FINAL REPORT

Economic Analysis of Climate Change Abatement Opportunities for Alberta

October 12, 2007

Contract 08-0133
Contract 08-0163

Prepared for:
Alberta Environment

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Executive Summary

Alberta is currently in the process of updating its Climate Change Action Plan. As part of this process, Alberta is interested in understanding the potential for greenhouse gas reductions throughout the economy. The primary objective of this report is to estimate the likely greenhouse gas reductions that would be available from several alternative greenhouse gas policies using a technologically detailed energy-economy model. In addition, the analysis in the report forecasts the economic impacts of those policies. This report is an initial exploration of greenhouse gas policies in Alberta. It is not an exhaustive exploration of policy alternatives, and does not prescribe a policy package that Alberta should implement.

We quantitatively estimated the response of the Alberta economy to two general types of greenhouse gas policy:

- **Carbon charges**, which require emitters of greenhouse gases to pay a fixed charge proportional to their emissions. This type of policy sends a marginal cost signal to all emitters throughout the economy and should result in economically efficient greenhouse gas emissions reductions throughout the economy. The analysis of carbon charges also provides information on the strength of policy required to reach a target for greenhouse gas emissions.
- **Regulations**, which require the use of certain types of technologies or processes in a given sector of the economy.

To determine the effect of each type of policy, we first developed a reference case to show the likely trajectory of greenhouse gas emissions in Alberta in the absence of climate change policies.

Reference case forecast

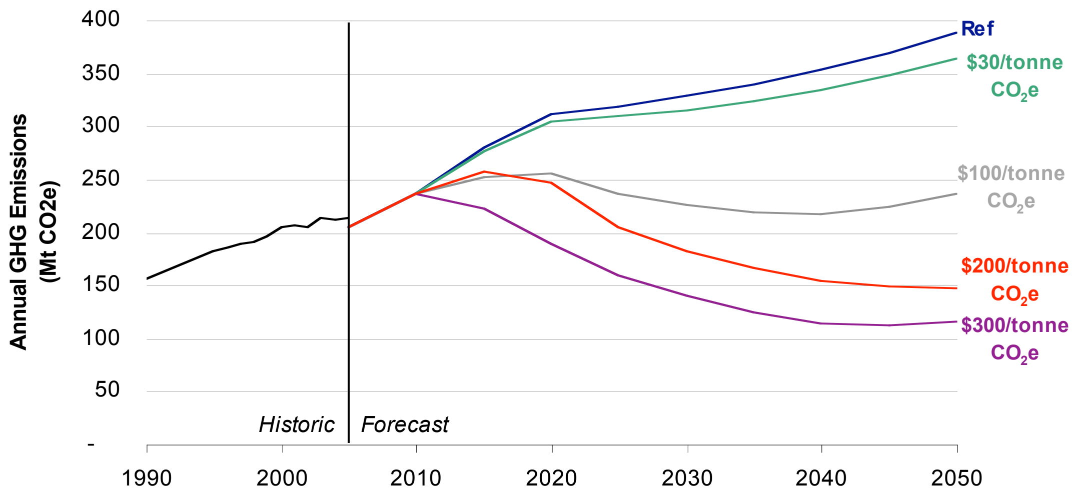
- **Alberta's emissions are likely to continue to increase rapidly in the absence of new climate change policies.** Our forecast is based on external assumptions about population growth, economic growth, fuel prices, and fossil fuel production, coupled with analysis of technological development and adoption over time. We project that Alberta's emissions will grow by roughly 50 percent from current levels by 2020 and by roughly 80 percent from current levels by 2050 in the absence of new climate change policies. The primary reasons for the growth in emissions are rapid expansion of production in the upstream oil sector (production is forecast to increase about fourfold by 2050), growth in the energy transformation sectors (primarily petroleum refining and electricity generation), and growth in the transportation sector.

Results of carbon charge modelling

- **Because Alberta is likely to undergo such fast growth in emissions in the reference case, reducing absolute emissions below 1990 levels is likely to be challenging. Even stabilizing emissions at current levels will require**

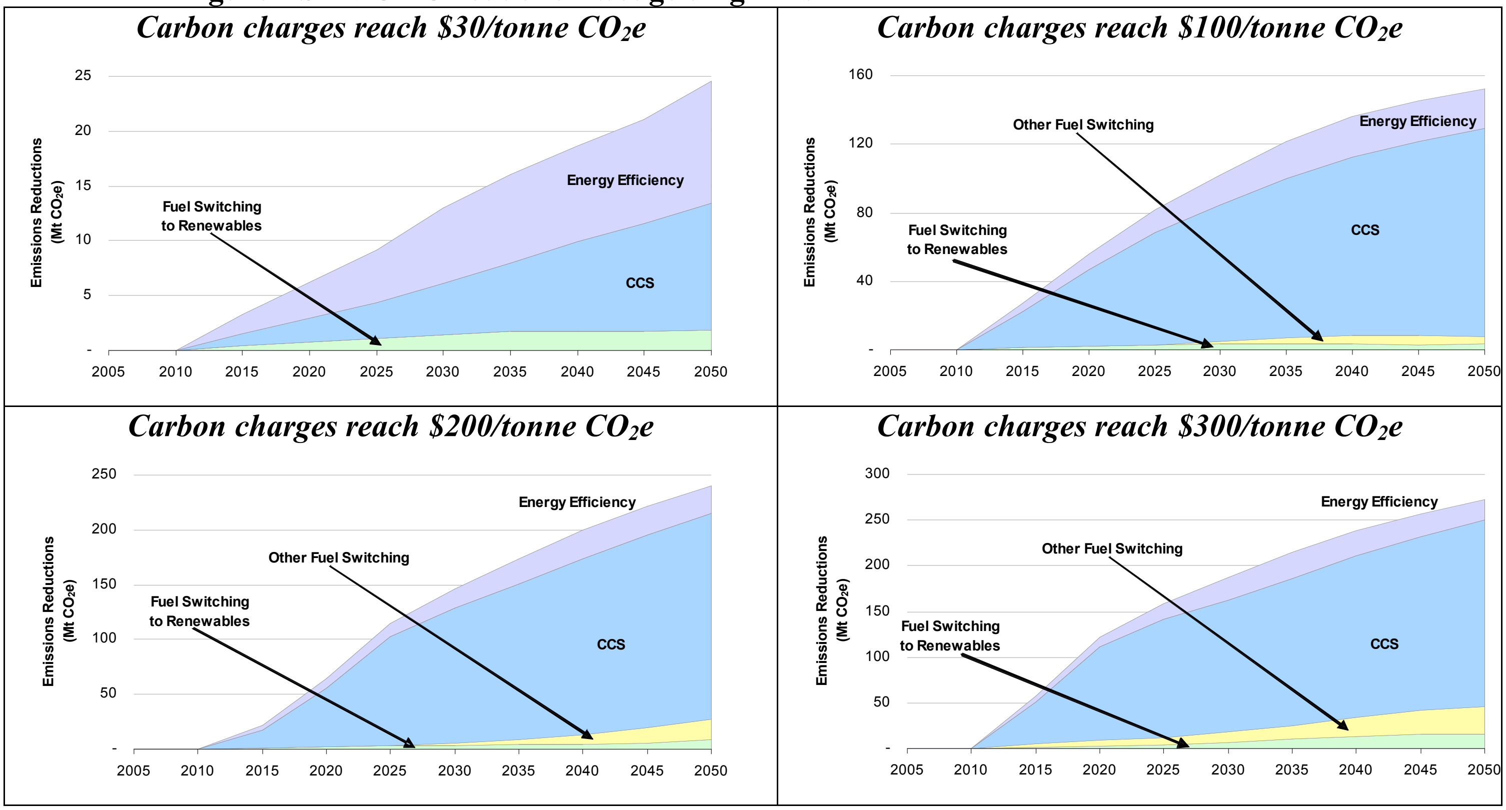
significant policy intervention. Figure ES-1 shows projected GHG emissions in the reference case as well as in several of the policy scenarios that were modelled for this report. All of the policies are *carbon charges*, which require emitters of greenhouse gases to pay a fixed charge proportional to their emissions. The figure shows that modest greenhouse gas policies (for example, where the carbon charge is \$30/t CO_2e) still allow significant growth in emissions from today's levels. Stronger polices (where the carbon charge reaches \$100/t CO_2e by 2050) can reduce emissions to around today's level by 2050. The policy where the carbon charge reaches \$200/t CO_2e by 2050 reduces emissions to 1990 levels by 2050; and when the carbon charges reaches \$300/tonne CO_2e, emissions decline by around 45% below 2005 levels by 2050.

Figure ES-1: GHG emissions in policy scenarios, excluding emissions from agroecosystems and waste



- **For large greenhouse gas reductions, carbon capture and storage is the key GHG-reduction action. Energy efficiency and fuel switching actions play a smaller role in reducing GHG emissions.** Figure ES- 2 breaks the emissions reductions associated with each of the policies that were modelled into *wedges*. It shows that when GHG policies are modest (e.g., when the carbon charge is \$30/t CO_2e), energy efficiency, fuel switching, and carbon capture and storage all contribute to overall emission reductions. At higher carbon charges, carbon capture and storage becomes more economic and contributes the largest share of overall emission reductions. The analysis suggests that for large, cost-effective GHG reductions, carbon capture and storage will be critical.

Figure ES- 2: GHG reduction wedge diagrams



- **Most cost-effective greenhouse gas reductions will occur in the upstream oil and gas and electricity generation sectors.** These sectors are projected to produce the most GHG emissions in the reference case, and also to offer potential for cost-effective GHG reductions. The upstream oil and gas and electricity generation sectors are the most likely candidates for cost-effective carbon capture and storage, which is likely to become economical at higher carbon charges.

- **Significant greenhouse gas reductions will likely cause household and vehicle energy bills to increase.** The likely impact of a carbon charge on household and vehicle energy bills ranges from modest increases in the least aggressive scenarios to more significant increases (40 percent and above) in the more aggressive scenarios. In each scenario, household energy bills increase most substantially when the policy is first implemented. However, as households respond to the policy by adopting more energy efficient technologies or switching to low emissions fuels, energy bills begin to decline. For the policy where carbon charges reach $100/tonne CO_2e, the analysis projects that household energy bills could increase initially by as much as 40 percent above the reference case. For the modest policy, household energy bills would increase much less (approximately 5 percent). As households adjust to the policy, the difference between the reference case and the policy declines substantially. At the end of the simulation, energy bills in the policy where carbon charges reach $200/tonne CO_2e are only 2 percent greater than in the reference case. For the more aggressive policies, the modelling also projects significant increases in gasoline price, which corresponds to increases of about 50 percent in annual vehicle fuel costs in the policy where carbon charges reach $200/tonne CO_2e. Again, the more modest policies simulated show much less effect on annual vehicle costs. Like household energy costs, the annual vehicle fuel costs would converge with the reference case over time, as the policy induced energy efficiency improvements in the vehicle stock. A policy that begins modestly and predictably increases in aggressiveness over time would help to mitigate economic impacts.

- **A broad market-based policy is unlikely to significantly reduce Alberta's economic growth.** The model used for this analysis is not a full economic equilibrium model and so cannot project impacts of the policy on the entire economy. However, the model suggests that even an aggressive carbon charge is unlikely to dramatically affect overall economic output in the portion of the economy covered by the model. With aggressive GHG policy, a structural shift in Alberta's energy sector from crude oil production towards electricity generation is possible. The economic effects of the policy will depend on the details of the policy that is applied (for example, how revenue raised from the policy is recycled throughout the economy).

Results of regulatory policy modelling

In addition to modelling the likely impact of broad carbon charges applied throughout the economy, we also estimated the likely impact of several specific regulatory policies on greenhouse gas emissions. The policies modelled here do not represent an exhaustive list of potential regulatory policies that could be applied in Alberta, and may not represent options being considered for implementation in Alberta. Based on the modelling, we found the following results:

- **A residential building code requiring Built Green™ Gold for new construction after 2010 would reduce Alberta's greenhouse gas emissions by about 0.3 Mt in 2025 and about 0.6 Mt in 2050, compared to the reference case.** The relatively modest overall impact of this regulation is due to the fact that Alberta's residential sector accounts for a very small fraction of total emissions and that energy efficiency is forecast to improve fairly quickly in the residential sector in the reference case.

- **A commercial building code requiring new construction to meet LEED Gold™ standards would reduce Alberta's emissions by 1 Mt in 2025 and about 5 Mt in 2050, compared to the reference case.** Similar to the regulation on residential buildings, the impact of this standard is modest because the commercial sector accounts for a small portion of Alberta's total emissions. However, the standard induces significant improvements in the energy efficiency and greenhouse gas intensity of commercial buildings.

- **A vehicle emissions standard that requires the average greenhouse gas intensity of vehicles sold in Alberta to match regulations in California would reduce emissions by 2 Mt in 2025 and 2 Mt in 2050.** The standard would induce an 18% improvement in the greenhouse gas intensity of the passenger vehicle stock in 2025. The impact of this policy is modest because its scope is limited to passenger vehicles in the transportation sector, while freight transportation and air travel are unaffected. The emissions reductions from the standard do not increase between 2025 and 2050, because the emissions intensity of passenger vehicles improves in the reference scenario while the policy stays constant.

- **Construction of a 2,200 MW nuclear plant in 2020 would reduce Alberta's emissions by about 11 Mt in 2050, compared to the reference case.** Because nuclear generated electricity produces no greenhouse gas emissions, construction of a nuclear plant would offset some of the demand for electricity generation from fossil fuel, and reduce GHG emissions.
- **A requirement for 20% of electric generation to be from renewable sources by 2020 would reduce emissions by about 5 Mt in 2025 and by about 6 Mt in 2050.** A greater generation from renewable energy sources offsets the demand for generation from fossil fuels.
- **A regulation requiring all large industrial facilities built after 2015 to capture and store greenhouse gases wherever possible would reduce emissions by about 61 Mt in 2025 and by 173 Mt in 2050.** A large fraction of Alberta's GHG emissions are from large industrial facilities, and this fraction will likely increase with continued growth in the oil industry. A stringent regulation requiring widespread capture and storage of GHG emissions would dramatically reduce overall emissions in Alberta. We also modelled a scenario where the carbon capture and storage policy was combined with a broad carbon charge covering the entire economy. We found that greenhouse gases would be reduced by about 70 Mt in 2025 and over 200 Mt in 2050 using this combination of policies.
- **A policy package that includes most of the regulatory policies discussed above would reduce emissions by about 68 Mt in 2025 and by about 181 Mt in 2050.** The policy package includes all the regulatory policies except the requirement for 20% of electric generation to be from renewable sources. The package does not include a carbon charge.

Figure ES- 3 shows the impact of the regulatory policies modelled compared to the reference case. The emissions trajectory for some of the policies is not illustrated because the impacts are modest.

Figure ES- 3: GHG emissions in regulation scenarios, excluding emissions from agroecosystems and waste

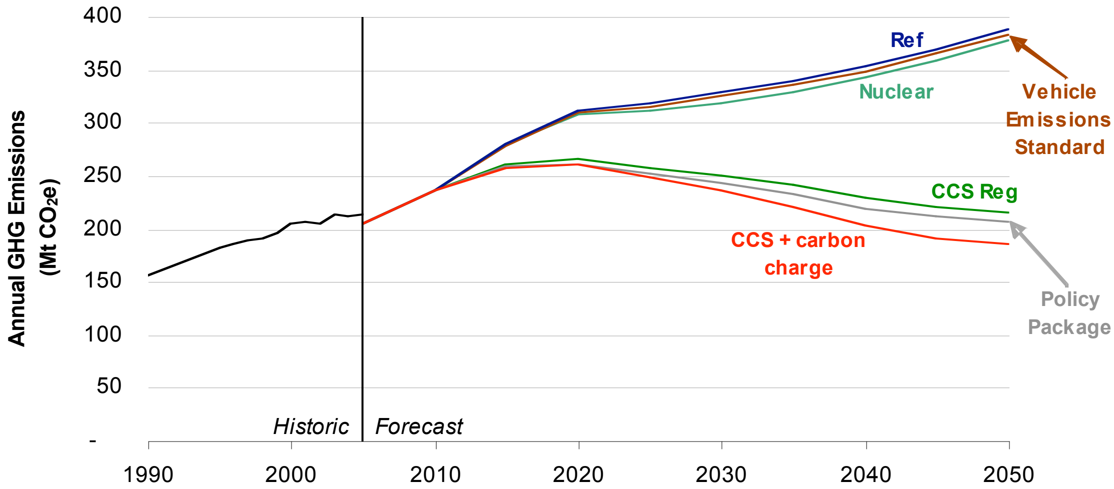


Table of Contents

List of Figures

List of Tables

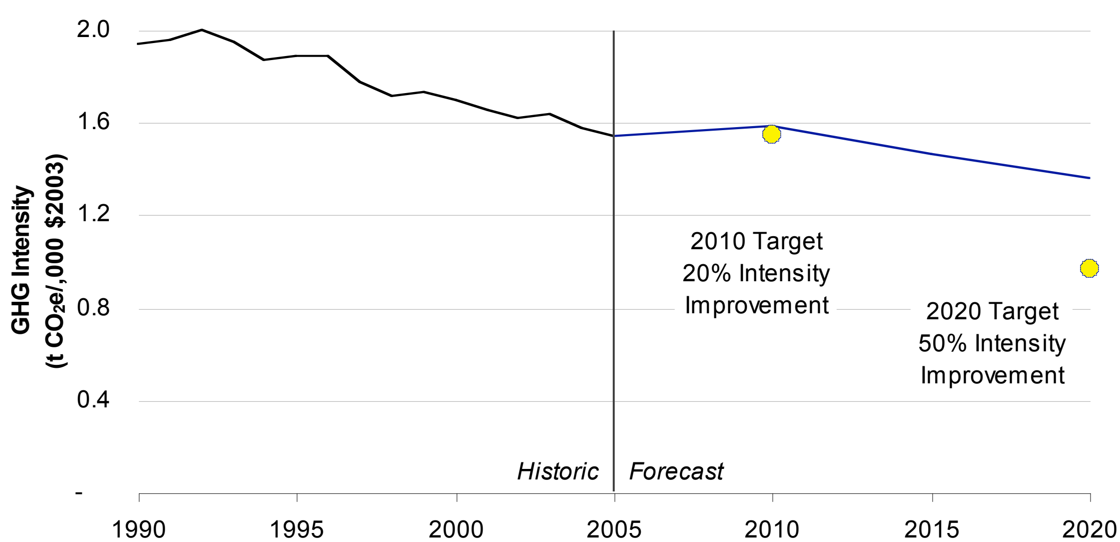
Introduction

Context

Alberta published its first Climate Change Action Plan in 2002. This plan set a target of reducing provincial greenhouse gas intensity (tonnes of greenhouse gases per dollar of gross provincial product) by 20 percent between 1990 and 2010, and by 50 percent by 2020.[1] In order to meet these targets, the Alberta government introduced several policies, with the most important being the *Climate Change and Emissions Management Act*. Under this legislation, large industrial facilities are required to reduce greenhouse gas intensity by 12 percent compared to their 2003 – 2005 baseline, starting in 2007. Supporting policies, including a domestic offset system and a technology investment fund, are also in the process of being developed.

Figure 1 shows Alberta's historic greenhouse gas intensity since 1990 as well as a forecast of emissions intensity through 2020. The figure suggests that Alberta is on track to meet its 2010 target with current policies, but that additional policies may be required to enable Alberta to reach its 2020 emissions intensity target.

Figure 1: Alberta historic and forecast reference case GHG intensity



Source: Historic data from Environment Canada, 2007, "Canada's Greenhouse Gas Inventory". Forecast data from Natural Resources Canada, 2006, "Canada's Energy Outlook: The Reference Case 2006". We use the NRCan forecast for this figure because it includes emissions from agroecosystems and waste, which are included in Alberta's targets.

[1] Alberta Environment, 2002, "Albertans and Climate Change: Taking Action", Government of Alberta.

Objective of this report

Alberta Environment has retained MK Jaccard and Associates for the purpose of providing an analysis of climate change mitigation options for Alberta to support the development of the Climate Change Action Plan. MKJA 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 magnitude of greenhouse gas reductions that would be obtained throughout the Alberta economy when different strengths of policy signals are applied. Policies are characterized using the concept of a *carbon charge*, which represents the financial signal required to stimulate different emissions-reducing actions throughout the economy. As part of the analysis, we show results using *wedge diagrams*, which categorize abatement measures into alternative designations for illustrative purposes. Finally, we also show the likely results of several regulatory policies designed to reduce emissions. This report does not prescribe a specific set of policies that Alberta should implement; its purpose is to provide information on some of the different policy instruments available to Alberta.

Structure of this report

We begin this report with an overview of the methodology used to produce the quantitative results, including a high-level 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 detailed analysis of quantitative policy analysis using carbon charges and the results of the regulatory policy analysis.

Methodology

The primary objective of this study is to project the economic and environmental impacts of various options for greenhouse gas policy in Alberta. In order to do this, the CIMS energy-economy model was updated to reflect recent provincial data and trends and used to analyze greenhouse gas charges in Alberta. 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 MK Jaccard 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 behavioural 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 behavioural-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.

Modelling scenarios

The primary purpose of the analysis reported here is to show how different options for greenhouse gas policy instruments could influence greenhouse gas emissions, economic output, and costs of compliance at a sectoral level. In order to determine the greenhouse gas abatement opportunities in Alberta over time, we use the concept of a reference scenario and a policy scenario. The reference scenario shows how the Alberta 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.

Carbon charges represent a generic market-based instrument for GHG reduction, such as an emission tax or a cap-and-trade system (in this case the carbon charge represents the equilibrium permit trading price). This type of policy is generally considered the most economically efficient and effective way to reduce greenhouse gas emissions, because it sends a consistent marginal cost signal throughout the economy. Simulating this type of policy is also useful because it explicitly conveys the strength of policy in consistent units (dollars per tonne of GHG reduced), and allows easy comparison of the results of one simulation to another.

We model several policy scenarios in order to provide a sense of the effect of different levels and trajectories of carbon charges on key outputs. In all scenarios, the carbon price is applied throughout the economy, on both energy related combustion emissions, non-energy emissions, fugitive and flaring emissions, and fixed process emissions.[2] The price on non carbon dioxide greenhouse gas emissions is based on the 100-year global warming potentials reported by the Intergovernmental Panel on Climate Change.[3]

Table 1 outlines the scenarios that were modelled. We model four flat carbon charge trajectories, where the price on carbon does not increase or decrease over time. We also model three escalating carbon charge scenarios, where the price on carbon increases over time. The escalating carbon charge scenarios allow firms and individuals to gradually adjust to higher carbon charges and should reduce the probability of economic dislocation during policy implementation, particularly if government communicates the carbon charge schedule to firms and individuals with advanced notice.

Table 1: Policy scenarios modelled in this report

Scenario	*2011-2015*	*2016-2020*	*2021-2025*	*2026-2030*	*2031-2035*	*2036-2040*	*2041-2045*	*2046-2050*
P1-F15	$15	$15	$15	$15	$15	$15	$15	$15
P2-F30	$30	$30	$30	$30	$30	$30	$30	$30
P3-F60	$60	$60	$60	$60	$60	$60	$60	$60
P4-F100	$100	$100	$100	$100	$100	$100	$100	$100
P5-Ea	$15	$30	$30	$60	$60	$60	$60	$100
P6-Eb	$30	$40	$50	$60	$70	$80	$90	$100
P7-Ec	$50	$75	$100	$150	$200	$200	$200	$200

Note: All carbon charges are presented in CDN$2003 / t CO_2e and are applied throughout the economy. In the "Scenario" column, we use the letter "F" to denote a flat carbon charge (no increases or decreases over time), and "E" to denote an escalating carbon charge.

In addition to the analysis of carbon charges, we modelled several other policy options. In particular, we modelled the following:

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[2] Because the current version of the CIMS model does not include a sub-model for agroecosystems or waste, the carbon charge is not extended to these sectors.

[3] Intergovernmental Panel on Climate Change, 2007, "The physical basis of climate change", IPCC WG1 AR4 Report.

- **Carbon capture and storage regulation for large industrial facilities.** We model a policy where all large new industrial facilities are required to incorporate carbon and storage by 2015 wherever possible. At the request of Alberta Environment, we modelled this policy in combination with the carbon charge schedule P5-Ea in Table 1.
- **Nuclear electricity generation plant constructed.** We model a scenario in which a 2,200 MW nuclear plant is commissioned to produce electricity for Alberta's grid in 2020.
- **Residential building code implemented.** We model a policy that requires new houses built in Alberta to be certified as Built Green™ Gold by 2010. Built Green™ Gold houses have an EnerGuide rating of at least 77, which represents an energy efficiency improvement of roughly 20 to 25 percent compared to current standard practice (current practice corresponds to an EnerGuide rating of about 68).
- **Vehicle emissions standard for new vehicles.** We model a policy that requires the average greenhouse gas intensity of new vehicles sold in Alberta to be less than a specified level. Table 2 illustrates the standard simulated for this project, and compares it to California's vehicle emissions standard (on which the policy modelled here is based). The key difference between California's standard and the standard modelled for this project is that California's standard applies different emissions requirements to small and large vehicles. The standard simulated for this project requires the average greenhouse gas intensity of all passenger vehicles to be less than a specific level. We also assume there are no changes to the standard after 2016.

Table 2: Maximum average fleet GHG standard modelled in this report

Year	Maximum average fleet GHG standard (g CO_2/km)		
	Proposed Regulation in California		Modelled in CIMS
	Passenger Cars / Small Trucks	Large Trucks	S5-VES
2011	166	243	174
2012	145	225	
2013	142	221	
2014	138	218	
2015	133	213	
2016	128	207	160

Source: Air Resources Board, California Environmental Protection Agency, 2007.

