional crude oil production is expected to account for only a small amount of total production.

Conversely, production of unconventional crude oil, from Alberta's oil sands, is forecast to increase dramatically during the forecast period. Total production of unconventional crude oil is expected to reach about 4.5 million barrels per day by 2025 and nearly 6.6 million barrels per day by 2050, a five-fold expansion in capacity from today's levels. Particularly rapid growth in the industry is expected in the coming two decades, both in blended bitumen operations and in synthetic crude oil operations.

According to the Alberta Energy and Utilities Board, the volume of crude bitumen in the oil sands is approximately 1.6 trillion barrels, with 175 billion barrels recoverable under current economic conditions and with existing technologies. The growth forecast of oil

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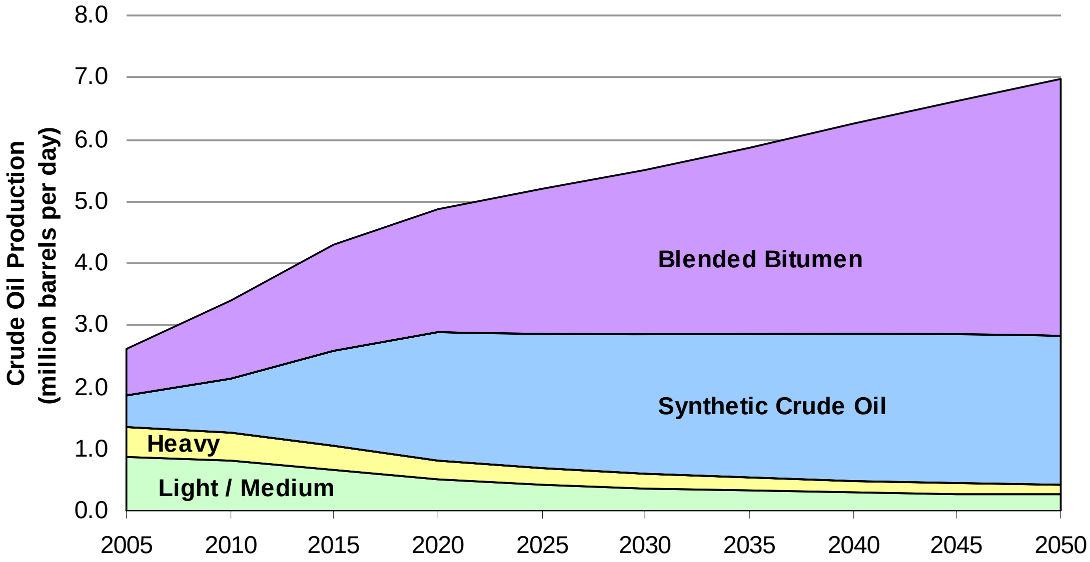
[5] Canadian Assocation of Petroleum Producers, 2007, "Crude oil forecast, markets, and pipeline expansions", June 2007. CAPP's forecast extends to 2025; after 2025, production in the sector is assumed to continue to grow for unconventional crude oil, and to continue to decline for conventional crude oil. The forecast after 2025 is very uncertain since projects are not announced with this much lead-time. CAPP's recent forecast is higher than the forecast adopted in NRCan's 2006 Energy Outlook.

sands development in our model has taken this resource constraint into consideration. During the modelling period, the forecasted cumulative output of blended bitumen and synthetic crude oil in Canada is about 73 billion barrels.

Figure 1: Crude oil supply forecast



Source: Forecast based on Moderate Growth case from Canadian Association of Petroleum Producers, 2007, “Crude oil forecast, markets, and pipeline expansions”.

Marketable natural gas production in Canada between 2000 and 2020 is grounded in Natural Resources Canada’s CEO 2006, but modified to reflect history and more recent material from the Canadian Association of Petroleum Producers and the Alberta Energy and Utility Board’s 2006 forecast. The growth rate forecast between 2015 and 2025 comes from a recent National Energy Board report.[6] Key recent changes include the delay of large-scale production of Arctic gas, transmitted via the Mackenzie Valley, until after 2013, higher estimates of accessible coal bed methane, and increased optimism about replacement of reserves from the Western Canadian Sedimentary Basin, which underlies BC, the Northwest Territories, Alberta, Saskatchewan and Manitoba. While much of the accessible and inexpensive conventional gas reserves have been depleted, drilling technology (e.g., side and angle drilling and search software) and the ability to access tight gas have improved such that larger than previously expected additions to reserves are expected up to 2015.

Figure 2 shows the forecast of marketable natural gas production that was adopted for this report. The figure shows that production peaks near 2015 and then begins to decline fairly quickly, even with a substantial increase in coal bed methane supply. Because coal

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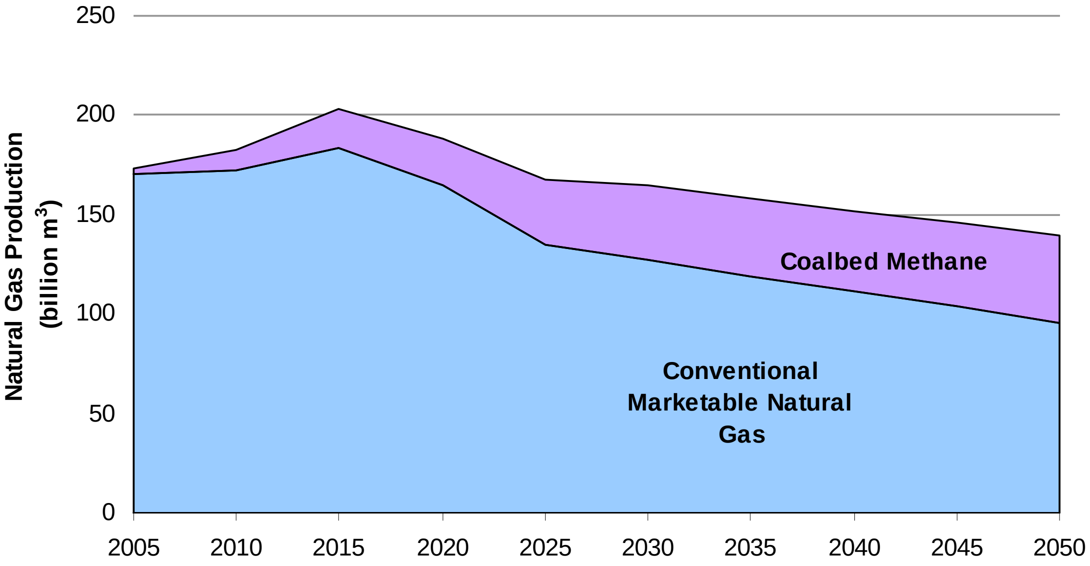
[6] Alberta Energy Utilities Board, 2006, “Alberta’s Energy Reserves 2005” and “Supply/Demand Outlook 2006-2015”; National Energy Board, 2003, “Canada’s Energy Future: Supply and Demand Forecast to 2025”; National Energy Board, 2004, “Canada’s Oil Sands: Challenges and Opportunities to 2015”.

bed methane is a relatively new resource, the forecast for extraction of coal bed methane adopted for this reference scenario is very uncertain.

Figure 2: Natural gas supply forecast



Source: Forecast based on Natural Resources Canada, “Canada’s Energy Outlook 2006”; Alberta Energy Utilities Board, “Alberta’s Energy Reserves 2005” and “Supply/Demand Outlook 2006-2015”; National Energy Board, 2007, “Canada’s Energy Future: Supply and Demand Forecast to 2030” and National Energy Board, 2004, “Canada’s Oil Sands: Challenges and Opportunities to 2015”.

The forecast of output for the electricity generation sector is based on the calculated demand from all other sectors in the model, and is adjusted to include net exports of electricity.[7] The forecast of output from the electricity generation sector does not include non-utility electricity generation, which is accounted for separately in the other sub-models (for example, electricity production by cogeneration in the oil sands is accounted for in the upstream oil sub-model).

The fuel source for electric generation varies considerably between provinces. British Columbia, Manitoba and Québec, have abundant hydroelectric potential, and most capacity additions until 2050 are forecasted to be hydroelectric. Ontario and the Atlantic provinces have a mixture of hydroelectric, nuclear and fossil fuel generation; while Alberta and Saskatchewan rely primarily on coal and natural gas to generate electricity. Figure 3 shows the reference case electricity generation by fuel type for Canada; generation by province is available in the appendix.

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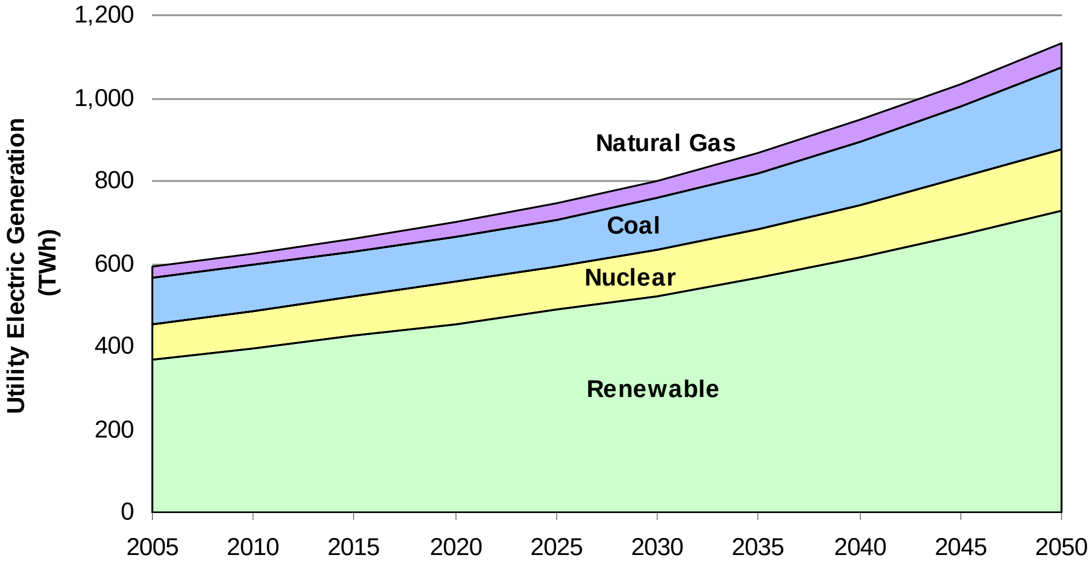
[7] Net exports of electricity are based on the recent Natural Resources Canada energy outlook through 2020 and are assumed to remain at historic levels thereafter.

Figure 3: Reference case utility electricity generation by fuel type



In the policy scenario, we assume that net exports of electricity and coal remain fixed at the levels in the reference case. For crude oil and natural gas in the policy scenarios, we assume that total provincial production of the commodity is fixed and adjust net exports based on the difference between total production and domestic demand. Although this assumption is likely imperfect, the US Energy Information Administration projects that international demand for crude oil and natural gas is likely to remain robust even with the introduction of climate change abatement policies.[8]

Table 3 summarizes the reference case economic output forecast that is adopted for this forecast. As has been emphasized throughout, this forecast reflects historic and anticipated future trends, but is highly uncertain, particularly in the later years of the forecast.

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[8] Energy Information Administration, 1998, "Impacts of the Kyoto Protocol on US Energy Markets and Economic Activity", United States Department of Energy.

Table 3: Reference case output forecast

	Units	*2010*	*2020*	*2030*	*2040*	*2050*
Demand Sectors						
Residential	*thousands of households*	13,545	15,222	16,566	17,253	17,815
Commercial	*million m^2 of floorspace*	729	911	1,091	1,316	1,561
Transportation						
Passenger	*billion passenger-km*	742	944	1,152	1,339	1,493
Freight	*billion tonne-km*	966	1,198	1,420	1,689	1,987
Manufacturing Industry						
Chemical Products	*million tonnes* [a]	19	22	24	27	30
Industrial Minerals	*million tonnes* [b]	18	21	25	29	33
Iron and Steel	*million tonnes*	15	16	18	20	22
Metal Smelting	*million tonnes* [c]	5	5	5	5	5
Mineral Mining	*million tonnes*	262	274	282	292	304
Pulp and Paper	*million tonnes* [d]	20	22	24	26	27
Other Manufacturing	*billion $2005*	205	260	318	391	472
Supply Sectors						
Electricity Generation	*TWh*	625	701	802	947	1,133
Petroleum Refining	*million m^3*	101	115	117	124	136
Crude Oil						
Conventional Light	*thousand barrels per day*	823	502	365	295	257
Conventional Heavy	*thousand barrels per day*	438	322	238	186	151
Synthetic Crude	*thousand barrels per day*	878	2,075	2,249	2,375	2,418
Blended bitumen	*thousand barrels per day*	1,244	1,967	2,663	3,396	4,160
Natural Gas	*billion m^3* [e]	179	179	149	135	121
Coal Mining	*million tonnes*	72	87	92	97	106
Biofuels Manufacturing	*PJ*	9	16	31	65	103

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

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

[c] metal smelting output is the sum of aluminium, copper, lead, magnesium, nickel, titanium and zinc smelting

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

[e] natural gas production includes coalbed methane

Energy prices

CIMS requires an external forecast for energy prices. As for sectoral output, fuel prices can change while a policy scenario is running if the policy induces changes in the cost of fuel production. Reference case prices for most fuels through 2020 are derived from the recent energy outlook published by Natural Resources Canada (the industrial and electricity coal price forecasts were derived from forecasts by the US Environmental Protection Agency). The price for petroleum products has been updated to reflect the recent increase in the price for crude oil, which at the time of writing had exceeded $140 per barrel. The price for petroleum products is based on historic data until May 2008 and the price for oil from the Energy Information Administration's most recent forecast.[9] Table 4 shows the fuel price forecast (excluding electricity) for Ontario that was used to develop the reference case forecast in this report. The values differ slightly by province depending on the supply cost and taxation, but prices in Ontario are reasonably representative of the prices in the rest of the country. Table 5 shows the price for electricity in each province. The forecasts for electricity prices are lower in provinces with greater hydroelectric potential – specifically British Columbia, Manitoba and Québec – and greater in provinces with fossil fuel generation. Like the other forecasts that are used as inputs to CIMS, it should be recognized that the fuel price forecast adopted here is highly 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.

Table 4: Reference case price forecast for key energy commodities in Ontario

	Units	*2010*	*2020*	*2030*	*2040*	*2050*
Crude Oil (WTI)	*2005$ US / barrel*	85.57	56.97	66.67	69.04	69.04
Natural Gas						
Industrial	*2005$ / GJ*	9.63	8.71	8.71	8.71	8.71
Residential	*2005$ / GJ*	12.63	11.30	11.30	11.30	11.30
Commercial	*2005$ / GJ*	11.01	9.87	9.87	9.87	9.87
Electricity Generation	*2005$ / GJ*	9.00	8.89	8.89	8.89	8.89
Coal						
Market	*2005$ / GJ*	3.36	3.36	3.36	3.36	3.36
Electricity Generation	*2005$ / GJ*	3.00	3.00	3.00	3.00	3.00
Gasoline	*2005¢ / L*	108.8	81.7	88.7	88.7	88.7
Diesel (Road)	*2005¢ / L*	98.9	73.0	80.1	80.1	80.1

Note: All prices other than the price for oil are in Canadian dollars.

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[9] Energy Information Administration, 2008, "Annual Energy Outlook, 2008", United States Department of Energy.

Table 5: Reference case electricity price forecast in each province

	Units	*2010*	*2020*	*2030*	*2040*	*2050*
Industrial						
British Columbia	*2005¢ / kWh*	4.0	3.5	3.5	3.5	3.5
Alberta	*2005¢ / kWh*	6.2	5.6	5.6	5.6	5.6
Saskatchewan	*2005¢ / kWh*	6.0	5.5	5.5	5.5	5.5
Manitoba	*2005¢ / kWh*	3.7	2.7	2.7	2.7	2.7
Ontario	*2005¢ / kWh*	6.5	7.0	7.0	7.0	7.0
Québec	*2005¢ / kWh*	4.2	3.4	3.4	3.4	3.4
Atlantic	*2005¢ / kWh*	7.4	7.2	7.2	7.2	7.2
Residential						
British Columbia	*2005¢ / kWh*	7.4	6.5	6.5	6.5	6.5
Alberta	*2005¢ / kWh*	8.7	9.5	9.5	9.5	9.5
Saskatchewan	*2005¢ / kWh*	8.1	7.3	7.3	7.3	7.3
Manitoba	*2005¢ / kWh*	6.3	4.9	4.9	4.9	4.9
Ontario	*2005¢ / kWh*	8.9	9.9	9.9	9.9	9.9
Québec	*2005¢ / kWh*	8.3	8.4	8.4	8.4	8.4
Atlantic	*2005¢ / kWh*	11.4	10.8	10.8	10.8	10.8
Commercial						
British Columbia	*2005¢ / kWh*	4.5	4.0	4.0	4.0	4.0
Alberta	*2005¢ / kWh*	6.4	6.7	6.7	6.7	6.7
Saskatchewan	*2005¢ / kWh*	8.9	7.9	7.9	7.9	7.9
Manitoba	*2005¢ / kWh*	4.1	2.9	2.9	2.9	2.9
Ontario	*2005¢ / kWh*	7.7	9.1	9.1	9.1	9.1
Québec	*2005¢ / kWh*	4.6	3.7	3.7	3.7	3.7
Atlantic	*2005¢ / kWh*	9.1	8.8	8.8	8.8	8.8

Note: All prices are in Canadian dollars.

Policies included in the reference case

Both the federal and provincial governments have developed energy and climate policies over the past few years. We have attempted to include the most important of these in the reference case developed here. In particular, we include:

- The federal renewable power production incentive, which provides $0.01/kWh of renewable energy production during the first 10 years after commissioning of a new renewable energy facility;
- The federal ethanol excise tax exemption of $0.10/L and provincial tax exemptions for ethanol;
- The federal minimum energy performance standards for household appliances, including furnace regulations requiring 90% efficiency in new natural gas furnaces starting in 2009;
- The federal ecoENERGY for Efficiency policy, which provides incentives towards the replacement of lower efficiency energy consuming equipment with more efficient equipment.

Reference case energy and emissions outlook

Based on the key economic assumptions highlighted above, we used CIMS to develop an integrated reference case forecast for energy consumption and greenhouse gas emissions through 2050. The CIMS model captures virtually all energy consumption and production in the economy.

The reference case forecast for total energy consumption is shown in Table 6, while Table 7, Table 8, and Table 9 show natural gas, refined petroleum product, and electricity consumption, respectively. The residual energy consumption of other fuel types (total minus natural gas, refined petroleum product, and electricity) is not explicitly shown in this report.

Table 6: Reference case total energy consumption

	Unit	*2010*	*2020*	*2030*	*2040*	*2050*
Demand Sectors						
Residential	*PJ*	1,417	1,567	1,760	1,977	2,303
Commercial	*PJ*	1,195	1,412	1,639	1,956	2,298
Transportation	*PJ*	2,889	3,522	3,728	4,077	4,557
Manufacturing Industry	*PJ*	2,352	2,527	2,770	3,105	3,497
Supply Sectors						
Electricity Generation	*PJ*	3,881	4,127	4,626	5,448	6,560
Petroleum Refining	*PJ*	351	423	457	511	571
Crude Oil	*PJ*	1,034	1,996	2,202	2,342	2,506
Natural Gas	*PJ*	692	607	512	457	403
Coal Mining	*PJ*	22	24	25	26	27
Biofuels Manufacturing	*PJ*	2	4	13	16	20
Total	*PJ*	13,836	16,208	17,731	19,914	22,743

Note: Producer consumption of energy (e.g., consumption of hog fuel in the pulp and paper sector or refinery gas in the petroleum refining sector) is included in these totals. Energy consumption in the electricity generation sector includes consumption of water, wind, nuclear, and biomass using coefficients adopted from the International Energy Agency.[10]

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[10] 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. Nuclear electricity generation is assumed to require 1 GJ of energy for each GJ of thermal energy generated.

Table 7: Reference case natural gas consumption

	Unit	2010	2020	2030	2040	2050
Demand Sectors						
Residential	PJ	645	737	766	758	737
Commercial	PJ	613	745	880	1,055	1,235
Transportation	PJ	8	2	1	1	0
Manufacturing Industry	PJ	762	821	907	1,060	1,245
Supply Sectors						
Electricity Generation	PJ	265	304	346	421	488
Petroleum Refining	PJ	80	110	128	147	166
Crude Oil	PJ	542	955	1,058	1,072	1,162
Natural Gas	PJ	624	535	448	397	347
Coal Mining	PJ	3	3	4	4	4
Biofuels Manufacturing	PJ	1	1	5	7	7
Total	PJ	3,543	4,213	4,543	4,922	5,392

Table 8: Reference case refined petroleum product consumption

	Unit	2010	2020	2030	2040	2050
Demand Sectors						
Residential	PJ	66	18	11	9	7
Commercial	PJ	58	40	33	37	43
Transportation	PJ	2,873	3,503	3,660	3,931	4,348
Manufacturing Industry	PJ	144	160	160	183	203
Supply Sectors						
Electricity Generation	PJ	105	56	6	5	5
Petroleum Refining	PJ	92	92	90	98	109
Crude Oil	PJ	75	89	115	188	236
Natural Gas	PJ	25	24	20	18	16
Coal Mining	PJ	6	8	8	9	10
Biofuels Manufacturing	PJ	1	1	2	3	5
Total	PJ	3,445	3,992	4,106	4,482	4,982

Table 9: Reference case electricity consumption

	Unit	2010	2020	2030	2040	2050
Demand Sectors						
Residential	PJ	638	749	919	1,149	1,502
Commercial	PJ	524	627	726	864	1,020
Transportation	PJ	7	10	45	83	102
Manufacturing Industry	PJ	706	715	752	830	926
Supply Sectors						
Electricity Generation	PJ	0	0	0	0	0
Petroleum Refining	PJ	15	15	14	15	16
Crude Oil	PJ	60	92	92	88	86
Natural Gas	PJ	42	47	44	42	40
Coal Mining	PJ	4	5	4	5	5
Biofuels Manufacturing	PJ	0	0	2	2	3
Total	PJ	1,995	2,260	2,597	3,077	3,700

Based on total energy consumption as well as on process emissions in the industrial and energy supply sectors, we calculate the greenhouse gas emissions associated with the reference case forecast, as shown in Table 10. While the CIMS model captures virtually all energy consumption and production in the economy, it does not capture the methane and nitrous oxide emissions from agriculture and the production of adipic and nitric acid, among other minor sectors. In 2005, these sectors represented about 10% of total greenhouse gas emissions, measured on an equivalent global warming potential basis.

Table 10: Reference case greenhouse gas emissions

	Unit	*2010*	*2020*	*2030*	*2040*	*2050*
Demand Sectors						
Residential	*Mt* CO_2e	39	40	41	40	39
Commercial	*Mt* CO_2e	35	41	47	56	66
Transportation	*Mt* CO_2e	208	253	263	282	312
Manufacturing Industry	*Mt* CO_2e	85	90	97	109	125
Landfills	*Mt* CO_2e	29	31	32	33	34
Supply Sectors						
Electricity Generation	*Mt* CO_2e	123	113	119	138	170
Petroleum Refining	*Mt* CO_2e	20	24	26	29	32
Crude Oil	*Mt* CO_2e	94	158	170	181	193
Natural Gas	*Mt* CO_2e	64	56	47	42	37
Coal Mining	*Mt* CO_2e	2	3	3	3	3
Biofuels Manufacturing	*Mt* CO_2e	0	0	1	1	1
Total	*Mt* CO_2e	698	807	845	915	1,012

Table 10 shows that in the absence of new policies to control greenhouse gas emissions, emissions are expected to grow from current levels in most sectors of the Canadian economy. Especially strong growth is expected in the crude oil and transportation sectors, as a result of rapidly expanding output.

Differences between the reference case and the reference case used in "Getting to 2050"

Since the modelling for *Getting to 2050*, CIMS has undergone several revisions, of which we highlight the most major changes:

- **The price for refined petroleum products was updated to account for the recent rise in the price for oil and to incorporate the latest forecast from the Energy Information Administration.** In *Getting to 2050*, the price for oil was based on a forecast from Natural Resources Canada's "Canada's Energy Outlook", which predicted that the world price oil would drop from $60 per barrel ($2003 US) in 2005 to $45 per barrel in 2010, and remain unchanged thereafter.[11] At the time of writing this report in 2008, the price for oil had just exceeded $140

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[11] The price for oil is based on the price of West Texas Intermediate at Cushing Oklahoma. Natural Resources Canada, 2006, "Canada's Energy Outlook".

per barrel. In order to account for the higher price for oil, we revised the price for oil based the historic prices between January 2006 and May 2008 and the latest forecast from the Energy Information Administration.[12] Table 11 shows the difference between the price for oil used in *Getting to 2050* and the price used in the current study.

Table 11: Difference between the price for oil in "Getting to 2050" and the current report ($2005 US / barrel)

	2006-2010	*2011-2015*	*2016-2020*	*2021-2025*	*2026-2030*	*2031-2050*
Getting to 2050	$46.84	$46.84	$46.84	$46.84	$46.84	$46.84
Current Report (Historic & EIA, 2008)	$85.57	$64.24	$56.97	$61.22	$66.67	$69.04

- **Revised growth rates for the crude oil sector.** We reduced the growth rates for the crude oil sector to reflect the most recent forecast from the Canadian Association of Petroleum Producers. In *Getting to 2050*, the output from the crude oil sector reached 8,200 barrels per day in 2050, whereas in the present study, output reaches 7,000 barrels per day. We also increased the output of blended bitumen and reduced the output of synthetic crude, which reduces the emissions from the sector. By 2050, greenhouse gas emissions from the petroleum crude sector are approximately 110 Mt CO_2e lower in the current reference case than in *Getting to 2050*.
- **Revised growth rates for the transportation sector.** Since *Getting to 2050*, we increased the growth rates for passenger kilometres travelled by air and by road in the transportation sector. We revised the growth rates to reflect the growth rates reported in Natural Resources Canada's "Canada's Energy Outlook" (2006). The higher growth rates increase emissions from transportation, although the increase in emissions is moderated by the higher price for oil. In 2050, transportation emissions are approximately 40 Mt CO_2e greater than in *Getting to 2050*.
- **Revised growth rates for the industrial sectors.** In order to develop a forecast of industrial output to 2050, we extended the forecast from Natural Resources Canada, which ends at 2020. Since, *Getting to 2050*, we have moderated our growth rates for many industrial sectors, which reduced emissions by approximately 60 Mt CO_2e.
- **New landfill model.** We added a landfill model to account for the emissions and abatement opportunities from Canada's landfills. By 2050, we forecast landfills will produce approximately 34 Mt CO_2e in the absence of any mitigation policy.

In total, the changes made to CIMS between the *Getting to 2050* study and the current report reduced total greenhouse gas emissions in 2050 from 1,190 Mt to 1,015 Mt CO_2e.

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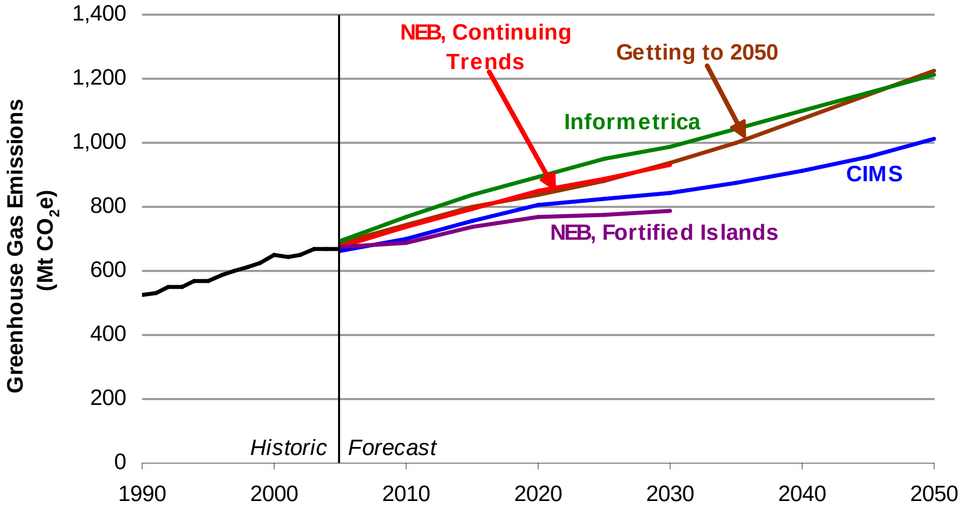
[12] Energy Information Administration, 2008, "Annual Energy Outlook, 2008", United States Department of Energy.