- **Commercial building code implemented.** We model a policy that requires all new commercial construction to meet LEED Gold™ standards. While commercial buildings can achieve LEED™ certification by incorporating several environmental improvements (e.g., improvements to waste management or a reduction in water use), we only model the standard's effect on energy intensity. We estimate that LEED Gold™ buildings are, on average, 51% more energy efficient than a building built to the current specifications of the Model National Energy Code of Canada for Buildings.[4]

- **Requirement for electricity to be generated from renewable sources.** We simulate a policy where 20% of electricity must be generated from renewable sources by 2020. Hydroelectric generation qualifies as a renewable source in this policy.
- **A policy package.** We model a policy that combines several of the regulatory policies discussed above. In particular, the policy package includes: 1) the carbon capture and storage regulation, 2) the nuclear plant built in 2020, 3) the new building standards for commercial and residential buildings, and 4) the vehicle emissions standard.[5]
- **A deep reduction policy.** We assess the stringency of carbon charge required to attain a 50% reduction in greenhouse gas emissions from 2005 levels by 2050. For this policy we simulate a ceiling on carbon charges equal to \$300/tonne CO_2e (2003\$).

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

[4] This is calculated using data on LEED™ buildings in Canada from Canada Green Building Council, 2007.

[5] The requirement for 20% of electricity to be generated from renewable sources was excluded from the policy package to ease the modelling.

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

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 45 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 reasonable "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.[6] 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 Infometrica for the federal government, which is depicted in Table 3.[7] The population forecast used here is similar to the medium growth scenario developed by Statistics Canada in a recent demographic forecast.[8]

Table 3: Alberta economic and demographic forecast

	Units	*2010*	*2020*	*2030*	*2040*	*2050*
Gross Domestic Product	*billion 2003$* [a]	180.7	224.0	268.7	324.6	385.1
Population	*thousands*	3,464	3,903	4,294	4,601	4,863

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

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

[7] 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.

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

The residential sector is anticipated to continue fairly rapid growth because of continued population growth in the province. The rate of both population growth and household formation are expected to slow later in the forecast from present levels, when Alberta's population is anticipated to be about one and a half times larger than the current level.

The commercial sector is expected to undergo rapid expansion, driven by expanding economic output in the province. 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 Alberta, fuelled by growth in population as well as income. These trends are expected to continue in general, but slow throughout the forecast period. Air travel continues to expand in importance, driven by rising incomes in Alberta. In the freight transportation sector, growth is expected to be even faster than in the passenger sector, because of quickly rising GDP and expansion of industrial output in particular.

Like other demand sectors, output is expected to grow in the industrial manufacturing sector. The demand for industrial minerals (cement and lime products) is expected to be particularly robust throughout the forecast period, while growth in the pulp and paper and chemical sectors is expected to be more muted. Continued growth is also expected in the other manufacturing sector, which is a catch-all sector that includes most smaller manufacturing facilities.

Energy supply sectors

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

Alberta's crude oil production forecast is shown in Figure 2 and is based on the moderate growth case of the Canadian Association of Petroleum Producers 2007 report.[9] The output of conventional crude oil (light & medium, and heavy) between 2025 and 2050 is projected to continue decline due to existing reserve depletion. By 2050, conventional crude oil production is expected to account for only a small amount of total production.

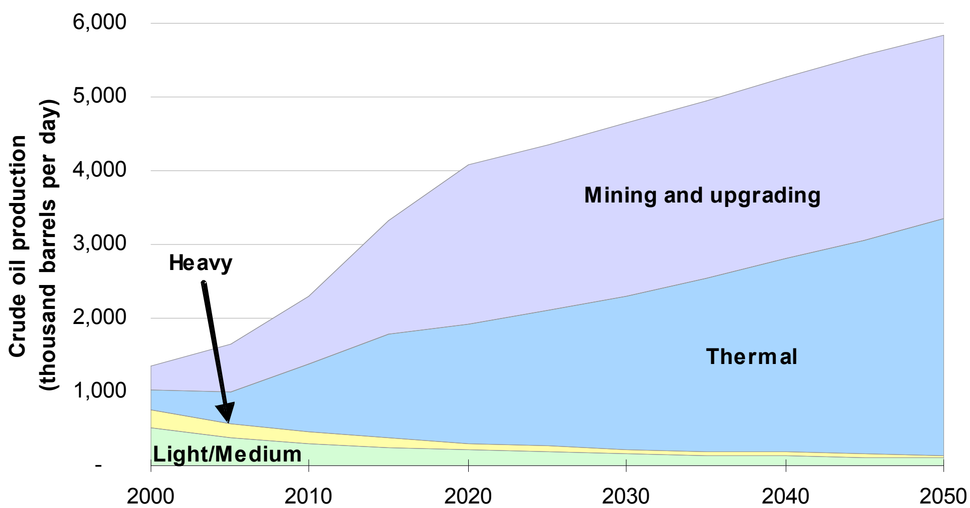
Conversely, production of unconventional crude oil from Alberta's oil sands is forecast to increase dramatically during the forecast period. Total production of crude oil from the oil sands is forecast to reach about 4.1 million barrels per day by 2025 and about 5.7

[9] 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 slowly for unconventional crude oil, and to continue to decline for conventional crude oiil. The forecast after 2025 is very uncertain, since projects are not announced with this much lead time. CAPPs recent forecast is higher than the forecast adopted in NRCan's 2006 Energy Outlook.

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 thermal (in-situ) operations and in mining and upgrading operations.

According to the Alberta Energy and Utilities Board, the volume of crude bitumen in the oil sands is estimated to be approximately 1.6 trillion barrels, with 175 billion barrels recoverable under current economic conditions and with current technologies. The growth forecast of oil sands development in our model has taken this resource constraint into consideration. During the modelling period, the forecasted cumulative output of in-situ bitumen and synthetic crude oil is about 72 billion barrels.

Figure 2: Crude oil supply forecast

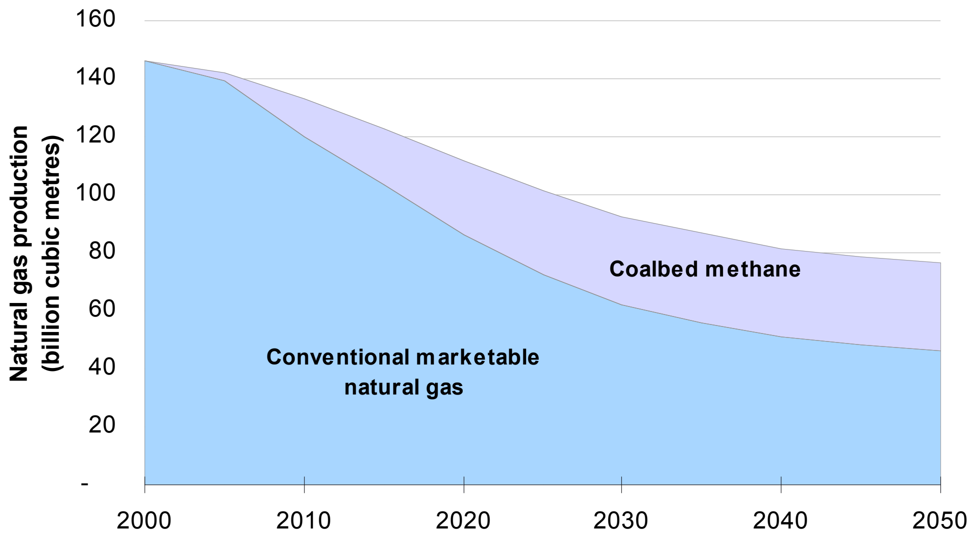


Source: Forecast based on Moderate Growth case from Canadian Association of Petroleum Producers, 2007, "Crude oil forecast, markets, and pipeline expansions", June 2007.

Marketable natural gas production in Alberta between 2000 and 2015 is based on 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.[10] Due to the depletion of conventional oil and gas reserves in Alberta, natural gas supply in Alberta is projected to continue to decline afterwards. However, the development of coal bed methane resources could offset part of the natural gas supply reduction during the modelling period. Figure 3 shows the forecast of marketable natural gas production that was adopted for this report. The figure shows that even with a substantial increase in coalbed methane supply, overall natural gas production is expected to decline steeply in the province. Because coalbed methane is a relatively new resource, the forecast for extraction of coalbed methane adopted for this reference scenario is very uncertain.

[10] 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".

Figure 3: Natural gas supply forecast



Source: Forecast based on 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".

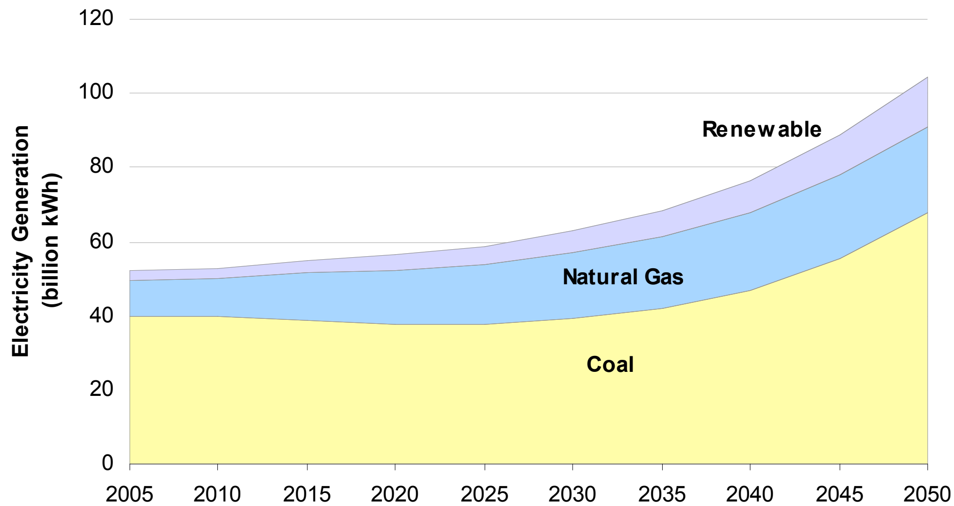
The forecast of output for the electricity generation sector is based on the calculated demand from all other sectors in the model, and is adjusted to include net exports of electricity.[11] The forecast of output from the electricity generation sector does not include non-utility electricity generation, 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).

Figure 4 shows the reference case electricity generation by fuel type. Total utility electricity generation is expected to increase only slightly in the coming decade, as non-utility generation increases rapidly.[12] Towards the end of the forecast period, utility electricity generation is forecast to increase again, such that by 2050, the electricity sector will be producing almost twice as much electricity as in 2005. In the reference case, the model forecasts that most electricity generation will continue to be provided from coal. Renewables (particularly wind, small hydro, and biomass) could provide a more significant portion of electricity generation by 2050.

[11] 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.

[12] AMEC Americas Limited, 2006, "Alberta 10-year Generation Outlook", Prepared for Alberta Electric System Operator.

Figure 4: Reference case utility electricity generation by fuel type



In the policy scenarios, 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.[13]

Table 4 summarized 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.

[13] 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. See Energy Information Administration, 1998, “Impacts of the Kyoto Protocol on US Energy Markets and Economic Activity”, United States Department of Energy.

Table 4: Reference case output forecast

	Units	2010	2020	2030	2040	2050
Demand Sectors						
Residential	*thousands of households*	1,345	1,562	1,724	1,851	1,960
Commercial	*million m^2 of floorspace*	91	109	130	157	187
Transportation						
Passenger	*billion passenger-km*	79	96	113	130	146
Freight	*billion tonne-km*	224	277	333	402	477
Manufacturing Industry						
Chemical Products	*million tonnes* [a]	14	15	16	17	18
Industrial Minerals	*million tonnes* [b]	2	3	3	4	5
Pulp and Paper	*million tonnes* [c]	0.4	0.4	0.4	0.4	0.4
Other Manufacturing	*million $2003*	16,023	22,371	31,132	38,036	40,500
Supply Sectors						
Crude Oil						
Conventional Light	*thousand barrels per day*	306	203	158	126	103
Conventional Heavy	*thousand barrels per day*	155	103	68	50	41
Oil Sands Mining	*thousand barrels per day*	932	2,148	2,349	2,469	2,494
Oil Sands Thermal	*thousand barrels per day*	909	1,616	2,080	2,614	3,206
Natural Gas	*billion m3* [d]	143	119	98	85	80
Coal Mining	*million tonnes*	37	52	54	60	74
Electricity Generation	*TWh*	49	52	59	71	97
Petroleum Refining	*million m^3*	26	31	37	48	58
Ethanol	*TJ*	382	643	792	1,051	1,549

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] pulp and paper output is the sum of linerboard, newsprint, coated and uncoated paper, tissue and market pulp production
[d] natural gas production includes coalbed methane

Energy prices

CIMS also requires an external forecast for fuel 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). For years after 2020, real oil and coal prices are assumed to remain flat, while the real natural gas price is assumed to gradually increase until it reaches an assumed future import price of liquefied natural gas, reflecting declining domestic supplies of natural gas. Table 5 shows the fuel price forecast that was used to develop the reference case forecast in this report. 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 5: Reference case price forecast for key energy commodities

	Units	*2010*	*2020*	*2030*	*2040*	*2050*
Crude Oil (WTI)	*2003$ / barrel*	52.65	49.5	49.5	49.5	49.5
Natural Gas						
Industrial	*2003$ / GJ*	7.5	6.84	8.47	10.49	12.98
Residential	*2003$ / GJ*	10.05	9.1	11.27	13.95	17.27
Commercial	*2003$ / GJ*	9.22	8.36	10.35	12.82	15.87
Electricity Generation	*2003$ / GJ*	7.78	7.37	9.13	11.3	13.99
Coal						
Market	*2003$ / GJ*	3.23	3.23	3.23	3.23	3.23
Electricity Generation	*2003$ / GJ*	1.17	1.42	1.42	1.42	1.42
Gasoline	*2003$ / GJ*	19.85	18.27	18.27	18.27	18.27
Diesel (Road)	*2003$ / GJ*	16.35	15.14	15.14	15.14	15.14
Electricity						
Industrial	*2003$ / GJ*	16.49	15.12	15.25	15.35	15.36
Residential	*2003$ / GJ*	23.13	25.73	25.95	26.12	26.15
Commercial	*2003$ / GJ*	17.10	18.12	18.27	18.39	18.41

Note: All prices 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 Alberta specified gas emitters framework, which requires facilities that emit at least 0.1 Mt of CO_2e in Alberta to reduce emissions intensity by 12% compared to a 2003-2005 baseline (there is a provision for purchases of credits from offset projects and from a technology fund at $15/t CO_2e);
- The federal ethanol excise tax exemption of $0.10/L and the provincial $0.09/L tax exemption 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 Transport policy, which provides up to $2,000 towards the purchase of a high efficiency vehicle;
- 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

	Units	*2010*	*2020*	*2030*	*2040*	*2050*
Demand Sectors						
Residential	*PJ*	191	206	211	204	176
Commercial	*PJ*	152	178	208	241	267
Transportation	*PJ*	414	491	565	649	693
Manufacturing Industry	*PJ*	305	335	381	407	429
Supply Sectors						
Crude Oil	*PJ*	944	1,848	2,024	2,124	2,252
Natural Gas	*PJ*	416	330	248	200	159
Coal Mining	*PJ*	8	11	11	12	15
Electricity Generation	*PJ*	553	538	554	642	861
Petroleum Refining	*PJ*	95	122	156	207	253
Ethanol	*PJ*	0	1	1	1	0
Total	***PJ***	***3,078***	***4,058***	***4,357***	***4,687***	***5,106***

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.[14]

[14] 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

	Units	2010	2020	2030	2040	2050
Demand Sectors						
Residential	PJ	156	168	168	147	96
Commercial	PJ	101	120	136	143	121
Transportation	PJ	0	0	0	0	0
Manufacturing Industry	PJ	170	177	187	167	120
Supply Sectors						
Crude Oil	PJ	544	1,049	1,108	932	672
Natural Gas	PJ	377	297	219	170	119
Coal Mining	PJ	1	2	3	3	3
Electricity Generation	PJ	99	115	126	148	159
Petroleum Refining	PJ	20	25	29	30	25
Ethanol	PJ	0	0	0	0	0
Total	***PJ***	***1,469***	***1,953***	***1,975***	***1,740***	***1,316***

Table 8: Reference case refined petroleum product consumption

	Units	2010	2020	2030	2040	2050
Demand Sectors						
Residential	PJ	1	2	4	9	13
Commercial	PJ	1	1	1	2	3
Transportation	PJ	413	489	562	645	677
Manufacturing Industry	PJ	4	8	12	15	20
Supply Sectors						
Crude Oil	PJ	258	396	484	734	1,091
Natural Gas	PJ	10	8	7	6	6
Coal Mining	PJ	2	3	3	4	4
Electricity Generation	PJ	0	1	2	3	8
Petroleum Refining	PJ	72	93	123	171	220
Ethanol	PJ	0	0	0	0	0
Total	***PJ***	***761***	***1,001***	***1,198***	***1,588***	***2,042***

Table 9: Reference case electricity consumption

	Units	2010	2020	2030	2040	2050
Demand Sectors						
Residential	PJ	34	36	40	48	67
Commercial	PJ	51	57	70	96	143
Transportation	PJ	1	1	1	2	10
Manufacturing Industry	PJ	44	46	57	69	84
Supply Sectors						
Crude Oil	PJ	13	18	15	9	4
Natural Gas	PJ	28	24	22	24	35
Coal Mining	PJ	3	3	3	3	4
Electricity Generation	PJ	0	0	0	0	0
Petroleum Refining	PJ	3	3	4	5	8
Ethanol	PJ	0	0	0	0	0
Total	***PJ***	***177***	***188***	***211***	***256***	***355***

Based on total energy consumption as well as on process emissions in the industrial sector and supply sectors, we calculate the greenhouse gas emissions associated with the reference case forecast, as shown in Table 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 the agriculture and waste sectors. In 2005, these sectors represented about 8% of total greenhouse gas emissions, measured on an equivalent global warming potential basis. As a result, the forecast presented here will underestimate the actual GHG emissions in the Alberta economy somewhat.

Table 10: Reference case greenhouse gas emissions

	Units	2010	2020	2030	2040	2050
Demand Sectors						
Residential	Mt of CO_2e	8	9	9	8	6
Commercial	Mt of CO_2e	5	6	7	7	6
Transportation	Mt of CO_2e	30	35	41	47	49
Manufacturing Industry	Mt of CO_2e	17	19	21	21	21
Supply Sectors						
Crude Oil	Mt of CO_2e	83	159	174	189	208
Natural Gas	Mt of CO_2e	40	32	25	19	15
Coal Mining	Mt of CO_2e	1	1	1	1	2
Electricity Generation	Mt of CO_2e	46	43	43	48	65
Petroleum Refining	Mt of CO_2e	5	7	9	12	15
Ethanol	Mt of CO_2e	0	0	0	0	0
Total	***Mt of CO_2e***	***235***	***311***	***328***	***353***	***387***

Note: CIMS does not include a waste or agroecosystems model and so does not include emissions from these sectors.

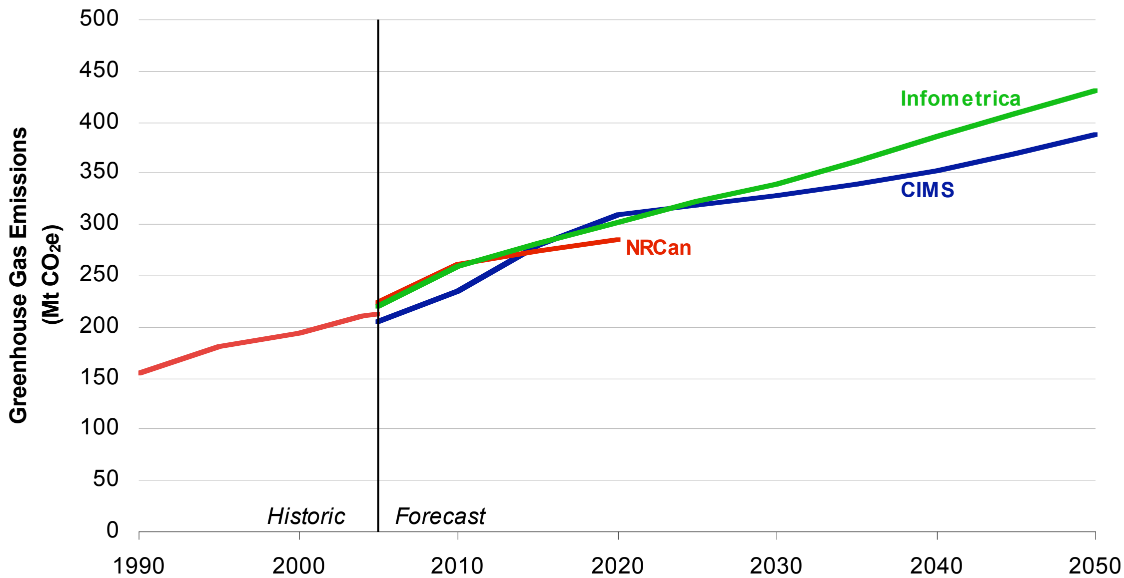
Table 10 shows that in the absence of new policies to control greenhouse gas emissions, emissions are expected to grow from current levels in all sectors of the Alberta economy except natural gas extraction. Especially strong growth is expected in the crude oil sector, as a result of rapidly expanding output in this sector.

The reference case in context

Figure 5 compares the total greenhouse gas emissions reported in this reference case to those in the Natural Resources Canada reference case and to a recent forecast by Infometrica Ltd. prepared for the federal government. With the NRCan and Informetrica forecasts adjusted to remove emissions from agroecosystems and waste, the three forecasts are generally quite similar. All show Alberta's energy-related greenhouse gas emissions increasing dramatically over time from about 150 Mt in 1990 to around 300 Mt by 2020, and around 400 Mt in 2050. The main reason for differences between the NRCan and CIMS forecasts is recent changes to the crude oil output forecast released by the Canadian Association of Petroleum Producers.

Total energy consumption is also very similar between the NRCan and CIMS forecasts, although there are some differences in the projections at a sectoral level.

Figure 5: Reference case greenhouse gas emissions



Note: This chart excludes emissions from agroecosystems and waste, which in 2005 represented about 8% of the Alberta total and is forecast (by Natural Resources Canada) to represent 6% of the total in 2020. The contribution from these sectors as a proportion of the total is likely to continue to decline over time. Historic emissions in this chart (1990-2005) are from Environment Canada's 2005 Greenhouse Gas Inventory.

Quantitative policy analysis

Context

The research summarized in this section is a quantitative exploration of the effect of several alternative greenhouse gas policies on the Alberta economy. The section begins with an analysis of policies that employ a carbon charge. Carbon charges capture the strength of a market-based policy signal required to achieve a given level of emissions reductions in a given timeframe. The carbon charges modelled here are roughly equivalent to an economy-wide tax on greenhouse gas emissions, or the selling price of emissions permits in an emissions cap-and-trade system.

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

- The analysis in this report is aimed at understanding the potential for reducing Alberta's greenhouse gas emissions. As a result, we restrict the analysis to domestic GHG reductions, and allow no purchases of international offset credits.
- The current version of CIMS does not include a representation of agroecosystems or the waste sector. As a result, the results shown here do not include abatement opportunities or emissions from these sectors.
- The technologies in CIMS are limited to foreseen technologies that are likely become commercially available in the timeframe of the analysis. However, high GHG prices could also stir the invention and commercialization of currently unforeseen low GHG 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 and storage (CCS) is 90% effective at removing carbon dioxide from a flue gas stream. After including an energy efficiency penalty, a technology with CCS has approximately 15% of the emissions of an equivalent technology without. Future developments may improve the capture efficiency of CCS; these are not included in the modelling here.
- No nuclear energy is allowed in Alberta either for thermal energy in the upstream oil sector or for electricity generation. We made this assumption 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. We test the results to the sensitivity of this assumption by including a run where nuclear electricity is generated in Alberta starting in 2020.
- All of the carbon charge policies simulated here are revenue neutral from a fiscal perspective, meaning that any revenue attained from the carbon charge is returned to the sector that paid it. As a result, a sector as a whole does not incur any net costs associated with paying an emissions tax, but only incurs the investment costs associated with abating its emissions.

- Policies that are introduced in Alberta do 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).

The modelling in this report only accounts for the cost of emissions abatement. Accounting for the human and environmental benefits of emissions abatement requires a separate methodology and is beyond the scope of this report. Because the benefits of emissions abatement are not systematically compared to the costs in this analysis, we are not able to make recommendations as to the optimal level of GHG reductions; this can only be done through careful comparison of the costs and benefits. Instead, the aim of this report is to conduct analysis of the effect of alternative policies on GHG emissions in Alberta. The results should be interpreted in this context.

Environmental impact of GHG charges

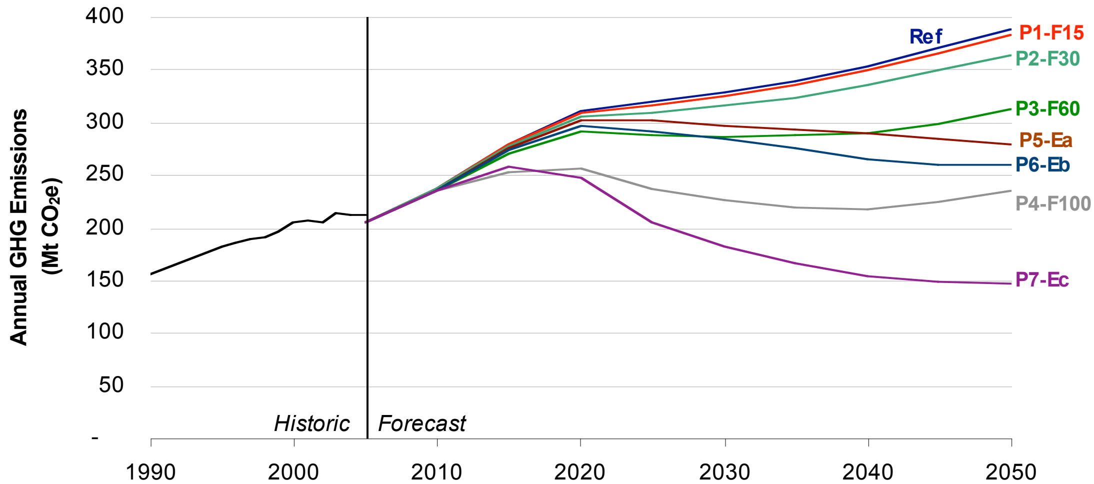
Effect of greenhouse gas charges on provincial emissions

Using the CIMS model, we simulated several greenhouse gas charges to capture the effect of climate change policy on both Alberta's emissions and economy. The actual greenhouse gas charge trajectories that were simulated are shown in Table 1, and range from a very modest GHG charge that is maintained at the same level throughout the simulation period to a charge that starts low and rises gradually to a much higher level over time.

Figure 6 shows the projected effect of the various levels of charges on greenhouse gas emissions in Alberta.[15] In the absence of new climate change policies, GHG emissions are projected to reach about 390 Mt CO_2e by 2050 (excluding emissions from agroecosystems and waste) – an increase of more than 80 percent over 2005 levels. The effect of carbon charges we modelled here range from modest reductions in emissions from the reference case to a 62% reduction from the reference case in 2050 in the most aggressive scenario. However, because Alberta's GHG emissions are projected to increase rapidly in the reference case, only the most aggressive of the policies simulated stabilized Alberta's emissions at its 1990 levels by 2050.

[15] The current version of the CIMS model does not include sub-models for agroecosystems or waste, and so all results here exclude emissions from these sectors. In 2005, these sectors accounted for about 8% of Alberta's greenhouse gas emissions. In the future, the relative importance of these sectors is likely to decrease (even as absolute emissions from these sectors is likely to continue to increase).

Figure 6: GHG emissions in the policy scenarios, excluding emissions from agroecosystems and waste



Source: Historic data are from Environment Canada, 2007, "Greenhouse Gas Inventory".

Figure 6 highlights the importance of capital stock inertia on greenhouse gas emissions. In many sectors of the economy, and in particular the heavy industrial and energy supply sectors, capital equipment lasts for many decades after it is purchased. As a result, it can take several decades for the economy to come to equilibrium after a climate change policy is first applied. Of particular importance is that greenhouse gases as far forward as 2050 can be significantly influenced by the type of policy that is applied today, since some of the equipment that is installed today will remain in service in 2050. If a relatively weak climate policy is applied today, achieving significant GHG reductions by 2050 will be significantly more challenging.

Table 11 shows the emissions reductions by sector for all the carbon charge scenarios we modelled. The values in the table represent a reduction from the reference case in a given year (e.g., the P4-F100 policy reduces Alberta's GHG emissions in 2050 by 152 Mt CO_2e from the reference case in 2050). The table shows that the emissions reductions in Alberta are likely to be concentrated in the crude oil, electricity generation, and transportation sectors. These sectors account for 83% of Alberta's GHG emissions in the reference case in 2050, and represent 89% of the reductions when a $100/tonne CO_2e carbon charge is applied.

Emissions reductions are especially concentrated in the crude oil and electricity generation sectors in both the $60 and $100/tonne CO_2e simulations. When carbon charges reach approximately $50 to $75/tonne CO_2e, we project that carbon capture and storage begins to become economically viable in these sectors, and the relatively widespread adoption of CCS at higher carbon prices causes large GHG reductions.

The run where carbon charges are maintained at $15/t CO_2e has very little effect on emissions, because the Specified Gas Emitters Framework already provides this signal to about 45% of the economy, and because the charge is low.

Table 11: Annual emissions reductions by sector (Mt CO_2e)

2025	P1-F15	P2-F30	P3-F60	P4-F100	P5-Ea	P6-Eb	P7-Ec
Alberta	2	9	31	82	17	27	115
Demand Sectors	1	3	7	12	4	6	13
Residential	0	0	1	1	0	1	1
Commercial	0	0	1	1	0	1	1
Transportation	1	2	3	5	2	3	6
Manufacturing	0	1	2	4	1	2	5
Supply Sectors	1	6	23	70	13	21	101
Crude Oil	1	4	18	56	10	16	85
Natural Gas	0	1	2	3	1	1	3
Coal Mining	0	0	0	0	0	0	0
Electricity Generation	-1	1	3	11	2	3	12
Petroleum Refining	0	0	0	1	0	0	1
Ethanol	0	0	0	0	0	0	0

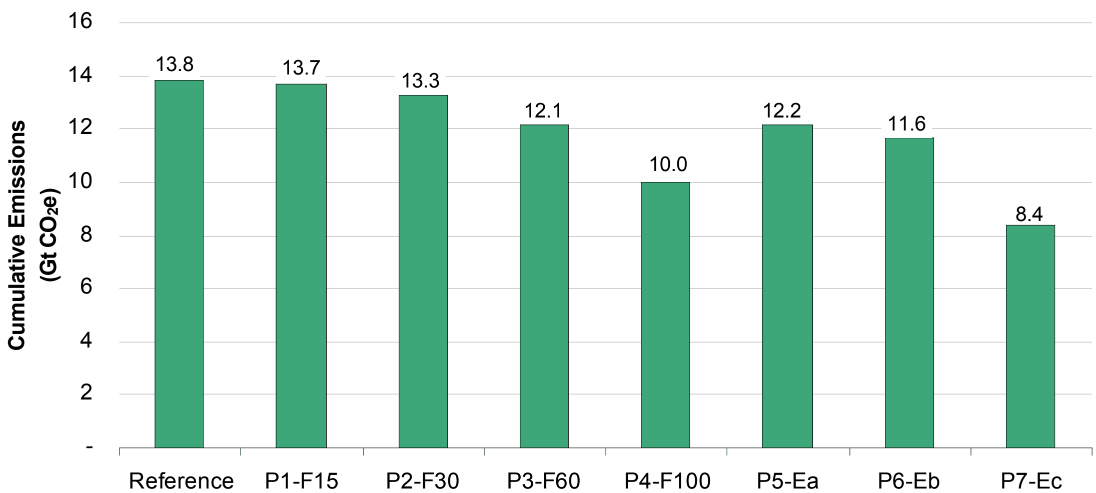
2050	P1-F15	P2-F30	P3-F60	P4-F100	P5-Ea	P6-Eb	P7-Ec
Alberta	5	25	76	152	108	127	241
Demand Sectors	4	10	18	28	22	25	47
Residential	1	1	2	3	2	3	4
Commercial	0	1	2	2	2	2	4
Transportation	2	7	12	16	13	14	25
Manufacturing	0	1	3	7	5	6	14
Supply Sectors	1	15	58	124	87	103	193
Crude Oil	2	11	40	90	62	74	140
Natural Gas	0	1	1	2	2	2	3
Coal Mining	0	0	0	0	0	0	0
Electricity Generation	-2	2	15	30	21	24	40
Petroleum Refining	0	1	2	3	2	3	10
Ethanol	0	0	0	0	0	0	0

The environmental impact caused by greenhouse gas emissions is associated more with their cumulative stock in the atmosphere than with their annual flow into the atmosphere, because GHG emissions reside for long periods in the atmosphere. As a result, the impact of Alberta's greenhouse gas emissions on the climate in 2050 will be determined more by the cumulative emissions between today and 2050 than by the annual emissions in 2050.[16]

[16] By contrast, for a flow pollutant like sulphur dioxide, the human health and environmental impact in 2050 is strongly related to emissions of sulphur dioxide in 2050.

Figure 7 shows the estimate of cumulative GHG emissions from 2008 to 2050 for the reference case and for each of the policies analyzed. In the reference case, cumulative emissions through 2050 are projected to be 13.8 Gt CO_2e (13.8 billion tonnes CO_2e), whereas in the most aggressive policy scenario (P7-Ec), cumulative emissions are 8.4 Gt CO_2e, or 40 percent lower than in the reference case. Cumulative emissions are influenced by a combination of the strength of the carbon charge and the period in which the carbon charge is implemented. When the strength of the policy does not change over time (as for each of the flat carbon charge scenarios), the stronger carbon charges yield lower cumulative emissions. When the trajectory of carbon prices is changed – as in the P4-F100 and P5-Ea scenarios which both reach \$100/tonne CO_2e in 2050 – cumulative emissions are influenced by the timing of the carbon charge. In P4-F100, the carbon charge reaches \$100/tonne CO_2e earlier in the simulation, and therefore exerts greater influence over the evolution of capital stocks purchased early in the simulation. As a result, cumulative emissions in the P4-F100 scenario are 2.2 Gt CO_2e (18%) lower than in P5-Ea.

Figure 7: Cumulative emissions from 2008 to 2050, excluding emissions from agroecosystems and waste



Greenhouse gas reduction "wedge" diagram

A wedge diagram is a useful heuristic because it shows the relative contribution of different actions in reducing total greenhouse gas emissions from their business as usual trend. In most cases, wedges are presented based on the *technical potential* for greenhouse gas reductions. While this can be a useful concept, it doesn't 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 present a wedge diagram for each policy based on the estimated response of firms and individuals to each of the carbon charges that were 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.

Figure 8 and Figure 9 show the wedge diagrams for each policy simulated. Figure 8 illustrates a standard wedge diagram, where the top of the stack of wedges corresponds to the reference case greenhouse gas emissions and each wedge illustrates the action undertaken to reduce emissions to their final level in the policy scenario. Figure 9 only illustrates the wedges (and omits the final GHG emissions after the policy has been applied) to highlight the actions that attain the emissions reduction in each policy scenario. Note that in Figure 9, the units on the y-axis have been changed so that the figures can be interpreted more clearly. We include the same wedge diagrams where the y-axis is unchanged in Appendix D.

Each wedge below corresponds to reductions of greenhouse gas 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 energy efficiency savings compared to the reference case. The wedge labelled "CCS" represents the greenhouse gas reductions from carbon capture and storage. The wedge labelled "Fuel Switching to Renewables" captures the greenhouse gas reductions associated with switches from fossil fuels to renewables for electricity generation (including wind, hydroelectricity, solar power, and biomass), for heating (solar thermal), and for transportation (including ethanol and biodiesel). The wedge labelled "Other Fuel switching" captures the greenhouse gas reductions associated with switching from more GHG-intense fossil fuels like coal to less GHG-intense fossil fuels like natural gas, as well as switches from fossil fuels to electricity. In Figure 8, the wedge entitled "Policy Emissions" represents the emissions that remain after the policy has been implemented.

Figure 8: Wedge diagram for P7-Ec, excluding emissions from agroecosystems and waste

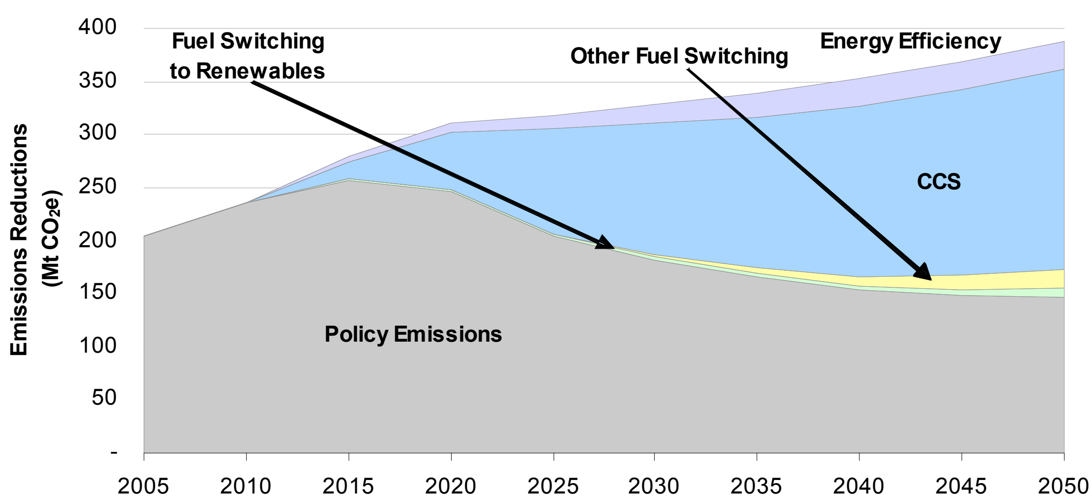
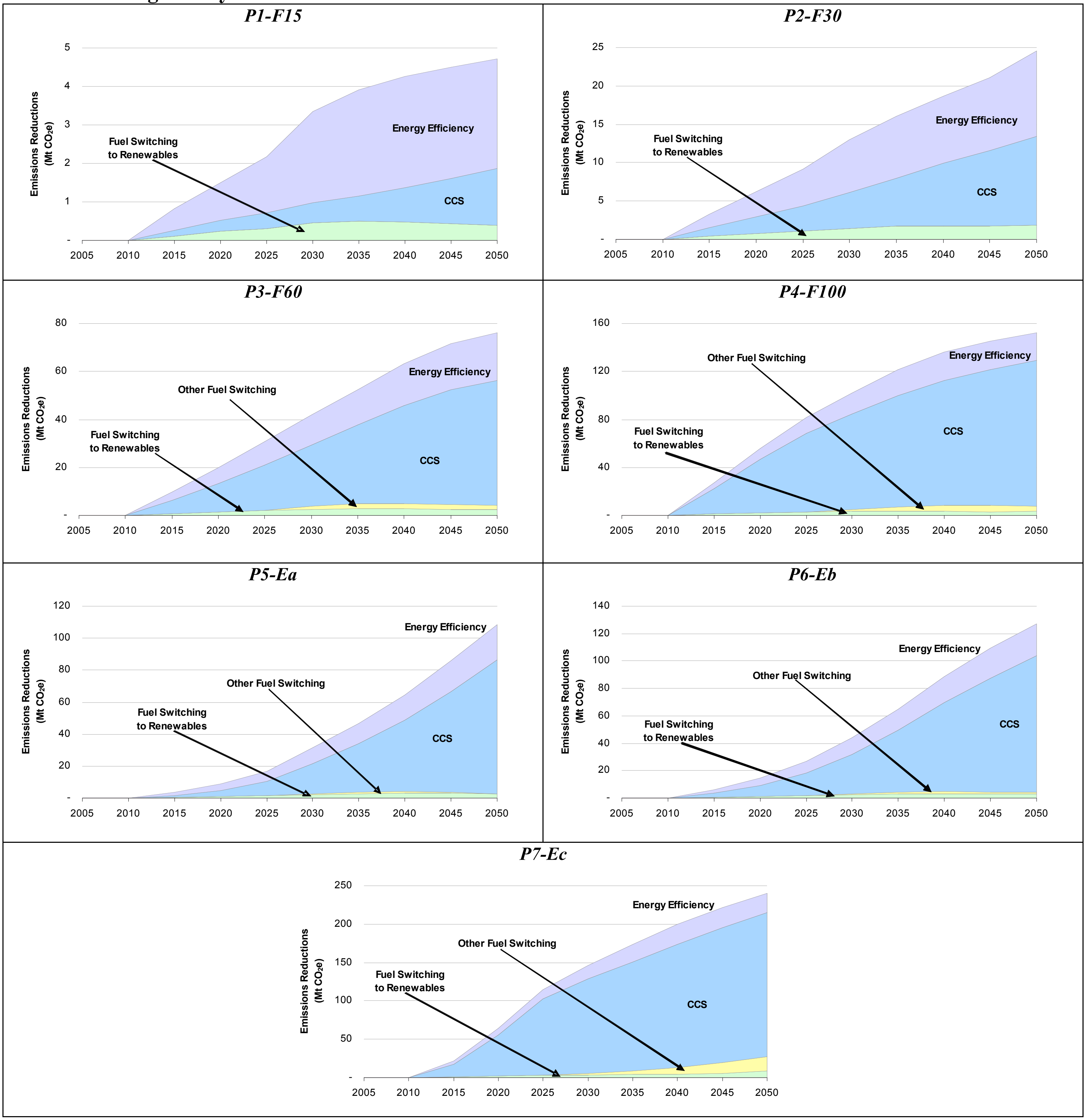


Figure 9: GHG reduction wedge diagrams for each policy, excluding emissions from agroecosystems and waste



The relative size of the GHG reduction wedges varies depending on the strength of the policy. In policy scenarios with low carbon charges – P1-F15 and P2-F30 – emissions reductions are attained mostly through actions to improve energy efficiency and fuel switching to fuels with low GHG intensity. As the carbon charge strengthens, an increasing amount of emissions reductions are attained through CCS. As discussed above, we project that CCS becomes an economically viable abatement option for carbon charges above approximately \$50 to \$75/tonne CO_2e.

Appendix C disaggregates the wedge analysis for each policy run by sector.

Sector specific results

In order to improve understanding of the results, we present detailed results at a sectoral level using key indicators of energy consumption and greenhouse gas emissions. Where possible, we put the indicators in context using historical data. In some sectors, historical indicators are not available due to the confidential nature of energy and greenhouse gas data (this is particularly the case in the industrial sector and in the oil and gas sector).

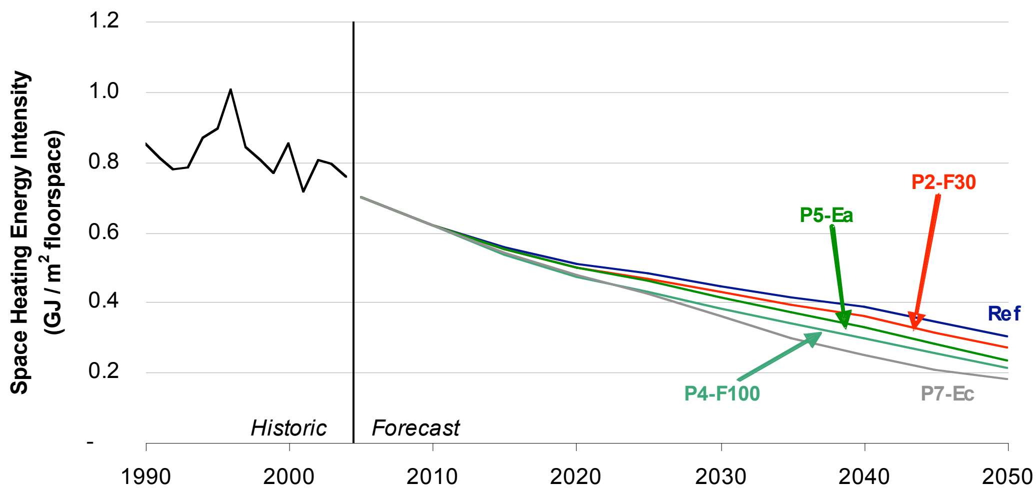
In each of the figures, we only illustrate the results for the reference case as well as policy scenarios P2-F30, P4-F100, P5-Ea, and P7-Ec. This was done to improve readability of the figures. Indicators for the other policy scenarios are available in the appendix. In order to ease the interpretation of figures where the trends are similar between policies, we only label the reference case and the strongest carbon charge scenario (P7-Ec). The unlabelled policy scenarios follow the order from the reference case to the strongest carbon charge, unless otherwise noted (the line closest to the reference case is P2-F30, followed by P5-Ea, P4-F100, and P7-Ec (which is labelled)).

Residential sector

In the residential sector, space heating and water heating account for approximately 88% of total energy consumption and almost all of the direct GHG emissions. As illustrated in Figure 10 through Figure 13, both space heating and water heating are expected to have significant improvements in energy and GHG intensity in the reference case. The improvements in space heating are largely due to the retirement or retrofit of old houses, which are generally less efficient than new houses, as well as regulations that require new natural gas furnaces to have an efficiency of at least 90%. The improvements to water heating are smaller than those for space heating, and are largely due to the turnover of less efficient old water heating equipment.

Figure 10 through Figure 13 illustrate that energy efficiency and GHG intensity improve as a result of the implementation of a carbon charge. GHG intensity generally improves more than energy efficiency as a result of the policy. The policies induce both energy efficiency and fuel switching actions, and switching to low emissions fuels reduces emissions but does not necessarily reduce energy consumption. At the end of the simulation in the P4-F100 scenario, we forecast that the energy and GHG intensity of space heating will be 29% and 61% below the reference case, respectively. The energy and GHG intensity of water heating is projected to be 17% and 32% below the reference case, respectively.[17]

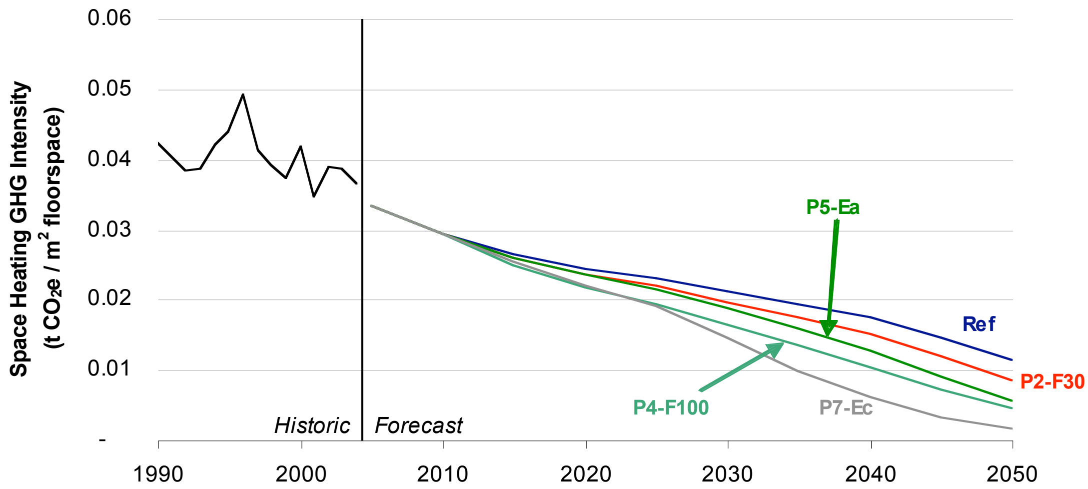
Figure 10: Residential space heating energy intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

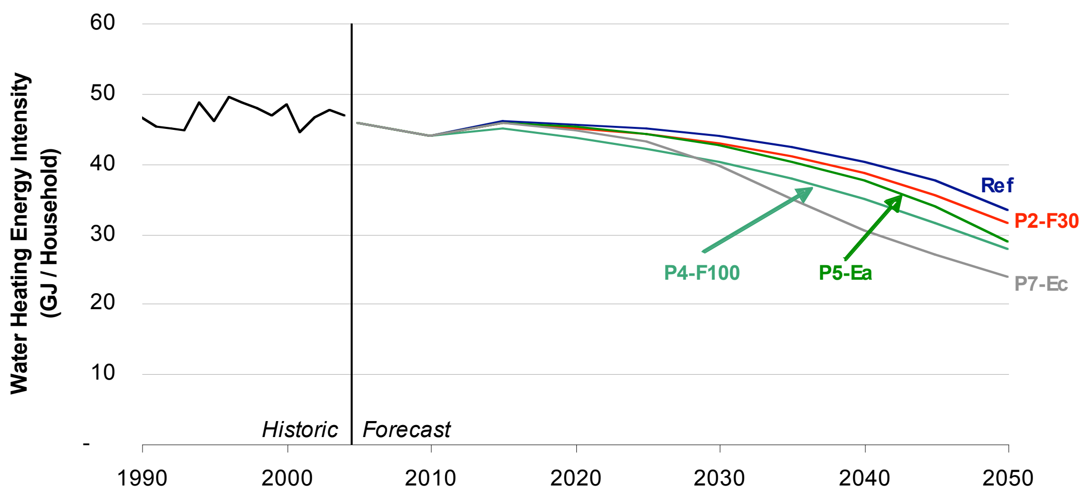
[17] Historic fluctuations in energy and GHG intensity are due largely to fluctuations in annual heating degree days. The figures also show a gap between the historic and forecast data because the historic data ends in 2004 and the forecast from CIMS begins in 2005.

Figure 11: Residential space heating direct GHG intensity



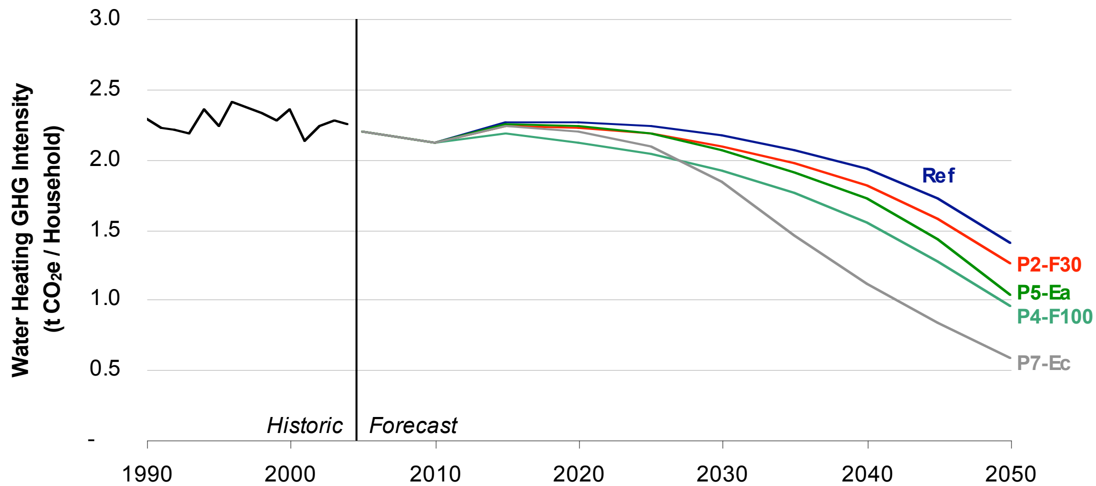
Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Figure 12: Residential water heating energy intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Figure 13: Residential water heating direct GHG intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

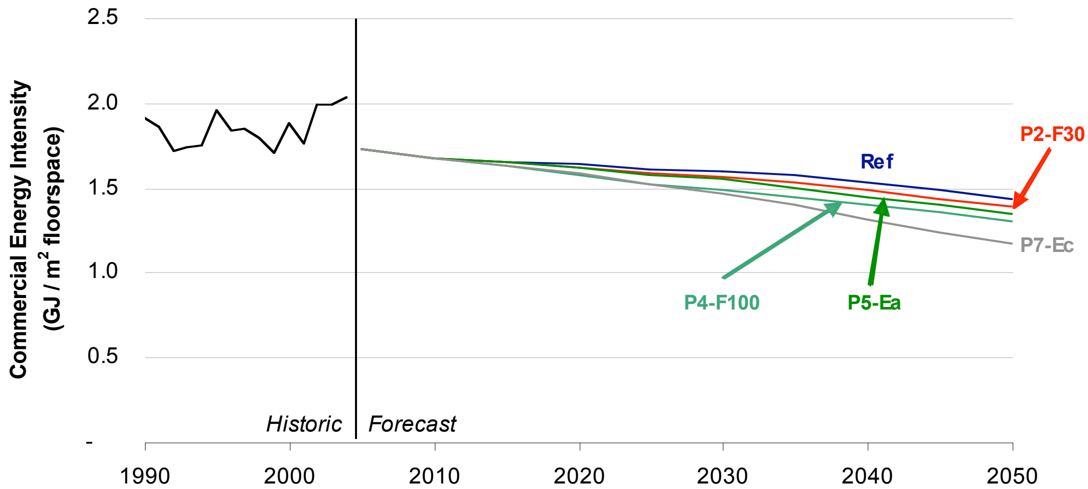
Commercial sector

Figure 14 and Figure 15 illustrate the energy and GHG intensity of the commercial sector in the reference and policy scenarios. Energy intensity is expected to improve in the reference case as a result of the turnover of building shells as well as the turnover of heating systems. GHG intensity is expected to improve significantly, partially due to the improvements in energy efficiency, but also due to fuel switching from natural gas to electricity as a result of higher natural gas prices.