The reference case in context

Figure 4 compares the total greenhouse gas emissions reported in this reference case to the reference case from *Getting to 2050*, a recent forecast by Informetrica Ltd. prepared for the federal government, and the recently released National Energy Board forecast. The National Energy Board published several forecasts with different assumptions about energy prices: in the "Continuing Trends" forecast, the price for oil declines to $50 US per barrel by 2010, and in the "Fortified Islands" forecast, the price for oil remains at $85 per barrel through 2030. The price forecast for oil used in the present study is between the two forecasts from National Energy Board.

The forecast of greenhouse gas emissions in this report is generally lower than the forecasts from other sources, including the forecast from *Getting to 2050*. The lower forecast is mostly due to the increase in oil prices, but also due to changes in sector growth rates.

Figure 4: Reference case greenhouse gas emissions



Note: This chart excludes emissions from agroecosystems and some other sectors, which in 2005 represented about 10% of the Canada's total. Historic emissions in this chart (1990-2005) are from Environment Canada, 2007, "National Inventory Report".

A roadmap to deep reductions in greenhouse gas emissions

Context

This section explores how a deep reduction in greenhouse gas emissions affects the major sectors of the economy that contribute to greenhouse gas emissions. It projects the environmental (measured in energy consumption and greenhouse gas emissions) and economic impacts (e.g., the cost of manufacturing cement or the cost of operating a household) of the reduction in greenhouse gas emissions. The section also forecasts the technological developments necessary to attain deep reductions in greenhouse gas emissions in each sector.

We use wedge diagrams to illustrate the relative contribution of different actions – taken by businesses and consumers – to a reduction in greenhouse gas emissions from their business as usual trajectory. In most cases, wedges are presented based on the *technical potential* for greenhouse gas reductions. While this can be a useful concept, it does not capture the relative cost of different actions, the behaviour and preferences of firms and individuals, the interaction between different actions, or the types and stringency of policies that might be necessary to trigger the actions. Using CIMS, we instead present a wedge diagram for each sector based on the estimated response of firms and individuals to the regulatory framework as 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, energy and goods and services prices and changes in output.

Each wedge below corresponds to reductions of GHG emissions relative to the reference case as a result of key actions. The top wedge labelled “Energy Efficiency” represents the greenhouse gas reductions caused by increases in energy efficiency. Energy efficiency improves significantly in the reference case, and it should be noted that the wedge shown here only depicts the supplemental energy efficiency savings compared to the reference case. The wedge labelled “Carbon Capture & Storage” represents the GHG reductions from carbon capture and storage. The adoption of carbon capture and storage often increases the energy requirements of a sector, and offsets energy efficiency improvements in other end-uses. In order to show how the decline in energy efficiency from carbon capture offsets the other energy efficiency improvements, we show a wedge labelled “Energy Efficiency, Carbon Capture Overlap”. The wedge labelled “Fuel Switching” captures the GHG reductions associated with switching from fuels with relatively higher GHG intensity (e.g., coal) to fuels with lower GHG intensity (e.g., natural gas or renewable fuels). The wedge labelled “Output” represents the reduction in GHG emissions caused by declines in production from the sector. We show additional wedges that represent other actions taken by firms to reduce their emissions, but that do not fall into the categories described above. These actions include flaring from landfill gas, improved computer controls in aluminium smelting that reduce the occurrence of anode events that produce perfluorocarbons, and actions taken by the upstream oil and gas sectors to reduce fugitive emissions.

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

- The current version of CIMS does not include a representation of agroecosystems, the production of nitric and adipic acid or some other minor sectors. As a result, the results shown here do not include the emissions or the abatement opportunities from these sectors. However, this analysis accounts for 90% of Canada's total greenhouse gas emissions.
- The technologies in CIMS are limited to foreseen technologies that are likely become commercially available in the timeframe of the analysis. However, high prices on greenhouse gas emissions could also stir the invention and commercialization of currently unforeseen low emissions technologies and processes. CIMS does not simulate the potential impact of these technologies, so it is likely that the modelling has missed some technological developments that could lower the long-term cost of carbon mitigation.
- Carbon capture is 90% effective at removing carbon dioxide from a flue gas stream. After including an energy efficiency penalty, a technology with carbon capture has approximately 15% of the emissions of an equivalent technology without. Future developments may improve capture efficiencies; these are not included in the modelling here.
- No nuclear energy is allowed in provinces that did not have nuclear electricity generation in 2005. Nuclear energy in other provinces has been constrained so that its share of total electric generation does not increase. We made these assumptions because the development of nuclear energy is a political decision as much as an economic one, and therefore difficult to simulate in an economic model.
- The carbon charge policy simulated here is 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.
- The policy does not change the world price for crude oil or the continental price for natural gas, and do not change the overall output of these sectors (although, since domestic demand can change, the net exports of these commodities can change).

Residential

Box 1: Key actions by the residential sector

- Most emissions reductions are attained through the adoption of electric space heating and water heating systems. By 2050, virtually the entire space heating stock consists of ground source heat pumps and electric baseboards, and the entire water heating stock is electric.
- Improving residential building shells (i.e., improved insulation or energy efficient windows) has a minimal role in the emissions reductions.

In the absence of any mitigation policy, the greenhouse gas emissions from the residential sector are projected to remain fairly stable at 40 Mt CO_2e between 2005 and 2050. In 2050, the residential is projected to contribute to around 3% of Canada's total greenhouse gas emissions.

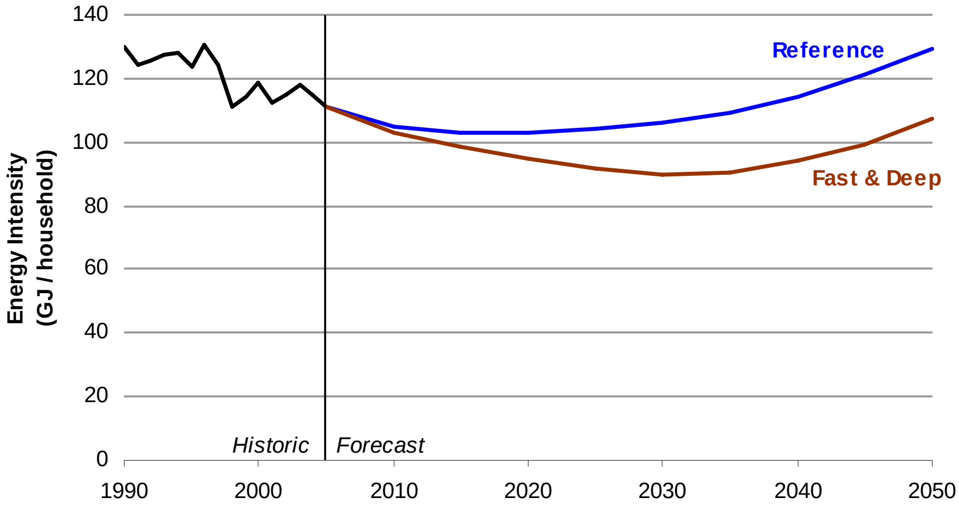
Two main energy end-uses produce almost all residential emissions: space heating accounts for approximately 58% of residential emissions, and water heating for around 42%. The emissions intensity of water heating is relatively similar across different provinces in Canada, but the emissions associated with space heating vary between provinces depending, largely, on two factors. First, provinces with low prices for electricity – especially British Columbia, Manitoba and Québec – have lower greenhouse gas intensity for space heating because of a greater installation of electric baseboards. Second, the demand for space heating varies depending on climate between different provinces. For example, British Columbia and Ontario are generally warmer and require less space heating over the winter. These factors combined, Alberta, Ontario and Saskatchewan have the highest emissions intensity per unit of space heating.

Environmental impact of policy

Energy and greenhouse gas intensity under the reference and policy scenarios are shown in Figure 5 and Figure 6. In the reference scenario, energy intensity generally increases while greenhouse gas intensity declines. The increase in energy intensity is largely because of an increase in the energy consumption by miscellaneous appliances (e.g., televisions, cell phones). The forecast of the demand for miscellaneous appliances was estimated from historic data, which show a substantial increase between 1990 and 2005. The increase in energy consumption does not affect greenhouse gas intensity, however, because most miscellaneous appliances consume electricity. Greenhouse gas intensity declines in the reference scenario due to mostly to energy efficiency improvements to residential shells and furnaces.

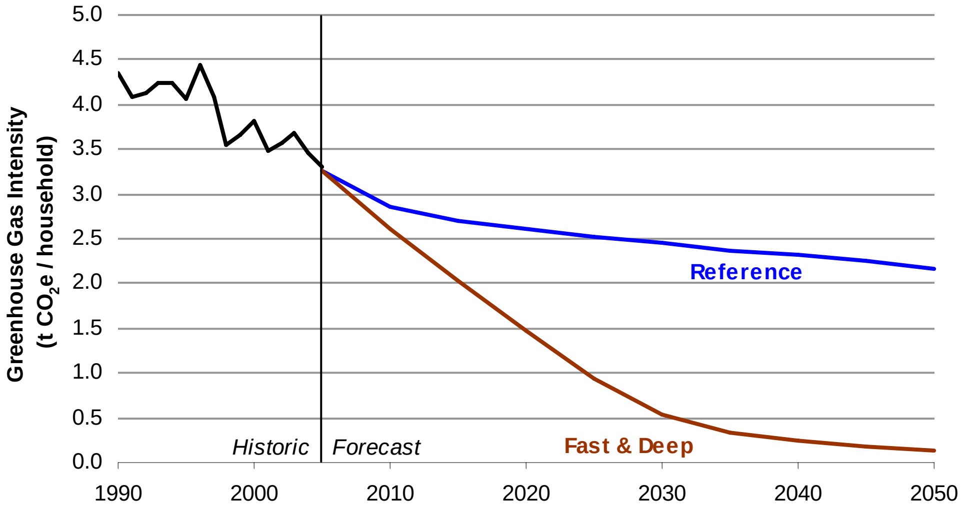
In the policy scenario, greenhouse gas intensity declines by 93% from the reference case projection. The installation of electric baseboards, ground source heat pumps and electric water heaters account for the majority of this decline.

Figure 5: Energy intensity of the residential sector



Source: Historic data are from NRCan, 2008, "Comprehensive Energy Use Database".

Figure 6: Greenhouse gas intensity of the residential sector



Source: Historic data are from NRCan, 2008, "Comprehensive Energy Use Database".

Table 12 shows the change in fuel shares in the residential sector. Households switch to electricity in response to the policy, most notably from natural gas. Air and ground source heat pumps attain a significant market share by the end of the simulation, but these technologies are shown to increase electricity consumption, rather than renewable consumption. The shift away from renewable energy is caused by a decline in biomass space heating, which produces significant methane emissions.[13]

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[13] Environment Canada, 2007, "National Inventory Report".

Table 12: Fuel switching in the residential sector

	2020	*2030*	*2040*	*2050*
Natural Gas	-18%	-32%	-34%	-30%
Electricity	20%	35%	36%	32%
Renewable	-2%	-2%	-1%	-1%

Economic impact of policy

Table 13 shows the increase in capital, operating and fuel costs that results from the policy's implementation. Energy costs increase most significantly, because the policy encourages fuel switching from natural gas to electricity, which has a higher price per unit of energy produced. The rise in capital costs are more modest because the uptake of electric baseboards by some households – which are cheaper to install than natural gas furnaces – offset the cost of ground source heat pumps installed by other households. Overall, the total increase in cost per household is a fraction of a percent. We do not discuss emissions costs in detail, because they are returned to the households in the policy scenario.

Table 13: Increase in cost by cost-type (2005$ / household)

	Increase in Costs (2005$ / household)			
	2020	*2030*	*2040*	*2050*
Total Cost	$305.44	$447.05	$384.49	$366.42
Capital Costs	$73.41	$124.56	$114.38	$118.19
Operating & Maintenance Costs	$4.02	$5.44	$5.01	$5.57
Energy Costs	$228.00	$317.05	$265.10	$242.67
Emissions Costs	$170.40	$163.37	$73.47	$41.40

Provincial discussion

In response to the policy, households in all provinces make a shift towards low-emissions systems for space heating, but some provinces show a greater adoption of ground source heat pumps while others show greater penetration of electric baseboards. In Ontario, Alberta and Saskatchewan, 37%, 61% and 33% of households have installed ground source heat pumps by 2050. British Columbia, Manitoba, Québec and the Atlantic provinces show greater penetration of electric baseboards. By the end of the policy simulation, the difference in the greenhouse gas intensity of space heating is negligible between provinces (see Table 14).

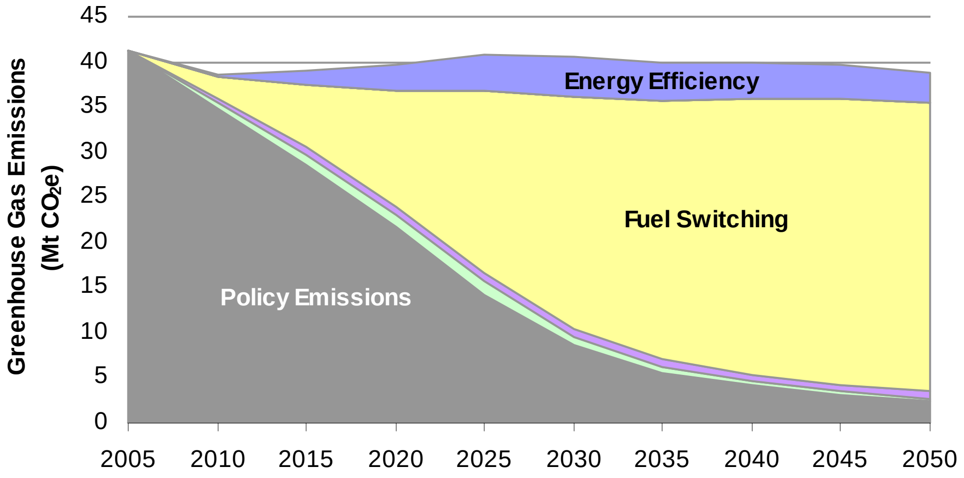
Table 14: Space heating emissions intensity by province

	Space Heating Emissions Intensity in Policy (t CO2e / m2 floorspace)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
British Columbia	0.004	0.001	0.001	0.000	-34%	-74%	-85%	-89%
Alberta	0.019	0.007	0.002	0.001	-31%	-73%	-92%	-97%
Saskatchewan	0.011	0.003	0.001	0.000	-42%	-82%	-96%	-98%
Manitoba	0.003	0.000	0.000	0.000	-57%	-96%	-99%	-99%
Ontario	0.010	0.004	0.002	0.001	-32%	-70%	-88%	-93%
Québec	0.001	0.000	0.000	0.000	-84%	-96%	-92%	-92%
Atlantic	0.005	0.001	0.000	0.000	-54%	-85%	-96%	-99%

Technology roadmap to low emissions in the residential sector

Figure 7 illustrates the actions that contribute to the decline in greenhouse gas emissions in the residential sector. Fuel switching accounts for approximately 83% of the reduction, while energy efficiency (e.g., the adoption of ground source heat pumps) contributes around 8%.

Figure 7: Wedge diagram for the residential sector



Residential shells show only a modest improvement in the policy scenario. The energy efficiency of building shells improves regardless of the policy – by 2050, residential shells are about 5% more efficient than standard construction in 2005. Whereas in the policy scenario, building shells improve slightly too around 8% more efficient than standard practices in 2005 (see Table 15).

Table 15: Improvement in residential shells over standard practices in 2005

	2020	*2030*	*2040*	*2050*
Reference Case	0.2%	0.9%	2.4%	4.5%
Fast & Deep	0.5%	2.1%	4.8%	7.8%
Increase due to Policy	0.3%	1.2%	2.3%	3.3%

The main action to reduce greenhouse gas emissions in the residential sector is the adoption of electric space heating systems – by 2050 in the policy scenario, over 97% of installed heating systems use electricity (see Table 16). The installation of electric baseboards and ground source heat pumps account for the majority of installations, while air source heat pumps account for the remainder. Table 17 shows that water heating also becomes mostly electric in response to the policy.

Table 16: Penetration of electric space heating systems

	Technology Penetration (% of total stock)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Electric Baseboards	46%	51%	51%	51%	14%	19%	19%	19%
Air Source Heat Pumps	19%	31%	21%	13%	10%	19%	8%	1%
Ground Source Heat Pumps	0%	6%	22%	33%	0%	6%	21%	29%

Table 17: Penetration of electric water heating systems

	Technology Penetration (% of total stock)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Electric Water Heating	60%	83%	89%	93%	35%	62%	69%	72%

Provinces with higher forecasted electricity prices in the policy scenario – especially Alberta, Saskatchewan Ontario and the Atlantic provinces – have greater incentives to reduce electricity costs by installing ground source heat pumps (see Table 18).

Table 18: Penetration of electric space heating systems by province in 2050

	Electric Baseboards	*ASHP*	*GSHP*
British Columbia	74%	13%	10%
Alberta	13%	10%	76%
Saskatchewan	44%	17%	38%
Manitoba	79%	12%	9%
Ontario	33%	19%	43%
Québec	94%	1%	3%
Atlantic	68%	5%	26%

The policy has a negligible impact on the capital expenditures of the sector (see Table 19). As discussed above, expenditures on ground source heat pumps tend to increase costs, but these are offset by reduced expenditures due to the installation of electric baseboards – which are generally cheaper to install than natural gas furnaces.

Table 19: Increase in capital expenditures in the residential sector

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	41	-117
Increase in Capital Expenditures (% above the reference case)	0%	0%

Commercial

Box 2: Key actions by the commercial sector

- The commercial sector reduces most of its greenhouse gas emissions through the adoption of electric heating systems – electric baseboards and ground source heat pumps. Ground source heat pumps have a greater adoption in provinces with greater increases in electricity prices in the policy scenario.
- Building shells do not improve substantially from the policy's implementation.

By the end of the simulation period, projected floor space in the commercial sector is expected to more than double, reaching 1,561 million m^2 in 2050. Greenhouse gas emissions mirror this growth and, in the absence of any emissions mitigation policy, increase from 34 Mt CO_2e in 2005 to 66 Mt CO_2e in 2050. Like the residential sector, space conditioning and water heating produce almost all commercial emissions: approximately 75% are attributed to space conditioning and 14% to water heating.

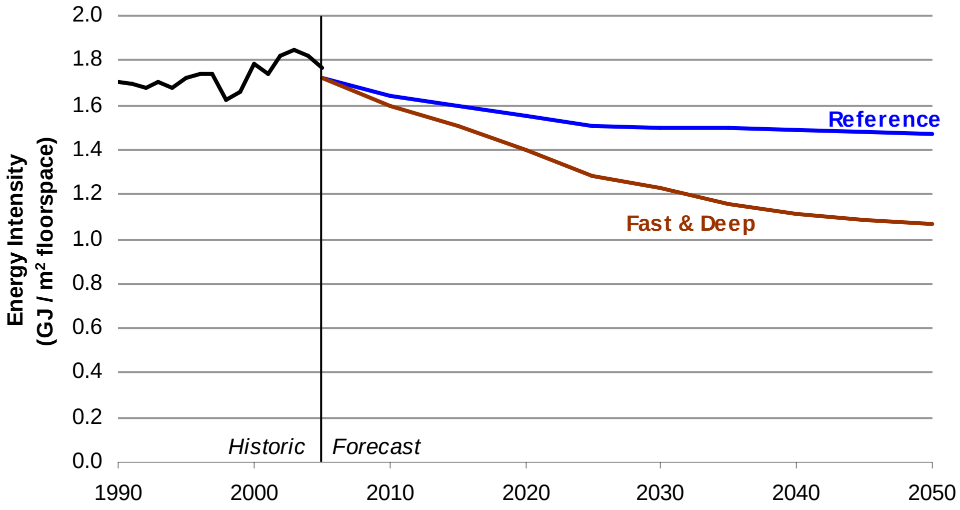
Many of the same factors responsible for provincial differences in the residential sector – differences in energy prices and climate – also influence the commercial sector. However at the beginning of the simulation, greenhouse gas intensity for space conditioning is reasonably similar among the provinces – around 0.05 t CO_2e per m^2 of floorspace for all provinces except British Columbia and Saskatchewan.

Environmental impact of policy

Figure 8 and Figure 9 show the energy and greenhouse gas intensity of the commercial sector in the reference and policy scenarios. In the absence of any policy, the improvement in energy and greenhouse gas intensity over time is mostly the result of improvements in building shells over time and the installation of electric heating systems in some provinces.

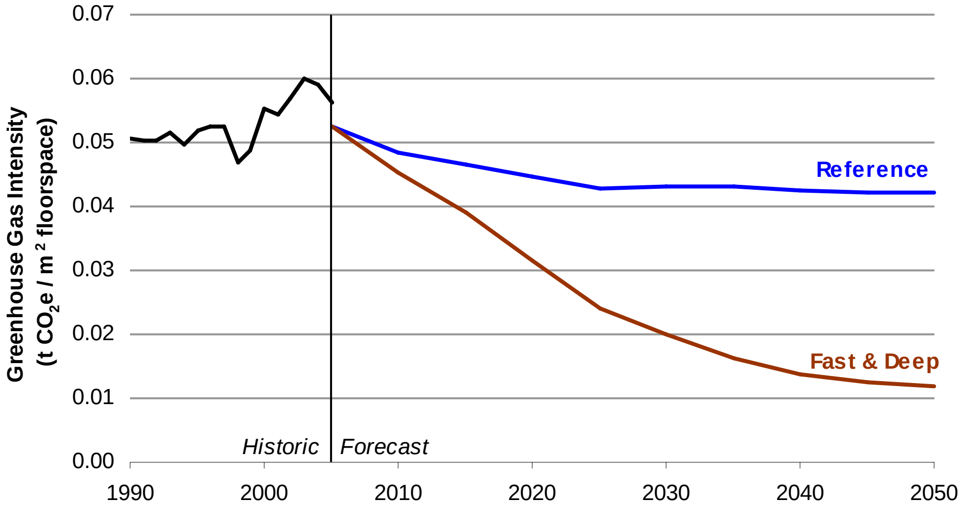
In the policy scenario, the adoption of electric space and water heating systems account for most of the reduction in energy and greenhouse gas intensity. By the end of the policy scenario, energy and greenhouse gas intensity decline by 38% and 70% from the reference case projection.

Figure 8: Energy intensity of the commercial sector



Source: Historic data are from NRCan, 2008, “Comprehensive Energy Use Database”.

Figure 9: Greenhouse gas intensity of the commercial sector



Source: Historic data are from NRCan, 2008, "Comprehensive Energy Use Database".

Table 20 shows the change in fuel shares in the commercial sector. Similar to the residential sector, the commercial sector switches to electricity in response to the policy, most notably from natural gas. The policy induces as significant penetration of ground source heat pumps, but these actions show up as an increase in electricity consumption, rather than an increase in renewable consumption.

Table 20: Fuel switching in the commercial sector

	2020	*2030*	*2040*	*2050*
Natural Gas	-12%	-24%	-32%	-35%
Electricity	12%	24%	33%	35%

Economic impact of policy

Table 21 shows the increase in capital, operating and fuel costs caused by the policy. Capital costs show the only significant increase because the policy encourages the installation of improved building shells and ground source heat pumps, both of which have higher capital requirements than alternative options. Conversely, energy costs decline from the energy efficiency improvements to shells as well as the installation of ground source heat pumps. Overall, the total increase in cost per m^2 of floorspace is a fraction of a percent. We do not discuss emissions costs because they are returned as a lump-sum to the commercial sector.

Table 21: Increase in cost by cost-type (2005$ / m^2 floorspace)

	Increase in Costs (2005$ / m2 floorspace)			
	2020	*2030*	*2040*	*2050*
Total Cost	-$0.20	$0.38	$0.21	$0.07
Capital Costs	-$0.54	$0.27	$0.90	$1.23
Operating & Maintenance Costs	$0.00	$0.00	$0.00	$0.00
Energy Costs	$0.34	$0.11	-$0.69	-$1.15
Emissions Costs	$3.63	$6.04	$4.14	$3.58

Provincial discussion

Similar to the residential sector, all provinces make a policy-induced shift towards more energy efficient building shells and electric space conditioning systems. In Ontario, Alberta, Saskatchewan, higher prices for electricity in the policy scenario encourage the adoption of ground source heat pumps, which meet most of the demand for space heating by 2050. British Columbia, Manitoba, and Québec, for whom electricity prices are lower in the policy scenario, favour electric baseboards for space heating. Though technology choices differ, by 2050 at least 90% of installed heating systems in all provinces are either electric baseboard or ground source heat pumps, and the greenhouse gas intensity of space heating reaches approximately the same level in all provinces. Table 22 shows the difference in te greenhouse gas intensity of space conditioning between provinces.

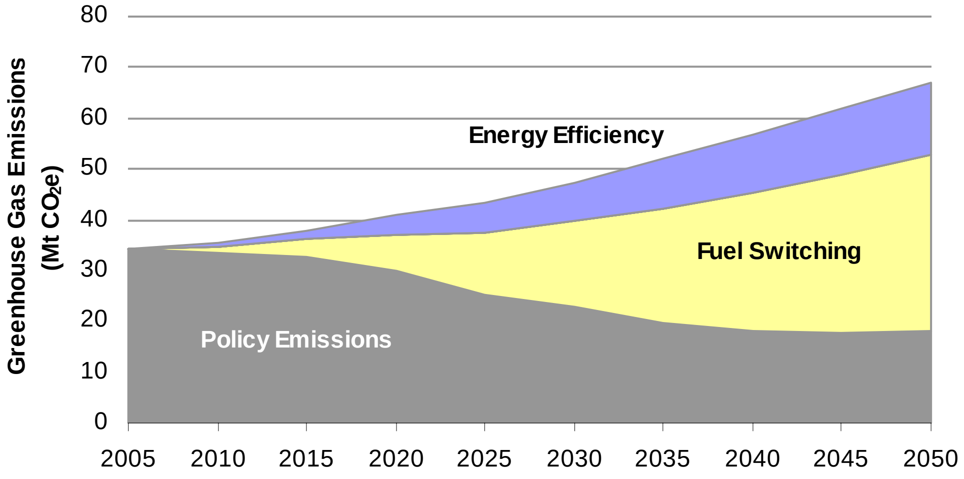
Table 22: Space conditioning emissions intensity by province

	Space Conditioning Emissions Intensity in Policy (t CO2e / m2 floorspace)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
British Columbia	0.017	0.011	0.008	0.008	-27%	-49%	-61%	-63%
Alberta	0.029	0.019	0.011	0.008	-32%	-57%	-74%	-80%
Saskatchewan	0.036	0.023	0.015	0.013	-27%	-49%	-65%	-70%
Manitoba	0.015	0.008	0.007	0.007	-28%	-46%	-47%	-47%
Ontario	0.029	0.019	0.010	0.007	-31%	-55%	-75%	-82%
Québec	0.015	0.008	0.007	0.007	-25%	-40%	-38%	-33%
Atlantic	0.027	0.017	0.010	0.007	-32%	-57%	-76%	-81%

Technology roadmap to low emissions for the commercial sector

Figure 10 illustrates the key actions that contribute to the decline in greenhouse gas emissions in the commercial sector: fuel switching accounts for approximately 70% of the reduction in greenhouse gas emissions, while energy efficiency actions account for around 30%. Some actions such as the adoption of ground source heat pumps can cause both improvements in energy efficiency and fuel switching to electricity.

Figure 10: Wedge diagram for the commercial sector



The policy does not induce significant improvements in building shells (see Table 23). In the reference case by 2050, the average building shell is around 8% better than standard construction from 2005; in the policy scenario, the average shell shows a small improvement to 9%.

Table 23: Improvement in commercial shells over standard practices in 2005

	2020	*2030*	*2040*	*2050*
Reference Case	1.9%	4.4%	6.4%	7.8%
Fast & Deep	2.6%	5.6%	7.7%	8.9%
Increase due to Policy	0.8%	1.2%	1.3%	1.1%

The main action that reduces the greenhouse gas emissions from the commercial sector is the adoption of electric heating systems. By 2050, the heating systems have almost been completely decarbonized, with electric baseboards and ground source heat pumps accounting for 97% of installed systems.