In the P4-F100 scenario, energy and GHG intensity decline by 9% and 39%, respectively, compared to the reference scenario in 2050. As in the residential sector, the decline in GHG intensity exceeds the decline in energy intensity due to fuel switching from natural gas to electricity, which does not necessarily reduce energy consumption, but reduces direct emissions.[18]

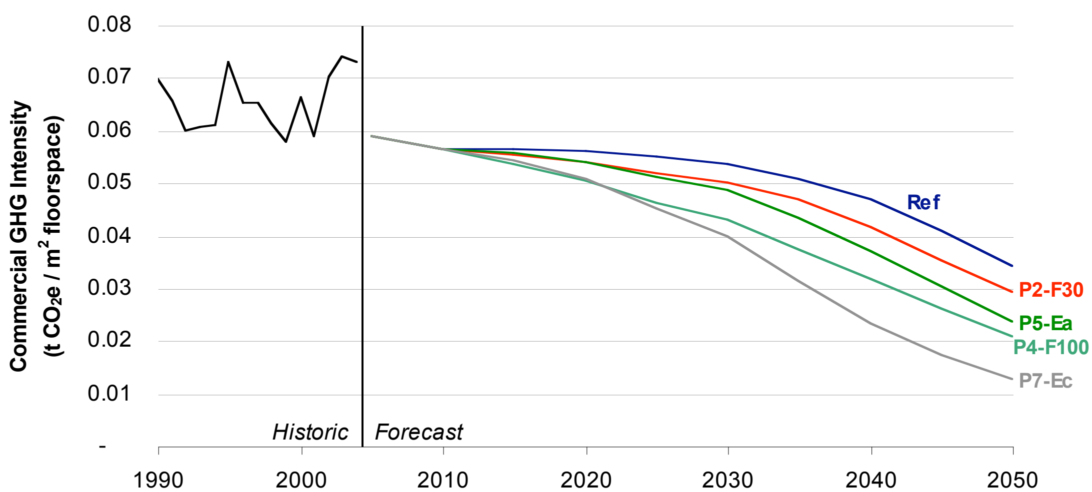
[18] Historic fluctuations in energy and GHG intensity are due largely to fluctuations in annual heating degree days.

Figure 14: Commercial building energy intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Figure 15: Commercial building direct GHG intensity



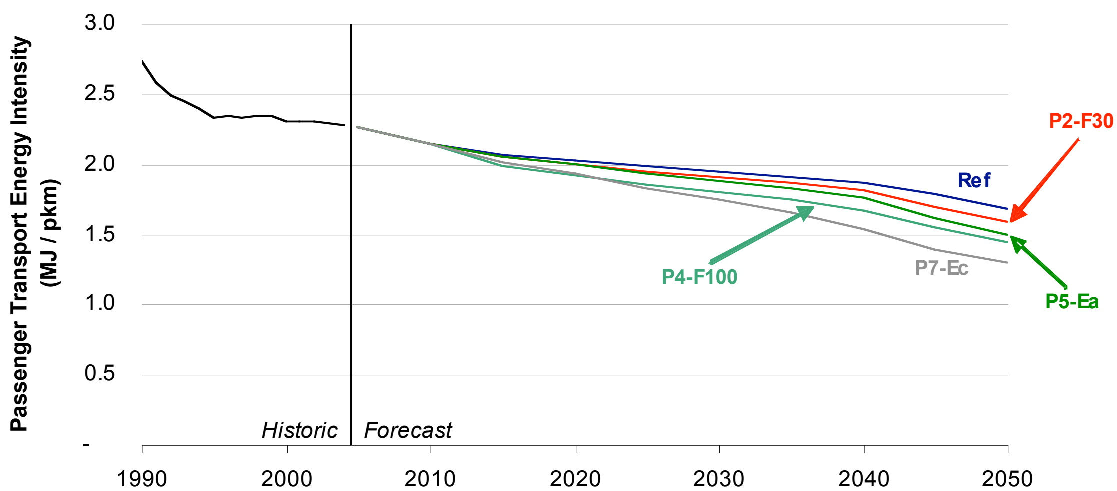
Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Transportation sector

Figure 16 and Figure 17 show the energy and GHG intensity of passenger transportation; and Figure 18 and Figure 19 show the intensity of passenger vehicles (in the figures, "vkm" refers to vehicle-kilometres travelled and "pkm" refers to passenger-kilometres travelled). The key difference between the two metrics is that the former includes the effect of mode switching (e.g.: switching to transit or a high occupancy vehicle); while the latter represents the intensity of passenger vehicles. The reference case shows significant declines in the energy and GHG intensities of both passenger and vehicle transport. We also show a larger decline in the GHG intensity of vehicle transport between 2040 and 2050. CIMS simulates a modest penetration of low emissions vehicles (e.g., advanced hybrid vehicles plug-in hybrid electric cars and trucks) during these years; however we recognize that the penetration of these vehicles is highly uncertain.

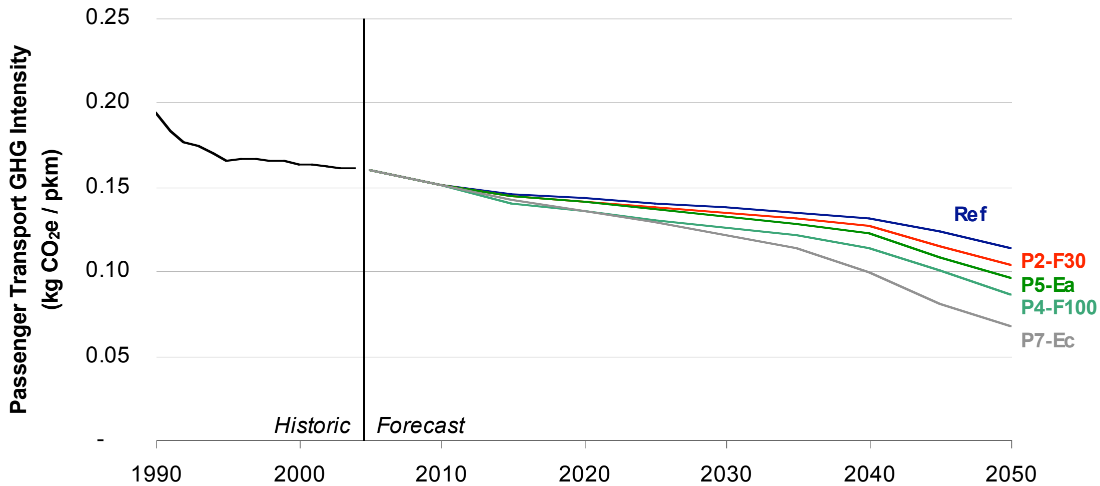
In each of the policy scenarios, energy efficiency actions (e.g., purchasing more efficient vehicles) and fuel switching (e.g., gasoline to ethanol or electricity) account for the largest portion of emissions reductions. Furthermore, energy efficiency actions are more important at the beginning of the simulation, and fuel switching actions become more important later in the simulation, because it may take several years to research and develop the infrastructure for vehicles that consume fuels other than gasoline. In 2050 in the P4-F100 scenario, the GHG intensity of passenger transport declines by 24% compared to the reference case.

Figure 16: Passenger transportation energy intensity



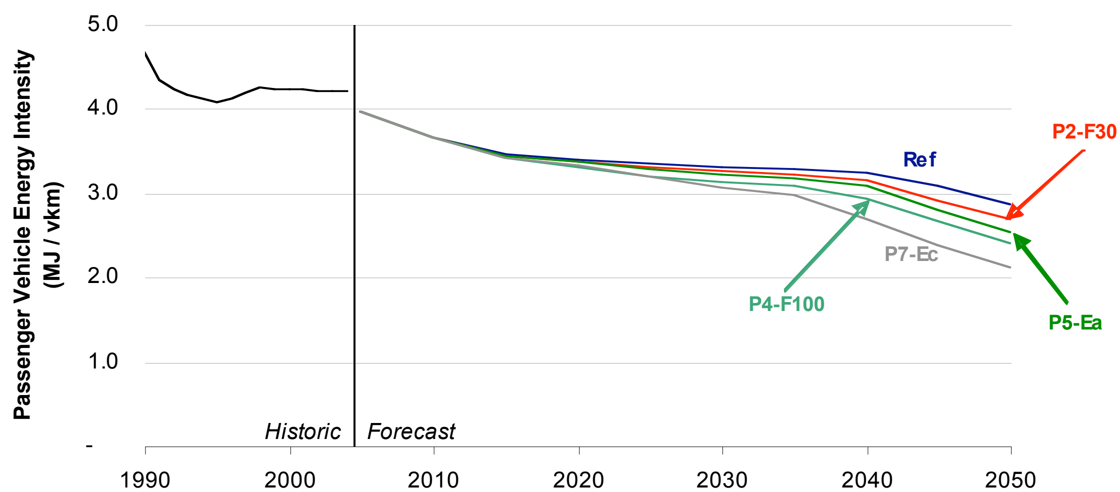
Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Figure 17: Passenger transportation GHG intensity



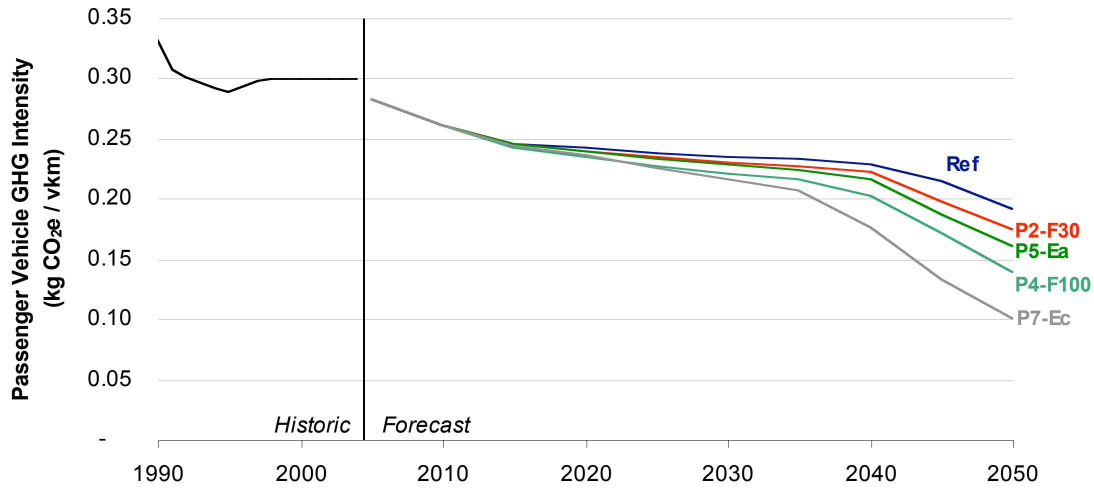
Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Figure 18: Passenger vehicle energy intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

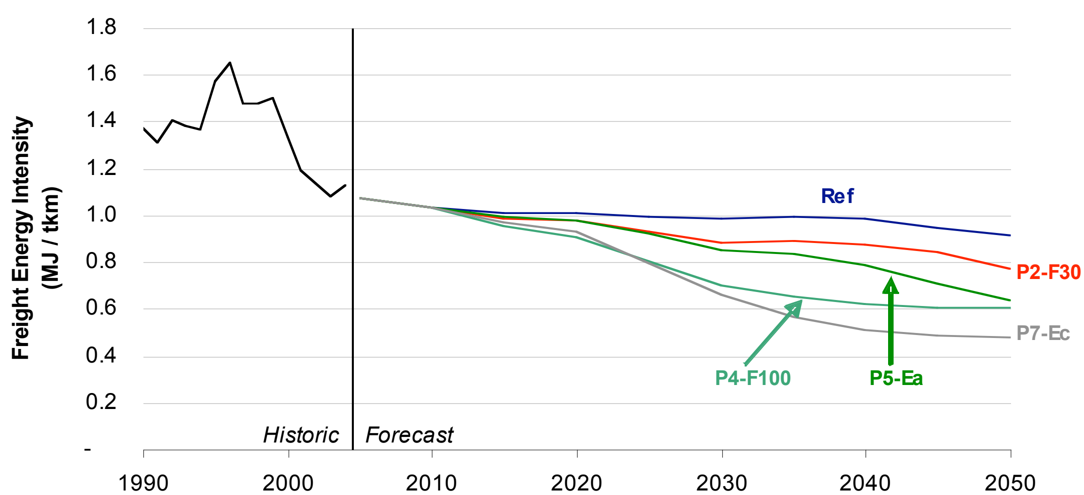
Figure 19: Passenger vehicle GHG intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

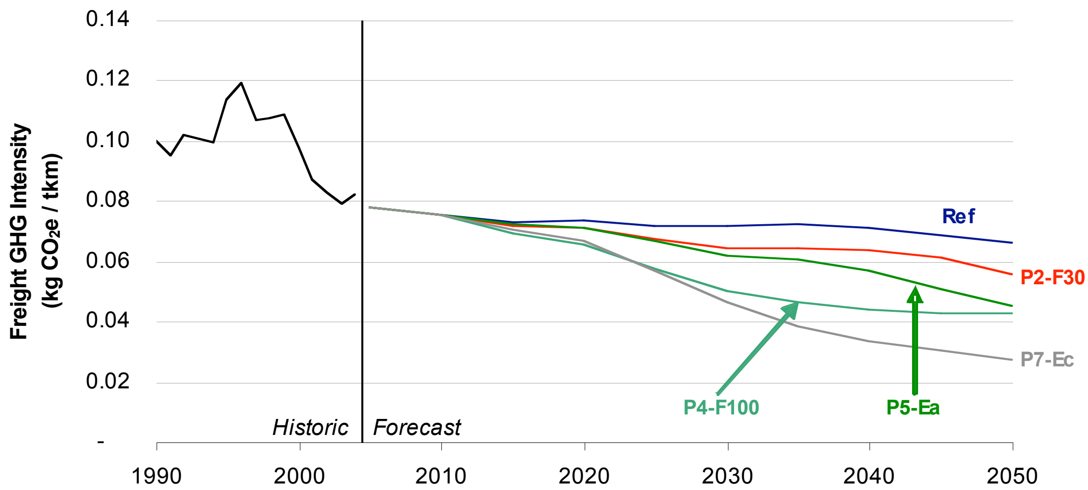
Figure 20 and Figure 21 show the energy and GHG intensity of freight transportation. The reference case illustrates small declines in intensity over time, due mostly to the gradual turnover of freight trucks. In the policy scenarios, the reductions are mostly due to energy efficiency improvements, with a small amount of mode switching from road transportation to rail.

Figure 20: Freight transportation energy intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Figure 21: Freight transportation GHG intensity



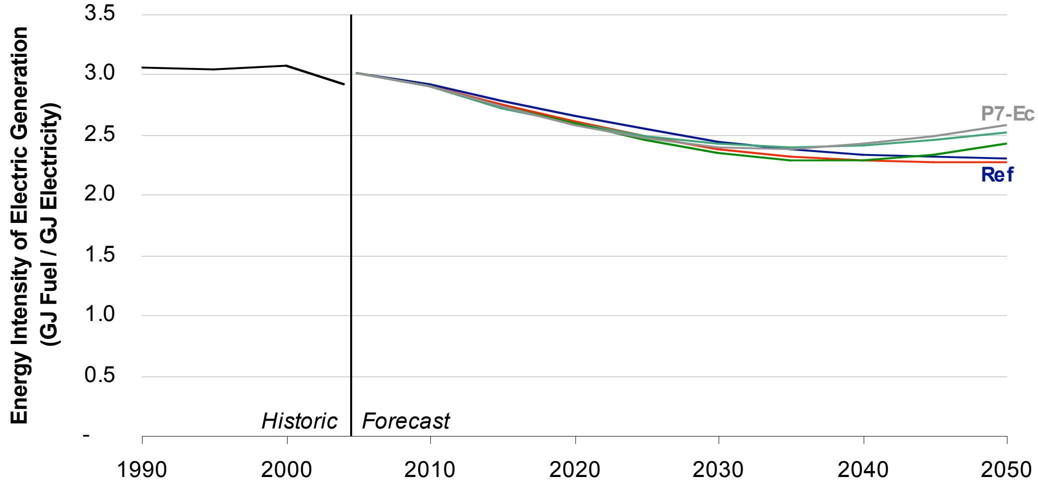
Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Electricity generation sector

Figure 22 and Figure 23 illustrate the energy and GHG intensity of electric generation. In the reference case, energy and GHG intensity decline largely due to improved efficiency at new coal and natural gas plants, as well as an increased penetration of renewables in the generation mix – in 2050, we forecast that about 13% of electricity is generated from renewables (including wind, hydroelectricity, and biomass).

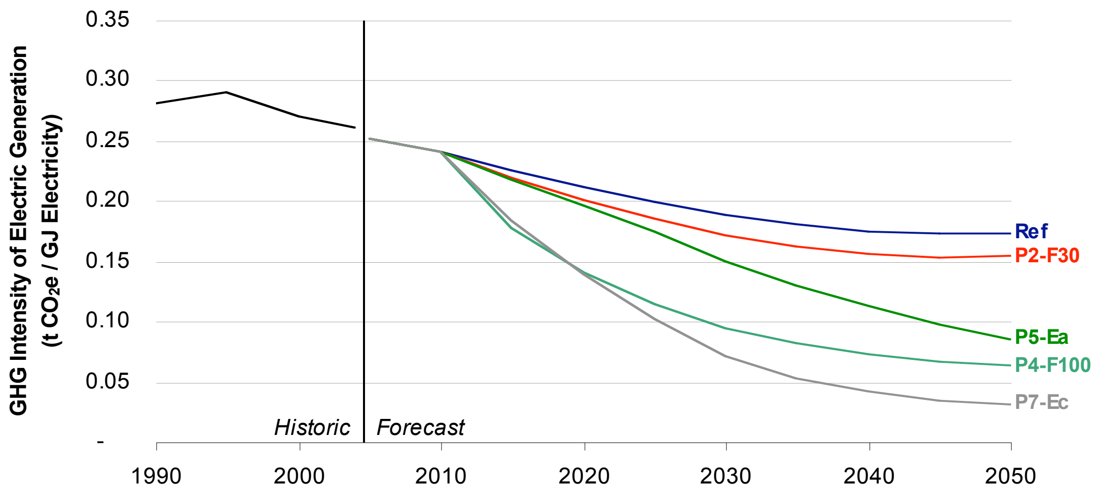
In the policy scenarios, energy intensity increases while GHG intensity declines. In 2050 in the P4-F100 scenario, the energy intensity of electric generation increases by 10%, while GHG intensity declines by 63% compared to the reference case. High carbon prices are projected to lead to larger portions of CCS and renewables in the generation mix. While CCS reduces GHG intensity, it increases energy intensity due to the greater energy requirements of capturing and storing carbon dioxide.

Figure 22: Electricity generation energy intensity



Source: Historic data from NRCan's "Canada's Energy Outlook", 2007.

Figure 23: Electricity generation GHG intensity



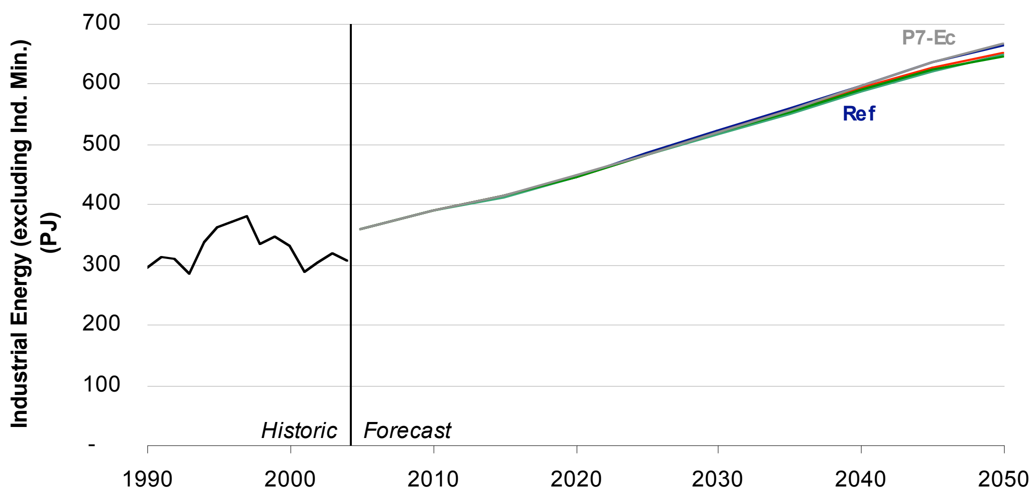
Source: Historic data from NRCan's "Canada's Energy Outlook", 2007.

Industrial manufacturing sectors

Figure 24 illustrates the energy consumption of the industrial sectors excluding industrial minerals; and Figure 25 illustrates the projected GHG emissions from all industrial sectors. In Figure 24, we exclude the industrial minerals sector because historic data for this sector are confidential. The forecast of energy consumption in the industrial manufacturing sectors does not correspond perfectly to historic data because CIMS includes the energy consumption forecasts of non-purchased fuels – such as black liquor, hog fuel, and still gas – but historic data on these fuels is unavailable, confidential or aggregated into other categories. Therefore, there is a small discrepancy between our forecast and historic data. We also do not compare our forecast of GHG emissions to historic data because a breakdown of emissions into categories comparable to CIMS is not available from Environment Canada's Greenhouse Gas Inventory.

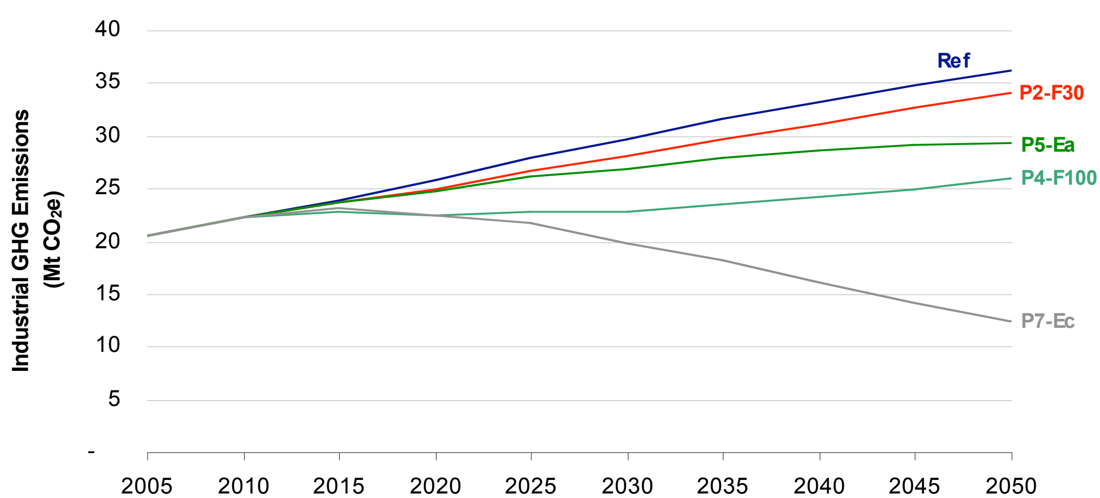
Figure 24 shows that carbon charges are unlikely to have a large effect on industrial energy consumption. The reductions in GHG emissions as a result of a policy are largely the result of fuel switching to lower emissions fuels – i.e., coal to natural gas or natural gas to electricity. Energy efficiency and CCS actions account for most of the remaining emissions reductions.

Figure 24: Industrial energy consumption (excludes industrial minerals)



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Figure 25: Industrial GHG emissions (includes industrial minerals)



Crude oil sector

The crude oil sector is expected to experience significant increases in production over the simulation period, as well as a rapid shift from conventional oil towards unconventional oil. We illustrate the energy and GHG intensity of the oil sands sectors in Figure 26 and Figure 27. Both of these figures include upgrading of mined bitumen into synthetic crude oil; historic data is not available for comparison. The reference case illustrates small declines in both energy and GHG intensity due to the retirement of old capital stock and its replacement with more efficient stocks. In the policy scenarios, energy intensity increases slightly while GHG intensity declines relative to the reference scenario. In 2050 in the P4-F100 scenario, energy intensity increases by 7% while GHG intensity declines by 42%, relative to the reference scenario. Similar to the electricity generation sector, the adoption of CCS reduces emissions intensity, but increases energy intensity.