Table 24: Penetration of commercial space-heating systems

	Technology Penetration (% of total stock)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Electric Furnaces	35%	42%	40%	36%	16%	24%	23%	20%
Ground Source Heat Pumps	16%	33%	52%	61%	10%	24%	41%	50%

Table 25 shows the penetration for electric furnaces and ground source heat pumps by province. British Columbia, Manitoba, Québec and the Atlantic provinces favour the installation of electric furnaces. Alberta, Saskatchewan and Ontario adopt a greater number of ground source heat pumps (GHSP) due, mostly, to higher electricity prices.

Table 25: Penetration of heating systems by province

	Electric Furnaces	*GSHP*
British Columbia	94%	4%
Alberta	32%	63%
Saskatchewan	11%	87%
Manitoba	53%	47%
Ontario	8%	89%
Québec	59%	41%
Atlantic	71%	23%

Capital expenditures by the commercial sector increase modestly in response to the policy (see Table 26). The decline in expenditures in the medium-term is mostly due to a greater penetration of electric baseboards, which have lower installation costs. In the long-term, capital expenditures increase due to the uptake of ground source heat pumps in many provinces.

Table 26: Increase in capital expenditures due to policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	-136	642
Increase in Capital Expenditures (% above the reference case)	-1%	2%

Transportation

Box 3: Key actions by the transportation sector

- The majority of emissions reductions are attained by fuel switching to electricity and renewable fuels (i.e., ethanol and biodiesel).
- By 2050 in the policy scenario, most passenger vehicles (85%) are plug-in hybrids.
- The policy also causes significant increases in freight transport by rail, which has lower energy and greenhouse gas intensity per tonne of freight travelled, and increases in passenger travel by transit.

Transportation is the largest contributor to Canada's greenhouse gas emissions by 2050, accounting for 310 Mt CO_2e and representing approximately 28% of total emissions.[14] Within the transportation sector, several end-uses contribute to greenhouse gas emissions, of which the most significant are passenger vehicles and road freight transportation. Passenger vehicles and road freight are each forecasted to represent approximately 40% of the transportation sector's emissions in 2050. Domestic aviation and domestic marine freight account for most of the remaining emissions.

The provincial differences in the transportation sector are relatively minor in comparison to other sectors, so we ignore them in this section. The key difference between different provinces is that coastal provinces have marine freight transportation, whereas in-land provinces do not.

Environmental impact of policy

Figure 11 and Figure 12 show the energy and greenhouse gas intensity of personal transportation. In the reference case, the decline in energy and emissions intensity is mostly the result of improvements in the energy efficiency of passenger vehicles. Energy efficiency for passenger vehicles declines due to improvements in engines (e.g., supercharged and turbo charged engines), as well as the adoption of hybrid cars, which account for 60% of the passenger vehicle stock in 2050.

After the policy's implementation, the energy and greenhouse gas intensity of passenger transportation decline by 23% and 68% from the reference case projection, respectively. The decline in emissions intensity is largely the result of a more rapid adoption of hybrid

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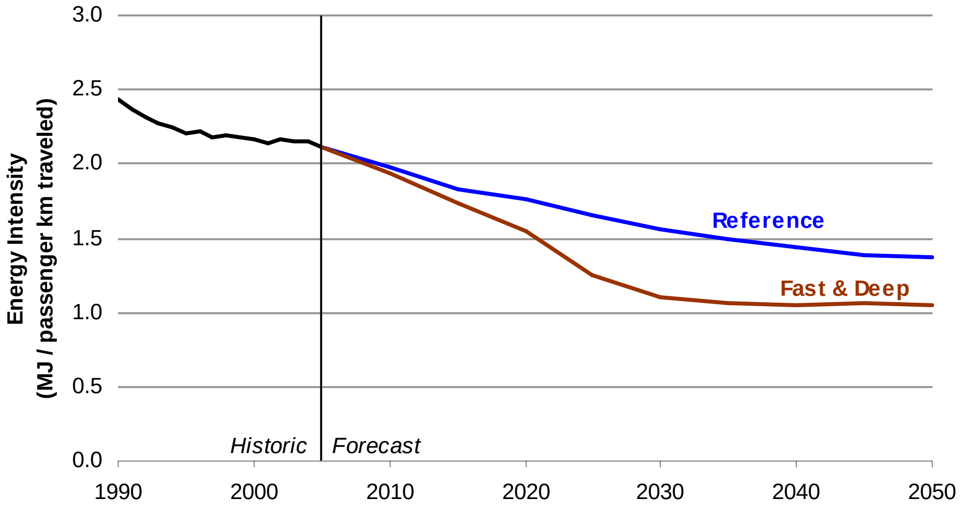
[14] The transportation sector excludes the greenhouse gas emissions associated with pipelines, which are accounted for in the fossil fuel extraction and refining industries.

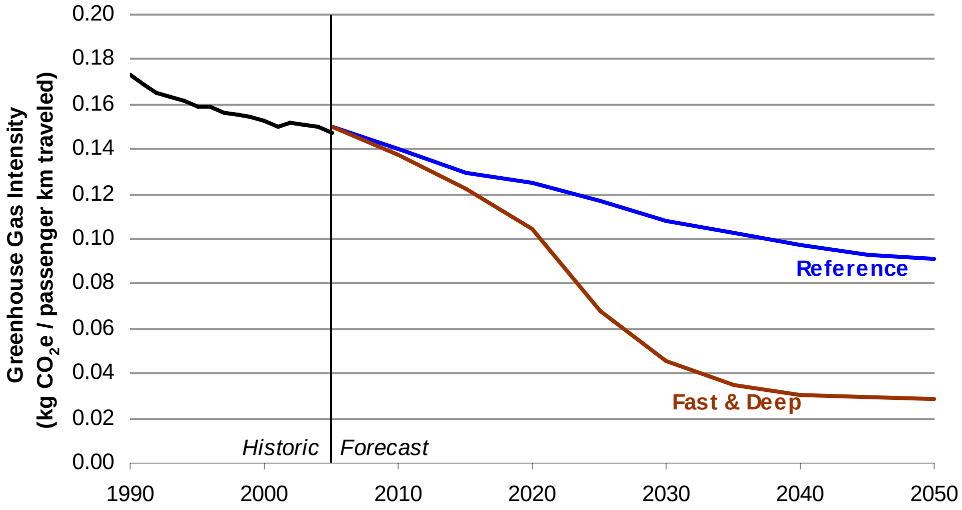
cars in the medium-term, and the adoption of plug-in hybrid vehicles and the consumption of biofuels (ethanol and biodiesel) in the long-term.

Figure 11: Energy intensity of personal transportation



Source: Historic data are from NRCan, 2008, “Comprehensive Energy Use Database”.

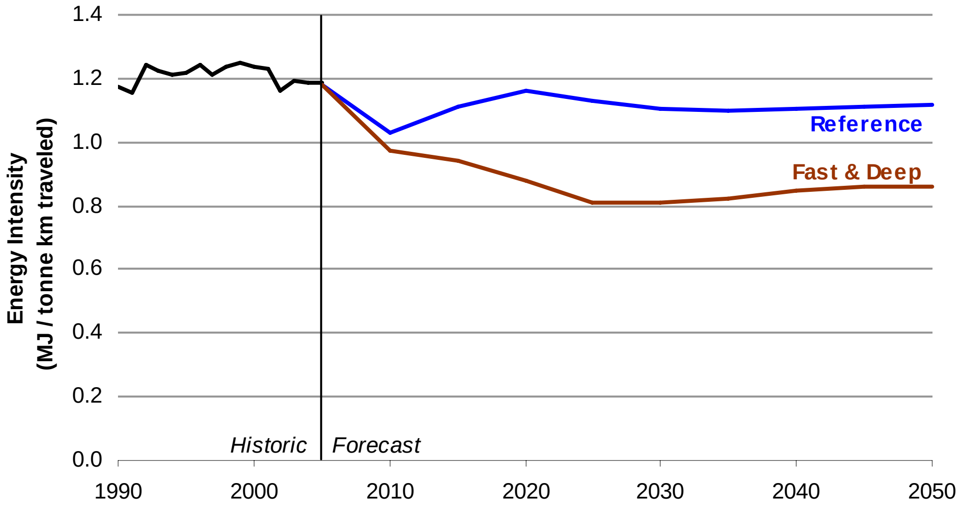
Figure 12: Greenhouse gas intensity of personal transportation



Source: Historic data are from NRCan, 2008, “Comprehensive Energy Use Database”.

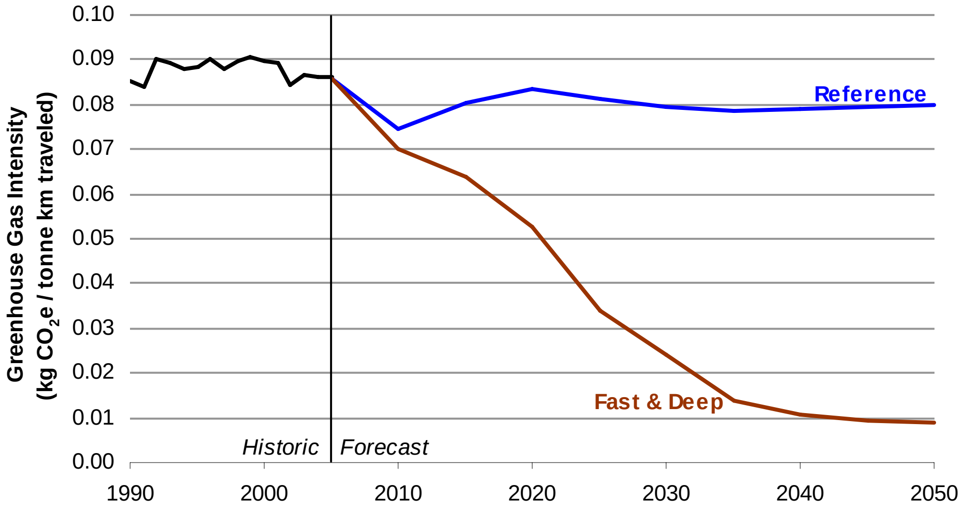
Figure 13 and Figure 14 show the energy and greenhouse gas intensity of freight transportation. Energy and greenhouse gas intensity decline in the reference case, but less significantly than in the personal transportation sector. In the policy scenario, the energy and greenhouse gas intensity of freight transportation decline from the reference case projection by 23% and 90%, respectively. The decline in emissions intensity is mostly the result of the converting the road freight fleet to biodiesel, and a mode shift towards more travel from rail.

Figure 13: Energy intensity of freight transportation



Source: Historic data are from NRCan, 2008, "Comprehensive Energy Use Database".

Figure 14: Greenhouse gas intensity of freight transportation



Source: Historic data are from NRCan, 2008, "Comprehensive Energy Use Database".

Table 27 shows that the fuel share of refined petroleum products declines as a result of the policy, and the share of electricity and renewable fuels increases. The increase in electricity consumption results mainly from the adoption of plug-in hybrid vehicles, which attain significant market shares by 2050.

Table 27: Fuel switching in transportation

	2020	*2030*	*2040*	*2050*
Refined Petroleum Products	-9%	-47%	-66%	-68%
Electricity	2%	9%	10%	10%
Renewable	7%	38%	55%	57%

Economic impact of policy

Table 28 and Table 29 show the rise in the costs of passenger and freight transportation caused by the policy. The costs of personal transportation decline by $12 per thousand person kilometre traveled, a 6% decrease. The policy induces people to purchase smaller passenger vehicles and, to a lesser extent, to take public transit; therefore reducing their costs of transporting themselves. The costs of freight transportation decline by approximately 6% in the policy scenario, mostly from a mode shift towards rail travel. We note that the decline in freight costs may be offset by rises in costs not represented in CIMS (e.g., warehousing).

Table 28: Increase in the cost of passenger transportation

	Increase in Costs (2005$ / '000 pkt)			
	2020	*2030*	*2040*	*2050*
Total Cost	-$16.51	-$24.05	-$13.56	-$12.00
Capital Costs	-$7.73	-$9.38	-$4.84	-$4.62
Operating & Maintenance Costs	-$4.36	-$5.42	-$3.61	-$3.51
Energy Costs	-$4.42	-$9.25	-$5.11	-$3.87
Emissions Costs	$12.00	$13.53	$9.20	$8.61

Table 29: Increase in the cost of freight transportation

	Increase in Costs (2005$ / '000 tkt)			
	2020	*2030*	*2040*	*2050*
Total Cost	-$15.25	-$12.14	-$4.45	-$4.46
Capital Costs	-$4.12	-$4.15	-$2.63	-$2.64
Operating & Maintenance Costs	-$5.86	-$5.60	-$4.71	-$5.10
Energy Costs	-$5.27	-$2.39	$2.89	$3.28
Emissions Costs	$8.75	$9.91	$4.87	$4.11

Technology roadmap to low emissions in transportation

Figure 15 shows the actions that contribute to the decline in greenhouse gas emissions from personal and freight transportation. The key actions that reduce emissions are fuel switching to renewables and electricity, and improvements in energy efficiency. These actions account for 205 Mt CO_2e and 40 Mt CO_2e of emissions reductions in 2050, respectively.

Figure 15: Wedge diagram for personal and freight transportation

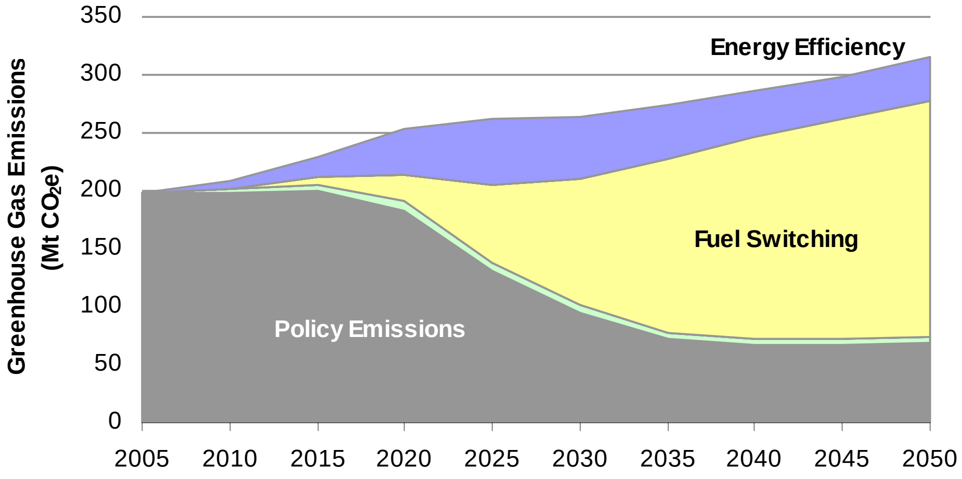


Table 30 shows the penetration of low- and zero-emissions passenger vehicles in the policy scenario, and it shows the increase relative to the reference case (i.e., a technology's penetration in policy minus its penetration in the reference case). The first response to the policy is that consumers begin purchasing hybrid vehicles. At the beginning of the policy simulation (up to 2030), the penetration of hybrid vehicles exceeds its penetration in the reference case, indicating that consumers select hybrid vehicles to reduce their emissions. By the end of the simulation, plug-in hybrids account for 83% of the passenger vehicle stock, while the penetration of hybrid vehicles is lower than its penetration in the reference case. Hybrid vehicles are likely a transition technology, where manufacturers accumulate experience with battery vehicles, and apply that learning to plug-in hybrid vehicles that enable greater long-term emissions reductions.

Table 30: Penetration of low- and zero-emission passenger vehicles

	Technology Penetration (% of total Stock)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Hybrid	3%	6%	11%	12%	2%	3%	-14%	-29%
Plug-in Hybrid	6%	18%	21%	21%	6%	10%	7%	6%
Plug-in Hybrid Ethanol	7%	51%	62%	62%	7%	50%	60%	59%

Table 31 shows mode shifting in personal transportation. By 2050, the policy induces a 3% increase in the occupancy of passenger vehicles, and it increase transit ridership by 14%. The increase in transit ridership and vehicle occupancy peaks in 2030 and declines thereafter due to two factors. First, the emissions costs of driving a passenger vehicle are greater in 2030 because the stock of vehicles is more greenhouse gas intensive. By 2050, the stock of vehicle produces fewer greenhouse gases per kilometre traveled and driving increases. Second, the cost of purchasing low and zero-emissions vehicles declines over the policy simulation as manufacturers accumulate experience with these vehicles. By 2050, the purchase cost of a low or zero-emission vehicle is lower than it was in 2030.

Table 31: Mode switching in personal transportation

	Mode Penetration				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Vehicle Occupancy (people per car)	2.3	2.3	2.3	2.2	5%	6%	4%	3%
Transit Ridership (billion pkm)	29.5	36.0	37.4	40.8	26%	27%	16%	14%

In freight transportation, the key actions that reduce greenhouse gas emissions are fuel switching to biodiesel in the road freight sector, and an increase in rail travel. Table 32 shows the fuel share for biodiesel, and Table 33 illustrates the tonnes kilometres traveled by rail and road transport. By 2050 in the policy scenario, almost all freight trucks consume biodiesel instead of refined petroleum products. Freight transport by rail increases in response to the policy. By 2050, rail freight accounts for about 70% of all freight transport.

Table 32: Fuel share for biodiesel among freight trucks

	Technology Penetration (% of total Stock)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Biodiesel fuel share	20%	72%	96%	97%	20%	72%	96%	97%

Table 33: Freight transport by mode

	Technology Penetration (tonnes km traveled)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Rail Freight	576	701	801	930	23%	19%	18%	20%
Truck Freight	194	211	312	379	-46%	-47%	-38%	-40%

Table 34 shows the increase in capital expenditures required to attain the reductions in the transportation sector. Capital expenditures decline in response to the policy for two reasons. First, the amount of freight travel declines, therefore reducing capital expenditures. Second, the policy encourages consumers to adopt smaller vehicles and, to a lesser extent, to take public transit, which have lower capital requirements per unit of passenger travel. The freight industry ships a greater portion of freight using rail, which also reduces capital expenditures.

Table 34: Increase in capital expenditures from policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	-8,414	-6,892
Increase in Capital Expenditures (% above the reference case)	-12%	-7%

Uncertainty in the analysis

The emissions reductions from the transportation sector are largely dependent on the availability of biofuels. The uncertainty associated with availability of renewable fuels is discussed in the section on biofuels.

Chemical products manufacturing

Box 4: Key actions by the chemical products sector

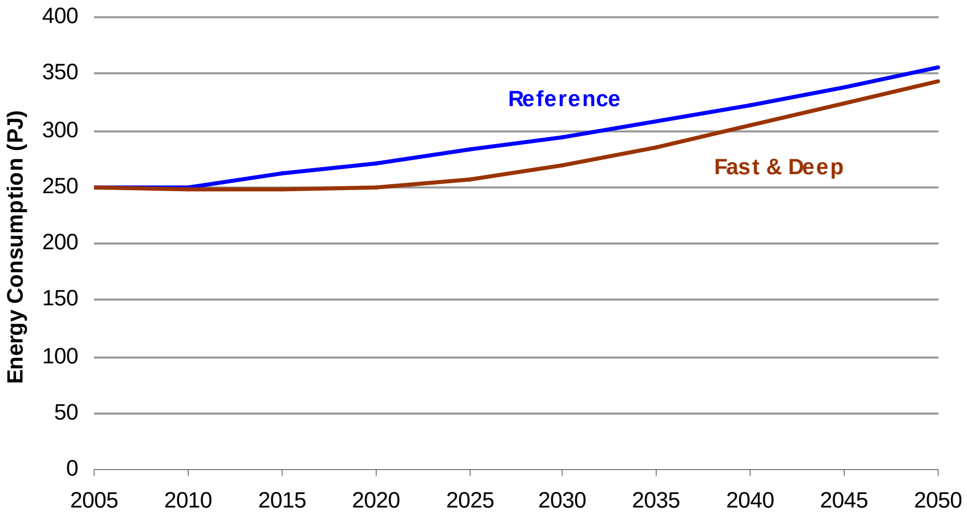
- Ammonia manufacturing produces a relatively pure stream of CO_2, offering substantial opportunity for the rapid penetration of carbon capture and storage. As early as 2020 in the policy scenario, 67% of ammonia production is associated with carbon capture.

Greenhouse gas emissions from the chemicals manufacturing sector were 11.2 Mt CO_2e in 2005 and are forecasted to rise to 16.2 Mt CO_2e by 2050. Alberta and Ontario account for 75% and 20% of greenhouse emissions from the sector, respectively. The remaining 5% of emissions originate from British Columbia and Québec. The production of process heat required in petrochemical manufacturing and process emissions from ammonia manufacturing are expected to be the largest sources of emissions.

Environmental impact of policy

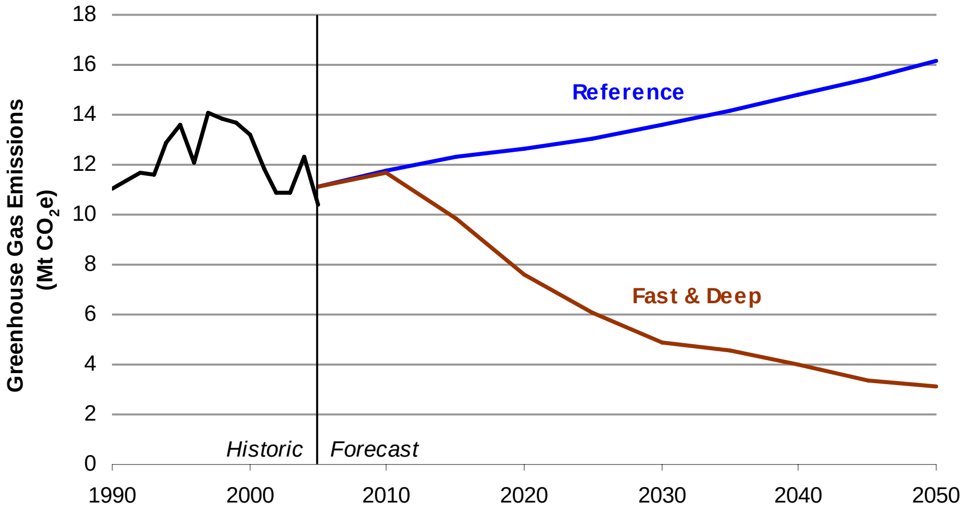
Figure 16 shows energy consumption of the chemicals manufacturing sector. The sector consumed 249 PJ in 2005, and in the reference scenario consumption rises to 355 PJ in 2050, an increase of 42%. Energy consumption is only slightly lower in the policy scenario, reaching 349 PJ in 2050. Energy efficiency improvements are outweighed by carbon capture and storage, which requires the use of additional energy.

Figure 16: Energy consumption of chemicals manufacturing



Greenhouse gas emissions also increase steadily in the reference scenario, from 11.2 Mt CO_2e in 2005 to 16.2 Mt CO_2e in 2050 (Figure 17). However, in the policy scenario the emissions drop sharply after 2015, reaching 3.4 Mt CO_2e in 2050. The dominant action responsible for decreasing emissions is carbon capture and storage associated with the production of ammonia and process heat.

Figure 17: Greenhouse gas emissions from chemicals manufacturing



Source: Historic data for combustion greenhouse gas emissions are from NRCan, 2008, "Comprehensive Energy Use Database"; historic data for process emissions are from Environment Canada, 2007, "National Inventory Report"

Table 35 shows the fuel switching which occurs across the chemicals sector in the policy scenario. Natural gas and refined petroleum products consumption is reduced in favour of electricity and coal. Coal consumption actually increases because of its potential to be combusted in boilers using carbon capture and storage.

Table 35: Fuel switching in the chemicals sector

	2020	*2030*	*2040*	*2050*
Natural Gas	-9%	-14%	-15%	-15%
Coal	3%	3%	2%	1%
Refined Petroleum Products	0%	0%	0%	0%
Electricity	6%	11%	13%	14%
Renewable	0%	0%	0%	0%

Economic impact of policy

Table 36 shows the increase in the cost of chemicals manufacturing that results from the policy. Energy costs increase the most due to the higher cost of electricity in the policy scenario. Overall, total costs are $22.18 per tonne higher in 2050 than in the reference scenario, an increase of 2.6%.

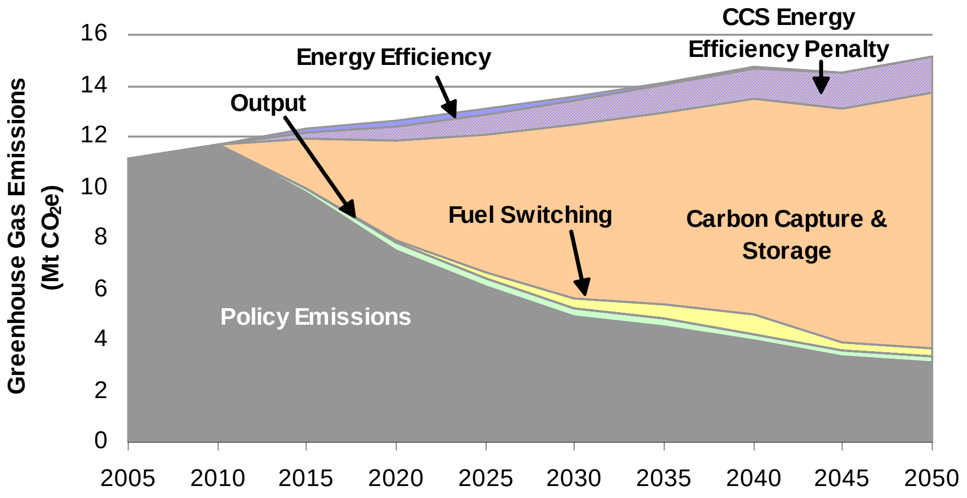
Table 36: Increase in the cost of chemicals manufacturing by component (2005$ / tonne product)

	Increase in Costs (2005$ / tonne product)			
	2020	*2030*	*2040*	*2050*
Total Cost	$7.70	$16.05	$19.26	$22.18
Capital Costs	$1.48	$2.63	$2.98	$3.20
Operating & Maintenance Costs	$3.39	$4.28	$4.56	$4.68
Energy Costs	$2.83	$9.14	$11.73	$14.29
Emissions Cost				

Technology roadmap to low emissions for chemical manufacturing

Figure 18 shows the actions that contribute to the reduction in emissions from chemicals manufacturing. The policy scenario results in 13 Mt CO_2e reductions in 2050. Carbon capture and storage is responsible for the majority of emissions reductions. In 2050, 10.0 Mt CO_2e is sequestered from ammonia production and boilers producing process heat. Fuel switching and decreased output account for 0.4 and 0.2 Mt CO_2e reductions in 2050, respectively. Greenhouse gas savings from energy efficiency improvements are outweighed by the increased energy required for carbon capture and storage.

Figure 18: Wedge diagram for the chemicals manufacturing sector



A relatively pure stream of process carbon dioxide is produced during hydrogen production for ammonia manufacturing, which requires steam reformation of methane.[15] The cost of carbon capture and storage associated with ammonia manufacturing is therefore relatively low because of this pure stream of CO_2. In addition, the majority of ammonia production occurs in Alberta (90%), which has extensive sedimentary layers appropriate for the geologic sequestration of CO_2.[16] The IPCC estimates the cost of carbon capture associated with ammonia production to be between 5 and 55US$ / tonne CO_2e.[17]

Table 37 shows the penetration of carbon capture and storage in ammonia production and process heat generation. In the policy scenario, 67% of ammonia production occurs in facilities using carbon capture and storage by 2020, rising to virtually 100% by 2040. The penetration of carbon capture and storage is less quick in process heat generation, reaching 66% in 2050. 5.4 Mt CO_2e is sequestered from ammonia production in 2050,

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[15] Environment Canada, 2007, “National Inventory Report.”

[16] ecoENERGY Carbon Capture and Storage Task Force, 2008, “Canada’s Fossil Energy Future,” http://www.energy.gov.ab.ca/Org/pdfs/Fossil_energy_e.pdf

[17] IPCC, 2006, “Carbon Dioxide Capture and Storage,” Cambridge: Cambridge University Press.

accounting for two thirds of carbon capture in the chemicals sector. The remaining 4.6 Mt CO_2e is sequestered from boilers providing process heat.

Table 37: Penetration of carbon capture and storage in chemicals manufacturing (% ammonia production and process heat generation)

	2010	*2020*	*2030*	*2040*	*2050*
Ammonia Production	0%	67%	93%	98%	99%
Process Heat Generation	0%	12%	38%	52%	66%

Table 38 shows the increase in capital expenditures from the policy scenario. Capital expenditures decrease in the policy scenario because output falls. In 2050, output decreases by 3% relative to the reference scenario. The decrease of annual capital expenditures is somewhat mitigated by the cost of carbon capture and storage.

Table 38: Increase in capital expenditures that results from policy

	Medium-Term (2011-2025)	*Long-term (2026-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	-7	-1
Increase in Capital Expenditures (% above the reference case)	-1%	0%

Uncertainty in the analysis

This analysis does not consider emissions reduction potential from adipic or nitric acid production. In 2005, adipic and nitric acid production generated for 1.4 Mt CO_2e.[18] A variety of abatement technologies are currently available that can reduce the majority of emissions from these production processes.[19]

Cement and lime manufacturing

Box 5: Key actions by the cement and lime manufacturing sector

- Most emissions reductions are attained through the adoption of carbon capture and storage.

In the absence of any mitigation policy, greenhouse gas emissions from cement and lime manufacturing are expected to rise from 15 Mt CO_2e in 2005 to 30 Mt CO_2e in 2050; by the end of the simulation period, the cement and lime sectors account for approximately 3% of Canada’s total greenhouse gas emissions. Almost all greenhouse gases are emitted during the operation of the cement and lime kilns, which require process heat to decompose calcium carbonate ($CaCO_3$) into lime (CaO). The calcination process also produces carbon dioxide in amounts that typically exceed that generated through

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[18]

[19] Environment Canada, 2008, “National Inventory Report”; Mainhardt & Kruger, 2008, “N_2O Emissions from Adipic Acid and Nitric Acid Production,” http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/3_2_Adipic_Acid_Nitric_Acid_Production.pdf

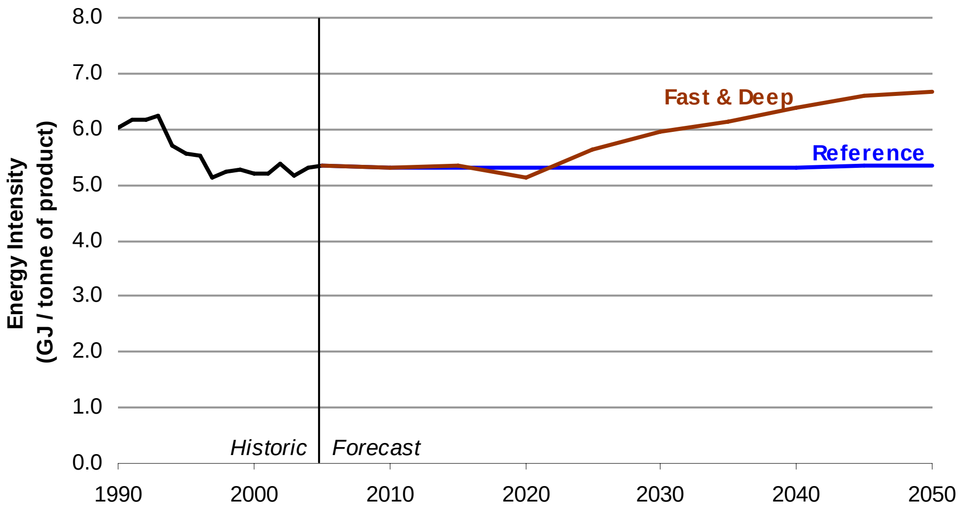
combustion alone. In the reference case scenario, coal combustion meets most of the demand for process heat.

Cement and lime manufacturing in all provinces is relatively similar, so we omit any provincial discussion from this section.

Environmental impact of policy

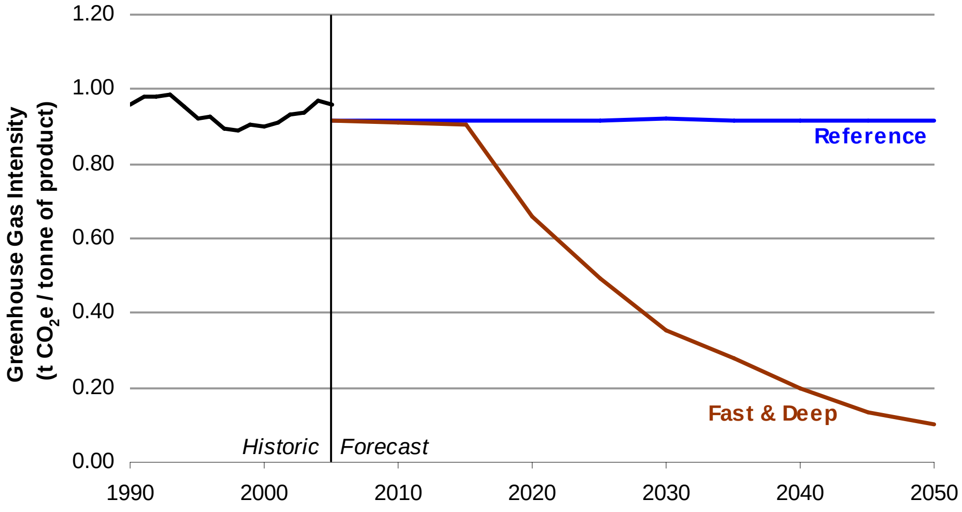
Figure 19 and Figure 20 show the energy and greenhouse gas intensity of cement and lime manufacturing. In the reference case, both the energy intensity and greenhouse gas intensity of these sectors remain stable because we project few opportunities for improvement in energy efficiency. In the policy scenario, energy intensity initially drops, but then increases as these sectors begins to adopt carbon capture and storage. The early decline is due mostly to a greater decline in the output of the lime sector relative to the cement sector. Lime production is more energy intensive than cement per tonne of product; thus this change does not represent a substantial improvement in the energy efficiency of the cement or lime sectors. By the end of the simulation period, the energy intensity of these sectors increases as they adopt carbon capture and storage. The greenhouse gas intensity of cement and lime manufacturing declines by 89% in the policy scenario.

Figure 19: Energy intensity of cement and lime manufacturing



Source: Historic data are from NRCan, 2008, “Comprehensive Energy Use Database”.

Figure 20: Greenhouse gas intensity of cement and lime manufacturing



Source: Historic data are from NRCan, 2008, "Comprehensive Energy Use Database".

Table 39 shows the change in fuel shares that results from the policy. By 2050, the sector increases its use of natural gas to provide the process heat for kiln operations, and it reduces its consumption of coal and refined petroleum products. The increase in electricity consumption is due to the electricity requirements for operating the carbon capture equipment.

Table 39: Fuel switching in cement and lime manufacturing

	2020	*2030*	*2040*	*2050*
Natural Gas	14%	32%	28%	24%
Coal	8%	-7%	-3%	1%
Refined Petroleum Products	-23%	-28%	-29%	-29%
Electricity	3%	5%	6%	6%
Other	-1%	-2%	-2%	-2%

Economic impact of policy

Table 40 shows the increase in the cost of cement and lime manufacturing. The cost of producing cement and lime rises by approximately $34 per tonne by 2050, an 11% increase from 2005. Capital and energy expenditures account for the greatest portion of the increase in costs because carbon capture increases the capital and energy requirements of producing a unit of cement or lime. Fuel switching to natural gas from coal adds to the increase in energy costs.

Table 40: Increase in the cost of cement and lime manufacturing (2005$ / tonne cement or lime)

	Increase in Costs (2005$ / tonne of product)			
	2020	*2030*	*2040*	*2050*
Total Cost	$11.24	$28.11	$32.32	$33.62
Capital Costs	$6.05	$11.24	$13.19	$13.40
Operating & Maintenance Costs	-$0.55	-$0.66	-$0.74	-$0.80
Energy Costs	$5.75	$17.53	$19.87	$21.01
Emissions Costs	$75.95	$105.73	$59.21	$31.13

Technology roadmap to low emissions for cement and lime manufacturing

Figure 21 shows the actions that contribute to the decline in greenhouse gas emissions for the cement and lime sector. In 2050, carbon capture and storage accounts for 70% of the emissions reductions, while fuel switching to natural gas and the decline in output each account for 15%.

Figure 21: Wedge diagram for cement and lime manufacturing

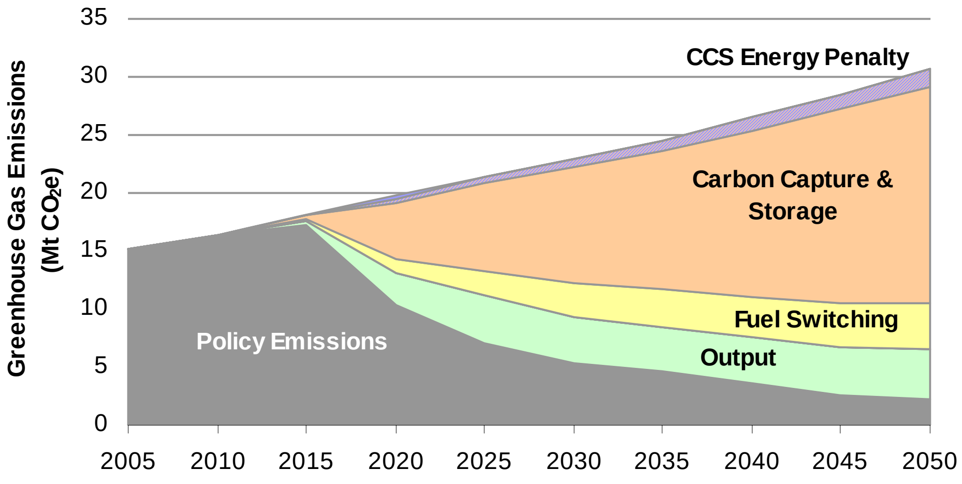


Table 41 illustrates the penetration of carbon capture in the cement and lime manufacturing sectors. The penetration in the cement industry is more rapid than in the lime industry because lime kilns are often small point-sources of greenhouse gas emissions. Therefore, the cost of pipeline construction is likely to be more expensive for the lime industry – the capital cost of building the pipeline is roughly the same, but it transports less carbon dioxide. By 2050, most lime and cement facilities in Canada employ carbon capture.

Table 41: Penetration of carbon capture and storage in cement and lime manufacturing

	2020	*2030*	*2040*	*2050*
Lime	11%	35%	68%	99%
Cement	48%	59%	85%	99%

In response to the policy, cement and lime manufacturing experience a decline in output. The decline in output offsets the increase in capital expenditures caused by the adoption of carbon capture. Table 42 shows the increase in capital expenditures caused by the policy.

Table 42: Increase in capital expenditures in cement and lime manufacturing

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	-227	-425
Increase in Capital Expenditures (% above the reference case)	-38%	-52%

Uncertainty in the analysis

Adding cementitious material (e.g., iron and steel blast furnace slag, pozzolanic earths or fly ash) to the ground clinker would reduce emissions intensity of the final product (ground clinker or the final end product, cement), and may be the initial response to any reduction technique in the cement industry. Adding cementitious material is not included in our analysis because the amount of cementitious material that can be added to cement is both regulated and limited (i.e., physical constraints). If the regulations are relaxed, the sector may attain appreciable emissions-reductions at little additional cost.[20]

This analysis shows a significant decline in output from the sector as a result of the policy's implementation. In our analysis, we have assumed that Canada remains an open economy and that many developing countries do not take the same efforts to reduce greenhouse gas emissions. As a result, the cement industry may have an incentive to move production overseas to a country with lower constraints on greenhouse gas emissions. We have not examined how policies can prevent the displacement of these industries.[21]

Iron and steel manufacturing

Box 6: Key actions by the iron and steel sector

- Most emissions reductions are attained through the adoption of carbon capture and storage.

Greenhouse gas emissions from the iron and steel manufacturing sector increase modestly in the reference case, from 15 Mt CO_2e in 2005 to 17 Mt CO_2e in 2050. In 2050, the iron and steel sector is projected to contribute 2% of Canada's total greenhouse gas emissions.

Steel can be produced in integrated steel mills or in mini-mills using electric arc furnaces. Integrated steel mills produce virgin steel from raw materials and are projected to contribute to approximately 51% of the sector's steel and 85% of the sector's greenhouse

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[20] Temporary note to reader. We need to verify whether cementitious material is if fact regulated.

[21] For information on policies to prevent the displacement of industries overseas, see Fischer C., Fox A., 2007, "Comparing policies to combat emissions leakage: Border tax adjustments versus rebates".

gas emissions by 2050. Currently, these mills produce steel using three energy and emissions intensive processes. First, the production of metallurgical coke, used to reduce iron ore to pig iron, requires process heat to bake coal in an airless chamber. In the blast furnace, which is responsible for approximately 70% of an integrated steel mill's greenhouse gas emissions, the coke is ignited at high temperature to produce carbon monoxide. The carbon monoxide strips oxygen from the iron ore to generate pig iron and carbon dioxide. Most of the remaining carbon monoxide within the flue gas is captured and used as fuel elsewhere in the plant. Steel is produced in the final phase, where high purity oxygen is passed over the molten iron to remove any excess carbon. The oxygen reacts with the carbon to produce carbon monoxide, which is again captured and used for fuel elsewhere in the plant, or carbon dioxide.[22]

Electric arc furnaces in mini-mills, which produce recycled steel, are expected to account for 49% of the sector's steel and 5% of its greenhouse gas emissions. Electric arc steel-making is much less energy and emissions intensive because it avoids the coking, blast furnace and basic oxygen furnace processes. It also uses electricity as the main source of energy, which does not produce direct greenhouse gas emissions. Some process emissions are generated as the carbon anodes oxidize, which are used to deliver electricity to the mass of steel. Fossil fuels may also be injected into the furnaces to purify the metals.

Environmental impact of policy

Figure 22 and Figure 23 illustrate the energy and greenhouse gas intensity of iron and steel making in Canada. Energy and greenhouse gas intensity decline in the reference case, largely due to an increase in production from electric arc furnaces, which rises from 36% of Canada's total steel output in 2005 to 49% in 2050. However, the energy and emissions intensity of both integrated mills and mini-mills decline in the reference case.

In the policy scenario, steel manufacturing becomes more energy intensive as a result of the energy penalty associated with carbon capture and storage. The increase in energy intensity caused by carbon capture and storage offsets any other improvements in energy efficiency, such as the adoption of the COREX® process in integrated steel making (which reduces the input of coal). Greenhouse gas intensity is projected to be 70% lower in the policy scenario projection (0.24 tonne CO_2e per tonne of steel) than in the reference case.

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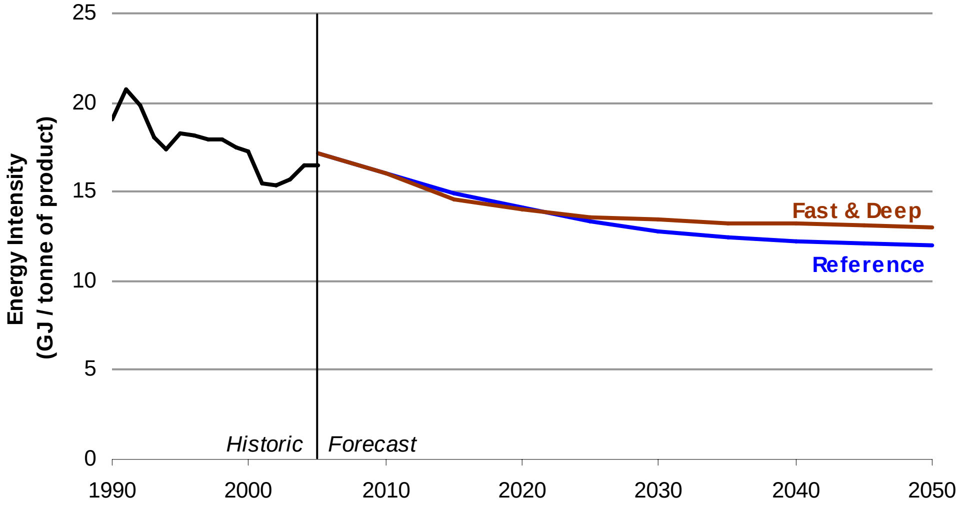
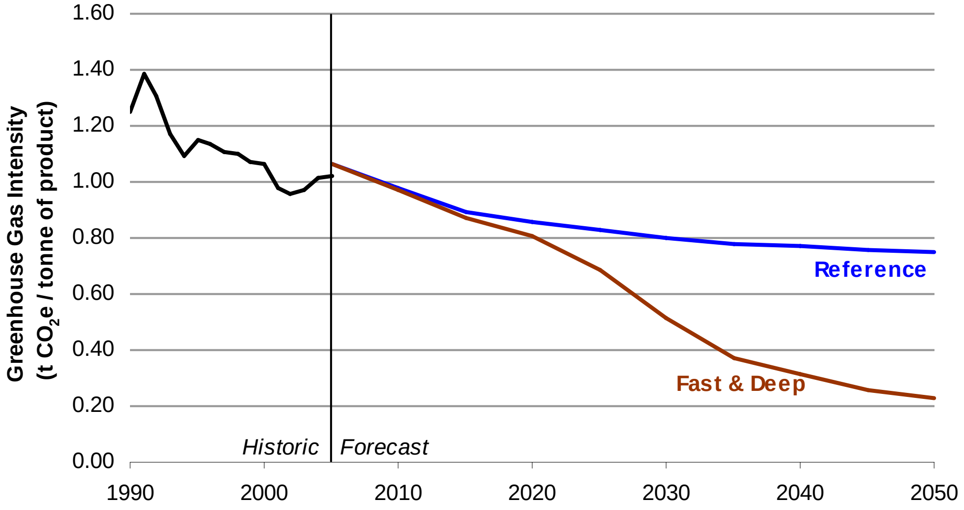
[22] Environmental protection agency, 1995, "AP-42", http://www.epa.gov/ttn/chief/ap42/; Intergovernmental Panel on Climate Change, 2005, "Carbon Dioxide Capture and Storage".

Figure 22: Energy intensity of iron and steel manufacturing



Source: Historic data are from CIEEDAC, 2008, "Database on Energy, Production and Intensity Indicators for Canadian Industry"

Figure 23: Greenhouse gas intensity of iron and steel manufacturing



Source: Historic data are from CIEEDAC, 2008, "Database on Energy, Production and Intensity Indicators for Canadian Industry"

Table 43 shows changes in fuel shares that result from the policy's implementation. The sector shows minor fuel switching to electricity from coal, refined petroleum products and natural gas. Many energy inputs into iron and steel making are not flexible because they are part of the production process – metallurgical coal is required to reduce iron ore into pig iron. The modest increase in electricity consumption is mostly from the electricity requirements of capturing the carbon dioxide from the flue gas.

Table 43: Fuel switching in iron and steel manufacturing

	2020	*2030*	*2040*	*2050*
Natural Gas	-1%	1%	1%	2%
Coal	1%	-3%	-5%	-6%
Refined Petroleum Products	0%	1%	2%	3%
Electricity	1%	1%	2%	2%

Economic impact of policy

Table 44 shows the increase in the cost of producing one tonne of steel as a result of the policy. In 2050, the cost of producing steel increases by $25 per tonne of steel, a 1.5% increase in the total cost. The rise in costs is mostly the result of increased capital and energy costs caused by the adoption of carbon capture and storage. Greater electricity and natural gas consumption also contribute to the higher energy costs.

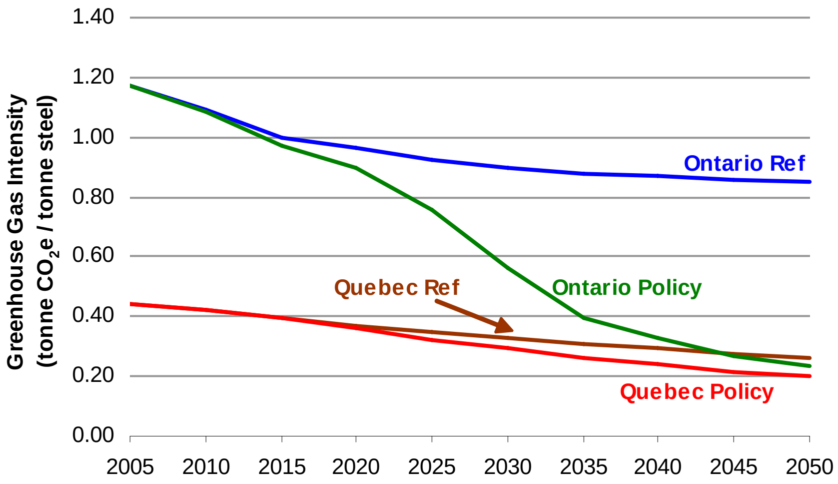
Table 44: Increase in the cost of steel manufacturing (2005$ / tonne of steel)

	Increase in Costs (2005$ / tonne of product)			
	2020	*2030*	*2040*	*2050*
Total Cost	$0.35	$14.68	$22.01	$24.92
Capital Costs	$0.30	$4.71	$6.80	$7.11
Operating & Maintenance Costs	-$1.46	-$0.83	-$0.83	-$0.48
Energy Costs	$1.51	$10.80	$16.04	$18.29
Emissions Costs	$92.69	$154.05	$93.61	$69.26

Provincial discussion

The iron and steel industry is concentrated in Ontario and Québec, with the remaining provinces only producing a minimal amount of steel. Ontario manufactures most of its steel in integrated steel mills, while in Québec, where electricity prices are cheaper, mini-mills account for the majority of steel production. As seen in Figure 24, the greenhouse gas intensity of steel making is substantially lower in Québec in the reference case, thus limiting opportunities to reduce emissions in that province. The greenhouse gas intensity in Ontario declines by 70% in response to the policy, whereas it declines by 16% in Québec.

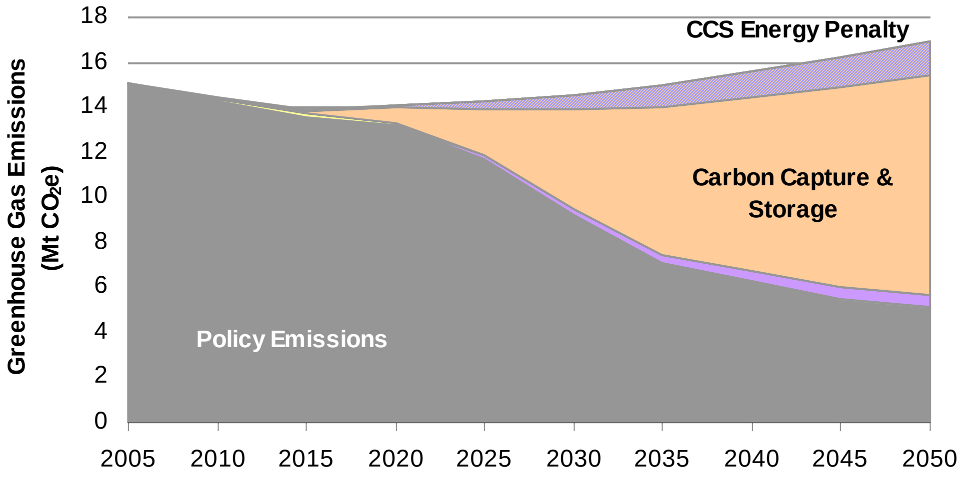
Figure 24: Greenhouse gas intensity of iron and steel manufacturing in Ontario and Québec



Technology roadmap to low emissions for iron and steel manufacturing

Figure 25 shows the wedge diagram for the iron and steel sector. Virtually all the emissions reductions are the result of the adoption of carbon capture and storage.

Figure 25: Wedge diagram for iron and steel manufacturing



Carbon capture and storage has the greatest potential for use in integrated steel mills, rather than mini-mills. The combustion of blast furnace gas yields a relatively pure stream of carbon dioxide (about 27% by volume) that can be captured. The cost of carbon capture from the blast furnace gas is uncertain and dependent on the size of the facility, but for large facilities, the cost could be as low as $35 / tonne CO_2e. The capture of carbon dioxide is also possible from the flue gas of the basic oxygen furnace and during the production of process heat. Table 45 shows the penetration of carbon capture and storage in integrated steel mills. Even though the data show a 93% penetration of carbon capture in 2050, it should be interpreted that all mills would employ carbon capture because there are only a few mills in Canada.

Table 45: Penetration of carbon capture and storage in integrated steel manufacturing

	2020	*2030*	*2040*	*2050*
Carbon Capture & Storage	8%	49%	81%	93%

Table 46 shows the capital expenditures required to attain the deep reduction in greenhouse gas emissions. The modest increase in capital expenditures – 3% – is mostly from expenditures on carbon capture equipment.

Table 46: Increase in capital expenditures caused by the policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	25	33
Increase in Capital Expenditures (% above the reference case)	3%	3%

Uncertainty in the analysis

Another factor that could reduce emissions, not included in our analysis, is an accelerated structural change towards producing more steel in mini-mills. Mini-mills produce approximately 0.13 t CO_2e per tonne of steel produced (although mini-mills are electricity intensive and may produce emissions at the point of electric generation), whereas integrated mills produce approximately 1.45 t CO_2e per tonne of steel (in 2005). The industry trend indicates a shift towards producing more steel in mini-mills regardless of the policy and this trend may accelerate in a greenhouse gas constrained future. An increase in mini-mill production would likely reduce the contribution of carbon capture and storage to greenhouse gas reduction, and a greater portion of the reduction would be attained through improved energy efficiency and fuel switching (mini-mills depend mostly on electricity). We note that an increase in mini-mill production may be limited by the availability of scrap steel.

Metal Smelting

Box 7: Key actions by the metal smelting sector

- The sector largely decarbonizes regardless of the policy, mostly due to the uptake of inert anodes in aluminium smelting. However, the policy accelerates the adoption of inert anodes.

Greenhouse gas emissions from metal smelting are expected to decline from 11 Mt CO_2e in 2005 to 4.8 Mt CO_2e in 2050 in the absence of any greenhouse mitigation policy. The decline in emissions occurs in spite of an 18% increase in the production from the sector between 2005 and 2050.

The metal smelting sector consists of several smelting industries, of which aluminium smelting is the most significant contributor to greenhouse gas emissions. In 2005, the aluminium smelting sector generated approximately 9 Mt CO_2e, however its contribution to sector emissions declines substantially over the simulation period, from 82% in 2005 to 45% in 2050. The majority of emissions from aluminium smelting are process emissions emitted during the smelting process. Current standard practice in aluminium smelting requires the dissolution of alumina (Al_2O_3) in a fluorine bath, where it is electrically reduced to aluminium (Al) using a carbon anode. In this process, the carbon anode reacts with free oxygen to produce carbon dioxide. Perfluorocarbons, which have 6,500 to 9,000 times the greenhouse warming effect of carbon dioxide, can also be produced in aluminum smelting during anode events. Anode events occur when the concentration of alumina around the carbon anode falls below approximately 2% by weight. During these events, the temperature around the anode rises and the fluorine bath can react with the anode to produce perfluorocarbons.[23]

The remaining sectors comprise copper, zinc, lead, and magnesium smelting, among other smelting industries. These sectors account for a small amount of emissions, and are not discussed in detail here. We also do not discuss any provincial discussion because this sector's contribution to total greenhouse gas emissions is minor.

Environmental impact of policy

Figure 26 and Figure 27 show the energy and greenhouse gas intensity of metal smelting. In the short-term, the decline in both intensity measures is the result of gradual replacement of Soderberg anodes with pre-baked anodes, which are less energy and greenhouse gas intensive. The decline in greenhouse gas intensity in the aluminium sector is also partially the result of the adoption of computer controls that reduce the occurrence of anode events. In the long-term, the decline in energy and greenhouse gas intensity in the reference case is primarily the result of the adoption of inert anodes. Inert anodes are not carbon based (metals are the most promising material to produce inert anodes) and are expected to be better electricity conductors thereby reducing both energy consumption and greenhouse gas emissions. Inert anodes are still in the experimental phase, but are expected to become available in the near future.[24] The energy and greenhouse gas intensity from other metal smelting declines, but not as dramatically.