Figure 26: Oil sands energy intensity

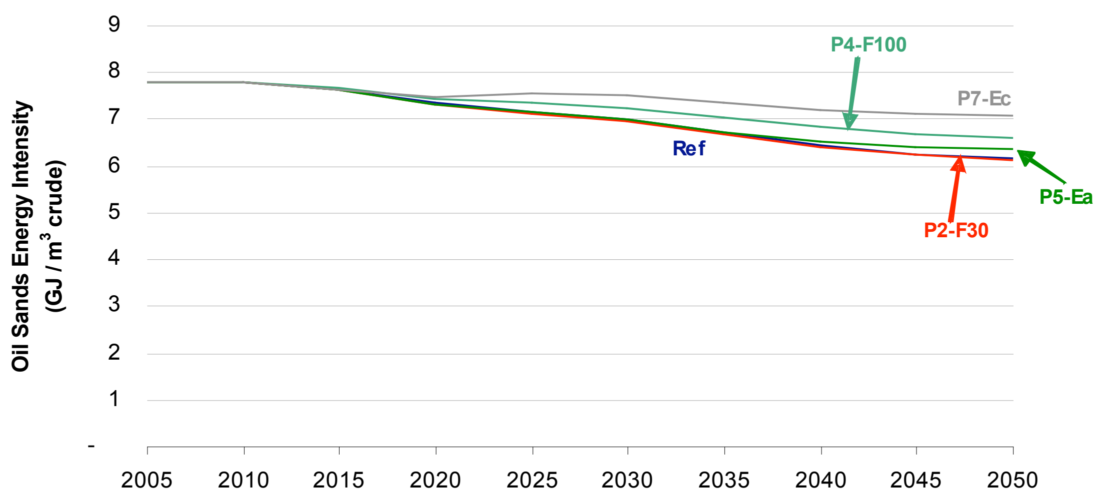
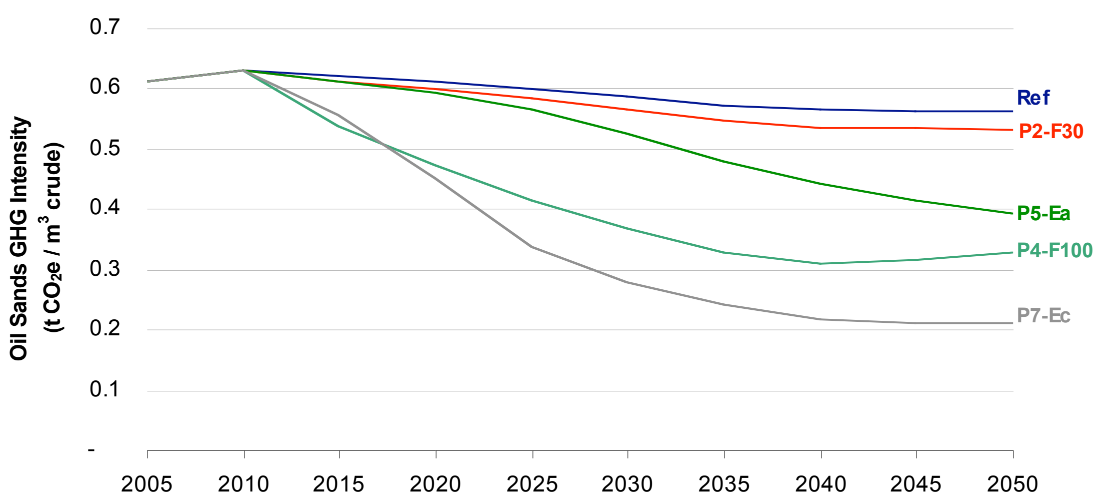


Figure 27: Oil sands GHG intensity



Economic impact of GHG charges

Overall economic impact

There is considerable debate about the appropriate measure for estimating the cost of greenhouse gas mitigation policies and actions. In this report, we present the cost of GHG abatement in terms of the effect on gross provincial product (GDP). This measure is useful because it is a widely reported measure of total economic output. However, several caveats should be made as to the appropriateness of this measure to guard against misinterpretation:

- CIMS is not a general equilibrium model, and focuses mostly on key energy-consuming sectors of the economy. In calculating the impacts of a policy on gross domestic product, by necessity we implicitly assume that other economic activity is unaffected by policies. Furthermore, CIMS does not capture the effects of a GHG policy on the wage rate or capital markets. Therefore, the estimates of GDP provided here should be interpreted as the impacts on economic activity that would occur if the activity from sectors excluded from CIMS is held constant. In reality, a GHG policy is likely to have feedbacks on activities excluded from CIMS. These could be positive or negative. Box 1 provides an example of how gross domestic product is calculated in this report, and it discusses some of the limitations of this method.

Box 1: GDP calculation example

Consider a policy that requires all new residential construction to meet the Built Green Gold™ standard. Because more energy efficient houses are likely to cost more, expenditure on residential construction is likely to increase as a result of the policy, increasing GDP. At the same time, household expenditure on energy will decrease, decreasing GDP. These components of GDP are captured in the CIMS model used for analysis here.

If the policy requires significant capital expenditure by households, other dynamics may be present that are not captured by CIMS, and which may bias the calculation of GDP reported here. First, if the household spends more on construction, it will have a smaller budget for other expenditures on goods (e.g., televisions, vehicles) and services (e.g., restaurants, accommodations). A reduction in expenditure in these sectors could reduce the output of these sectors (and also reduce the demand for goods and services by these sectors), which could reduce GDP (depending on whether the goods and services are imported or produced domestically). Second, if the household spends more on construction, there could be a feedback effect on the interest rate, which would affect expenditures throughout the economy. Third, the policy could have an affect on the labour market, which could affect the household budget as well as the use of labour throughout the economy.

Since CIMS only includes the direct effects of a policy on GDP, and none of the indirect feedbacks, it is likely biased. Without using a general equilibrium model for the entire economy, it is impossible to predict the direction of the bias. As a result, *the GDP impacts reported here should not be used as estimates of the policy on the GDP of the* *total economy, but estimates of the impact of a policy on the GDP of sectors covered by CIMS, with all else held constant.* In reality, as discussed, all else is unlikely to be held constant.

- While gross domestic product is a standard measure of overall economic activity, it is not a measure of welfare. GDP is roughly analogous to the price of all goods and services consumed multiplied by the physical output of these goods and services.[19] In the analysis conducted here, the price of many goods and services throughout the economy is forecast to increase as a result of climate policy, and overall physical consumption of these goods and services has fallen in response to the price increase. This implies some welfare loss associated with reduced consumption. However, GDP does not fall significantly, because the remaining consumption is multiplied by a higher price. In some cases (the electricity sector in particular), GDP is forecast to increase substantially as a result of increased consumption of a product (electricity). This would be associated with welfare losses, which are not accounted for using GDP.

Table 12 shows the projected impact of each policy simulation on the gross domestic product in Alberta's energy supply and demand sectors. Both the effect on total GDP as well as the effect on individual sub-sectors of the economy is shown.

[19] Gross domestic product (GDP) is the standard measure used to calculate changes in a firm or sector's financial output for purposes of its contribution to sectoral or national income. GDP, also known as value added, is the sum of expenditures on capital, labour, and natural resources, the three "primary factors" of production, to produce a given good or service. The purpose of the GDP accounting method is to provide a consistent measure of national income, from an expenditure point of view, that eliminates the double counting of expenditure: once capital, labour and natural resources are counted, they then become an "intermediate input" to other processes, where they are not counted again. This system also accommodates the complexities of international production and consumption: it allows firms in Canada to import intermediate inputs and use them combined with capital and labour to create new goods, and in the process not over-represent Canadian "income content" accruable to this new product.

Table 12: Estimated effect of carbon charges on gross domestic product in sectors covered by CIMS (millions of $2003)

				2025			
	P1-F15	*P2-F30*	*P3-F60*	*P4-F100*	*P5-Ea*	*P6-Eb*	*P7-Ec*
Total GDP Change	-281	-2	-230	365	-292	45	517
Percent GDP Change	-0.11%	0.00%	-0.09%	0.15%	-0.12%	0.02%	0.21%
Demand Sectors							
Residential	12	24	49	84	28	38	80
Commercial	-7	-13	-28	-62	-19	-26	-79
Transportation	-334	-130	-746	-909	-557	-397	-880
Manufacturing Industry	-1	4	15	35	9	14	49
Supply Sectors							
Crude Oil	-45	-105	-147	-588	-115	-134	-1,137
Natural Gas	-1	0	3	-22	1	1	-31
Coal Mining	0	-1	-2	-2	-1	-1	-2
Electricity Generation	108	243	676	1,902	391	590	2,588
Petroleum Refining	-12	-26	-53	-81	-31	-43	-80
Ethanol	1	2	4	7	2	3	8

				2050			
	P1-F15	*P2-F30*	*P3-F60*	*P4-F100*	*P5-Ea*	*P6-Eb*	*P7-Ec*
Total GDP Change	-176	-318	-552	908	410	603	5,146
Percent GDP Change	-0.05%	-0.08%	-0.14%	0.24%	0.11%	0.16%	1.34%
Demand Sectors							
Residential	12	23	38	53	44	49	60
Commercial	-3	-11	-44	-43	-61	-66	22
Transportation	-262	-413	-718	-7	-827	-626	-1,664
Manufacturing Industry	-2	-3	2	37	5	15	97
Supply Sectors							
Crude Oil	-183	-654	-1,809	-4,042	-2,780	-3,430	-6,048
Natural Gas	14	34	42	46	42	42	58
Coal Mining	-1	-4	-9	-12	-11	-12	-7
Electricity Generation	285	801	2,095	4,971	4,161	4,791	12,559
Petroleum Refining	-41	-118	-202	-247	-217	-242	-235
Ethanol	4	28	52	151	56	83	305

Throughout all the simulations, we forecast reductions in GDP from the crude oil extraction, petroleum refining, and transportation sectors and large increases in GDP from the electricity sector. At lower carbon charges, the net effect on GDP is slightly negative, while at higher carbon charges, the net effect on GDP is slightly positive for sectors covered by the CIMS model.

We explain the key dynamics underlying these results for the three most affected sectors:

- **Electricity generation sector** - Gross domestic product in the electricity sector rises substantially in all scenarios, for two main reasons. First, when a carbon charge is applied, energy-using sectors react by consuming relatively more electricity (which is less GHG intense at the point of end use) and less fossil fuels (which are more GHG intense at the point of end use). In the more aggressive policy scenarios, this results in the electricity sector growing substantially more than in the reference case. Second, when the carbon charges are applied, the electricity sector invests heavily in new electricity generating technologies, including fossil fuel generation with carbon capture and storage and renewable electricity generation, in response to the carbon price. Both of these trends (increases in overall capacity and investments in emissions abatement) require significant new capital investments in the electricity sector. These increased capital expenditures in the electricity sector correspond to increased GDP.[20]

- **Crude oil sector –** Gross domestic product in the crude oil sector is forecast to be reduced as a result of the implementation of carbon charges. In the modelling, we assumed that policies in Alberta would not affect the world price for crude oil. Likewise, we assumed that the total production of crude oil in Alberta would be unchanged as a result of Alberta's policies (however the balance of exports and domestic consumption can change as a result of policies in the model).[21] As a result, the gross output of the crude oil sector does not vary with the implementation of policy. Gross domestic product in the sector is equal to gross output less intermediate inputs (expenditures on fuel, and other intermediate goods). The modelling forecast significant increases in expenditures on intermediate inputs as a result of climate change policies because of fuel switching towards more expensive lower carbon fuels, equating to a reduction in GDP.

  The reduction in GDP shown here would reduce rent (excess profit) in the industry. Because the royalties collected by government are related to economic rent in the industry, some of the loss in GDP shown here would correspond to a loss in government revenue.

- **Transport sector –** Gross domestic product in the transport sector is expected to fall as a result of implementation of carbon charges. Expenditure on personal and freight transportation falls, reducing GDP, mainly due to substitution away from more expensive low-efficiency vehicles like large pickup trucks and sport utility

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[20] Gross domestic product is normally calculated by summing the expenditures in a sector on capital and labour. In the electricity sector, these expenditures increase as a result of policy as explained above, which increases GDP. GDP can also be calculated by summing the income in a sector. In the electricity sector, the income is equal to the price of electricity multiplied by the sales of electricity (minus the expenditures on intermediate inputs). When a policy is applied, both the price of electricity increases (because of increased abatement expenditures in the electricity sector) and the sales of electricity increase (because of fuel switching into electricity in the energy-consuming sectors). As a result, the GDP of the sector is increased.

[21] While this assumption is unlikely to hold perfectly, world price of crude oil is forecast to remain quite high in the future, likely above the cost of producing crude oil in Alberta (this leads to economic rents). Increases in the cost of producing crude oil in Alberta would likely reduce excess rents, but not significantly reduce production.

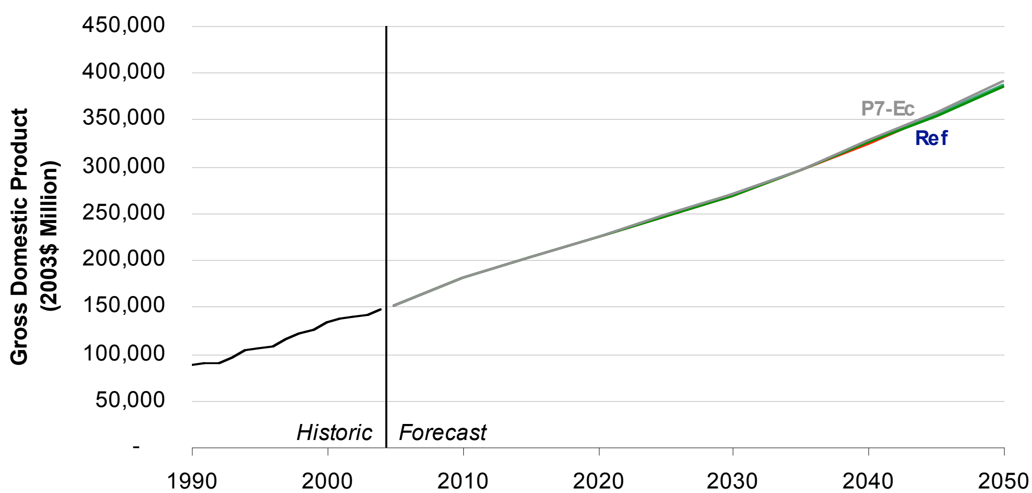
vehicles to less expensive high efficiency vehicles. Mode switching from single occupancy vehicles to high occupancy vehicles and to public transit also reduces expenditures in the transport sector.

The dynamics for all the simulations are generally similar, except stronger with the increase in GHG price. At higher carbon prices, the net gain in GDP is larger. This seemingly counter intuitive response is mainly due to the necessary capital expenditures in electricity production.

Finally, we reiterate that CIMS is not a full equilibrium model, with full modelling of labour and capital markets and structural shifts in non-energy intensive sectors. Our results show a significant increase in investments in the energy production and transformation sectors, but this increase may be accompanied by a reduction in investments in non-energy intensive sectors. While CIMS is an appropriate tool for analysis of the transforming effects of energy policy on the energy-using capital stock and general economy over time, full analysis of the effects of the potentially significant structural change we describe should be completed with a dedicated general equilibrium model.

Despite these caveats, the results do indicate that the overall effect of policies to reduce GHG emissions in Alberta is unlikely to be large, especially when compared to total GDP growth over in the future. Figure 28 shows projected GDP growth in Alberta in the reference case and in the four flat policy scenarios. Overall effects are projected to be nearly imperceptible over a 45-year period, once future growth in GDP is accounted for.

Figure 28: Alberta GDP in the alternative scenarios



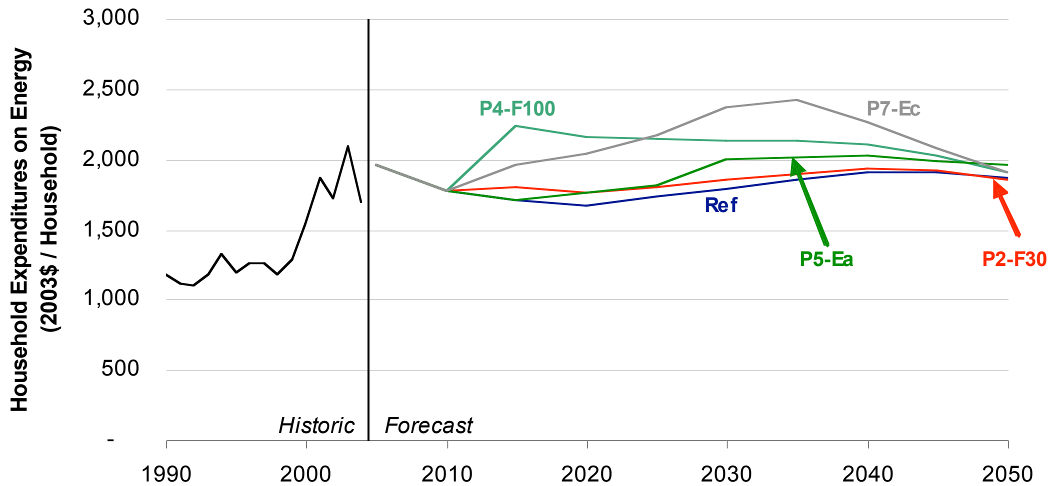
Source: Historic and reference scenario data from Infometrica, "Demographic and population projections to 2050", 2007.

Sector specific results

In addition to overall economic impact, we provide some analysis of economic impact of the policies at a sector level. Where possible, we provide historic data for context.

- **Residential** – Figure 29 shows the projected change in household expenditures on energy as a result of the implementation of carbon charges throughout the economy. Historical data are provided for context. The figure shows that real household energy expenditures are projected to decline slightly from today's levels as a result of improved energy efficiency as well as declining real fuel prices. When GHG policies are implemented, household expenditures on energy are projected to increase by as much as 40 percent in the P4-F100 scenario. The increases are most severe in the near term, when the capital stock is relatively fixed. In the longer term, increases are much smaller as household stock becomes more efficient in response to higher energy prices.

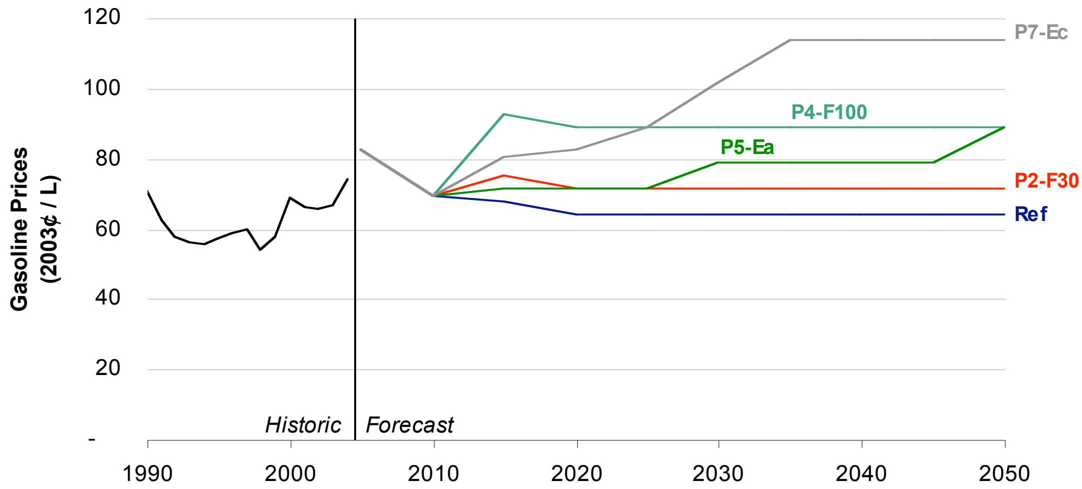
Figure 29: Household expenditures on energy



Source: Historic data on energy consumption from NRCan's "Comprehensive Energy Use Database", 2007; historic data on electricity prices from Hydro-Quebéc's "Comparison of Electricity Prices in Major North American Cities"; historic data on natural gas prices from CANSIM, Table 129-0003, "Sales of Natural Gas Monthly".

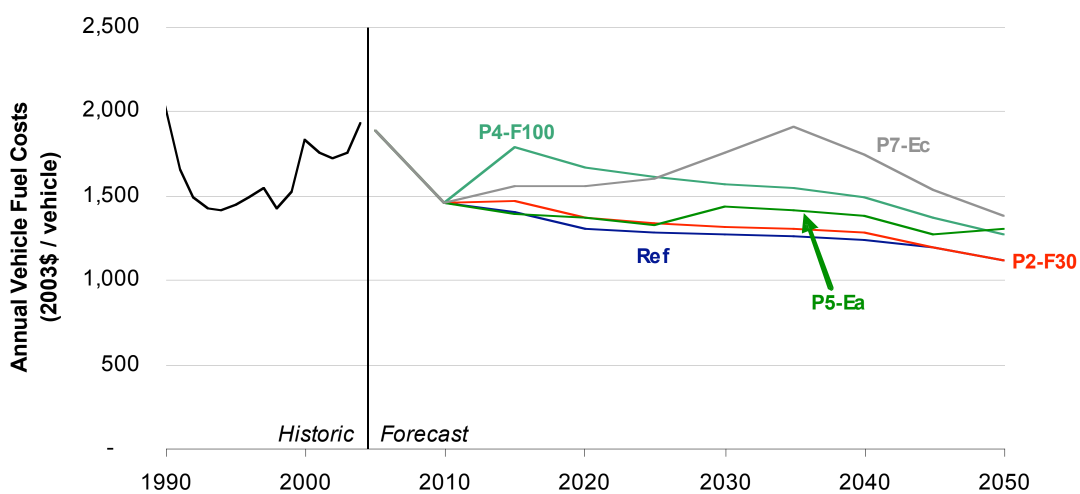
- **Transportation** – Figure 30 shows projected changes in gasoline prices resulting from policy implementation. In the reference case, gasoline prices are expected to decline from current levels due to projected decreases in real crude oil price. In the P4-F100 scenario, gasoline price is expected to increase by around 40 percent compared to the reference case. Figure 31 shows annual vehicle fuel costs. Like gasoline prices, annual fuel costs are expected to decline from today's high levels because of the projection of declining real crude oil prices. Increasing vehicle efficiency also contributes to a decline in annual vehicle expenditure on energy. When policies are applied, vehicle fuel costs increase significantly in the near term before moderating in the longer term, as the vehicle stock responds to higher fuel prices.

Figure 30: Gasoline price



Source: Historic data from CANSIM, Table 329-0009, "Average Retail Prices for Gasoline and Fuel Oil by Urban Centres, Monthly".

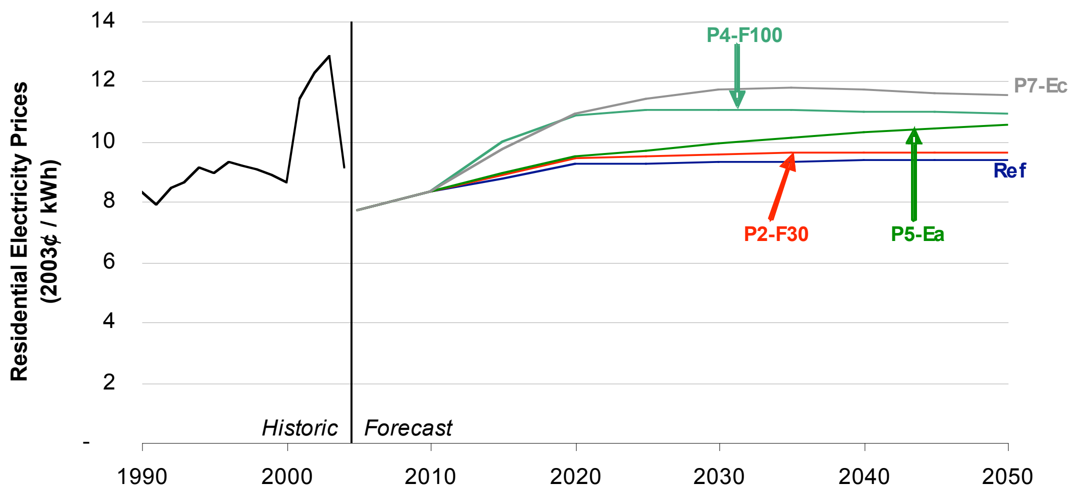
Figure 31: Annual vehicle fuel cost



Source: Historic data on vehicle energy consumption from NRCan's "Comprehensive Energy Use Database", 2007; historic data on fuel prices from CANSIM, Table 329-0009, "Average Retail Prices for Gasoline and Fuel Oil by Urban Centres, Monthly".

- **Electricity generation** – Figure 32 shows the forecast of residential electricity prices in Alberta. Prices are projected to increase gradually in the reference case, as new capital investments are required. Prices increase much more rapidly in the aggressive policy scenario, because significant abatement expenditures (primarily carbon capture and storage and renewable energy investments) occur in the electricity generation sector. These higher electricity prices cause some energy efficiency and conservation investments in the residential sector, and in other electricity consuming sectors.

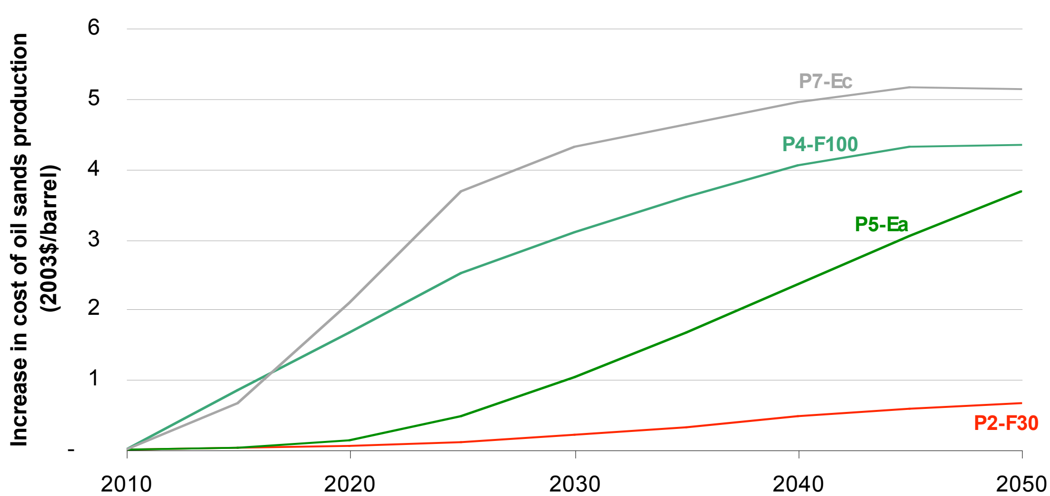
Figure 32: Electricity Prices (Residential)



Source: Historic data from Hydro-Quebéc's "Comparison of Electricity Prices in Major North American Cities".