The policy causes a slight improvement in energy and greenhouse gas intensity. Improvement from the reference scenario is modest because inert anodes are expected to be adopted regardless of the policy.

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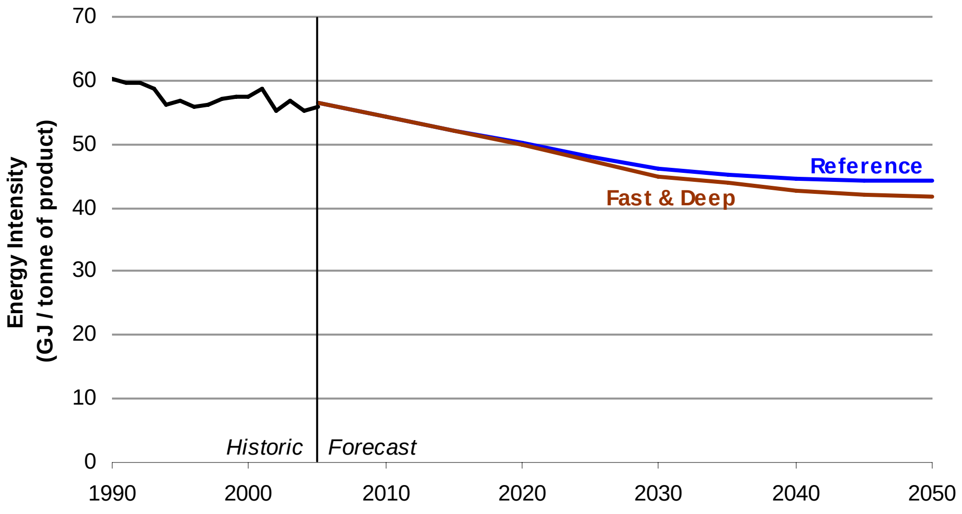
[23] Environment Canada, 2007, "National Inventory Report".

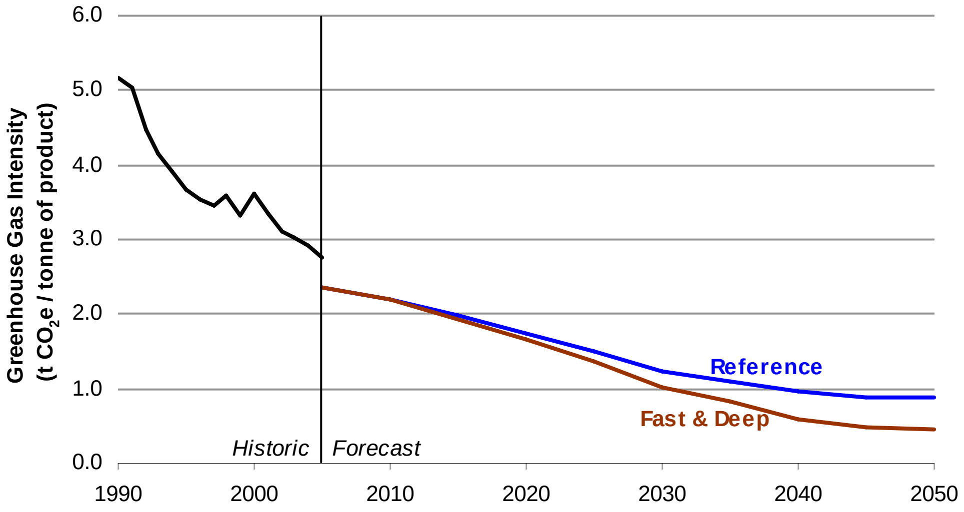
[24] Sadoway, 2001, "Inert Anodes for the Hall-Heroult Cell: The Ultimate Materials Challenge", *JOM*, 34-35.

Figure 26: Energy intensity of metal smelting



Source: Historic data are from CIEEDAC, 2008, "Database on Energy, Production and Intensity Indicators for Canadian Industry"

Figure 27: Greenhouse gas intensity of metal smelting



Source: Historic data are from CIEEDAC, 2008, "Database on Energy, Production and Intensity Indicators for Canadian Industry"

Table 47 shows the change in fuel shares for the metal smelting sector. The share of electricity consumption increases in response to the policy, mostly from fuel switching in the smelting of metals other than aluminium. Aluminium is already relatively electricity intensive, and there are fewer opportunities to fuel switch.

Table 47: Fuel switching in metal smelting

	2020	*2030*	*2040*	*2050*
Natural Gas	-1%	-2%	-2%	-2%
Coal	0%	-2%	-3%	-4%
Refined Petroleum Products	0%	-1%	-1%	-1%
Electricity	1%	4%	5%	6%

Economic impact of policy

Table 48 shows the increase in cost of metal smelting caused by the policy. By 2050, the cost of smelting increases by $5 per tonne of production ($2005), a negligible increase in the total costs of the sector. The increase in cost is relatively evenly divided between an increase in capital and energy costs. The increase in capital costs is mostly attributed to the adoption of inert anodes, whereas the increase in energy costs is mostly attributed to the increase in electricity prices (and energy costs) that results from the policy. Operating and maintenance costs decline because inert anodes are forecasted to require less maintenance.

Table 48: Increase in cost of metal smelting

	Increase in Costs (2005$ / tonne of product)			
	2020	*2030*	*2040*	*2050*
Total Cost	$32.99	$34.24	$15.61	$4.91
Capital Costs	$2.65	$7.89	$8.84	$9.85
Operating & Maintenance Costs	-$2.00	-$6.16	-$13.10	-$15.17
Energy Costs	$32.34	$32.52	$19.87	$10.22
Emissions Costs	$190.65	$302.41	$178.77	$138.08

Technology roadmap to low emissions for the metal smelting sector

Figure 28 shows the actions that contribute to emissions reductions in the metal smelting sector. The adoption of inert anodes and fuel switching to electricity each account for approximately 45% of the emissions reductions.

Figure 28: Wedge diagram for metal smelting

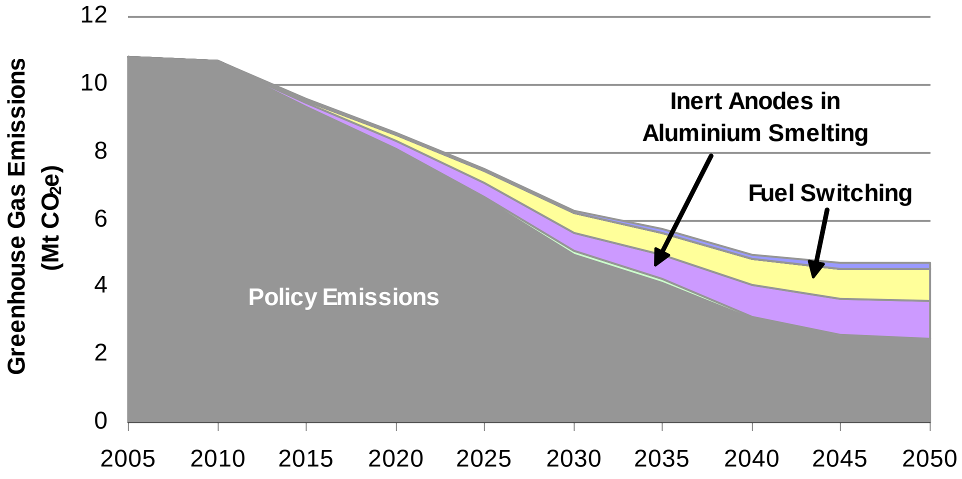


Table 49 shows the penetration of key abatement technologies in the aluminium-smelting sector as a percentage of total installed stock. The policy induces a more rapid adoption of inert anodes, which eliminate most of the carbon dioxide and perfluorocarbons emitted by the industry. By 2050, the majority of aluminium-smelting plants in Canada are projected to use inert anodes.

Table 49: Penetration of key technologies in aluminium smelting

	Policy Penetration of Anodes (%)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Pre-baked Anodes with computer Controls	48%	49%	32%	9%	-1%	-6%	-12%	-17%
Inert Anodes	11%	36%	66%	91%	2%	7%	13%	19%

The remaining emissions reductions in the metal smelting sector are mostly from fuel switching to electricity for the production of process heat in the smelting of other metals. In total these actions amount to a 1 Mt CO_2e reduction in greenhouse gases.

Table 50 shows the increase in capital expenditures caused by the policy. The moderate decline in capital expenditures in the medium-term is due to a small decline in the output from the sector (approximately 2%). In the long-term, output returns to its business-as-usual trajectory, but the capital requirements increase from the uptake of inert anodes.

Table 50: Increase in capital expenditures from the policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	-8	9
Increase in Capital Expenditures (% above the reference case)	-1%	1%

Uncertainty in the analysis

The key uncertainty with this analysis is whether and when inert anodes for aluminium smelting become available. If inert anodes do not become available and the sector continues to rely on carbon-based anodes, the emissions reductions from the aluminium sector may not be possible. Perfluorocarbons can be largely abated through improved computer controls, but the sector would still produce a substantial amount of process carbon dioxide due to the degradation of the anodes.

Mineral and Coal Mining

Box 8: Key actions by the mineral and coal mining sectors

- The sector does not play a large role in Canada's total emissions or emissions reductions, but most emissions reductions are attained through fuel switcing to electricity and renewable fuels.

The mineral and coal mining sectors are forecasted to emit 12 Mt CO_2e by 2050, and account for around 1% of Canada's total greenhouse gas emissions. Two end-uses account for 95% of the sectors' greenhouse gas emissions: 1) cleaning or concentrating mineral ores or coal before transport, which requires hot water in some cases, 2) the extraction and transport of ores and coal, which produces combustion emissions. We ignore any provincial disaggregations for mineral and coal mining because the sector contributes little to Canada's total emissions.

Environmental impact of policy

Figure 29 and Figure 30 show the energy and greenhouse gas intensity of mineral and coal mining. In the reference case, the rise in the intensity measures is mostly due to accelerated growth rates in Saskatchewan's potash mining sector, which is more energy and greenhouse gas intensive. The energy and emissions intensity for individual sectors is relatively stable.

The policy induces a 50% decline in greenhouse gas intensity from the reference scenario. This decline is mostly a result of the electrification of hot water production for cleaning systems and the adoption of renewable fuels for extraction and transportation of mineral ores and coal.

Figure 29: Energy intensity of mineral and coal mining

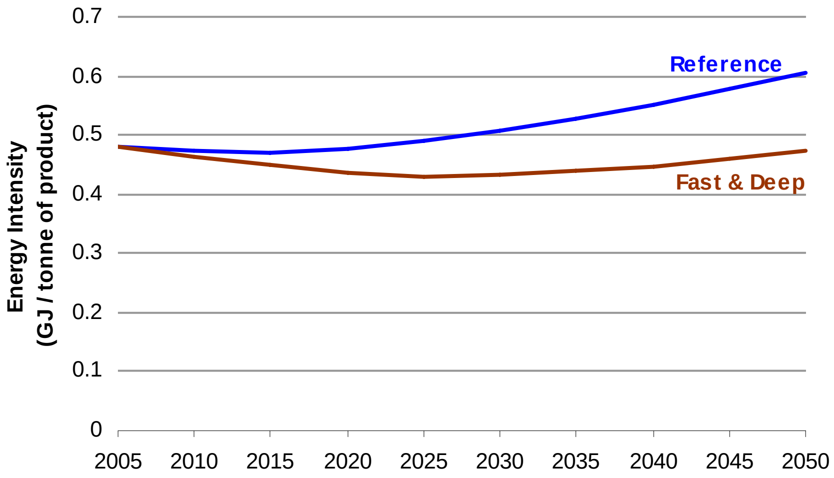


Figure 30: Greenhouse gas intensity of mineral and coal mining

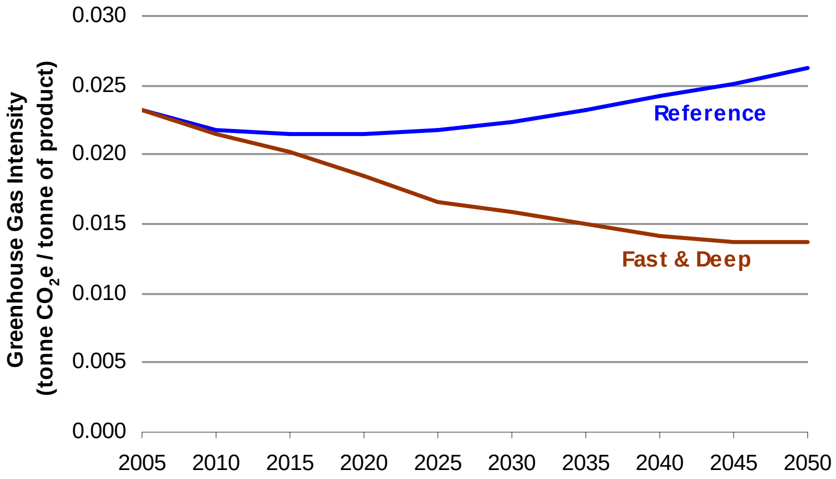


Table 51 illustrates the sectors' switch to electricity and renewable fuels in response to the policy. In some mining operations, electric conveyors may be used instead of diesel motors and electricity can be used to heat water instead of natural gas. Renewable biofuels are used to power trucks and excavators.

Table 51: Fuel switching in mineral and coal mining

	2020	*2030*	*2040*	*2050*
Natural Gas	-6%	-14%	-22%	-27%
Coal	0%	-1%	-2%	-2%
Refined Petroleum Products	-2%	-3%	-4%	-3%
Electricity	6%	15%	24%	29%
Renewable	2%	3%	4%	5%

Economic impact of policy

The financial costs of operation decline by approximately 4%, in response to the policy. Electric motors and heaters have lower capital and maintenance requirements, but have greater energy costs due to the higher price for electricity.

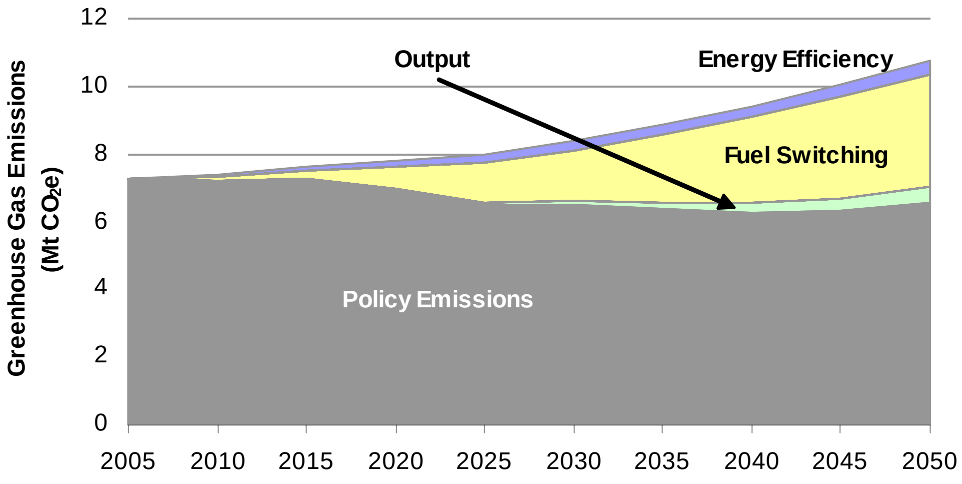
Table 52: Increase in cost of mining

	Increase in Costs (2005$ / tonne of product)			
	2020	*2030*	*2040*	*2050*
Total Cost	-$0.92	-$1.71	-$2.33	-$2.76
Capital Costs	-$0.69	-$1.29	-$1.79	-$2.13
Operating & Maintenance Costs	-$0.23	-$0.42	-$0.58	-$0.69
Energy Costs	-$0.01	$0.00	$0.05	$0.05
Emissions Cost	$2.12	$4.78	$4.24	$4.10

Technology roadmap to low emissions for mineral and coal mining

Figure 31 shows that fuel switching to electricity and renewables accounts for the majority of the reductions in greenhouse gas emissions.

Figure 31: Wedge diagram for mineral and coal mining



Will add rest later.

Pulp and paper manufacturing

Box 9: Key actions by the pulp and paper manufacturing sector

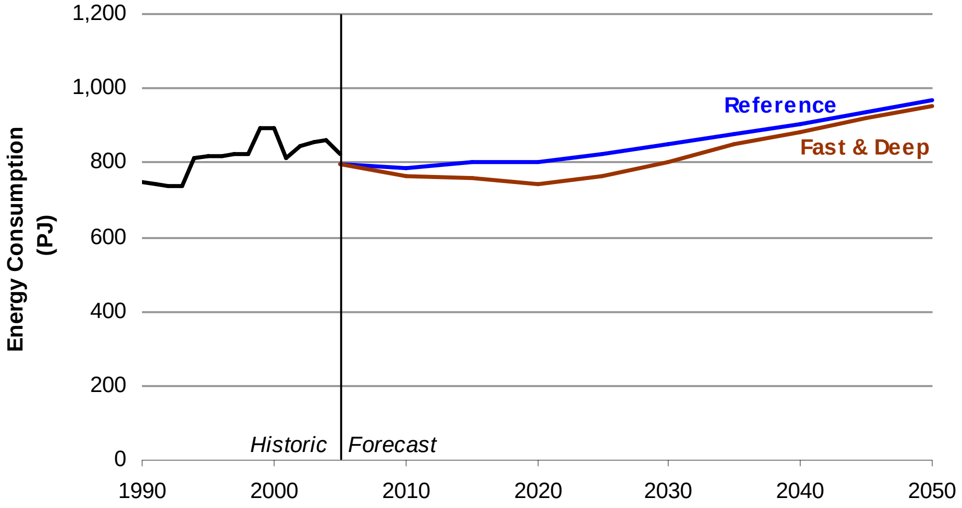
- The pulp and paper sector largely decarbonizes regardless of the policy.

The pulp and paper sector largely decarbonizes in the reference case, where greenhouse gas emissions decline from 7 Mt CO_2e in 2005 to 2 Mt CO_2e in 2050. This decline occurs despite a 37% increase in the output of pulp and paper products. The sector is mostly concentrated in Québec, with smaller sectors in British Columbia and Ontario. The differences between these provinces are relatively small, so we exclude a provincial discussion.

Environmental impact of policy

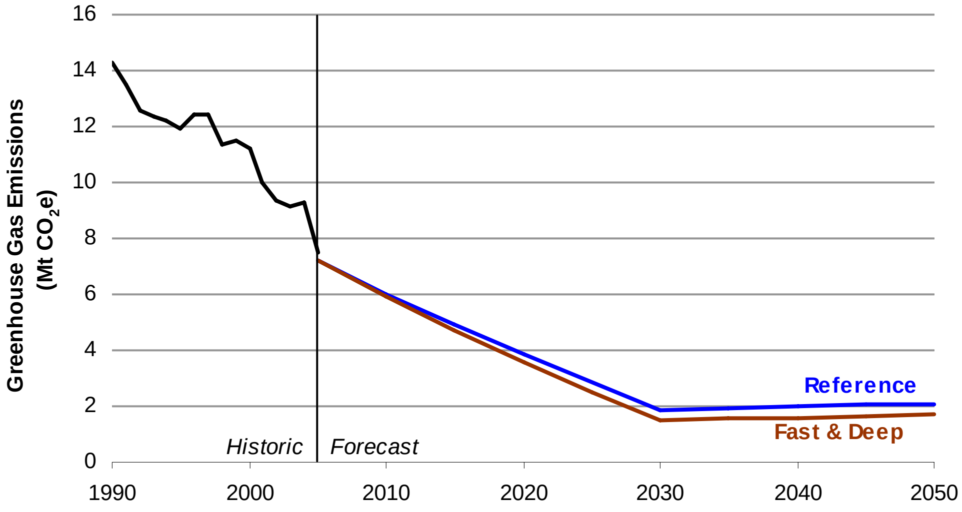
Figure 32 and Figure 33 illustrate the total energy consumption and greenhouse gas emissions from the sector. In the reference case, energy consumption and greenhouse gas emissions roughly follow historical trends, with a moderate increase in energy consumption and a significant decline of 70% in greenhouse gas emissions over the simulation period. The sector has an abundance of waste wood material and by-products from the pulping process (i.e., black liquor) that can be used as fuel. Since 1990, the sector has gradually displaced the consumption of fossil fuels in favour of renewable fuels. In the policy scenario, this trend is accelerated.

Figure 32: Energy consumption of pulp and paper manufacturing



Source: Historic data are from NRCan, 2008, “Comprehensive Energy Use Database”.

Figure 33: Greenhouse gas emissions from pulp and paper manufacturing



Source: Historic data are from NRCan, 2008, “Comprehensive Energy Use Database”.

Table 53 shows that the share of renewable fuels increases slightly in response to the policy. In the policy scenario, renewable fuels supply 95% of the process heat required of the sector by 2050.

Table 53: Fuel switching in pulp and paper manufacturing

	2020	*2030*	*2040*	*2050*
Electricity	2%	1%	0%	0%
Renewable	-2%	-1%	1%	1%

Economic impact of policy

Table 54 shows the increase in cost of manufacturing pulp and paper products that results from the policy’s implementation. The impacts are minor since the policy merely accelerates ongoing trends. In this case, the policy causes a modest increase in the total cost of producing pulp and paper products – a fraction of a percent.

Table 54: Increase in cost of pulp and paper manufacturing ($2005 / tonne of product)

	Increase in Costs (2005$ / tonne of product)			
	2020	*2030*	*2040*	*2050*
Total Cost	$2.90	$5.67	$4.04	$2.21
Capital Costs	-$3.93	-$2.12	$0.05	$0.44
Operating & Maintenance Costs	-$2.30	-$1.20	$0.18	$0.57
Energy Costs	$9.13	$8.98	$3.80	$1.20
Emissions Costs	$19.32	$19.41	$18.91	$18.59

Technology roadmap to low emissions for pulp and paper manufacturing

Figure 34 shows that fuel switching to renewables accounts for most of the emissions reductions of the sector. These actions reduce emissions by 0.4 Mt CO_2e .

Figure 34: Wedge diagram for pulp and paper manufacturing

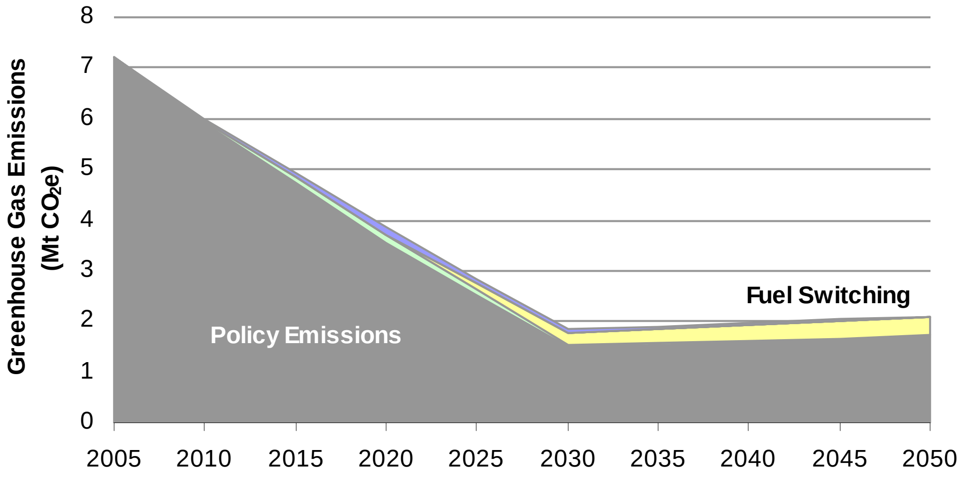


Table 55 shows heat production from the renewable waste fuels as a percentage of total heat production. By 2030, almost all heat production comes from renewable fuels.

Table 55: Heat production from wood and spent pulping liquor

	2020	*2030*	*2040*	*2050*
Heat Production from Renewable	83%	98%	98%	98%

Table 56 shows that the capital expenditures from the sector decline slightly as a result of the policy. This drop in capital expenditures is primarily due to a modest decline in the output from the sector.

Table 56: Increase in capital expenditures from policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	-54	-33
Increase in Capital Expenditures (% above the reference case)	-3%	-2%

Other Manufacturing

Box 10: Key actions by the other manufacturing sector

- The other manufacturing sector reduces its emissions by switching consumption away from fossil fuels towards of electricity.

The gross domestic product of the other manufacturing sector grows over the simulation period by 160% to $472 billion in 2050. By 2050, the other manufacturing sector is projected to generate 47 Mt CO_2e, about 5% of Canada’s total greenhouse gas emissions.

Process heating and water heating account for the majority of greenhouse gas emissions from the sector, with process heating contributing approximately 79% and water heating accounting for the most of the remainder. The difference between provinces is fairly minor, so this section excludes a provincial discussion.

Environmental impact of policy

Figure 35 and Figure 36 show the energy and greenhouse gas intensity of the other manufacturing sector in the reference and policy scenarios. In the reference case, energy and greenhouse gas intensity remain fairly stable despite significant historical declines. This discrepancy is likely because gross domestic product is used as the measure of the sector's output, rather than physical production. Energy and emissions intensity measures based on gross domestic product are imperfect measures of intensity because energy consumption and emissions are based on physical output (i.e., the number of cars built rather than the value-added by each car). Additionally, energy intensity can decline in response to structural shifts within the sector. If a sub-sector with low intensity begins to contribute more to gross domestic product, the intensity from the sector as a whole would decline. We have not examined the degree to which these factors have contributed to the historic decline in energy and greenhouse gas intensity.

In the policy scenario, energy intensity declines slightly from the reference case projection, while greenhouse gas intensity declines by 82% from the reference case projection by 2050. The decline in greenhouse gas intensity is primarily due to the adoption of technologies that consume electricity rather than fossil fuels.

Figure 35: Energy intensity of other manufacturing

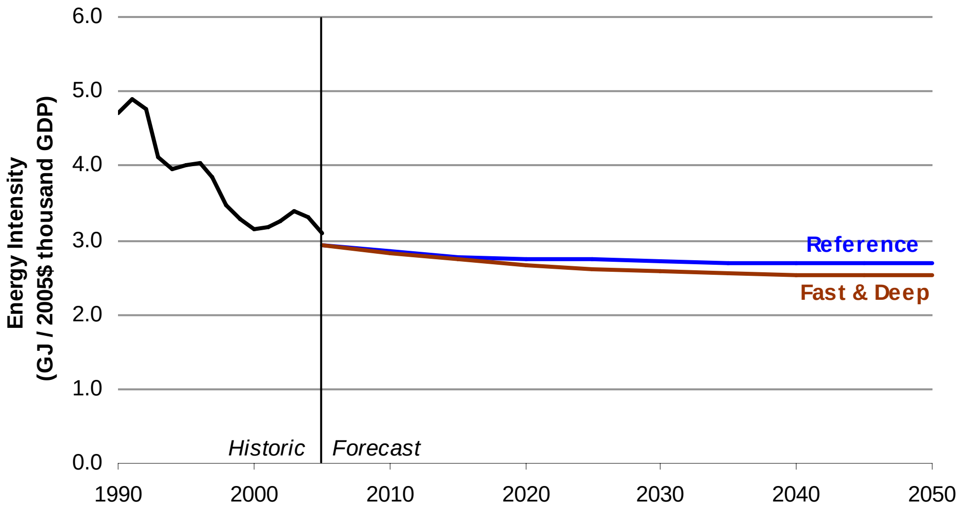


Figure 36: Greenhouse gas intensity of other manufacturing

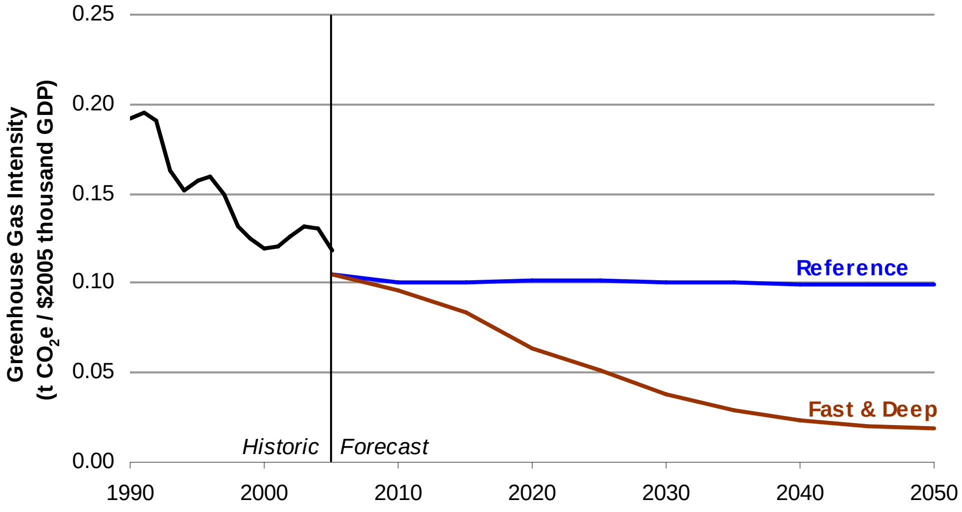


Table 57 shows change in fuel shares in the other manufacturing sector. Fuel consumption switches predominantly to electricity throughout the period, most notably from natural gas and refined petroleum products. The share of renewable energy in the form of biomass also rises as the use of wood-fuelled boilers increases.