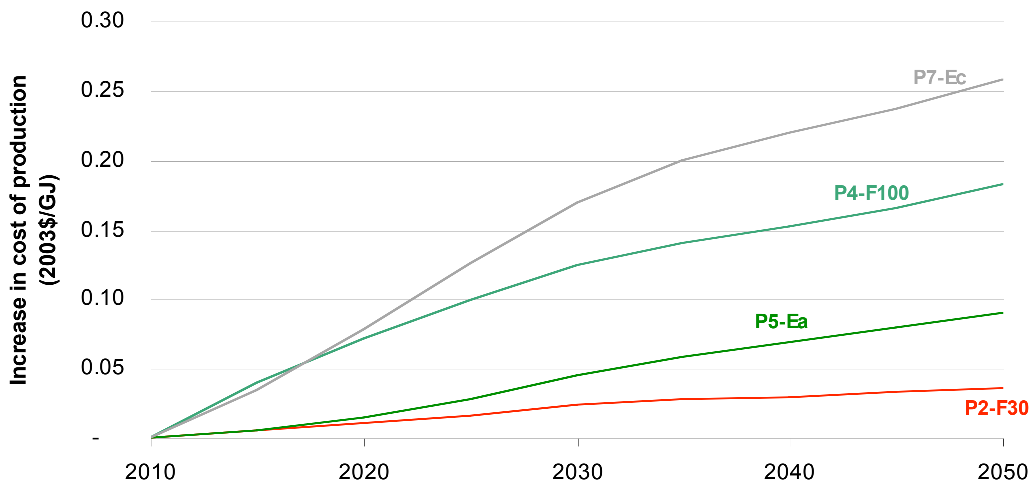
- **Crude oil** – Figure 33 shows the increase in the cost of producing a barrel of oil from Alberta's oil sands. The increase in costs range from less than $1 per barrel to around $5 per barrel in the most aggressive scenario. The costs of production increase most in the most aggressive scenario, due primarily to the costs associated with carbon capture and storage.

Figure 33: Increase in the cost of oil sands production



- **Natural gas** – Figure 34 shows the increase in cost of producing natural gas for several of the policy scenarios. The increase in costs is the result of carbon capture and storage in natural gas processing plants, as well as some leak detention and repair programs.

Figure 34: Increase in the cost of natural gas production



➢ **Industrial sectors** – Table 13 shows the projected increase in the cost of production for the industrial sectors covered by CIMS. The biggest increases occur in the energy supply sectors, especially the electricity generation and crude oil sectors, which are particularly GHG-intensive.

Table 13: Projected increase in cost of production for energy supply and demand industries due to policy

2025	P1-F15	P2-F30	P3-F60	P4-F100	P5-Ea	P6-Eb	P7-Ec
Manufacturing Industry							
Chemical Products	0%	0%	1%	2%	1%	1%	3%
Industrial Minerals	0%	0%	2%	3%	1%	1%	3%
Other Manufacturing	0%	0%	0%	0%	0%	0%	0%
Pulp and Paper	0%	0%	0%	1%	0%	0%	1%
Supply Sectors							
Crude Oil	0%	0%	1%	5%	1%	1%	8%
Natural Gas	0%	0%	1%	2%	0%	1%	2%
Coal Mining	0%	0%	1%	1%	0%	0%	1%
Electricity Generation	1%	3%	8%	19%	4%	7%	23%
Petroleum Refining	0%	0%	0%	0%	0%	0%	0%
Ethanol	0%	0%	-6%	-11%	-1%	-3%	-11%

2050	P1-F15	P2-F30	P3-F60	P4-F100	P5-Ea	P6-Eb	P7-Ec
Manufacturing Industry							
Chemical Products	0%	1%	2%	5%	3%	4%	9%
Industrial Minerals	0%	0%	1%	4%	2%	3%	7%
Other Manufacturing	0%	0%	0%	0%	0%	0%	0%
Pulp and Paper	0%	0%	0%	1%	1%	1%	1%
Supply Sectors							
Crude Oil	0%	1%	5%	9%	7%	8%	11%
Natural Gas	0%	1%	2%	3%	2%	2%	4%
Coal Mining	0%	0%	1%	1%	1%	1%	2%
Electricity Generation	0%	3%	10%	17%	13%	14%	23%
Petroleum Refining	0%	0%	0%	0%	0%	0%	2%
Ethanol	-2%	-4%	-5%	-6%	-5%	-5%	-5%

Note: * We assumed a world price for crude oil that was unaffected by Alberta's GHG policies. Because crude oil represents the largest portion of expenditures in the petroleum refining sector, total cost of production remained relatively unchanged as a result of the policies, despite significant abatement expenditures.

Policy analyses

In addition to the carbon charges, we modelled the impact of several policy options on Alberta's GHG emissions. In particular, we modelled the following policies:

- **The carbon charge schedule specified for P5-Ea combined with a regulation that requires all large industrial facilities built after 2015 to capture and store their emissions (S1-EaCCS).** The CCS regulation covers electricity generation, petroleum refining, natural gas processing, and oil sands facilities and all large industrial manufacturing facilities.

- **The carbon capture and storage regulation simulated in S1-EaCCS applied on its own (S2-CCS).** This policy excludes the carbon charge from S1-EaCCS.
- **A change to the residential building code (S3-RBC).** We model a policy that requires new houses built in Alberta to be certified as Built Green™ Gold after 2010.
- **Construction of a new nuclear electricity generation plant (S4-NUC).** We model a scenario in which a 2,200 MW nuclear plant is commissioned to produce electricity for Alberta's grid in 2020.
- **A vehicle emissions standard for new vehicles (S5-VES).** We model a policy where new passenger vehicles sold in Alberta must have an average greenhouse gas intensity below the levels specified in Table 14.

Table 14: Maximum average fleet GHG standard modelled in this report

	2011-2015	*2016-2020*	*2021-onwards*
Vehicle Emissions Standard (g CO_2/km)	174	160	160

- **A revision to the commercial building code (S6-LEED).** We model a policy that requires all new commercial construction to meet LEED Gold™ standards after 2010.
- **Requirement for electricity generated from renewable sources (S7-REN).** We simulate a policy where 20% of electricity must be generated from renewable sources by 2020.
- **Policy Package (S8-PKG).** We model a policy package that includes several regulations targeted at different sectors of the economy. The policy package includes: 1) a requirement for all new large industrial facilities built after 2015 to capture and store their greenhouse gas emissions (S2-CCS); 2) a revision to residential building codes (S3-RBC); 3) the commissioning of 2,200 MW of nuclear power electricity generation in 2020 (S4-NUC); 4) the vehicle emissions standard for new vehicles (S5-VES); and 5) the commercial building code revision (S6-LEED).[22]

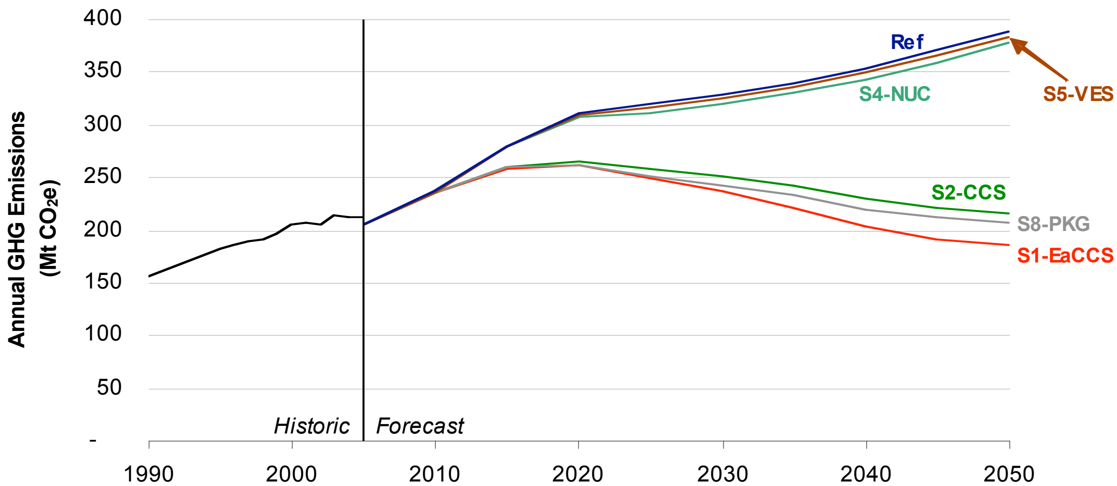
Figure 35 illustrates the projection of Alberta's GHG emissions in several of the policies, and Source: Historic data are from Environment Canada, 2007, "Greenhouse Gas Inventory".

Table 15 shows the emissions reductions from the reference projection by sector.[23] S3-RBC, S4-NUC, S5-VES, S6-LEED, S7-REN produce modest reductions in GHG emissions, because the scope of the policies is limited to a few sectors – the residential sector in S3-RBC, the electricity generation sector in S4-NUC and S7-REN, the transportation sector in S5-VES, and the commercial sector in S6-LEED. S1-EaCCS, S2-

[22] The electricity renewable standard has been excluded from the policy package to ease the modelling.
[23] S3-RBC, S6-LEED and S7-REN have been removed from Figure 35 because the difference between these simulations and S5-VES is small.

CCS and S8-PKG, however, target a larger portion of the economy. The carbon capture and storage regulation (simulated in each of the policies) targets sectors which are responsible for the majority of Alberta's emissions. S1-EaCCS adds a carbon charge to the CCS regulation, while S8-PKG adds additional regulations to cover emissions in sectors unaffected by the CCS regulation.

Figure 35: GHG emissions in each policy analysis



Source: Historic data are from Environment Canada, 2007, "Greenhouse Gas Inventory".

Table 15: Annual Emissions Reductions by Sector (Mt CO_2e)

	2025							
	S1-EaCCS	*S2-CCS*	*S3-RBC*	*S4-NUC*	*S5-VES*	*S6-LEED*	*S7-REN*	*P8-PKG*
Alberta Total	69	61	0.3	7	2	1	5	68
Demand Sectors								
Residential	0	0	0.4	0	0	0	0	0
Commercial	0	0	0	0	0	3	0	3
Transportation	2	0	0	0	2	0	0	2
Manufacturing Industry	5	5	0	0	0	0	0	5
Supply Sectors								
Crude Oil	46	42	0	0	0	0	0	42
Natural Gas	1	1	0	0	0	0	0	1
Coal Mining	0	0	0	0	0	0	0	0
Electricity Generation	11	11	-0.2	8	0	-2	4	12
Petroleum Refining	3	3	0	0	0	0	0	3
Ethanol	0	0	0	0	0	0	0	0

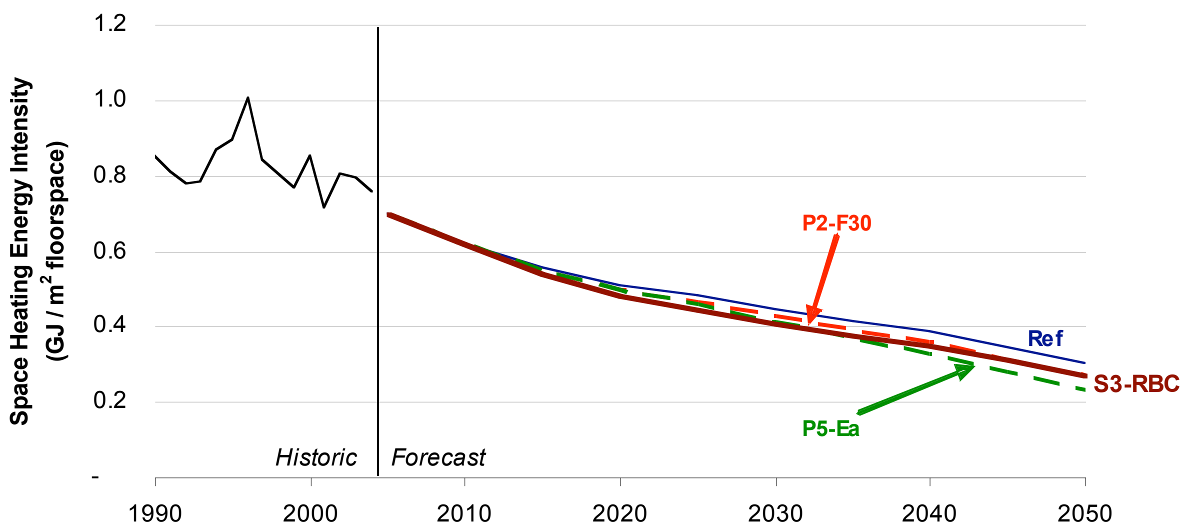
	2050							
	S1-EaCCS	*S2-CCS*	*S3-RBC*	*S4-NUC*	*S5-VES*	*S6-LEED*	*S7-REN*	*P8-PKG*
Alberta Total	203	173	0.6	11	2	5	6	181
Demand Sectors								
Residential	2	-2	0.4	0	0	0	0	-1
Commercial	1	-2	0	-1	0	5	0	4
Transportation	13	0	0	0	2	0	0	2
Manufacturing Industry	15	13	0	0	0	0	0	13
Supply Sectors								
Crude Oil	109	99	0	0	0	0	0	99
Natural Gas	2	0	0	0	0	0	0	0
Coal Mining	0	0	0	0	0	0	0	0
Electricity Generation	51	53	0.3	12	0	0	6	53
Petroleum Refining	12	11	0	0	0	0	0	11
Ethanol	0	0	0	0	0	0	0	0

We present sector specific indicators on energy and greenhouse gas emissions for the regulatory policies below. In each figure, we show the indicators for different levels of carbon charges to enable a comparison between the effectiveness of the different policies. We also provide an estimate of the implicit carbon charge for several of the regulations. The implicit carbon charge is a measure of the level of carbon charge that would be required to induce similar abatement actions as the regulation. We only present select indicators in this section, but full results are available in the appendix.

Residential sector

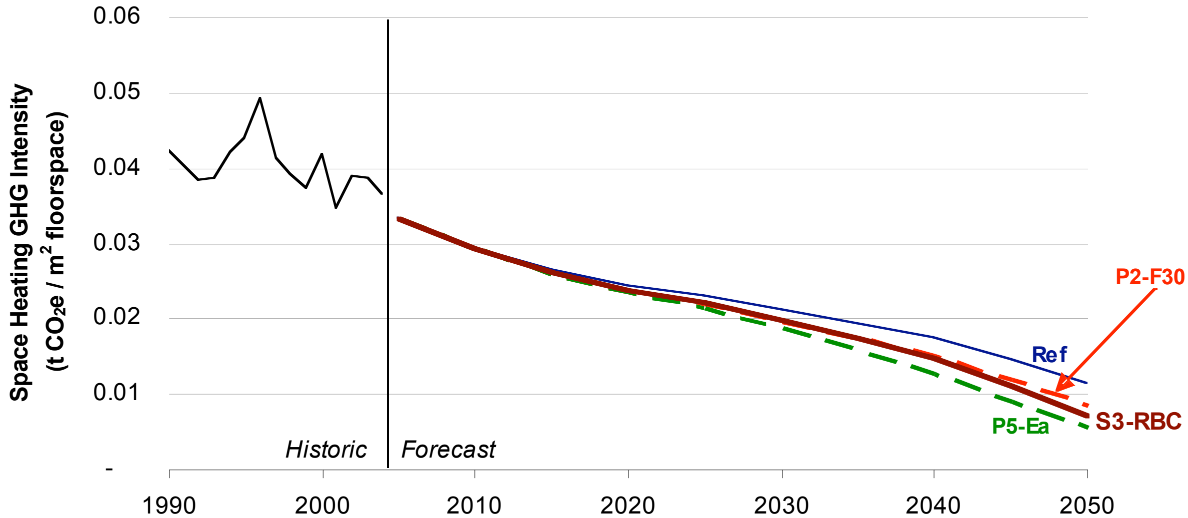
Figure 36 and Figure 37 show the energy and greenhouse gas intensity of residential space heating in the S3-RBC scenario. As illustrated, the requirement for all new Alberta homes to meet the Built Green™ Gold standard after 2010 leads to similar declines in energy and greenhouse gas intensity as the flat $30/tonne CO_2e carbon charge (P2-F30). One reason why the change in building codes does not attain greater declines in energy and greenhouse gas intensity is that the regulation only requires improvement of residential shells, whereas carbon charges induce GHG reductions throughout the entire house (e.g., furnaces, shells, lighting, appliances). Table 16 shows the implicit charge on greenhouse gas emissions from revising the residential building codes. The implicit GHG charges are relatively high because more efficient buildings only have a modest impact on greenhouse gas emissions.

Figure 36: Residential space heating energy intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Figure 37: Residential space heating direct GHG intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Table 16: Implicit GHG charge for S3-RBC

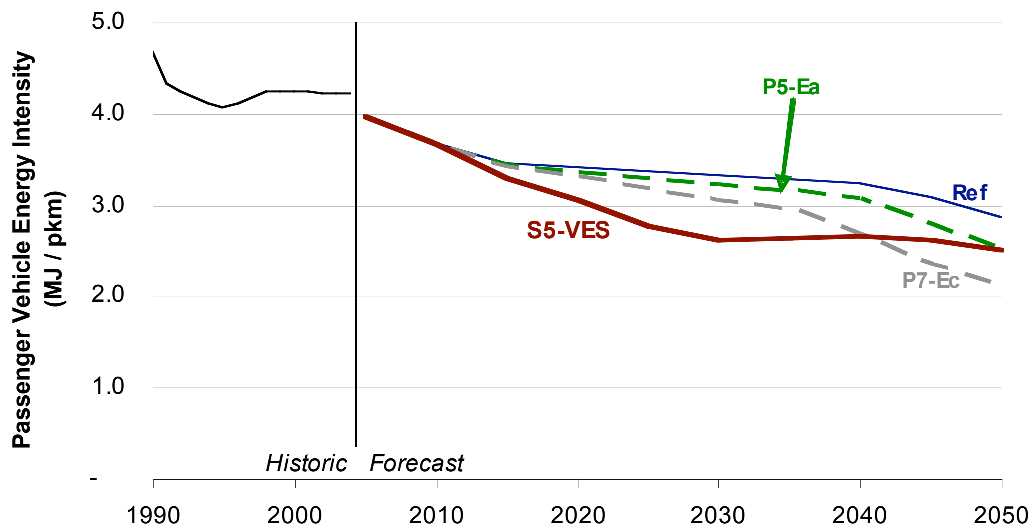
	2015	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
GHG Tax (2003$/tonne CO_2e)	1,770	1,330	880	430	210	200	190	170

Passenger transportation sector

Figure 38 and Figure 39 show the energy and greenhouse gas intensity of passenger vehicles in the S5-VES scenario.[24] At the beginning of the simulation, the vehicle emissions standard induces greater reductions in energy and greenhouse gas intensity than the carbon charges applied in the P5-Ea or P7-Ec scenarios. The standard requires a greater adoption of low emissions vehicles than occurs in P5-Ea or P7-E; therefore, the implicit greenhouse gas charge of the standard – illustrated in Table 17 – is greater than the carbon charge applied in P5-Ea or P7-Ec. Towards the end of the simulation, the carbon charge scenarios induce a greater adoption of low emissions vehicles than is required by the vehicle emissions standard.

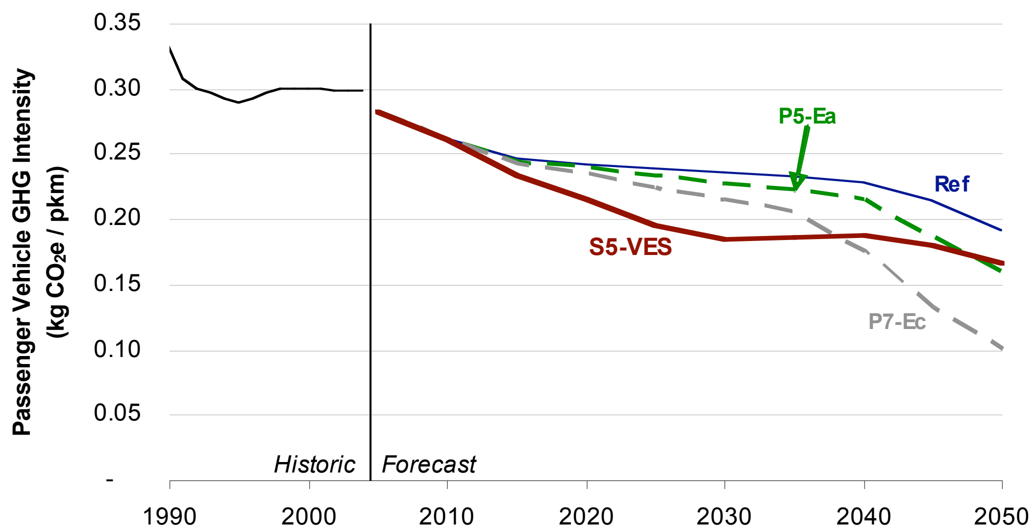
[24] The intensity indicators for S8-PKG are not illustrated because they show a similar trend to S5-VES.

Figure 38: Passenger vehicle energy intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Figure 39: Passenger vehicle GHG intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

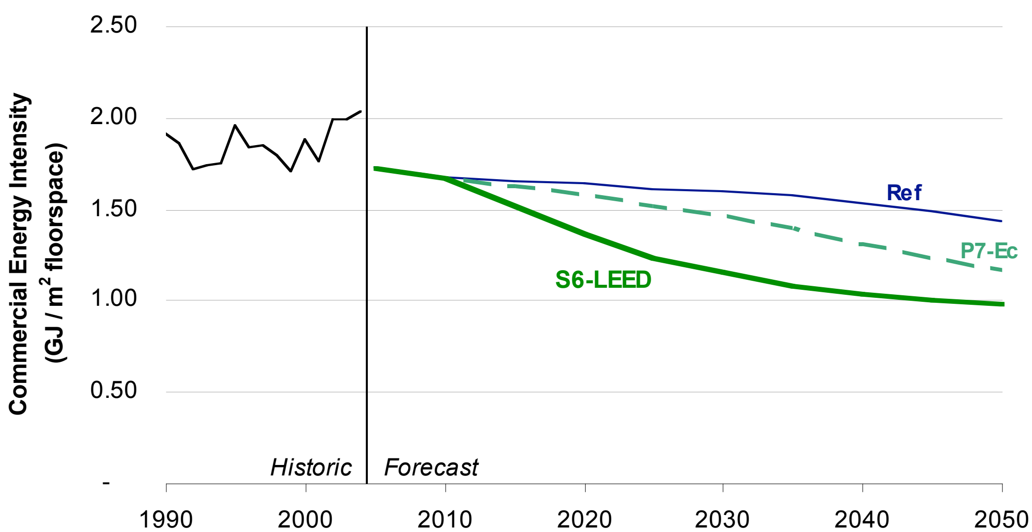
Table 17: Implicit GHG charge for S5-VES

	2011-2015	*2016-2020*	*2021-2025*	*2026-2030*	*2031-2035*	*2036-2040*	*2041-2045*	*2046-2050*
Implicit GHG charge (2003$/tonne CO_2e)	$175	$120	$90	$60	$30	NA	NA	NA

Commercial sector

Figure 40 and Figure 41 show the energy and greenhouse gas intensity of commercial buildings in the S6-LEED scenario.[25] The requirement for new construction to meet LEED Gold™ standards after 2010 induces greater improvements in both energy and greenhouse gas intensity than the carbon charge simulated in P7-Ec. Unlike the revision to the residential building code, this standard induces energy efficiency improvements to most aspects of commercial buildings. The key actions that contribute to the decline in energy intensity are improvements to the outside shells, space heating systems and water heating systems. The implicit GHG charge at the beginning of the regulation, illustrated in Table 18, is much greater than the carbon charge simulated in P7-Ec. The regulation requires a greater improvement in energy efficiency than occurs in the P7-Ec scenario.

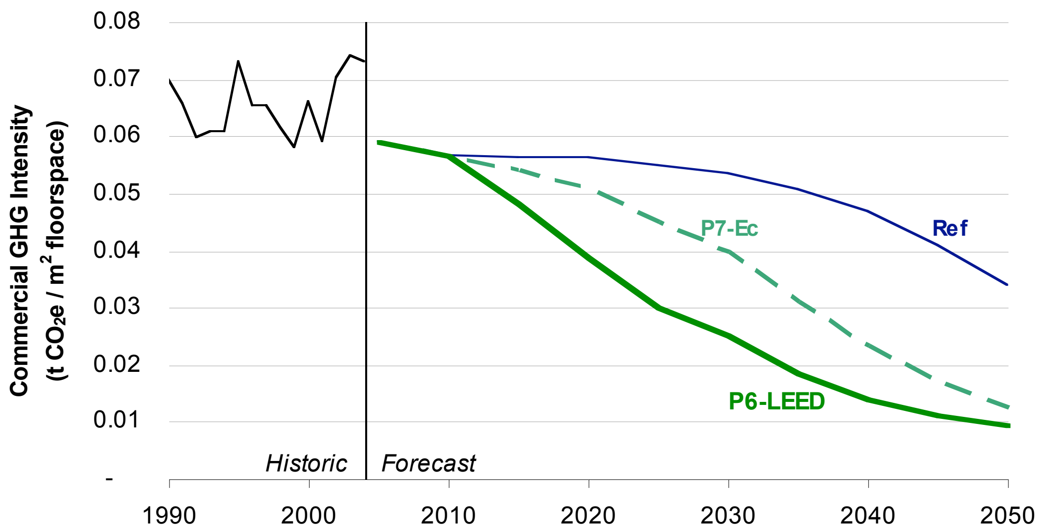
Figure 40: Commercial building energy intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

[25] The intensity indicators for S8-PKG are not illustrated because they show a similar trend to S6-LEED.