Table 57: Fuel switching in the other manufacturing sector

	2020	*2030*	*2040*	*2050*
Natural Gas	-19%	-34%	-42%	-45%
Coal	0%	-1%	-1%	-2%
Refined Petroleum Products	-5%	-7%	-8%	-7%
Electricity	21%	38%	47%	50%
Renewable	3%	4%	4%	4%

Economic impact of policy

Table 58 shows how capital, operating and fuel costs contribute to total costs in the other manufacturing sector over the study period. The total increase in cost in the other manufacturing sector is just under 3%, and the rise in energy costs accounts for the entire increase, while capital and operating costs decline. These changes are due to the uptake of electric heating systems, which require less maintenance and have lower capital investments, but have higher energy costs because electricity is more expensive per unit of energy produced. The energy costs are further increased by the higher price of electricity caused by the policy.

Table 58: Increase in cost by cost-type (2005$ / 2005$ thousand GDP)

	Increase in Costs (2005$/thousand 2005$ GDP)			
	2020	*2030*	*2040*	*2050*
Total Cost	$3.04	$6.18	$8.03	$8.51
Capital Costs	-$0.01	-$0.08	-$0.13	-$0.12
Operating & Maintenance Costs	-$0.01	-$0.05	-$0.06	-$0.06
Energy Costs	$3.07	$6.30	$8.22	$8.69
Emissions Cost	$7.37	$11.35	$6.89	$5.65

Technology roadmap to low emissions for the other manufacturing sector

Figure 37 illustrates the actions that contribute to the decline in greenhouse gas emissions in the other manufacturing sector: fuel switching accounts for almost all of the emissions reductions.

Figure 37: Wedge diagram for other manufacturing

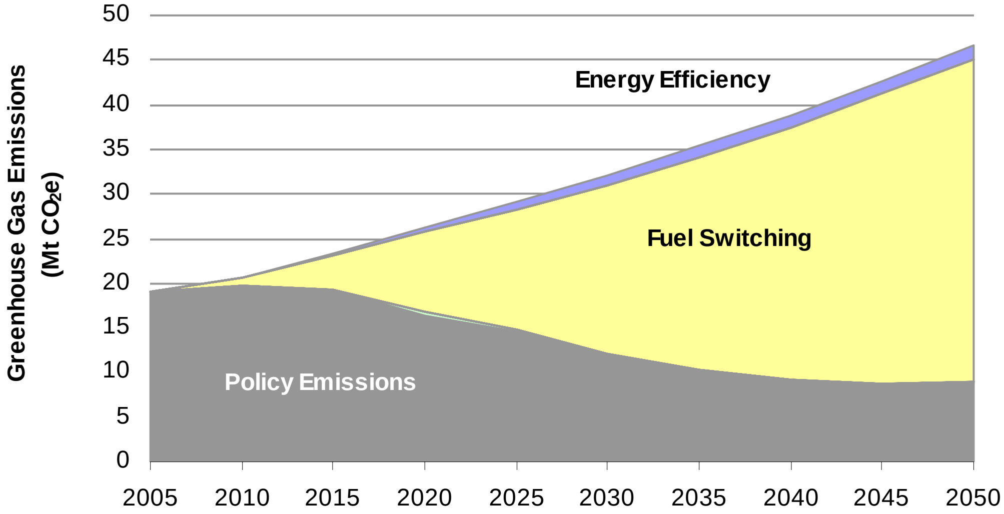


Table 59 and Table 60 display the penetration rates of key abatement technologies in process heating and water heating systems for the other manufacturing sector as a percentage of total installed stock. In 2050, electric and biomass fuelled heat systems show an overall penetration rate of nearly 69%, with electric systems comprising nearly 62% of that total. While water heating constitutes a smaller portion of total emissions within the other manufacturing sector, more aggressive penetration is seen by abatement technologies for water heating because improvements in these systems are less costly than improvements in process heating systems. By 2050 electric water heaters have meet over 99% of the demand for hot water.

Table 59: Penetration of other manufacturing process heat systems

	Technology Penetration (% of total stock)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Electric Heating Systems	31.7%	48.2%	59.1%	61.9%	18.8%	34.9%	45.6%	48.4%
Biomass Heating Systems	7.2%	7.5%	7.4%	7.5%	3.0%	3.4%	3.4%	3.5%

Table 60: Penetration of other manufacturing water heating systems

	Technology Penetration (% of total stock)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Electric Water Heating	79.3%	98.4%	99.2%	99.2%	38.0%	57.1%	58.2%	58.6%

Table 61 shows that the capital expenditures by the sector decline in response to the policy. Expenditures decline due to a modest decline in output and the investment in electric boilers and heaters which are cheaper relative to those using fossil fuels.

Table 61: Increase in capital expenditures due to policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	-33	-42
Increase in Capital Expenditures (% above the reference case)	-3%	-2%

Electricity Generation

Box 11: Key actions by the utility electricity generation sector

- Electricity supply expands to meet an increased demand for electricity in the policy scenario. By 2050, electricity supply reaches 1,700 TWh per year.
- Carbon capture and storage is the key action to reduce the direct greenhouse gas emissions of the sector.
- The expansion of electric generation from renewable sources (especially, hydro and wind) reduces greenhouse gas emissions at the point of electricity consumption. Most new renewable capacity is added in provinces already dependent on generation from renewables – British Columbia, Manitoba and Québec – and does not reduce emissions at the point of electricity production. The expansion of electricity generation from renewables enables other sectors (e.g., residential and commercial) to reduce fossil fuel consumption by switching to electricity.

In the absence of any mitigation policy, the greenhouse gas emissions from the utility generation of electricity are expected to grow from 129 Mt CO_2e in 2005 to 170 Mt CO_2e by 2050. The projected rise is mainly the result of an increase in electricity generation from approximately 600 TWh in 2005 to over 1,100 TWh in 2050. Over this period, generation from fossil fuels remains relatively stable – generation from coal and natural gas remain at approximately 18% and 5% between 2005 and 2050, respectively.

More than in most other sectors of the economy, the electricity-generation sector has substantial differences between provinces. British Columbia, Manitoba and Québec rely heavily on hydroelectricity. Alberta and Saskatchewan do not have the same potential for hydroelectric power, but have an abundance of fossil fuels – especially coal. In Ontario, nuclear generation is projected to contribute 43% of total generation by 2050, while coal and renewables (mostly hydroelectricity with some wind) account for 27% and 26%, respectively. The Ontario government has stated that it will close all coal plants in

Ontario by 2014, so we have simulated the closure of all single cycle coal plants, but allowed the competition of new coal plants with improved energy efficiency and environmental controls.[25] In the Atlantic Provinces, electric generation by utilities is expected to be 77% hydroelectric by 2050 due to production from Labrador, which is mostly exported to Québec. The Atlantic Provinces also generate electricity from coal, nuclear, and a small amount of natural gas in 2050. Because provincial differences in this sector are significant, we provide a more detailed discussion at a provincial level.

Environmental impact of policy

Figure 38 and Figure 39 show the energy and greenhouse gas intensity of electric generation by utilities.[26] In the reference case, energy and greenhouse gas intensity decline over the simulation period. Although electricity generation by fuel remains relatively unchanged between 2005 and 2050, single cycle coal and natural gas plants are gradually replaced with advanced coal technologies and combined cycle natural gas plants. The decline in greenhouse gas intensity in the reference case is mostly due to the improvement in energy intensity.

In the policy scenario, greenhouse gas intensity drops to 0.02 tonnes CO_2e / MWh in 2050, an 83% decline from the reference case projection, while energy intensity increases by 10%. The decline in greenhouse gas intensity is primarily the result of an increase in carbon capture and storage in Alberta, Saskatchewan and Ontario. The addition of new renewable capacity in British Columbia, Manitoba and Québec has little impact on greenhouse gas intensity, because these provinces have low emissions regardless of the policy. Energy intensity is higher in the policy scenario due to the energy penalty associated with carbon capture and storage.

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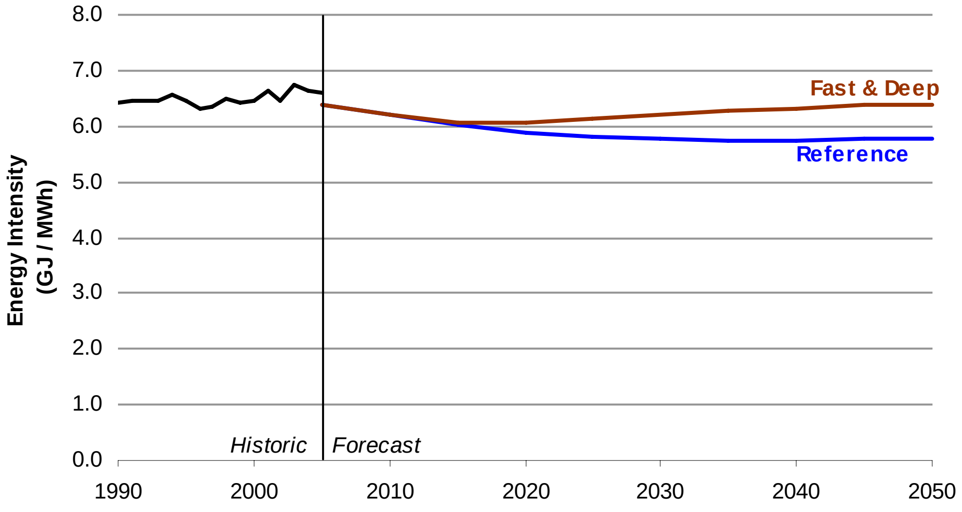
[25] Ontario Ministry of Energy and Infrastructure, 2008, http://www.energy.gov.on.ca/index.cfm?fuseaction=english.news&body=yes&news_id=176.

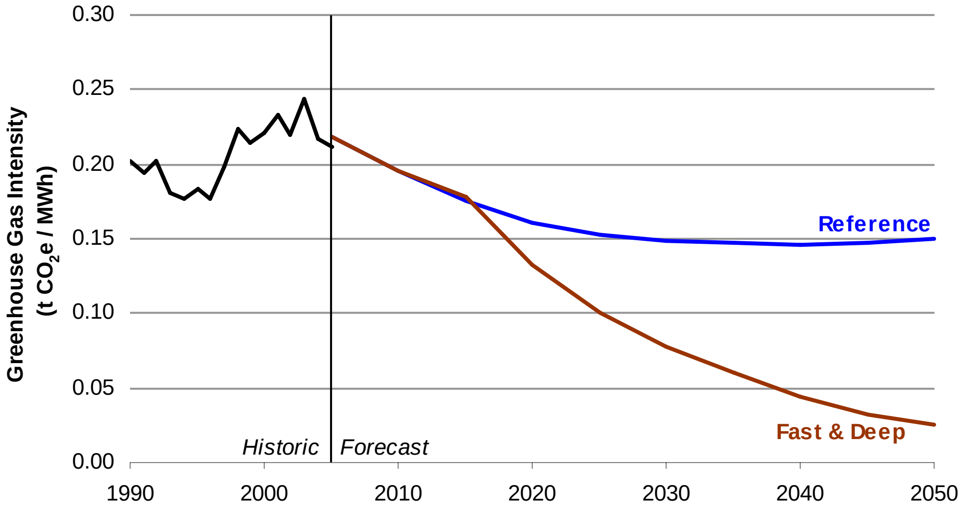
[26] Renewable electricity generation is assumed to require 1 GJ of energy (e.g., wind, hydro) for each GJ of electricity generated. Nuclear electricity generation is assumed to require 1 GJ of energy for each GJ of thermal energy generated. See International Energy Agency, 2007, “Energy Balances of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

Figure 38: Energy intensity of utility electricity generation



Source: Historic data are from NRCan, 2008, "Comprehensive Energy Use Database".

Figure 39: Greenhouse gas intensity of utility electricity generation



Source: Historic data are from NRCan, 2008, "Comprehensive Energy Use Database".

Table 62 shows the greenhouse gas intensity for Alberta, Saskatchewan, Ontario and the Atlantic provinces. We exclude the provinces that rely mostly on hydroelectric generation because their greenhouse gas intensities are low in the reference case and remain so after the policy's implementation (approximately 0.01 tonnes CO_2e / MWh in 2005). The greenhouse gas intensities for all provinces are available in the Appendix. The adoption of carbon capture and storage is the most important action to reduce greenhouse gas intensity in Alberta and Saskatchewan. In Ontario and the Atlantic provinces, carbon capture and storage also plays a significant role, but an increase in electricity production from renewable sources also contributes to the reduction in greenhouse gas intensity.

Table 62: Greenhouse gas intensity of electric generation by utilities by province

	Greenhouse Gas Intensity (t CO_2e / MWh)				*Decline due to Policy (t CO_2e / MWh)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Alberta	0.51	0.27	0.15	0.08	0.20	0.37	0.43	0.46
Saskatchewan	0.54	0.30	0.15	0.09	0.22	0.43	0.54	0.59
Ontario	0.13	0.09	0.05	0.03	0.02	0.08	0.14	0.18
Atlantic	0.13	0.04	0.02	0.01	0.03	0.07	0.09	0.11

Table 63 shows the increase in electricity generation that results from the policy's implementation by fuel and generation type. Both the electricity generation using carbon capture and the generation from renewables rise dramatically in response to the policy – the generation using carbon capture and generation from renewables each account for approximately 45% of the increase.

Table 63: Increase in generation of electricity by fuel and generation type (TWh)

	2020	*2030*	*2040*	*2050*
Renewable	91	187	256	304
Nuclear	25	59	80	85
Coal	5	-37	-106	-188
Natural Gas	-11	-28	-41	-50
Carbon Capture & Storage	57	183	309	429
Total Increase in Generation	167	364	498	579

Economic impact of policy

Table 64 shows the increase in the cost of electricity generation. Alberta and Saskatchewan show the largest increase in the cost of producing electricity, mostly because their electricity sectors were projected to be more greenhouse gas intensive and therefore require greater capital investments to decarbonize. The rise in electricity costs is more modest in the remaining provinces. In the predominately hydroelectric provinces, the greater costs are mostly due to the substantial increase in electric capacity, which requires new capital investments.

Table 64: Increase in the cost of electricity generation by province (2005$ / MWh)

	2020	*2030*	*2040*	*2050*
Canada (weighted by generation)	$8.60	$13.54	$13.55	$12.42
British Columbia	$11.15	$12.76	$11.13	$8.71
Alberta	$15.29	$22.09	$19.79	$18.32
Saskatchewan	$10.84	$16.11	$17.51	$18.50
Manitoba	$6.28	$7.46	$6.24	$4.83
Ontario	$5.40	$7.69	$8.10	$8.63
Québec	$4.01	$5.61	$5.13	$4.19
Atlantic	$2.22	$6.71	$7.55	$8.27

Table 65 separates the total costs into capital expenditures, operating and energy costs. An increase in capital expenditures contributes most significantly to the rise in costs, whereas energy cost increases are modest. The adoption of carbon capture and storage increases coal consumption, but the price for coal is relatively low. Additionally, the adoption of renewable electricity generation reduces energy costs.

Table 65: Increase in the cost of electricity generation by cost component (2005$ / MWh)

	Increase in Costs (2005$ / MWh)			
	2020	*2030*	*2040*	*2050*
Total Cost	$8.60	$13.54	$13.55	$12.42
Capital Costs	$7.25	$10.34	$9.68	$8.28
Operating & Maintenance Costs	$0.73	$1.28	$1.59	$1.79
Energy Costs	$0.61	$1.92	$2.27	$2.35
Emissions Costs	$16.45	$25.18	$14.35	$8.10

Technology roadmap to low emissions for electricity generation

Figure 40 shows the actions that contribute to the emissions reductions in the electricity generation sector: carbon capture accounts for the majority of reductions. Carbon capture (excluding transport) at integrated gasification combined cycle coal and combined cycle natural gas plants is expected to cost between $15 and $75 (USD) per tonne of CO_2e avoided.[27] The emissions charge in the policy scenario should be sufficient to prevent any new construction of fossil fuel plants without carbon capture. Furthermore, it is likely to induce many utilities to retrofit existing fossil fuel plants.

The figure only shows a small reduction from fuel switching to renewables, even though generation from renewable sources increases by 43% in the policy scenario. Most renewable capacity is added in provinces that already have low greenhouse gas intensity, and does not reduce the direct emissions from the sector. However, the expansion of the electricity sector in these provinces enables other sectors (e.g., residential and commercial sectors) to reduce fossil fuel consumption in favour of electricity consumption.

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[27] Intergovernmental Panel on Climate Change, 2005, “Carbon Dioxide Capture and Storage”.

Figure 40: Wedge diagram for utility electricity generation

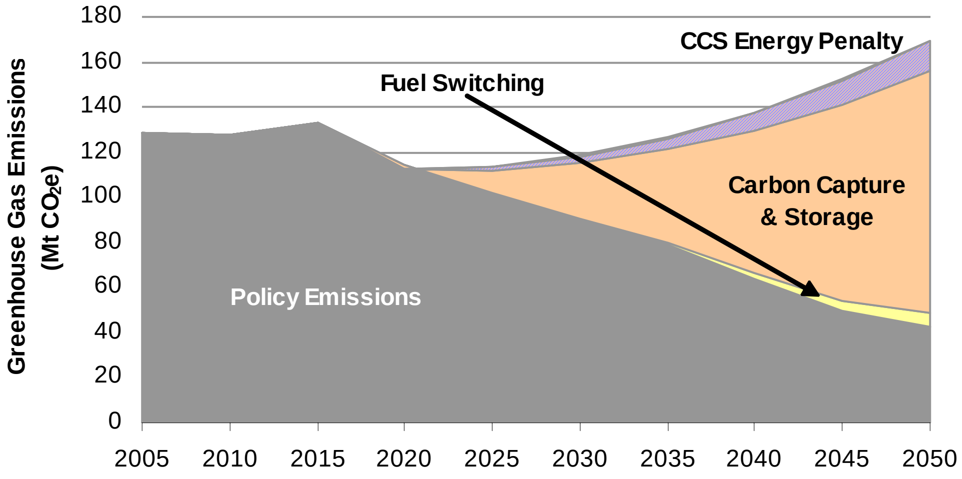


Table 66 shows the generation from zero- and low-emission technologies in the policy scenario. By 2050, the electricity stock has been almost completely de-carbonized. Generation by hydroelectric power plants accounts for the majority of generation (52%). Integrated gasification combined cycle coal plants and combined cycle natural gas turbines with carbon capture (IGCC CCS and NGCC CCS) account for 17% and 7% of total installed capacity, respectively. The pulverized coal plants with carbon capture (PC CCS) are mostly existing facilities that have been retrofitted.

Table 66: Generation by plant type (TWh)

	Total Generation (TWh)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Hydro	505	633	759	890	17%	31%	37%	39%
Wind	33	63	91	110	84%	118%	104%	77%
Renew	3	7	10	13	117%	150%	144%	134%
Nuclear	124	168	204	232	26%	54%	64%	57%
PC CCS	11	23	28	30	NA	NA	NA	NA
IGCC CCS	26	100	195	300	NA	NA	NA	NA
NGCC CCS	25	71	105	126	NA	NA	NA	NA
Total Generation	868	1,166	1,445	1,712	24%	45%	53%	51%

Table 67, Table 68 and Table 69 show electricity generation by plant type in different regions in Canada. Carbon capture plays a significant role in Alberta and Saskatchewan, while the hydroelectric provinces generally increase generation from hydropower in response to the policy. Ontario and the Atlantic provinces show increases in generation from fossil energy using carbon capture and storage, nuclear energy and renewable energy.

Table 67: Generation by plant type in Alberta and Saskatchewan (TWh)

	Total Generation (TWh)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Hydro	12	17	22	27	30%	65%	87%	99%
Wind	6	12	17	20	111%	159%	146%	106%
Renew	0	1	1	2	139%	215%	239%	272%
Nuclear	0	0	0	0	NA	NA	NA	NA
PC CCS	8	16	19	20	NA	NA	NA	NA
IGCC CCS	15	54	104	158	NA	NA	NA	NA
NGCC CCS	15	41	61	72	NA	NA	NA	NA
Total Generation	137	198	256	304	40%	80%	102%	103%

Table 68: Generation by plant type in Ontario and the Atlantic Provinces (TWh)

	Total Generation (TWh)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Hydro	103	134	166	196	21%	44%	59%	69%
Wind	19	35	49	60	72%	114%	104%	80%
Renew	1	2	3	4	130%	212%	204%	206%
Nuclear	115	157	193	220	26%	55%	66%	59%
PC CCS	3	7	9	10	NA	NA	NA	NA
IGCC CCS	11	46	90	142	NA	NA	NA	NA
NGCC CCS	7	22	32	39	NA	NA	NA	NA
Total Generation	317	444	562	674	28%	57%	65%	61%

Table 69: Generation by plant type in British Columbia, Manitoba and Québec (TWh)

	Total Generation (TWh)				*Increase due to Policy (%)*			
	2020	*2030*	*2040*	*2050*	*2020*	*2030*	*2040*	*2050*
Hydro	390	483	571	668	16%	27%	30%	31%
Wind	7	17	25	31	99%	103%	83%	58%
Renew	2	4	5	7	108%	118%	106%	89%
Nuclear	8	10	12	12	26%	40%	39%	28%
PC CCS	0	0	0	0	NA	NA	NA	NA
IGCC CCS	0	0	0	0	NA	NA	NA	NA
NGCC CCS	2	8	12	16	NA	NA	NA	NA
Total Generation	414	524	627	735	17%	28%	31%	30%

Table 70 shows the increase in capital expenditures from the policy scenario. Capital expenditures must rise to meet the growth in the demand for electricity that results from the policy, as well as a more capital intensive electricity stock.

Table 70: Increase in capital expenditures that results from policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	12,512	9,553
Increase in Capital Expenditures (% above the reference case)	148%	67%

Uncertainty in the analysis

In this analysis, we have constrained the construction of new nuclear plants in provinces that had nuclear plants in 2005, and prevented the construction of nuclear plants in provinces that did not already have them. We assume that the adoption of nuclear generation technologies will be a political rather than economic decision. If the constraints on nuclear power are relaxed, it could substantially contribute to emissions reductions. The adoption of nuclear power would likely reduce the contribution of carbon capture and storage to emissions reduction.

We have not simulated how changes in the inter-provincial or international trade of electricity could contribute to the emissions reductions from the province. It may be possible for provinces with hydroelectric potential to increase generation and export excess production to provinces with higher greenhouse gas intensities.

Petroleum Refining

Box 12: Key actions by the petroleum refining sector

- The output of refined petroleum products declines in the policy scenario due to increases in biofuel consumption in the transportation sector. The decline in output is responsible for most of the emissions reductions.
- The remaining emissions reductions are attained through the adoption of carbon capture and storage.

In the absence of any GHG mitigation policy, the petroleum refining sector is expected to play an increasingly important role in Canada's total greenhouse gas emissions. Greenhouse gas emissions from petroleum refining are expected to rise in the reference case from approximately 19 Mt CO_2e in 2005 to 32 Mt CO_2e by 2050, which would account for 3% of Canada's projected greenhouse gas emissions.

The petroleum refining sector transforms crude oil into gasoline and diesel, mainly for use as transportation fuels. Demand for refining is therefore linked to demand for fuels from transportation – if transportation becomes more efficient or fossil substitutes such as ethanol become available in significant quantity at a reasonable cost, demand for petroleum products will fall.

Crude oil comes in widely variable "grades", generally classed as light, medium, heavy and synthetic. All grades are transformed into useful products such as gasoline and diesel through the refining process. Lighter crude has generally less carbon and more hydrogen, and heavy crude the opposite. Lighter crude is the more desirable feedstock because it is more similar to the most desirable final products (i.e. gasoline and diesel), but as cheap and easy to access light crude deposits have been depleted worldwide, there is a general trend towards use of heavier crudes, which are also more plentiful. Much of Canada's remaining known onshore crude is heavy crude, and the amount of heavy crude to be processed in Canada is projected to increase significantly.

The process of refining divides into four main processes: 1) distillation (separation of the components of crude by variable volatilability); 2) cracking (breaking of longer, less useful carbon chains into shorter chains); 3) coking (reduction of the carbon content of crude through direct removal); and 4) hydrotreating (the addition of hydrogen to carbon chains to produce useful products like gasoline). The amount of each process necessary depends on the desired end product, but heavier crudes in generally require more cracking, coking and hydrotreating. All of these processes require significant amounts of process heat.

Environmental impact of policy

The increase in energy and greenhouse gas emissions in the reference case is the result of increased demand for petroleum products, in addition to the ongoing switch from lighter to heavier crudes (Figure 41 and Figure 42). Both energy consumption and greenhouse gas emissions decline in the policy scenario, mostly due to an increase in biofuel demand from transportation and an associated the decline in the demand and supply of petroleum products. By 2050 in the policy scenario, the output of refined petroleum is 65% lower than in the reference projection. The adoption of carbon capture and storage also contributes to the decline in greenhouse gas emissions.

Figure 41: Energy consumption for petroleum refining

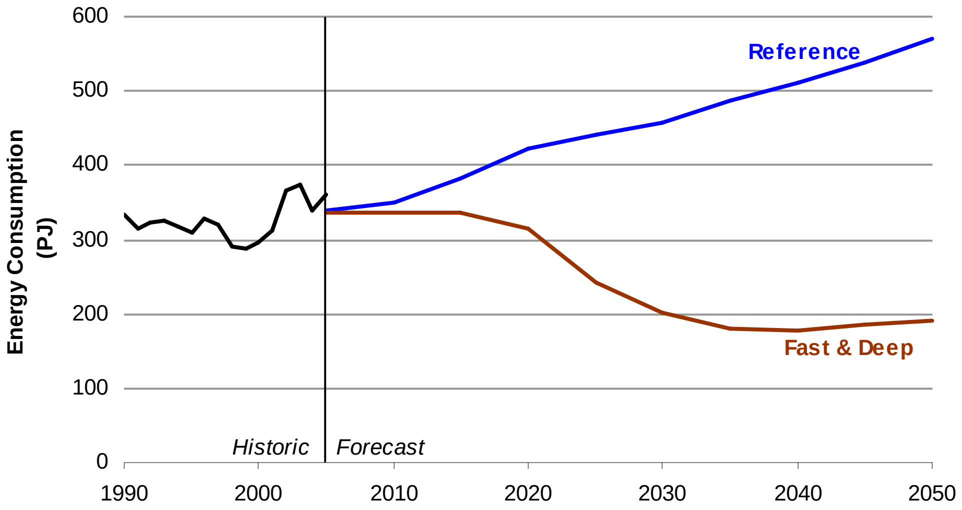
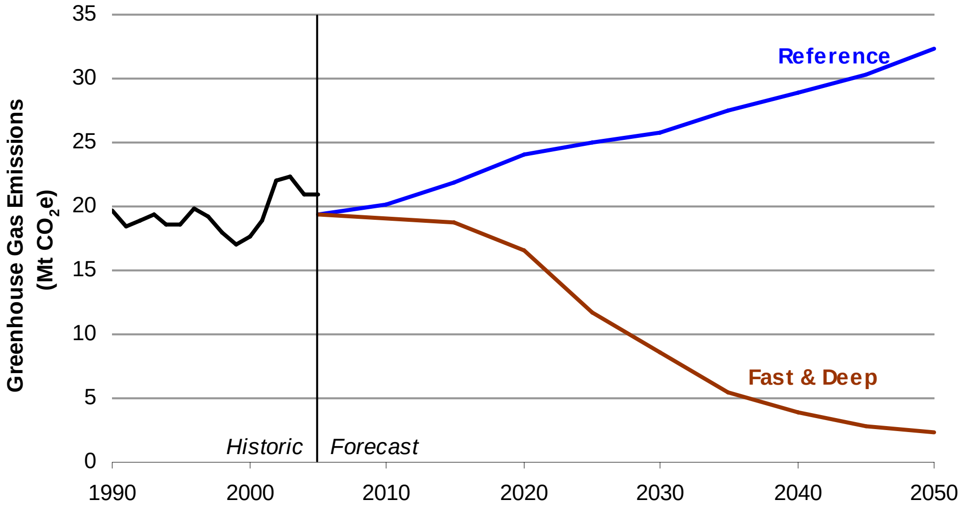


Figure 42: Greenhouse gas emissions for petroleum refining



While the reduction in output and the use of CCS contribute to most of the emissions reductions, fuel switching to electricity modestly reduces greenhouse gas emission. Table 71 shows that natural gas use falls about 18% by 2050, while electricity use rises by about 22%.