Figure 41: Commercial building direct GHG intensity



Source: Historic data from NRCan's "Comprehensive Energy Use Database", 2007.

Table 18: Implicit GHG charge for S6-LEED

	2011-2015	2016-2020	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050
Implicit GHG charge (2003$/tonne CO_2e)	410	350	295	250	195	155	125	95

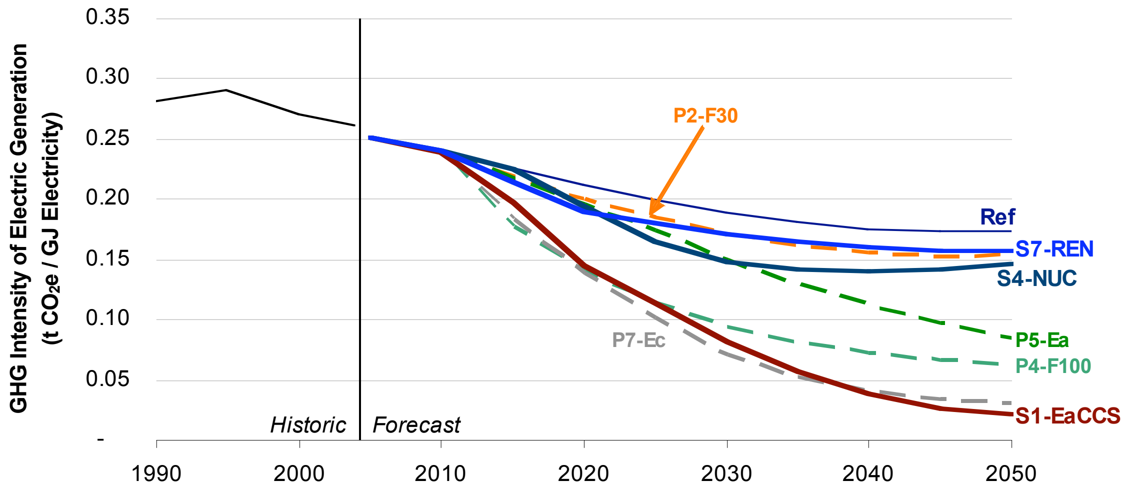
Electricity generation sector

Figure 42 shows the greenhouse gas intensity of electricity generation in the S1-EaCCS, S4-NUC and S7-REN scenarios.[26] The results show that both the construction of a 2,200 MW nuclear plant and the requirement for 20% of electricity generation to be from renewable sources by 2020 would reduce the emissions intensity of electricity generation to roughly the same level as a $30/tonne CO2e carbon charge by 2050. The construction of the nuclear plant yields a slightly greater reduction in greenhouse gas intensity because it leads to a greater installation of electric capacity from zero emissions sources. The scenarios that employ the carbon capture and storage regulation generally follow the intensity of the most aggressive carbon charge scenario (P7-Ec). The policies yield similar results because they all lead to a full application of carbon capture and storage – which is the main action to reduce emissions in each scenario. Source: Historic data from NRCan's "Canada's Energy Outlook", 2007.

Table 19 shows the implicit GHG charge of requiring 20% of electric generation to be from renewables by 2020.

[26] The intensity indicators for S2-CCS and S8-PKG are not illustrated because they show a similar trend to S1-EaCCS.

Figure 42: Electricity generation GHG intensity



Source: Historic data from NRCan's "Canada's Energy Outlook", 2007.

Table 19: Implicit GHG charge for S7-REN

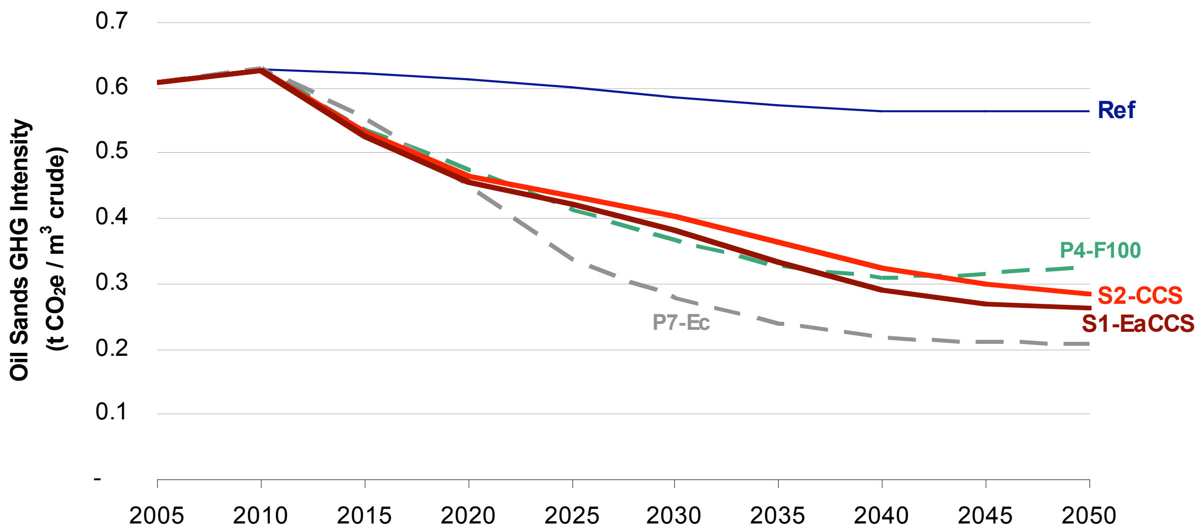
	2011-2015	*2016-2020*	*2021-onward*
Implicit GHG charge (2003$/tonne CO_2e)	$40	$40	NA

Crude oil sector

Figure 43 shows the greenhouse gas intensity of the oil sands in the S1-EaCCS and S2-CCS scenarios.[27] The decline in intensity in each scenario by 2050 is less than in the most aggressive carbon charge scenario (P7-Ec). While carbon capture and storage is a key action to reduce emissions in the sector, switching to low emissions fuels and energy efficiency actions contribute to significant emissions reductions in the P7-Ec scenario. S2-CCS, which does not apply a carbon charge, does not encourage these actions; and S1-EaCCS, which employs a less aggressive carbon charge than P7-Ec, does not encourage these actions to the same extent.

[27] The intensity indicator for S8-PKG is not illustrated because it shows a similar trend to S2-CCS.

Figure 43: Oil sands GHG intensity



Industrial Sectors

Figure 44 shows the greenhouse gas emissions in the industrial manufacturing sectors.[28] S1-EaCCS and S2-CCS lead to larger emissions reductions than the P7-Ec scenario because they encourage a greater application of carbon capture and storage. Carbon capture and storage is not fully applied in P7-Ec, because the carbon charges are not high enough at the beginning of the simulation to make CCS economically viable in all industrial sectors. The difference in the emissions trajectories between the S1-EaCCS and S2-CCS can be attributed to the carbon charge applied in S1-EaCCS, which encourages fuel switching and energy efficiency actions in addition to carbon capture and storage.

[28] The intensity indicator for S8-PKG is not illustrated because it shows a similar trend to S2-CCS.

Figure 44: Industrial GHG emissions

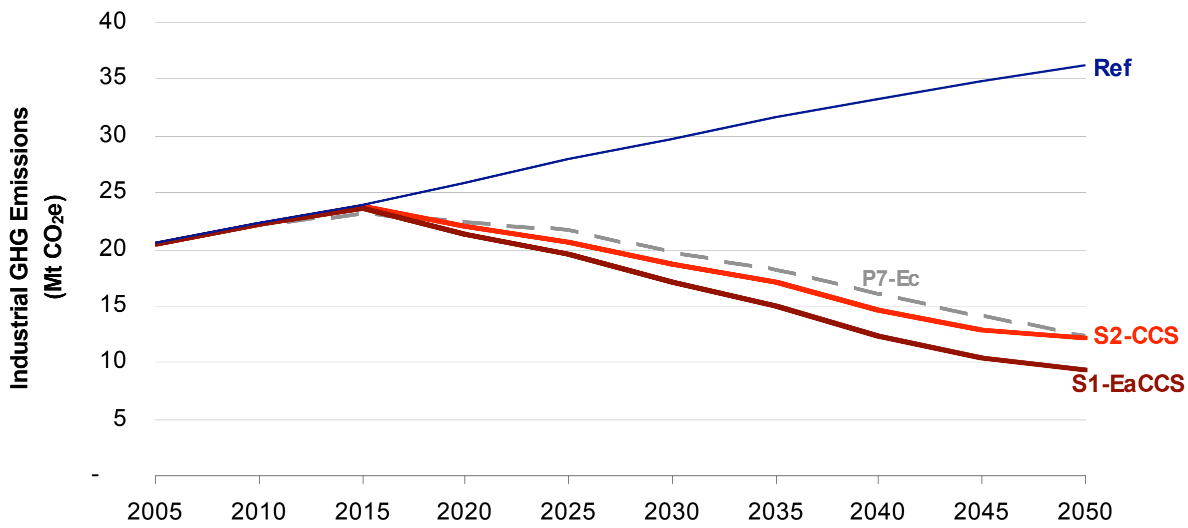
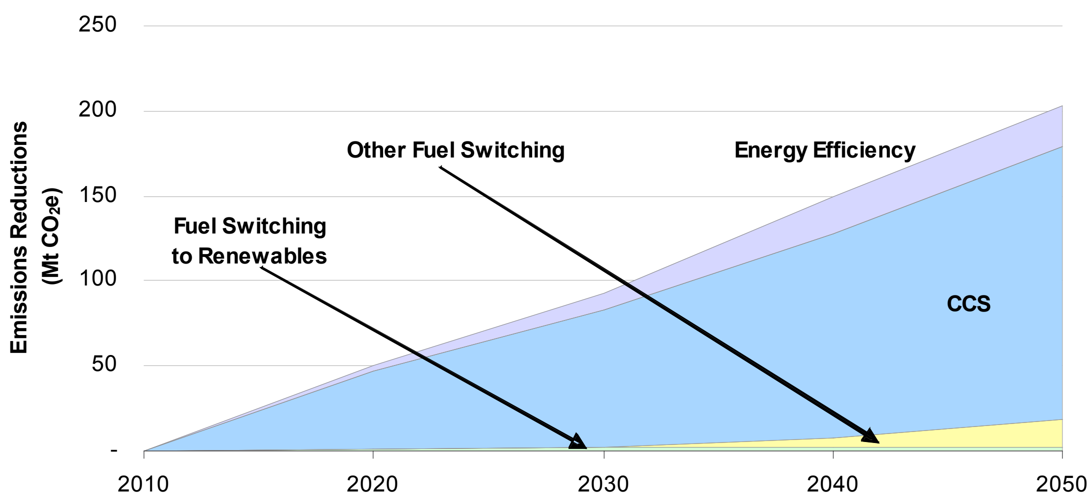


Figure 45 shows the wedge diagram for S1-EaCCS. Almost all reductions come from carbon capture and storage.

Figure 45: GHG reduction wedge diagram for S1-EaCCS



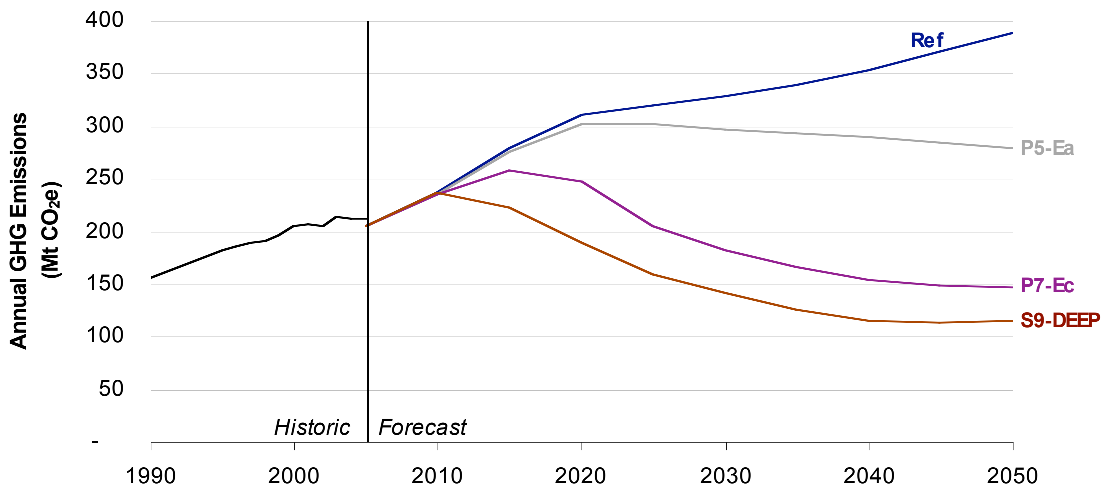
Deep reduction policy

The final purpose of this report is to assess the stringency of carbon charge required to attain a deep reduction in greenhouse gas emissions – 50% below 2005 levels by 2050. For this policy, we simulated a ceiling on carbon charges equal to $300/tonne CO_2e (2003$). Figure 46 shows the greenhouse gas projection, and Source: Historic data are from Environment Canada, 2007, "Greenhouse Gas Inventory".

Table 20 shows the carbon charge and the final sectoral emissions in the deep reduction policy (S9-DEEP). A carbon charge that rises to \$300/tonne CO_2e reduces emissions by 44% below 2005 levels, or 26% below 1990 levels. In other words, this policy still does not reduce emissions by 50% relative to 2005 levels by 2050. Source: Historic data are from Environment Canada, 2007, "Greenhouse Gas Inventory".

Table 20 shows that in 2050 in the deep reduction scenario, 91% of the greenhouse gas emissions that remain are from four sectors –crude oil, natural gas, electricity generation, and transportation.

Figure 46: GHG emissions in the deep reduction scenario, excluding emissions from agrosystems and waste



Source: Historic data are from Environment Canada, 2007, "Greenhouse Gas Inventory".

Table 20: Carbon charge and GHG emissions in the S9-DEEP scenario

	2020	*2030*	*2040*	*2050*
Carbon Charge (2003\$/tonne CO_2e)	\$100	\$300	\$300	\$300
Alberta Total Emissions (Mt CO_2e)	189	140	114	115
Demand Sectors				
Residential	7	4	2	1
Commercial	5	4	2	1
Transportation	29	20	15	15
Manufacturing Industry	14	10	7	5
Supply Sectors				
Crude Oil	68	59	54	61
Natural Gas	28	19	14	12
Coal Mining	1	1	1	1
Electricity Generation	30	19	16	18
Petroleum Refining	6	5	2	2
Ethanol	0	0	0	0

In each of these sectors, low emissions technologies have fully penetrated the market, however some emissions remain unabated for several reasons:

- **The expected economic growth from 2005 to 2050 makes a 50% reduction target difficult to attain.** Greenhouse gas emissions are expected to almost double between 2005 and 2050, if no additional policies are implemented. Therefore, greenhouse gas intensity would have to decline substantially to maintain emissions in 2050 at their 2005 levels. Greenhouse gas intensity would have to decline even more dramatically to attain a deep (50%) reduction in emissions.
- **Carbon capture and storage only reduces greenhouse gas emissions by 85% in comparison to an equivalent technology.** In the crude oil, natural gas, and electricity sectors, carbon capture and storage becomes widely adopted in the deep reduction scenario; however, these technologies still emit a small amount of greenhouse gas emissions. A large portion of the emissions that remain at the end of S9-DEEP are unabated emissions from technologies that employ carbon capture and storage. It is possible that the capture rate from carbon capture technologies will improve beyond the 85% that is modelled in CIMS, which would further reduce emissions.
- **There may be technical limits to abatement in the crude oil and natural gas sectors.** While there are many opportunities for abating greenhouse gas emissions in these sectors, some emissions may lack abatement options. For example, the oil sands exposed during mining operations emit a large amount of methane emissions, for which we do not foresee an abatement option. Therefore, we assume that a minimum amount of emissions will occur as long as there is activity in the sector. It is possible that new technologies or processes will be developed to reduce these emissions, which are not currently included in the CIMS model.
- **There may be technical limits to abatement in the transportation sector.** In 2050, CIMS simulates a relatively full penetration of low emissions technologies in the transportation sector. For example, hybrid and plug-in hybrid vehicles account for the majority of the stock of passenger vehicles in 2050. However, many of these technologies still produce a small amount of emissions (hybrid vehicles still consume some fossil fuel).
- **CIMS may lack abatement options that emerge in response to a strong carbon charge**. CIMS has a detailed representation of individual technologies, but it is limited to technologies that are presently available, or technologies that currently exist and may be commercialized in the foreseeable future (e.g., carbon capture and storage or electric cars). It does not include technologies that may be invented in response to a policy. For example, carbon capture and storage as currently planned reduces emissions by approximately 85%, but it is possible that methods to improve capture efficiency could be developed if a strong signal is

sent to emitters. Additionally, innovative ways to capture or prevent the methane emissions from exposed oil sands may emerge if a strong policy were levied; producers could also decide to only extract bitumen using in-situ methods, with much lower fugitive emissions.

Figure 47 shows the wedge diagram for the deep reduction policy. Carbon capture and storage plays a dominant role in reducing emissions, while fuel switching and energy efficiency measures account for approximately 25% of the total reductions.

Figure 47: GHG reduction wedge diagram for S9-DEEP

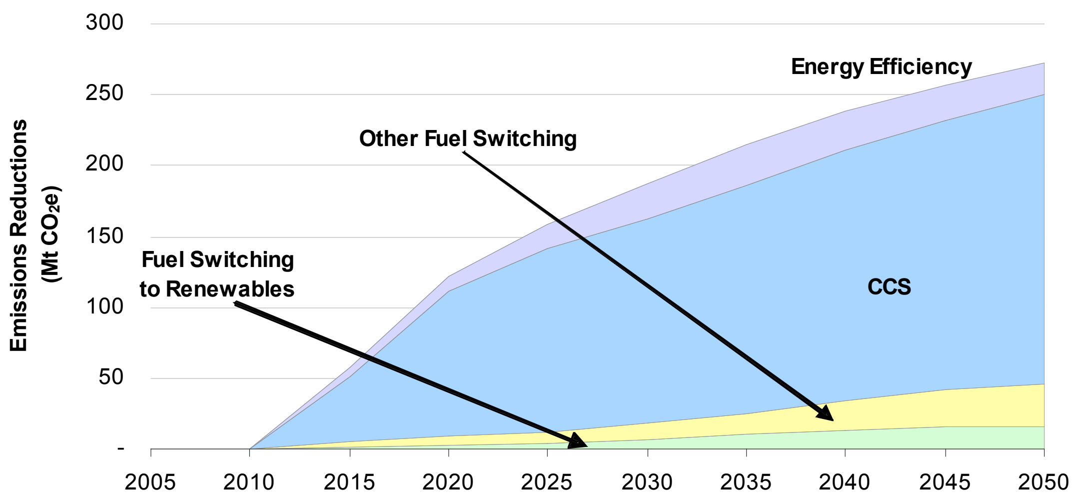


Table 21 shows the projected impact of S9-DEEP on the gross domestic product of Alberta's energy supply and demand sectors.

Table 21: Estimated effect of S9-DEEP on gross domestic product in sectors covered by CIMS (millions of $2003)

	S9-DEEP	
	2025	***2050***
Total GDP Change	988	6,585
Percent GDP Change	0.40%	1.71%
Demand Sectors		
Residential	116	39
Commercial	-21	112
Transportation	-2,435	-1,382
Manufacturing Industry	69	103
Supply Sectors		
Crude Oil	-1,879	-6,906
Natural Gas	-80	66
Coal Mining	-2	-4
Electricity Generation	5,328	14,444
Petroleum Refining	-127	-313
Ethanol	20	425

The economic impacts of S9-DEEP are generally similar to the impacts of the other carbon charges, except the impacts are stronger. Again we reiterate that CIMS is not a full equilibrium model, with full modelling of labour and capital markets and structural shifts in non-energy intensive sectors. In order to accurately estimate the impact on GDP, it would be necessary to account for the policy's effects on all markets and sectors of the economy.

Appendix A – CIMS model description

Introduction to the CIMS model

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

CIMS simulations reflect the energy, economic and physical output, GHG emissions, and CAC emissions from its sub-models as shown in Table 22. CIMS does not include agricultural land-use, the waste sector, solvent, or hydrofluorocarbon (HFC) emissions. As a result, the GHG emissions in CIMS represent only about 80% of the Canadian total (about 82% of the Alberta total). CIMS covers nearly all CAC emissions in Canada except those from open sources (like forest fires, soils, and dust from roads).

Table 22: Sector Sub-models in CIMS

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

* Metal smelting includes Aluminium.

Model structure and simulation of capital stock turnover

As a technology vintage model, CIMS tracks the evolution of capital stocks over time through retirements, retrofits, and new purchases, in which consumers and businesses make sequential acquisitions with limited foresight about the future. This is particularly important for understanding the implications of alternative time paths for emissions reductions. The model calculates energy costs (and emissions) for each energy service in the economy, such as heated commercial floor space or person kilometres travelled. In each time period, capital stocks are retired according to an age-dependent function (although retrofit of un-retired stocks is possible if warranted by changing economic conditions), and demand for new stocks grows or declines depending on the initial exogenous forecast of economic output, and then the subsequent interplay of energy supply-demand with the macroeconomic module. A model simulation iterates between energy supply-demand and the macroeconomic module until energy price changes fall below a threshold value, and repeats this convergence procedure in each subsequent five-year period of a complete run.

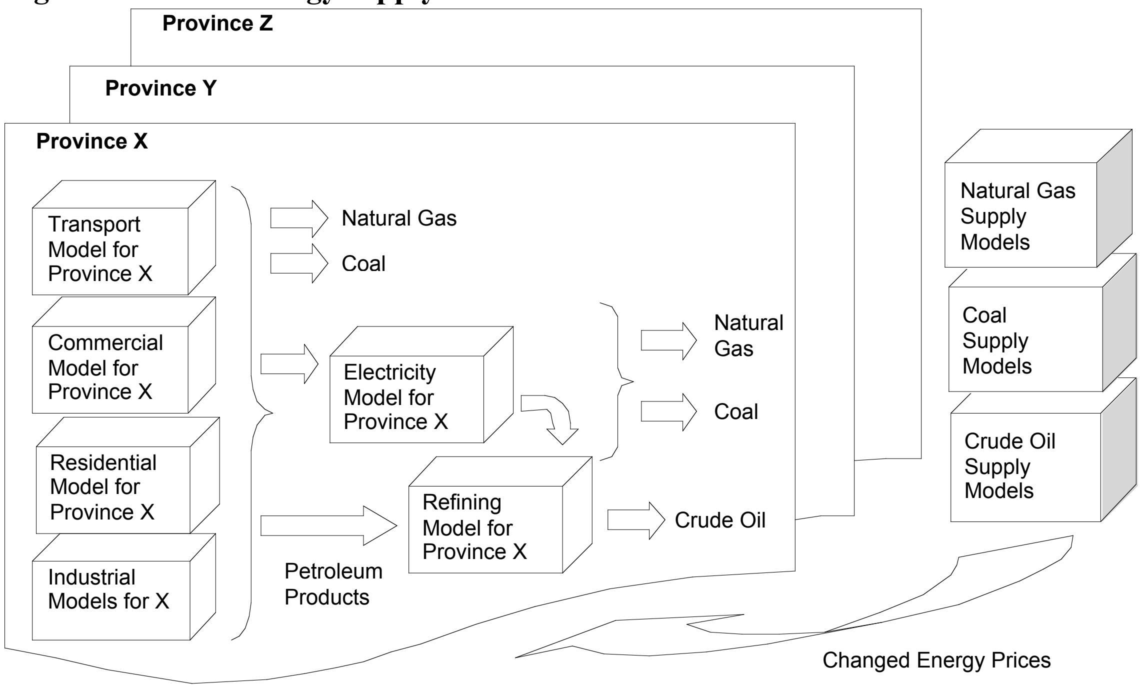
CIMS simulates the competition of technologies at each energy service node in the economy based on a comparison of their life cycle cost (LCC) and some technology-specific controls, such as a maximum market share limit in the cases where a technology is constrained by physical, technical or regulatory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

Equilibrium feedbacks in CIMS

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

CIMS estimates the effect of a policy by comparing a business-as-usual forecast to one where the policy is added to the simulation. The model solves for the policy effect in two phases in each run period. In the first phase, an energy policy (e.g., ranging from a national emissions price to a technology specific constraint or subsidy, or some combination thereof) is first applied to the final goods and services production side of the economy, where goods and services producers and consumers choose capital stocks based on CIMS' technological choice functions. Based on this initial run, the model then calculates the demand for electricity, refined petroleum products and primary energy commodities, and calculates their cost of production. If the price of any of these commodities has changed by a threshold amount from the business-as-usual case, then supply and demand are considered to be out of equilibrium, and the model is re-run based on prices calculated from the new costs of production. The model will re-run until a new equilibrium set of energy prices and demands is reached. Figure 48 provides a schematic of this process. For this project, while the quantities produced of all energy commodities were set endogenously using demand and supply balancing, endogenous pricing was used only for electricity and refined petroleum products; natural gas, crude oil and coal prices remained at exogenously forecast levels (described later in this section), since Canada is assumed to be a price-taker for these fuels.

Figure 48: CIMS energy supply and demand flow model



In the second phase, once a new set of energy prices and demands under policy has been found, the model measures how the cost of producing traded goods and services has changed given the new energy prices and other effects of the policy. For internationally traded goods, such as lumber and passenger vehicles, CIMS adjusts demand using price elasticities that provide a long-run demand response that blends domestic and international demand for these goods (the "Armington" specification).[29] Freight transportation is driven by changes in the combined value added of the industrial sectors, while personal transportation is adjusted using a personal kilometres-travelled elasticity (-0.02). Residential and commercial floor space is adjusted by a sequential substitution of home energy consumption vs. other goods (0.5), consumption vs. savings (1.29) and goods vs. leisure (0.82). If demand for any good or service has shifted more than a threshold amount, supply and demand are considered to be out of balance and the model re-runs using these new demands. The model continues re-running until both energy and goods and services supply and demand come into balance, and repeats this balancing procedure in each subsequent five-year period of a complete run.