Table 71: Fuel switching in petroleum refining

	2020	*2030*	*2040*	*2050*
Natural Gas	-3%	-7%	-14%	-18%
Refined Petroleum Products	-1%	-1%	0%	2%
Electricity	4%	8%	18%	22%
Other	0%	0%	-4%	-6%

Economic impact of policy

The most important impact of the policy on refining per unit costs is on purchased energy, specifically natural gas and electricity. As the sector demands more electricity and the price for electricity increases in the policy scenario, the energy costs from the sector rise. Overall, the cost of refining petroleum increase by 1.5%.

Table 72: Increase in the cost of petroleum refining (2005¢ / L of refined petroleum)

	Increase in Costs (2005¢ / L RPP)			
	2020	*2030*	*2040*	*2050*
Total Cost	0.1	0.1	0.6	1.0
Capital Costs	0.0	0.0	0.1	0.1
Operating & Maintenance Costs	0.0	0.0	0.0	0.0
Energy Costs	0.1	0.2	0.6	0.8
Emissions Cost	2.2	4.6	2.5	1.5

Provincial discussion

Canada's refining capacity is concentrated in Alberta and Saskatchewan, which process mainly local heavy crude but also some synthetic light crude, and Ontario and Québec, where it processes imported light crude from Norway, the United Kingdom and other oil exporting countries. Refining in Canada mainly meets domestic transportation demand; and this demand and associated supply is projected to fall in all provinces.

Technology roadmap to low emissions for the petroleum extraction sector

The decline in output from the petroleum refining accounts for over 50% of the sectors emissions reductions in 2050, while carbon capture and storage accounts for approximately 35% (see Figure 43). As discussed above, the decline in output is mostly due to the uptake of renewable fuels and electricity in the transportation sector.

Figure 43: Wedge diagram for the petroleum refining sector

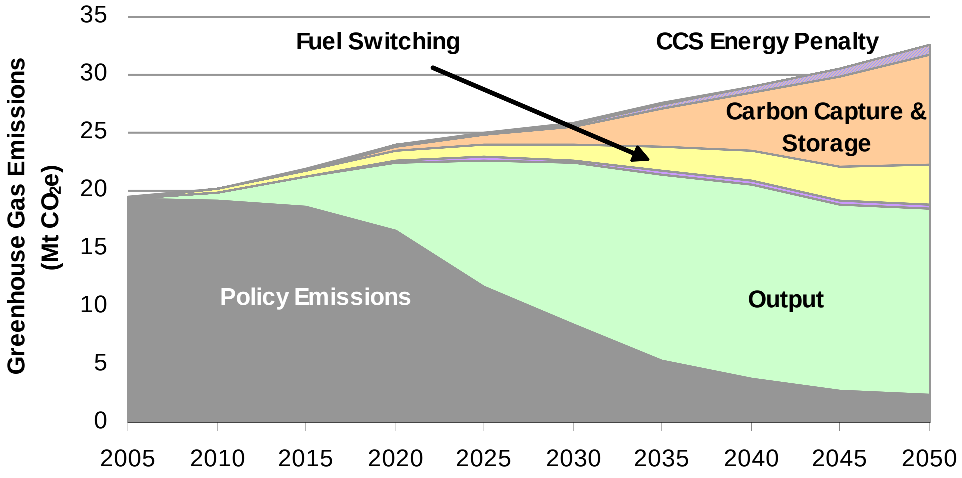


Table 73 show the penetration of carbon capture and storage in petroleum refining. By 2050, most process heat – 86% – is produced using capture equipment.

Table 73: Penetration of carbon capture and storage

	2020	*2030*	*2040*	*2050*
Carbon Capture & Storage	5%	21%	63%	86%

The reduction in demand for refined petroleum products has the largest impact on the capital expenditures of the sector. Capital expenditures decline by approximately 55% in response to the policy.

Table 74: Increase in capital expenditures from policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	-270	-399
Increase in Capital Expenditures (% above the reference case)	-55%	-60%

Petroleum Extraction

Box 13: Key actions by the petroleum crude sector

- ➢ The petroleum crude sector is forecasted to expand considerably due to the development of Alberta's oil sands. By 2050, the sector is expected to produce 190 Mt CO_2e in the absence of any mitigation policy.
- ➢ The key action to reduce greenhouse gas emissions is the adoption of carbon capture and storage, which contributes to 85% of the sectors greenhouse gas emissions reductions.
- ➢ Hydrogen production in oil sands upgraders may be an early opportunity for adopting carbon capture and storage.

The petroleum extraction sector is expected to play an increasingly important role in Canada's total greenhouse gas emissions. In the absence of any mitigation policy, the greenhouse gas emissions from petroleum extraction are expected to rise from approximately 66 Mt CO_2e in 2005 to 190 Mt CO_2e by 2050, which would account for 17% of Canada's projected greenhouse gas emissions in 2050. The projected increase in emissions is partially due to a substantial growth in petroleum production, which increases from 2.6 million barrels per day in 2005 to 7.0 million barrels per day in 2050. The sector is also projected to become more greenhouse gas intensive over the period, as the conventional production of petroleum declines and unconventional production from Alberta's oil sands increases. By 2050, the production of petroleum from oil sands (which includes synthetic crude oil and blended bitumen) is projected to reach 6.6 million barrels per day and emit 185 Mt CO_2e per year.

Within the oil sands sector, the main source of greenhouse gas emissions is from the production of process heat for oil sands upgrading and bitumen extraction from in-situ operations. In 2000, the production of process heat for oil sands upgrading accounted for approximately 78% of the greenhouse gas emissions from oil sands upgrading. Most of the remaining greenhouse gas emissions are process emissions from the production of hydrogen in oil sands upgrading, which accounted for approximately 14% of total upgrading emissions in 2000.[28] Most of the emissions from the conventional production of petroleum are fugitive emissions from oil well operations.

Environmental impact of policy

Figure 44 and Figure 45 illustrate the energy and greenhouse gas intensity of the petroleum industry in the reference case and in the policy scenario. In the reference case, both the energy and greenhouse gas intensity of petroleum extraction increases until 2020, and then begins to decline. The rise in energy and greenhouse gas intensity until 2020 is the result of the projected increase in unconventional oil production relative to conventional production. After 2020, unconventional production dominates the industry,

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[28] Source??

and energy and greenhouse gas intensity declines due to improving energy efficiency of unconventional production.

In the policy scenario, energy intensity increases as a result of the policy's implementation. Carbon capture and storage accounts for the majority of the decline in greenhouse gas intensity, but capturing carbon dioxide increases the energy requirements of producing petroleum. The greenhouse gas intensity of oil production is projected to decline from approximately 0.07 tonnes CO_2e per barrel in 2005 to 0.015 tonnes CO_2e per barrel in 2050. The intensity figures for each sub-sector within the petroleum crude sector (i.e., the production of conventional crude, synthetic crude and blended bitumen) are available in the Appendix.

Figure 44: Energy intensity of petroleum production

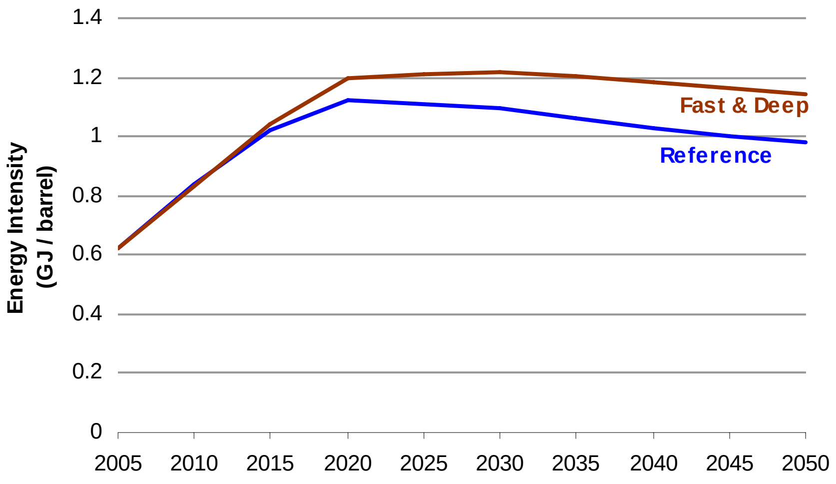

Figure 45: Greenhouse gas intensity of petroleum production

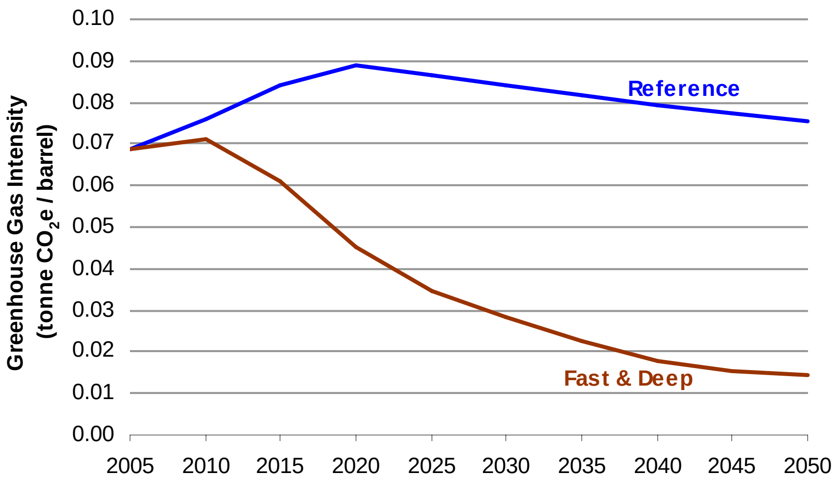

Table 75 shows the change in fuel shares in the petroleum extraction sector. Overall, the amount of fuel switching is relatively modest in comparison to other sectors. In general, the sector switches from refined petroleum products to electricity. We have excluded the option for the industry to produce process heat and electricity from nuclear energy because the decision is more political than economic. However, nuclear energy is an option in Alberta's oil sands.

Table 75: Fuel switching in the petroleum extraction sector

	2020	2030	2040	2050
Natural Gas	-1%	-1%	-1%	-1%
Coal	0%	-1%	-1%	-1%
Refined Petroleum Products	-1%	-2%	-4%	-5%
Electricity	2%	3%	5%	6%
Nuclear	0%	0%	0%	0%

Economic impact of policy

Table 76 shows the increase in the cost of producing oil for each sub-sector of the industry. In the policy scenario, the cost of oil production rises by $3.23 per barrel, a 14% increase. The increase in the cost of producing oil in the policy scenario is primarily a result of the adoption of carbon capture and storage. Carbon capture and storage requires greater capital investments and energy costs due to higher energy intensity. The production of synthetic crude from oil sands upgrading facilities experiences the greatest increase in the cost of production – in 2050, the cost of producing a barrel of synthetic crude from oil sands is $5.72 ($2005) greater than in the reference case. The cost increase of producing blended bitumen is lower largely because the bitumen is not upgraded.

Table 76: Increase in the cost of oil production by sub-sector (2005$ / barrel)

	2020	2030	2040	2050
All Production	$1.88	$2.69	$3.12	$3.23
Conventional	$1.18	$1.73	$1.83	$1.93
Synthetic	$3.28	$4.65	$5.48	$5.72
Blended bitumen	$0.69	$1.25	$1.65	$1.90

Table 77 shows how capital, operating and fuel costs contribute to the rise in cost of producing a barrel of oil. Energy costs increase significantly for two main reasons. First, the sector becomes more energy intensive per barrel of oil produced, largely due to the energy penalty associated with carbon capture and storage. Second, the policy encourages fuel switching away from petroleum products (e.g., petroleum coke and heavy fuel oil) to natural gas and electricity, which are forecasted to have higher prices. Energy costs in the petroleum extraction sector increase proportionally more in relation to other cost components when compared to other sectors (e.g., electricity) because it continues to rely heavily on natural gas and electricity. The electricity sector continues to use coal, which is cheaper per unit of energy produced. Capital costs also increase significantly, mostly due to the adoption of carbon capture and storage.

Table 77: Increase in the cost of oil production by cost type (2005$ / barrel)

	Increase in Costs (2005$ / barrel)			
	2020	*2030*	*2040*	*2050*
Total Cost	$1.88	$2.69	$3.12	$3.23
Capital Costs	$0.87	$1.09	$1.14	$1.10
Operating & Maintenance Costs	$0.23	$0.33	$0.40	$0.40
Energy Costs	$0.77	$1.26	$1.58	$1.72
Emissions Cost	$5.17	$8.46	$5.34	$4.36

Provincial discussion

The production of crude oil is forecasted to be highly concentrated within Alberta as the production of conventional crude declines and the production of synthetic crude and blended bitumen from Alberta's oil sands increases. By 2050, Alberta is expected to produce approximately 6.7 million barrels per day, which will account for approximately 95% of Canada's total crude oil production. Therefore, the results shown above are mostly indicative of petroleum sector within Alberta. The remaining oil-producing provinces are expected to produce conventional crude.[29]

Figure 46 shows the greenhouse gas intensity of conventional crude production outside Alberta. The increase in greenhouse gas intensity in the reference case is due to the relative decline of light and medium production (which is less greenhouse gas intensive) in comparison to the production of heavy crude. The policy encourages the adoption of technologies that limit the amount of fugitive emissions from conventional oil production. As a result, the greenhouse gas intensity of oil production declines by approximately 80% from the business-as-usual projection.

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[29] The potential development of oil sands in Saskatchewan has not been considered in this analysis. However, this development is a strong possibility (National Energy Board, 2007, "Canada's Energy Future"). The remaining provinces are not currently known to have any unconventional sources of petroleum that could be developed.

Figure 46: Greenhouse gas intensity of conventional crude outside Alberta

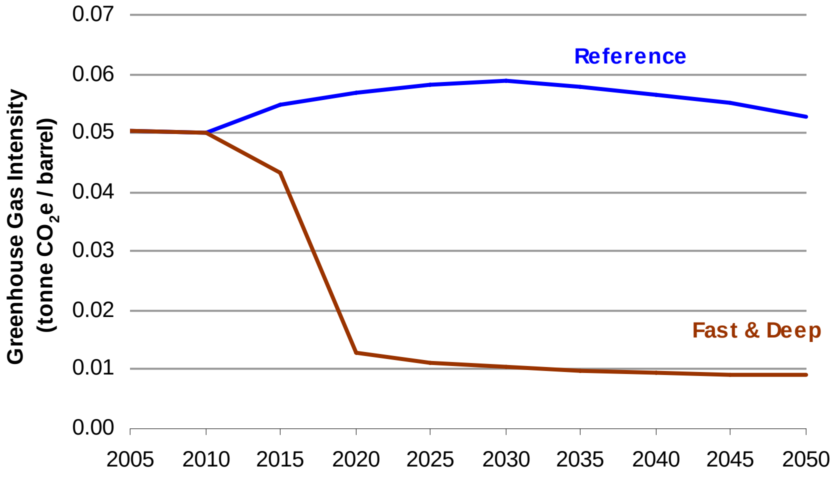


Table 78 shows the cost of oil production outside Alberta. The adoption of abatement technologies increases the cost of producing a barrel of oil by $1.55 ($2005) or approximately 7% in 2050. The increase in cost of production is lower outside Alberta because all production is forecasted to be conventional.

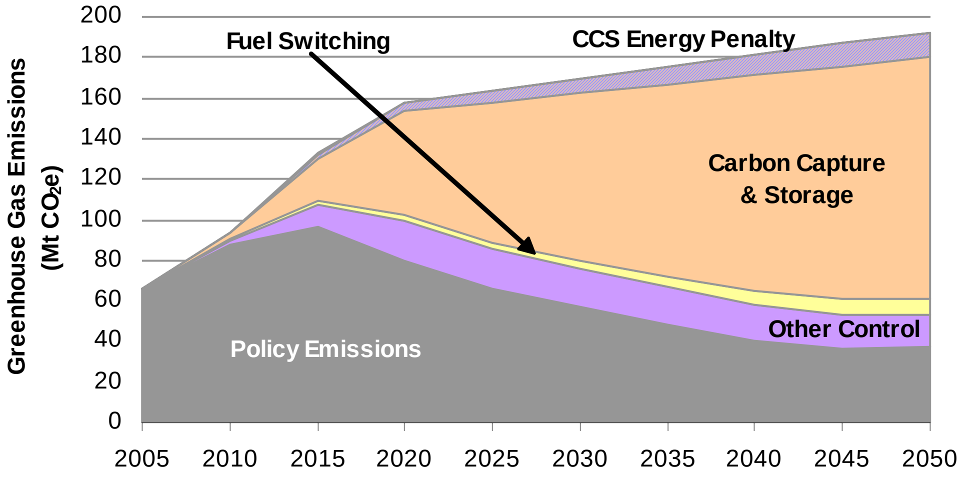
Table 78: Increase in the cost of oil production outside Alberta ($2005 / barrel)

	2020	*2030*	*2040*	*2050*
All Production	$0.87	$1.33	$1.46	$1.55

Technology roadmap to low emissions for the petroleum extraction sector

Figure 47 shows the actions that contribute to the decline in greenhouse gas emissions in the petroleum extraction sector. Carbon capture and storage accounts for approximately 85% of the reduction in greenhouse gas emissions in 2050, while other controls (e.g., leak detection and repair programs) and fuel switching to low carbon fuels account for approximately 10% and 5% of emissions reductions, respectively.

Figure 47: Wedge diagram for petroleum extraction



The oil sands sector employs three processes which are suitable for carbon capture and storage: 1) the production of hydrogen in oil sands upgrading, 2) the production of process heat for oil sands upgrading, and 3) the production of steam for in-situ operations. Hydrogen production via steam methane reforming or coke gasification can be designed or retrofitted to produce a relatively pure stream of carbon dioxide, which avoids the costly process of separating the carbon dioxide from other flue gases. Estimates of the costs of carbon capture from hydrogen production range from $5-50 / tonne CO_2e. Therefore, hydrogen production represents an opportunity for the early adoption for carbon capture.[30]

The emissions generated during the production of process heat for oil sands upgrading and from bitumen extraction at in-situ operations can also be captured. The cost of carbon capture from these sources is likely to be similar to the costs of capture from the electricity generation sector – between $15 and $75 ($US) per tonne of CO_2e avoided.[31]

Table 79 shows the penetration of carbon capture and storage in the oil sands sector in the Fast & Deep scenario as a percentage of total installed stock. Hydrogen production shows the fastest penetration of carbon capture and storage, while penetration is slightly slower for the production of process heat for upgrading and steam production in in-situ extraction. By 2050, all hydrogen production and oil sands upgrading should employ carbon capture and storage. Steam and heat production in in-situ operations predominately adopt carbon capture and storage, however a small portion of steam is produced from low emissions sources of energy (e.g., electricity). In-situ operations could also use nuclear energy to produce heat and steam if it becomes politically acceptable to do so. As discussed above, the option of nuclear power in this sector has been excluded from this analysis.

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[30] Intergovernmental Panel on Climate Change, 2005, “Carbon Dioxide Capture and Storage”; Keith D., 2002, “Toward a Strategy for Implementing CO_2 Capture and Storage in Canada”.

[31] Intergovernmental Panel on Climate Change, 2005, “Carbon Dioxide Capture and Storage”.

Table 79: Penetration of carbon capture and storage in oil sands sector

	2020	*2030*	*2040*	*2050*
Hydrogen Production	91%	98%	100%	100%
Oil Sands Upgrading	58%	88%	96%	99%
In-situ	35%	54%	57%	55%

In addition to carbon capture and storage, Figure 47 shows significant emissions reductions from fuel switching and from actions that reduce fugitive emissions, such as leak detection and repair programs. The sector switches from petroleum products (e.g., petroleum coke and heavy fuel oil) to natural gas and electricity as a result of the policy, primarily for steam and heat production. The reductions from fuel switching to natural gas occur primarily from fuel switching from petroleum coke to natural gas during the production of process heat and steam.

Our analysis includes several in-situ extraction technologies with the potential to greatly reduce steam requirement for extraction. These include solvent-based systems to reduce the viscosity of the bitumen (e.g., VAPEX) and underground combustion processes (e.g., Toe to Heel) that liquefy and push the bitumen to the surface. We expect these technologies to be adopted regardless of the policy because they reduce energy costs, but the policy is likely to accelerate their adoption. Overall, these technologies are projected to improve the energy efficiency of the sector over time, but not significantly in response to the policy.

Table 80 shows the increase in capital expenditures caused by the policy. The capital expenditures required to attain the emissions reductions in the petroleum extraction sector are 23% greater in the medium-term, and 17% greater in the long-term. The rise in capital expenditures is greater in the medium-term due to the retrofitting of existing oil sands upgraders with carbon capture equipment. In the long-term, most investments in carbon capture are made to new facilities.

Table 80: Increase in capital expenditures from the policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	1,236	768
Increase in Capital Expenditures (% above the reference case)	23%	17%

Uncertainty in the analysis

The petroleum crude sector may have the option to use nuclear energy to produce the process heat and steam required for oil sands upgrading and bitumen extraction in mining and in-situ operations. We have excluded this option from the analysis because the decision is more political than economic. The adoption of nuclear energy to power oil sands production would significantly reduce the role of carbon capture and storage in heat production. Nuclear power could also be used to produce hydrogen by electrolysis.

The impact of the policy on the output from the sector is also significantly uncertain. In this analysis, we assume that the Canadian production of petroleum will not change when the policy is implemented. We also assume that the demand for petroleum will remain significant even in a greenhouse gas constrained future (i.e., there will continue to be demand for petroleum products, especially from the transportation sector). Finally, we assume that the selling price of petroleum (i.e., the global price for oil) will exceed the cost of producing it in Canada regardless of the policy – in other words, the sector generates economic profits or rents. However, if the price for oil is lower than forecasted, the policy may reduce production from high cost sources of petroleum.

Natural Gas Extraction

Box 14: Key actions by the natural gas extraction sector

- Most emissions reductions are attained from carbon capture and storage.
- The separation of formation carbon dioxide from raw natural gas is likely to be an early opportunity to adopt carbon capture. The process produces a relatively pure stream of carbon dioxide, which can be captured at low cost – approximately $20 per tonne CO_2e.

The natural gas extraction and processing sector is projected to play a declining role in Canada's greenhouse gas emissions, as the output from conventional natural gas fields declines. The development of coal bed methane partially offsets the decline from conventional fields, but total output is projected to decrease from 174 billion m^3 in 2005 to 140 billion m^3 in 2050. In the reference case, greenhouse gas emissions also decline from 65 Mt CO_2e in 2005 to 37 Mt CO_2e in 2050, reflecting a reduction in output. Approximately half of the greenhouse gas emissions are from combustion sources – engines and the production of process heat at natural gas processing plants – while half are process emissions. Process emissions from natural gas extraction include formation carbon dioxide, fugitive emissions from natural gas wells and leaks from pipelines. Formation carbon dioxide is extracted from the well with the raw natural gas; the carbon dioxide is removed and vented before it is marketed.

Environmental impact of policy

Figure 48 and Figure 49 show the energy and greenhouse gas intensity of the natural gas sector in the reference and policy scenario. The energy and greenhouse gas intensity of the industry decline in the reference case, mostly as a result of improvements in the energy efficiency of natural gas extraction and processing. These improvements offset the transition towards extracting natural gas from coal beds, which is more energy and greenhouse gas intensive. Greenhouse gas emissions intensity further declines from a modest adoption of leak detection and repair programs, which increase costs but also increase the output of natural gas.

In the policy scenario, the sector becomes more energy efficient, as a result of greater energy efficiency in natural gas extraction and processing. These improvements in energy efficiency offset the energy efficiency penalty associated with carbon capture and storage. The greenhouse gas intensity of natural gas extraction also drops as a result of carbon capture of the formation carbon dioxide and the combustion emissions from processing plants, as well as from leak detection and repair programs.

Figure 48: Energy intensity of natural gas extraction

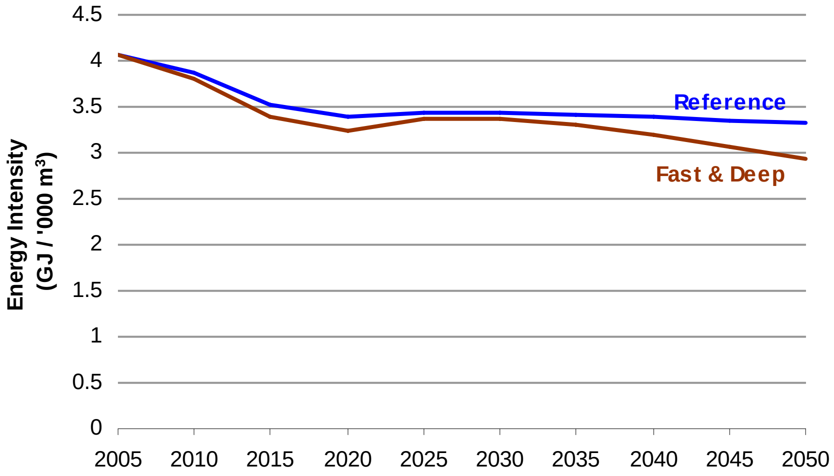


Figure 49: Greenhouse gas intensity of natural gas extraction

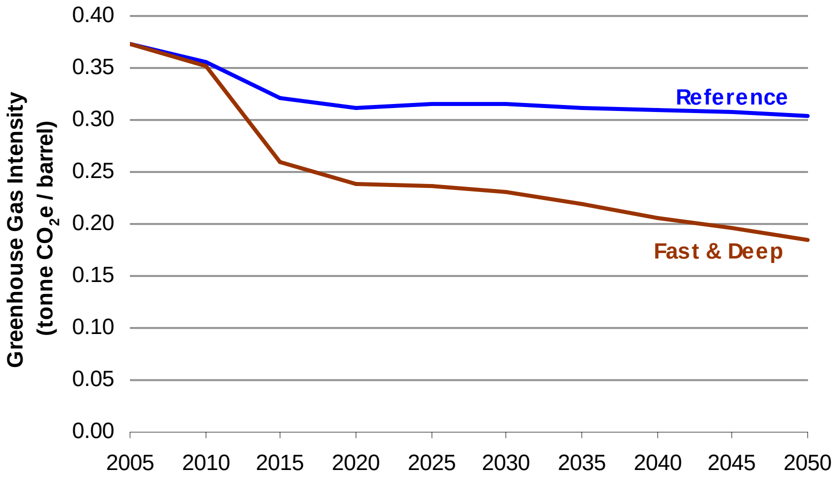


Table 81 shows change in fuel share that result from the policy. The increase in the share of electricity and the decline in natural gas are mostly due to a greater use of electric motors to drive pipelines and operate natural gas wells.

Table 81: Fuel switching in the natural gas extraction sector

	2020	*2030*	*2040*	*2050*
Natural Gas	-4%	-6%	-11%	-19%
Refined Petroleum Products	0%	0%	1%	1%
Electricity	3%	6%	11%	18%

Economic impact of policy

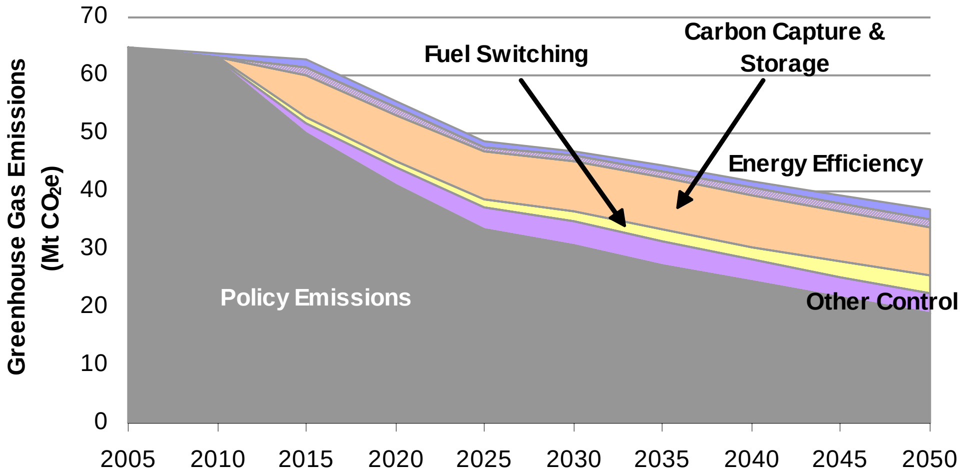
Table 82 shows the rise in the costs of extracting and transporting natural gas that results from the policy. Overall, the cost of production increases by approximately 2%, with a rise in capital expenditures per unit of natural gas production accounting for the greatest portion of the increase. Carbon capture and leak detection programs require greater capital expenditures.

Table 82: Cost of natural gas extraction
Will add later

Technology roadmap to low emissions for the petroleum extraction sector

Figure 50 shows the actions that contribute to the emissions reductions in the natural gas sector. Carbon capture and storage accounts for approximately 45% of the emissions reductions, while leak detection and repair programs and fuel switching each account for about 20%.

Figure 50: Wedge diagram for natural gas extraction



Capturing formation carbon dioxide from this sector is likely to be an early opportunity for implementing carbon capture and storage. In response to regulations on flaring acid gas (H_2S), one option for disposing this gas in small plants is to store the entire acid gas stream (including the formation carbon dioxide) in a geological formation. Carbon capture and storage from these sources would have little to zero additional cost. For larger plants, which are more likely to recover the sulphur instead of store the entire acid gas stream, carbon capture is still a relatively cheap option because the technology can be designed or retrofitted to produce a relatively pure stream of carbon dioxide. The cost of capturing formation carbon dioxide is estimated at approximately \$20/tonne CO_2e.[32] Carbon capture from combustion sources is likely to have similar costs to combustion sources in other sectors, which will likely be closer to \$50/tonne CO_2e. Table 83 shows the penetration of carbon capture for formation carbon dioxide and the combustion sources in natural gas processing plants.

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[32] Keith, 2002, "Toward a Strategy for Implementing CO_2 Capture and Storage in Canada".

Table 83: Penetration of carbon capture in natural gas extraction

	2020	*2030*	*2040*	*2050*
Formation Carbon Dioxide	100%	100%	100%	100%
Combustion Emissions in Processing Plants	32%	63%	98%	100%

In addition to carbon capture, the sector reduces fugitive emissions through leak detection and repair programs. These programs identify and fix leaks in natural gas wells and pipelines. Table 84 shows fugitive emissions per unit of natural gas production. Fugitive emissions decline regardless of the policy because the reduction of fugitive methane increases natural gas production. However fugitive emissions decline by 28% from the reference case projection in the policy scenario.

Table 84: Fugitive emission rate from natural gas wells and pipelines

	Fugitive Emissions (tonne CO_2e / '000 m^3)			
	2020	*2030*	*2040*	*2050*
Reference Case	0.098	0.094	0.091	0.089
Fast & Deep	0.081	0.070	0.067	0.064
Reduction due to Policy (%)	17%	25%	27%	28%

The motors that drive pipelines and operate wells may either use electricity or natural gas. Table 85 shows the penetration of electric motors for operating wells and pipelines. By 2050, close to 80% of all motors use electricity, a 60% increase from the reference case projection.

Table 85: Penetration of electric motors for operating wells and pipelines

	Penetration of Electric motors (%)			
	2020	*2030*	*2040*	*2050*
Reference Case	8%	12%	15%	18%
Fast & Deep	22%	33%	53%	77%
Increase due to Policy (%)	13%	22%	38%	59%

Table 86 shows that attaining the deep reductions in greenhouse gas emissions requires around a 5% increase capital expenditures over the reference case. The increase in capital costs is mostly from the addition of carbon capture and storage equipment to abate formation carbon dioxide, although the capture equipment is likely to be cheaper than for combustion emissions.

Table 86: Increase in capital expenditures that results from policy

	Medium-Term (2011-2030)	*Long-term (2031-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	88	127
Increase in Capital Expenditures (% above the reference case)	4%	6%

Biofuels Manufacturing

Box 15: Key actions by the biofuels manufacturing sector

- The policy induces a significant increase in the production of biofuels. In the reference projection, the demand and production of biofuels is negligible, but increases to 2,095 PJ in 2050 in the policy scenario.
- In the policy scenario, the sector reduces its greenhouse gas intensity by adopting carbon capture and storage, and producing ethanol from cellulose instead of corn.

The production of biofuels (liquid transport fuels derived from biomass) is expected to remain relatively minor in the reference scenario, reaching just 103 PJ in 2050. However, substituting conventional fossil fuels with biofuels has the potential to reduce greenhouse gas emissions from the transportation sector, and other sectors such as petroleum extraction and mining. Production of biofuels increases dramatically in the policy scenario, reaching 2,095 PJ in 2050. Switching to biofuels reduces greenhouse gas emissions by 174 Mt CO_2e in 2050, accounting for 16% of total emissions reductions for Canada.

Several types of biofuels exist, with multiple methods of producing them. The two dominant forms of biofuels today are ethanol and esters, the latter more commonly known as biodiesel. Ethanol is usually produced from sugar or starchy crops, and in Canada, it is primarily distilled from corn and wheat, while biodiesel is produced mainly from oil-seed crops, such as rapeseed, palm and sunflowers.[33] Ethanol can be used in most automotive engines when blended in low concentrations with gasoline, but requires modifications to the vehicle engine to be used in high or pure blends. However, biodiesel can be used easily in most compression-ignition engines in its pure form or blended with conventional diesel fuel.[34] Some types of biodiesel freeze at lower temperatures than others, although fuel additives and engine block or fuel filter heaters can remedy this problem.[35]

The production of agricultural crops and the conversion of these crops into biofuels requires energy; however advanced methods of producing biofuels (such as enzymatic hydrolysis and gasification of woody ligno-cellulosic feedstock) may reduce these requirements in the future. Note that the following discussion concerning biofuels manufacturing ignores inter-provincial differences because production processes are likely to be similar among regions.

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[33] Natural Resources Canada, 2006, "Ethanol: The Road to a Greener Future," http://oee.nrcan.gc.ca/publications/infosource/pub/vehiclefuels/ethanol/M92_257_2003.cfm

[34] International Energy Agency, 2006, "World Energy Outlook," Paris: OECD/IEA.

[35] Natural Resources Canada, 2008, "Biodiesel: Safety & Performance," http://www.oee.nrcan.gc.ca/transportation/fuels/biodiesel/biodiesel-safety.cfm?attr=8

Environmental impact of policy

Figure 51 and Figure 52 show the energy intensity of ethanol and biodiesel production over time for the reference and policy scenarios. The energy intensity of ethanol production decreases markedly in both the reference and policy scenarios, due to the adoption of cellulosic production techniques which are less energy intensive. In the policy scenario, the energy intensity of ethanol production reaches 0.07 GJ / GJ ethanol by 2050, 92% lower than in 2005 and 64% lower than the reference projection for 2050. The energy intensity of biodiesel production does not change significantly in the reference or policy scenario, remaining at about 0.20 GJ / GJ biodiesel.

Figure 51: Energy intensity of ethanol production

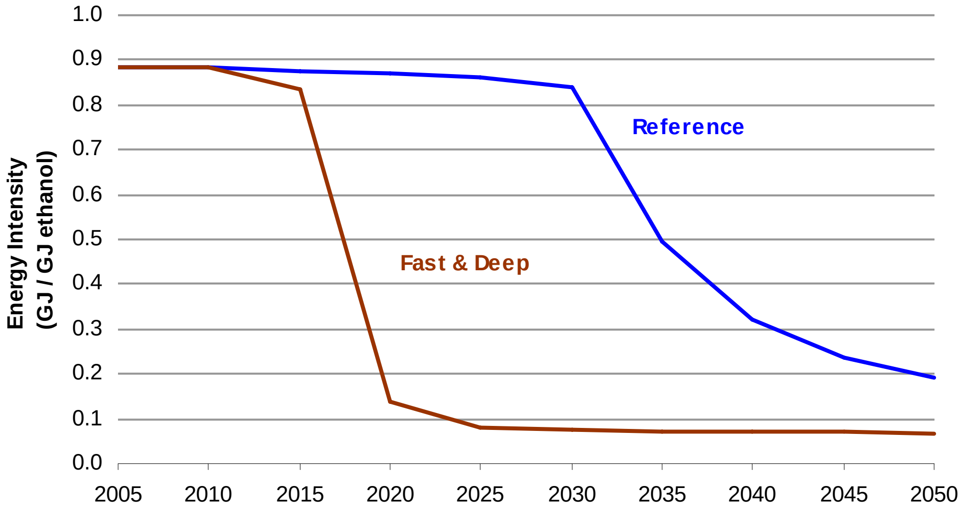

Figure 52: Energy intensity of biodiesel production

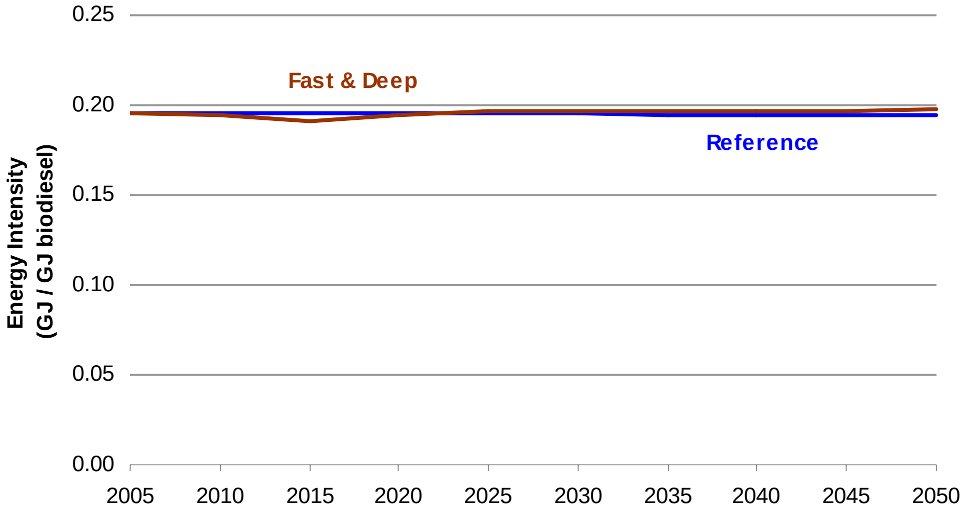

Figure 53 and Figure 54 show the greenhouse gas intensity of ethanol and biodiesel production in the reference and policy scenarios. The greenhouse gas intensity decreases substantially in both scenarios, but is accelerated in the policy scenario. In the policy scenario, the greenhouse gas intensity of ethanol production drops from 0.045 t CO_2e / GJ ethanol in 2005 to 0.002 t CO_2e / GJ ethanol in 2050, a decrease of 95%. The switch to cellulosic production methods plays a large role in reducing GHG emissions from ethanol production. The greenhouse gas intensity of biodiesel production also decreases substantially, from 0.015 t CO_2e / GJ biodiesel in 2005 to 0.004 t CO_2e / GJ biodiesel in 2050, a decrease of 73%. The decline in greenhouse gas intensity from biodiesel production is mostly from installing electric boilers and adopting carbon capture and storage.

Figure 53: Greenhouse gas intensity of ethanol production

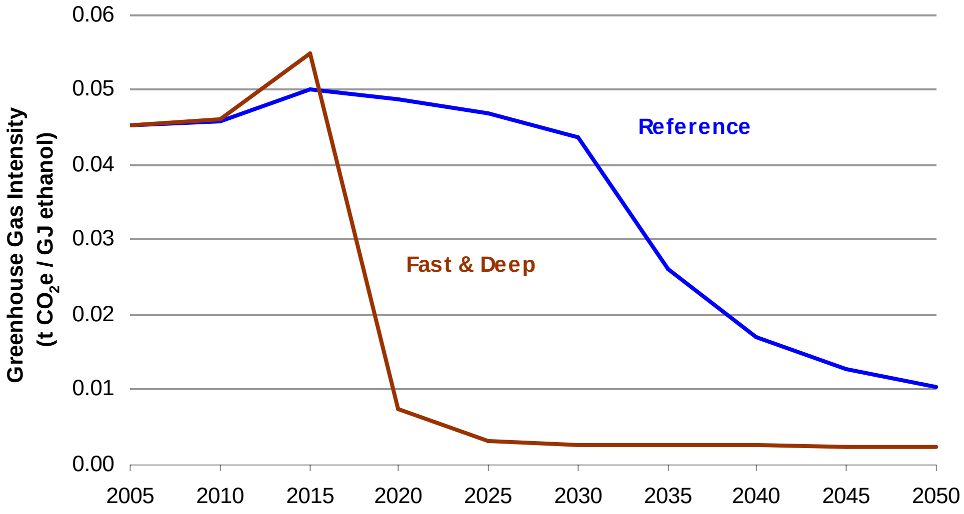

Figure 54: Greenhouse gas intensity of biodiesel production

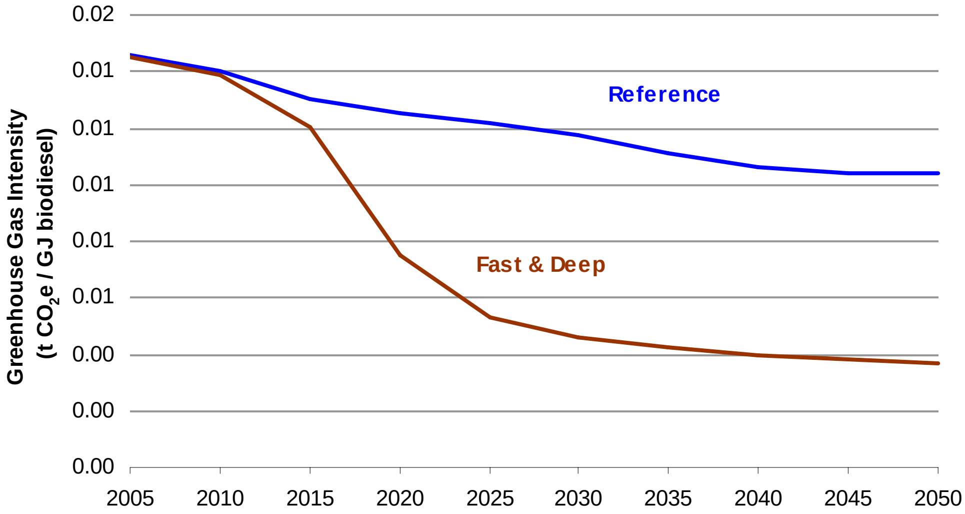

Table 87 shows the change in fuel shares that result from the policy scenario. Overall, the sector shifts from coal and natural gas towards electricity and renewable energy. The majority of the observed shifts in fuel consumption occur from the energy used to produce process heat, although agricultural machinery contributes to part of the shift towards renewable energy.

Table 87: Fuel switching in the biofuels sector (% change from reference case)

	2020	*2030*	*2040*	*2050*
Natural Gas	-14%	-18%	-15%	-11%
Coal	-9%	-14%	-12%	-12%
Refined Petroleum Products	3%	10%	3%	-1%
Electricity	16%	15%	14%	15%
Renewable	4%	8%	9%	9%

Economic impact of policy

Table 88 and Table 89 show the increase in production costs relative to the reference case for ethanol and biodiesel, respectively. Production costs for ethanol decrease because the policy scenario results in a more rapid and widespread adoption of cellulosic ethanol production, which require up to 90% less energy. The capital requirements of producing a unit of ethanol also decline, as manufacturers accumulate experience more rapidly with cellulosic ethanol. In 2050, ethanol production costs are 6% lower than in the reference case and 36% lower than in 2005. On the other hand, production costs for biodiesel increase modestly, and in 2050 are 3% higher than in the reference case. This increase is due to the higher energy cost of electricity and renewable energy relative to conventional fossil fuels in the policy scenario.

Table 88: Increase in the cost of ethanol production by cost component (2005$ / GJ biofuel)

	Increase in Costs (2005$ / GJ)			
	2020	*2030*	*2040*	*2050*
Total Cost	-$4.11	-$7.01	-$2.15	-$1.03
Capital Costs	$2.03	-$0.50	-$0.10	-$0.04
Operating & Maintenance Costs	-$0.17	-$0.18	-$0.06	-$0.03
Energy Costs	-$5.98	-$6.33	-$1.99	-$0.96
Emissions Costs	$0.86	$0.84	$0.77	$0.69

Table 89: Increase in the cost of biodiesel production by cost component (2005$ / GJ biofuel)

	Increase in Costs (2005$ / GJ)			
	2020	*2030*	*2040*	*2050*
Total Cost	$0.47	$0.67	$0.61	$0.60
Capital Costs	$0.05	$0.09	$0.12	$0.11
Operating & Maintenance Costs	-$0.01	-$0.01	$0.00	$0.00
Energy Costs	$0.43	$0.59	$0.50	$0.49
Emissions Costs	$0.86	$1.39	$1.20	$1.10

Technology roadmap to low emissions for the biofuels sector

The increase in biofuels production in the policy scenario results in a dramatic increase in energy consumption and GHG emissions from this sector. However, emissions from other sectors are reduced as they switch from conventional fossil fuels to biofuels. Most of the declines in emissions intensity are the result of improved energy efficiency and carbon capture and storage. Table 90 shows the emissions reductions by action in biofuels manufacturing.

Table 90: Emissions reductions by action in biofuels manufacturing (Mt CO_2e)

	2020	*2030*	*2040*	*2050*
Output	-1.95	-5.98	-8.06	-8.75
Fuel Switching	0.13	0.35	0.44	0.45
CCS	0.08	0.44	0.64	0.81
CCS Energy Efficiency Penalty	0.01	0.06	0.08	0.10
Energy Efficiency	0.28	1.36	0.98	0.72
Total Reductions	-1.44	-3.77	-5.93	-6.68

Switching to cellulosic ethanol production methods substantially reduces the energy intensity of producing biofuels. Conventional ethanol production from corn currently accounts for all ethanol production. In the reference scenario, the share of cellulosic ethanol captures 84% of the market in 2050 (see Table 91). The development of cellulosic ethanol technology is accelerated in the policy scenario, with this technology accounting for all production by 2030.

Table 91: Penetration of cellulosic ethanol (% of ethanol production)

	2020	*2030*	*2040*	*2050*
Reference	0%	3%	68%	84%
Policy	91%	99%	100%	100%

The policy scenario results in a large switch away from conventional fossil fuel-fired heat production towards electricity and carbon capture and storage. Table 92 shows the penetration of these technologies in the biofuels sector. By 2050, heat production using electricity and carbon capture and storage for virtually the entire market share. Just under half of the greenhouse gas emissions from this sector are captured in 2050, amounting to 5.2 out of 11.5 Mt CO_2e.

Table 92: Penetration of electricity and carbon capture and storage in heat production

	2010	*2020*	*2030*	*2040*	*2050*
Electric	0%	25%	44%	49%	52%
Carbon Capture and Storage	2%	37%	45%	46%	46%

Table 93 shows the increase in capital expenditures from the policy scenario. Capital expenditures must rise dramatically to meet the rapid growth in demand for biofuels that results from the policy.

Table 93: Increase in capital expenditures that results from policy

	Medium-Term (2011-2025)	*Long-term (2026-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	1,516	2,634
Increase in Capital Expenditures (% above the reference case)	3,466%	1,802%

Uncertainty in the analysis

Several sources of uncertainty are present in the analysis of the biofuels sector. First, as agricultural land is devoted to the production of biofuel crops, the costs of these crops should increase as less additional land is available for production. However, the possibility for alternative inputs (such as a variety of fibres for cellulosic ethanol) and higher agricultural yields may diminish these price feedbacks.[36] This analysis assumes that the cost of agricultural inputs does not vary according to production of biofuels.

Second, a variety of other factors could impact the potential for biofuels to reduce greenhouse gas emissions in Canada. For example, concerns about food costs and land availability could minimize the desired role for biofuels; alternatively, additional support could be given to biofuels in order to increase revenue for agricultural producers.

Landfills

Box 16: Key actions by the landfill sector

- Capturing and flaring landfill gas, which has high concentrations of methane, may be an early opportunity for abating greenhouse gas emissions in Canada. By 2020, the policy induces almost all landfills in Canada to control landfill gas emissions.

Canadian landfills emitted approximately 27.5 Mt CO_2e in 2005, and in the reference scenario are expected to emit 33.9 Mt by 2050.[37] The decomposition of organic waste in these landfills produces methane and carbon dioxide, which are generally released into the atmosphere. Some landfills already capture and flare landfill gas to control odours or to generate electricity from methane, although the capture of landfill gas is unlikely to expand substantially without a policy intervention.

In 2005, about 29% of landfill waste was subjected to gas flaring across Canada, and less than 1% of waste was used for electricity generation. The remaining 70% of landfill waste was not subject to any control measures. Although the current status of flaring varies among provinces, the following discussion ignores regional differences because the potential for mitigation actions is judged to be largely similar.

Environmental impact of policy

Landfills may present an early opportunity for reducing greenhouse gas emissions. In the reference scenario, the greenhouse gas intensity of landfills falls slightly, from 1.01 tonnes CO_2e / tonne waste in 2005 to 1.00 tonnes CO_2e in 2050 (see Figure 55). However, in the policy scenario greenhouse gas intensity drops dramatically and is only 0.16 tonnes CO_2e in 2015, a decrease of 84%.

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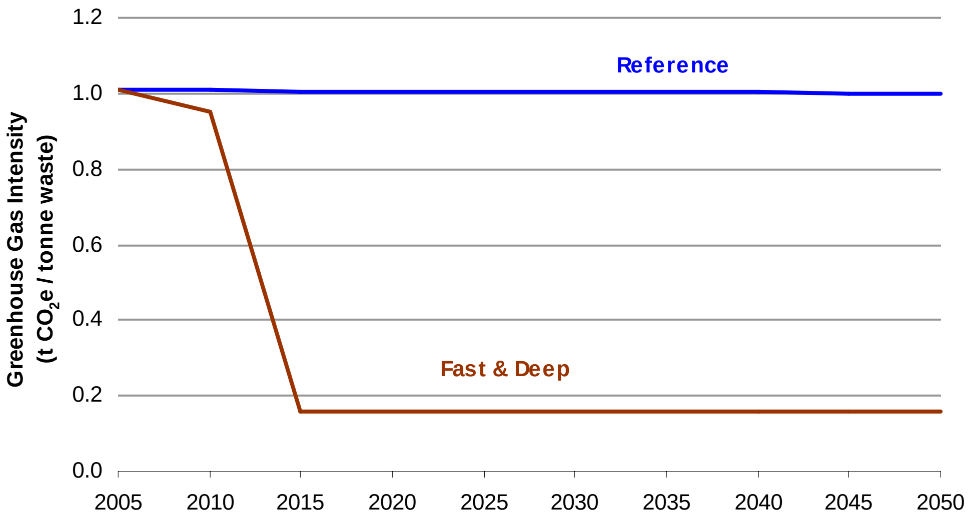
[36] International Energy Agency, 2006, “World Energy Outlook,” Paris: OECD/IEA.

[37] Note that Environment Canada has recently revised this estimate downward to 21 Mt CO_2e in 2005 (Environment Canada, 2008, “National Inventory Report”)

Figure 55: Greenhouse gas intensity of landfills



Economic impact of policy

The costs of capturing landfill gas are presented in Table 94. Capital costs and operating and maintenance costs increase significantly relative to the reference scenario, but are offset in large part by revenue from electricity generation. In 2050, total costs are $5.71 per tonne of waste higher than in the reference scenario.

Table 94: Increase in the cost of landfill waste processing by component (2005$ / tonne waste)

	Increase in Costs (2005$ / tonne waste)			
	2020	*2030*	*2040*	*2050*
Total Cost	$5.49	$5.39	$5.56	$5.71
Capital Costs	$7.43	$8.33	$8.92	$9.32
Operating & Maintenance Costs	$3.65	$4.10	$4.35	$4.51
Energy Costs	-$5.59	-$7.04	-$7.71	-$8.12
Emissions Costs	$18.50	$48.26	$48.26	$48.26

Technology roadmap to low emissions for the petroleum extraction sector

The wedge diagram in Figure 56 illustrates the rapid reduction of emissions from Canada's landfills. By 2015, greenhouse gas emissions are only 4.6 Mt CO_2e – 84% below the reference scenario. The reduction in emissions is possible because of a rapid uptake of flaring and electricity generation among landfills. In the reference scenario, 70% of landfill waste is not subjected to any greenhouse gas control. In the policy scenario, all landfill waste is subjected to control measures by 2015 (see Table 95). After 2015, the proportion of waste which is used to generate electricity gradually increases, reaching 62% in 2050. By 2050, the sector generates 5.4 TWh of electricity.

Figure 56: Wedge diagram for landfills

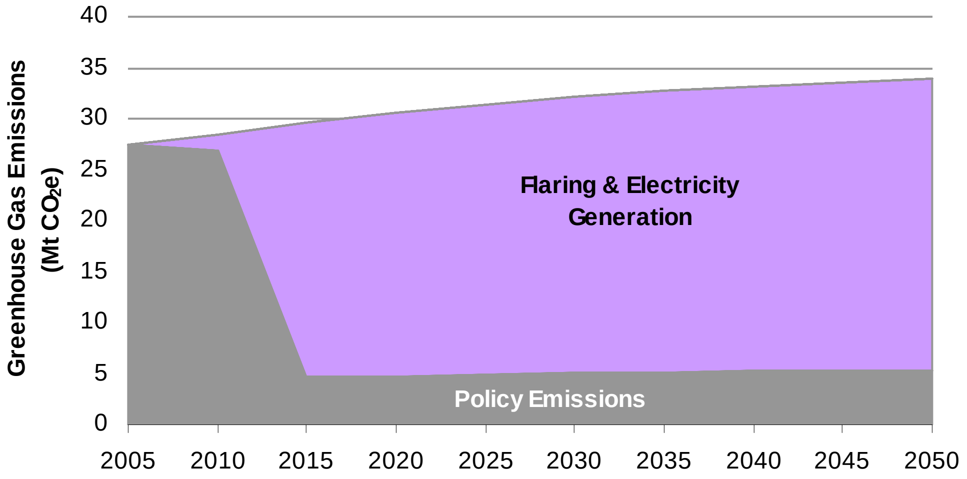


Table 95: Proportion of landfill waste subjected to greenhouse gas control measures

	2010	*2020*	*2030*	*2040*	*2050*
No Control	66%	0%	0%	0%	0%
Flaring	31%	61%	50%	43%	38%
Electricity Generation	3%	39%	50%	57%	62%

Table 96 shows the increase in capital expenditures from the policy scenario. Capital expenditures must rise dramatically to cap landfill and install the flaring equipment, especially in the medium term.

Table 96: Increase in capital expenditures that results from policy

	Medium-Term (2011-2025)	*Long-term (2026-2050)*
Increase in Annual Capital Expenditures (2005$ Millions)	70	19
Increase in Capital Expenditures (% above the reference case)	1,656%	570%

Uncertainty in the analysis

This analysis assumes that all landfills are capable of capturing and flaring landfill gas. The cost of capturing and flaring landfill gas varies depending on the size of the landfill, and whether the landfill gas could be used to generate electricity. However, most landfills in Canada should capture and flare their emissions once the price for emissions has exceeded $80/tonne CO_2e.[38]

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[38] Marbek, 2002, “Business Plan for GMIF Investments: Landfill Gas Sector”.