Empirical basis of parameter values

Technical and market literature provide the conventional bottom-up data on the costs and energy efficiency of new technologies. Because there are few detailed surveys of the annual energy consumption of the individual capital stocks tracked by the model (especially smaller units), these must be estimated from surveys at different levels of

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

technological detail and by calibrating the model's simulated energy consumption to real-world aggregate data for a base year.

Fuel-based GHGs emissions are calculated directly from CIMS' estimates of fuel consumption and the GHG coefficient of the fuel type. Process-based GHGs emissions are estimated based on technological performance or chemical stoichiometric proportions. CIMS tracks the emissions of all types of GHGs, and reports these emissions in terms of carbon dioxide equivalents.[30]

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

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

Simulating endogenous technological change with CIMS

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

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

Appendix B – Detailed quantitative results

Reference Case

	2020	2030	2040	2050
Carbon Charges (2003\$/tonne CO_2e) [1]	\$15	\$15	\$15	\$15

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	311	328	353	387
Demand Sectors				
Residential	9	9	8	6
Commercial	6	7	7	6
Transportation	35	41	47	49
Manufacturing Industry	19	21	21	21
Supply Sectors				
Crude Oil	159	174	189	208
Natural Gas	32	25	19	15
Coal Mining	1	1	1	2
Electricity Generation	43	43	48	65
Petroleum Refining	7	9	12	15
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,058	4,357	4,687	5,106
Demand Sectors				
Residential	206	211	204	176
Commercial	178	208	241	267
Transportation	491	565	649	693
Manufacturing Industry	335	381	407	429
Supply Sectors				
Crude Oil	1,848	2,024	2,124	2,252
Natural Gas	330	248	200	159
Coal Mining	11	11	12	15
Electricity Generation	538	554	642	861
Petroleum Refining	122	156	207	253
Ethanol	1	1	1	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,953	1,975	1,740	1,316
Coal	801	835	926	1,167
Petroleum Products	1,001	1,198	1,588	2,042
Electricity	188	211	256	355
Renewable	66	85	119	164
Other	50	54	58	63

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	0	0	0	0

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.51	0.45	0.39	0.30
Space Heating (t CO_2e/m^2 floorspace)	0.024	0.021	0.018	0.011
Hot Water Heating (GJ/household)	46	44	40	33
Hot Water Heating (t CO_2e/household)	2.3	2.2	1.9	1.4
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.6	13.4
Annual Energy Costs (2003$/household) [2]	$1,665	$1,790	$1,901	$1,859
Natural Gas Price (2003$/GJ) [2]	$9.10	$11.27	$13.95	$17.27
Electricity Price (2003¢/kWh) [2]	9.2	9.3	9.4	9.3
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.64	1.59	1.53	1.43
GHG Intensity (t CO_2e/m^2 floorspace)	0.06	0.05	0.05	0.03
Transportation				
Personal Energy Intensity (MJ/pkt)	2.03	1.94	1.86	1.68
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.14	0.13	0.11
Vehicle Energy Intensity (MJ/vkt)	3.40	3.31	3.23	2.85
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.23	0.19
Freight Energy Intensity (MJ/tkt)	1.01	0.98	0.98	0.91
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.07	0.07	0.07
Annual Vehicle Fuel Costs (2003$/vehicle) [2]	$1,301	$1,264	$1,236	$1,115
Gasoline Price (2003¢/L) [2]	64.0	64.0	64.0	64.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.65	2.44	2.33	2.30
GHG Intensity (t CO_2e/GJ Electricity)	0.21	0.19	0.17	0.17
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.33	6.96	6.42	6.13
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.61	0.59	0.56	0.56

[1] Represents the shadow price on greenhouse gas emissions in the specified gas emitters framework.
[2] Represents the absolute cost or price, whereas the subsequent tables represents an increase over the reference case.

P1-F15

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e)	$15	$15	$15	$15

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	309	325	349	383
Demand Sectors				
Residential	8	8	8	5
Commercial	6	7	7	6
Transportation	35	39	45	47
Manufacturing Industry	18	20	20	21
Supply Sectors				
Crude Oil	158	172	187	206
Natural Gas	32	24	19	15
Coal Mining	1	1	1	2
Electricity Generation	43	44	50	67
Petroleum Refining	7	9	12	15
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,053	4,336	4,665	5,086
Demand Sectors				
Residential	204	207	198	170
Commercial	177	205	237	263
Transportation	485	543	624	665
Manufacturing Industry	336	381	408	430
Supply Sectors				
Crude Oil	1,845	2,021	2,121	2,248
Natural Gas	329	246	197	157
Coal Mining	11	11	12	15
Electricity Generation	546	567	664	889
Petroleum Refining	121	153	203	248
Ethanol	1	1	0	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,957	1,981	1,749	1,322
Coal	804	840	937	1,183
Petroleum Products	981	1,151	1,525	1,978
Electricity	191	216	265	366
Renewable	71	95	131	174
Other	50	54	58	63

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	-315	-180	-91	-176

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.50	0.44	0.37	0.28
Space Heating (t CO_2e/m^2 floorspace)	0.024	0.020	0.016	0.010
Hot Water Heating (GJ/household)	45	43	39	32
Hot Water Heating (t CO_2e/household)	2.2	2.1	1.9	1.3
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.6	13.4
Increase in Annual Energy Costs (2003$/household) [1]	$5	-$9	-$20	-$30
Increase in Natural Gas Price (2003$/GJ) [1]	$0.75	$0.75	$0.75	$0.75
Increase in Electricity Price (2003¢/kWh) [1]	0.1	0.1	0.0	0.0
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.62	1.58	1.51	1.41
GHG Intensity (t CO_2e/m^2 floorspace)	0.06	0.05	0.04	0.03
Transportation				
Personal Energy Intensity (MJ/pkt)	2.01	1.92	1.84	1.63
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.14	0.13	0.11
Vehicle Energy Intensity (MJ/vkt)	3.39	3.28	3.19	2.76
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.23	0.18
Freight Energy Intensity (MJ/tkt)	0.99	0.92	0.92	0.86
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.07	0.07	0.06
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [1]	-$6	-$12	-$13	-$30
Increase in Gasoline Price (2003¢/L) [1]	3.7	3.7	3.7	3.7
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.64	2.43	2.33	2.30
GHG Intensity (t CO_2e/GJ Electricity)	0.21	0.19	0.17	0.17
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.32	6.95	6.41	6.13
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.61	0.58	0.56	0.55
Increase in Cost of Oil Sands Production (2003$/barrel) [1]	0.00	0.03	0.09	0.14
Increase in Cost of Gas Production (2003$/GJ) [1]	0.00	0.01	0.01	0.01

[1] Represents an increase over the reference case.

P2-F30

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e)	$30	$30	$30	$30

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	304	315	334	363
Demand Sectors				
Residential	8	8	7	5
Commercial	6	7	7	5
Transportation	34	38	43	42
Manufacturing Industry	18	19	19	20
Supply Sectors				
Crude Oil	155	168	180	197
Natural Gas	32	24	19	15
Coal Mining	1	1	1	2
Electricity Generation	43	42	47	63
Petroleum Refining	7	9	12	14
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,041	4,309	4,640	5,033
Demand Sectors				
Residential	203	203	192	163
Commercial	175	203	233	259
Transportation	480	526	602	609
Manufacturing Industry	336	382	409	431
Supply Sectors				
Crude Oil	1,837	2,010	2,108	2,238
Natural Gas	327	244	193	154
Coal Mining	11	11	12	15
Electricity Generation	552	578	688	923
Petroleum Refining	120	151	200	240
Ethanol	1	1	0	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,981	2,029	1,828	1,405
Coal	789	812	905	1,155
Petroleum Products	947	1,081	1,420	1,833
Electricity	196	225	281	385
Renewable	79	108	148	193
Other	50	54	58	63

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	-152	-425	-327	-318

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.50	0.43	0.36	0.27
Space Heating (t CO_2e/m^2 floorspace)	0.024	0.020	0.015	0.008
Hot Water Heating (GJ/household)	45	43	39	31
Hot Water Heating (t CO_2e/household)	2.2	2.1	1.8	1.2
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.6	13.4
Increase in Annual Energy Costs (2003$/household) [1]	$91	$56	$24	-$15
Increase in Natural Gas Price (2003$/GJ) [1]	$1.50	$1.50	$1.50	$1.50
Increase in Electricity Price (2003¢/kWh) [1]	0.2	0.3	0.3	0.3
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.61	1.56	1.48	1.39
GHG Intensity (t CO_2e/m^2 floorspace)	0.05	0.05	0.04	0.03
Transportation				
Personal Energy Intensity (MJ/pkt)	2.00	1.90	1.82	1.58
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.13	0.13	0.10
Vehicle Energy Intensity (MJ/vkt)	3.37	3.25	3.16	2.68
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.22	0.17
Freight Energy Intensity (MJ/tkt)	0.98	0.88	0.87	0.77
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.06	0.06	0.06
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [1]	$60	$45	$40	-$3
Increase in Gasoline Price (2003¢/L) [1]	7.5	7.5	7.5	7.5
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.61	2.38	2.28	2.26
GHG Intensity (t CO_2e/GJ Electricity)	0.20	0.17	0.16	0.15
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.29	6.93	6.39	6.12
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.60	0.57	0.53	0.53
Increase in Cost of Oil Sands Production (2003$/barrel) [1]	0.04	0.20	0.47	0.67
Increase in Cost of Gas Production (2003$/GJ) [1]	0.01	0.02	0.03	0.04

[1] Represents an increase over the reference case.

P3-F60

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e)	$60	$60	$60	$60

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	291	286	289	311
Demand Sectors				
Residential	8	8	6	4
Commercial	6	6	6	5
Transportation	34	35	38	37
Manufacturing Industry	17	17	17	18
Supply Sectors				
Crude Oil	147	150	152	169
Natural Gas	31	23	18	14
Coal Mining	1	1	1	2
Electricity Generation	41	38	40	50
Petroleum Refining	7	8	11	13
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,031	4,293	4,637	5,094
Demand Sectors				
Residential	199	195	181	152
Commercial	173	199	226	253
Transportation	469	495	539	548
Manufacturing Industry	337	385	413	434
Supply Sectors				
Crude Oil	1,823	1,996	2,100	2,243
Natural Gas	323	237	187	150
Coal Mining	11	11	12	15
Electricity Generation	577	628	787	1,069
Petroleum Refining	119	147	191	231
Ethanol	1	1	1	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	2,005	2,098	1,991	1,619
Coal	776	789	891	1,169
Petroleum Products	900	975	1,206	1,600
Electricity	208	247	318	428
Renewable	93	130	172	214
Other	50	54	58	63

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	-124	-508	-278	-552

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.49	0.41	0.33	0.24
Space Heating (t CO_2e/m^2 floorspace)	0.023	0.018	0.013	0.006
Hot Water Heating (GJ/household)	44	42	37	30
Hot Water Heating (t CO_2e/household)	2.2	2.0	1.7	1.1
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.5	13.3
Increase in Annual Energy Costs (2003$/household) [1]	$263	$180	$106	$19
Increase in Natural Gas Price (2003$/GJ) [1]	$3.00	$3.00	$3.00	$3.00
Increase in Electricity Price (2003¢/kWh) [1]	0.6	0.8	0.9	0.9
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.59	1.53	1.44	1.36
GHG Intensity (t CO_2e/m^2 floorspace)	0.05	0.05	0.04	0.03
Transportation				
Personal Energy Intensity (MJ/pkt)	1.97	1.86	1.75	1.52
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.13	0.12	0.10
Vehicle Energy Intensity (MJ/vkt)	3.34	3.19	3.08	2.57
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.21	0.16
Freight Energy Intensity (MJ/tkt)	0.95	0.80	0.74	0.65
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.06	0.05	0.05
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [1]	$190	$158	$140	$68
Increase in Gasoline Price (2003¢/L) [1]	15.0	15.0	15.0	15.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.57	2.35	2.29	2.34
GHG Intensity (t CO_2e/GJ Electricity)	0.18	0.14	0.12	0.11
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.27	6.95	6.46	6.22
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.56	0.50	0.45	0.45
Increase in Cost of Oil Sands Production (2003$/barrel) [1]	0.45	1.22	2.05	2.58
Increase in Cost of Gas Production (2003$/GJ) [1]	0.03	0.07	0.09	0.11

[1] Represents an increase over the reference case.

P4-F100

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e)	$100	$100	$100	$100

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	255	226	217	235
Demand Sectors				
Residential	8	7	5	3
Commercial	5	6	5	4
Transportation	32	32	33	33
Manufacturing Industry	16	15	14	14
Supply Sectors				
Crude Oil	121	106	102	119
Natural Gas	30	22	16	13
Coal Mining	1	1	1	2
Electricity Generation	35	29	30	35
Petroleum Refining	7	8	10	12
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,079	4,393	4,840	5,450
Demand Sectors				
Residential	193	185	169	140
Commercial	171	194	220	242
Transportation	453	453	478	509
Manufacturing Industry	338	389	418	441
Supply Sectors				
Crude Oil	1,840	2,042	2,181	2,339
Natural Gas	318	230	180	145
Coal Mining	11	11	12	15
Electricity Generation	640	749	999	1,392
Petroleum Refining	117	141	184	226
Ethanol	1	1	1	1

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	2,041	2,194	2,237	1,911
Coal	794	835	984	1,338
Petroleum Products	860	872	979	1,377
Electricity	227	284	381	515
Renewable	107	155	200	247
Other	50	54	59	64

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	280	372	262	908

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.47	0.38	0.30	0.21
Space Heating (t CO_2e/m^2 floorspace)	0.022	0.016	0.010	0.004
Hot Water Heating (GJ/household)	44	40	35	28
Hot Water Heating (t CO_2e/household)	2.1	1.9	1.5	1.0
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	14.9	14.4	13.1
Increase in Annual Energy Costs (2003$/household) [1]	$495	$341	$199	$43
Increase in Natural Gas Price (2003$/GJ) [1]	$5.01	$5.01	$5.01	$5.01
Increase in Electricity Price (2003¢/kWh) [1]	1.6	1.7	1.6	1.6
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.57	1.49	1.40	1.30
GHG Intensity (t CO_2e/m^2 floorspace)	0.05	0.04	0.03	0.02
Transportation				
Personal Energy Intensity (MJ/pkt)	1.92	1.80	1.67	1.43
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.13	0.11	0.09
Vehicle Energy Intensity (MJ/vkt)	3.31	3.12	2.94	2.40
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.23	0.22	0.20	0.14
Freight Energy Intensity (MJ/tkt)	0.91	0.70	0.62	0.60
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.05	0.04	0.04
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [1]	$360	$302	$251	$146
Increase in Gasoline Price (2003¢/L) [1]	25.0	25.0	25.0	25.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.58	2.41	2.40	2.52
GHG Intensity (t CO_2e/GJ Electricity)	0.14	0.09	0.07	0.06
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.41	7.21	6.81	6.58
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.47	0.37	0.31	0.33
Increase in Cost of Oil Sands Production (2003$/barrel) [1]	1.66	3.08	4.04	4.34
Increase in Cost of Gas Production (2003$/GJ) [1]	0.07	0.12	0.15	0.18

[1] Represents an increase over the reference case.

P5-Ea

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e)	$30	$60	$60	$100

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	302	297	288	279
Demand Sectors				
Residential	8	8	6	4
Commercial	6	6	6	4
Transportation	34	37	39	36
Manufacturing Industry	18	18	17	16
Supply Sectors				
Crude Oil	154	156	149	146
Natural Gas	32	23	18	14
Coal Mining	1	1	1	2
Electricity Generation	42	39	40	44
Petroleum Refining	7	9	11	13
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,037	4,307	4,684	5,296
Demand Sectors				
Residential	203	200	182	148
Commercial	175	201	227	251
Transportation	480	514	559	535
Manufacturing Industry	337	383	412	436
Supply Sectors				
Crude Oil	1,835	2,004	2,106	2,269
Natural Gas	327	240	188	148
Coal Mining	11	11	12	15
Electricity Generation	549	605	804	1,265
Petroleum Refining	120	149	194	229
Ethanol	1	1	1	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,984	2,068	1,986	1,726
Coal	781	795	909	1,285
Petroleum Products	942	1,028	1,227	1,493
Electricity	197	239	326	489
Renewable	83	122	178	239
Other	50	54	59	64

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	-104	-348	158	410

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.50	0.41	0.33	0.23
Space Heating (t CO_2e/m^2 floorspace)	0.023	0.019	0.013	0.006
Hot Water Heating (GJ/household)	45	42	37	29
Hot Water Heating (t CO_2e/household)	2.2	2.1	1.7	1.0
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.5	13.3
Increase in Annual Energy Costs (2003$/household) [1]	$93	$202	$120	$96
Increase in Natural Gas Price (2003$/GJ) [1]	$1.50	$3.00	$3.00	$5.01
Increase in Electricity Price (2003¢/kWh) [1]	0.3	0.6	0.9	1.2
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.61	1.54	1.45	1.35
GHG Intensity (t CO_2e/m^2 floorspace)	0.05	0.05	0.04	0.02
Transportation				
Personal Energy Intensity (MJ/pkt)	2.00	1.88	1.76	1.50
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.13	0.12	0.10
Vehicle Energy Intensity (MJ/vkt)	3.37	3.22	3.08	2.54
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.22	0.16
Freight Energy Intensity (MJ/tkt)	0.98	0.85	0.79	0.63
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.06	0.06	0.05
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [1]	$59	$170	$142	$188
Increase in Gasoline Price (2003¢/L) [1]	7.5	15.0	15.0	25.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.58	2.34	2.28	2.42
GHG Intensity (t CO_2e/GJ Electricity)	0.20	0.15	0.11	0.08
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.29	6.96	6.50	6.34
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.59	0.52	0.44	0.39
Increase in Cost of Oil Sands Production (2003$/barrel) [1]	0.15	1.03	2.35	3.68
Increase in Cost of Gas Production (2003$/GJ) [1]	0.01	0.05	0.07	0.09

[1] Represents an increase over the reference case.

P6-Eb

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e)	$40	$60	$80	$100

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	296	284	264	260
Demand Sectors				
Residential	8	8	6	3
Commercial	6	6	5	4
Transportation	34	36	37	35
Manufacturing Industry	17	17	17	15
Supply Sectors				
Crude Oil	150	147	133	134
Natural Gas	31	23	17	14
Coal Mining	1	1	1	2
Electricity Generation	41	37	36	41
Petroleum Refining	7	8	11	12
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,032	4,304	4,731	5,369
Demand Sectors				
Residential	201	197	177	144
Commercial	174	200	225	248
Transportation	475	502	528	516
Manufacturing Industry	338	385	414	438
Supply Sectors				
Crude Oil	1,828	1,999	2,121	2,292
Natural Gas	325	238	186	147
Coal Mining	11	11	12	15
Electricity Generation	560	626	879	1,342
Petroleum Refining	120	147	190	226
Ethanol	1	1	1	1

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,995	2,095	2,070	1,818
Coal	776	791	935	1,319
Petroleum Products	921	987	1,132	1,413
Electricity	202	247	349	509
Renewable	88	130	186	245
Other	50	54	59	64

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	-355	9	175	603

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.49	0.41	0.31	0.22
Space Heating (t CO_2e/m^2 floorspace)	0.023	0.018	0.012	0.005
Hot Water Heating (GJ/household)	45	42	37	28
Hot Water Heating (t CO_2e/household)	2.2	2.0	1.6	1.0
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.5	13.2
Increase in Annual Energy Costs (2003$/household) [1]	$152	$196	$175	$70
Increase in Natural Gas Price (2003$/GJ) [1]	$2.00	$3.00	$4.01	$5.01
Increase in Electricity Price (2003¢/kWh) [1]	0.4	0.8	1.2	1.4
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.60	1.53	1.43	1.33
GHG Intensity (t CO_2e/m^2 floorspace)	0.05	0.05	0.03	0.02
Transportation				
Personal Energy Intensity (MJ/pkt)	1.99	1.86	1.73	1.48
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.13	0.12	0.09
Vehicle Energy Intensity (MJ/vkt)	3.36	3.20	3.04	2.49
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.21	0.15
Freight Energy Intensity (MJ/tkt)	0.97	0.82	0.72	0.60
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.06	0.05	0.04
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [1]	$102	$161	$211	$175
Increase in Gasoline Price (2003¢/L) [1]	10.0	15.0	20.0	25.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.57	2.34	2.32	2.46
GHG Intensity (t CO_2e/GJ Electricity)	0.19	0.14	0.10	0.07
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.28	6.97	6.58	6.43
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.58	0.49	0.39	0.36
Increase in Cost of Oil Sands Production (2003$/barrel) [1]	0.32	1.49	3.13	4.23
Increase in Cost of Gas Production (2003$/GJ) [1]	0.02	0.06	0.09	0.12

[1] Represents an increase over the reference case.

P7-Ec

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e)	$75	$150	$200	$200

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	246	182	153	147
Demand Sectors				
Residential	8	7	4	2
Commercial	6	5	4	2
Transportation	33	30	27	23
Manufacturing Industry	16	13	10	8
Supply Sectors				
Crude Oil	112	73	63	68
Natural Gas	30	21	15	12
Coal Mining	1	1	1	1
Electricity Generation	34	26	23	25
Petroleum Refining	7	7	6	5
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,096	4,555	5,237	6,197
Demand Sectors				
Residential	195	179	147	122
Commercial	171	190	205	219
Transportation	458	433	419	434
Manufacturing Industry	340	392	427	457
Supply Sectors				
Crude Oil	1,853	2,118	2,300	2,526
Natural Gas	317	225	174	140
Coal Mining	11	11	12	15
Electricity Generation	633	866	1,366	2,053
Petroleum Refining	117	140	185	229
Ethanol	1	1	1	2

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	2,052	2,291	2,411	2,127
Coal	792	869	1,124	1,670
Petroleum Products	868	837	873	1,244
Electricity	225	330	514	735
Renewable	108	172	251	352
Other	50	56	63	70

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	128	916	2,587	5,146

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.48	0.36	0.25	0.18
Space Heating (t CO_2e/m^2 floorspace)	0.022	0.015	0.006	0.002
Hot Water Heating (GJ/household)	45	40	30	24
Hot Water Heating (t CO_2e/household)	2.2	1.8	1.1	0.6
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	14.9	14.3	12.9
Increase in Annual Energy Costs (2003$/household) [1]	$376	$570	$358	$44
Increase in Natural Gas Price (2003$/GJ) [1]	$3.76	$7.51	$10.01	$10.01
Increase in Electricity Price (2003¢/kWh) [1]	1.7	2.4	2.3	2.2
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.58	1.46	1.31	1.17
GHG Intensity (t CO_2e/m^2 floorspace)	0.05	0.04	0.02	0.01
Transportation				
Personal Energy Intensity (MJ/pkt)	1.93	1.74	1.53	1.30
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.12	0.10	0.07
Vehicle Energy Intensity (MJ/vkt)	3.32	3.07	2.70	2.12
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.22	0.18	0.10
Freight Energy Intensity (MJ/tkt)	0.92	0.66	0.51	0.48
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.05	0.03	0.03
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [1]	$249	$490	$502	$260
Increase in Gasoline Price (2003¢/L) [1]	18.7	37.5	49.9	49.9
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.57	2.39	2.42	2.57
GHG Intensity (t CO_2e/GJ Electricity)	0.14	0.07	0.04	0.03
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.47	7.49	7.16	7.07
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.45	0.28	0.22	0.21
Increase in Cost of Oil Sands Production (2003$/barrel) [1]	2.10	4.30	4.96	5.12
Increase in Cost of Gas Production (2003$/GJ) [1]	0.08	0.17	0.22	0.26

[1] Represents an increase over the reference case.

S1-EaCCS

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e)	$30	$60	$60	$100

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	260	235	203	184
Demand Sectors				
Residential	8	8	7	4
Commercial	6	7	7	6
Transportation	34	37	39	36
Manufacturing Industry	16	12	9	6
Supply Sectors				
Crude Oil	121	116	101	100
Natural Gas	31	23	17	14
Coal Mining	1	1	1	2
Electricity Generation	36	26	18	14
Petroleum Refining	6	5	4	3
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,237	4,667	5,372	6,170
Demand Sectors				
Residential	202	200	186	151
Commercial	176	204	234	257
Transportation	479	510	556	533
Manufacturing Industry	343	402	439	468
Supply Sectors				
Crude Oil	1,922	2,126	2,305	2,492
Natural Gas	327	242	190	150
Coal Mining	11	11	12	15
Electricity Generation	653	809	1,224	1,836
Petroleum Refining	125	164	225	269
Ethanol	1	1	1	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	2,089	2,233	2,202	1,903
Coal	855	940	1,234	1,770
Petroleum Products	935	1,030	1,276	1,580
Electricity	217	272	395	580
Renewable	91	137	206	272
Other	50	54	59	65

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	502	1,431	2,943	4,244

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.50	0.42	0.34	0.24
Space Heating (t CO_2e/m^2 floorspace)	0.024	0.020	0.015	0.007
Hot Water Heating (GJ/household)	45	43	38	30
Hot Water Heating (t CO_2e/household)	2.3	2.1	1.8	1.2
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.4	13.1
Increase in Annual Energy Costs (2003$/household) [1]	$150	$230	$176	$176
Increase in Natural Gas Price (2003$/GJ) [1]	$1.50	$3.00	$3.00	$5.01
Increase in Electricity Price (2003¢/kWh) [1]	1.6	2.0	2.1	2.0
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.62	1.57	1.49	1.38
GHG Intensity (t CO_2e/m^2 floorspace)	0.06	0.05	0.04	0.03
Transportation				
Personal Energy Intensity (MJ/pkt)	2.00	1.88	1.76	1.51
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.13	0.12	0.10
Vehicle Energy Intensity (MJ/vkt)	3.37	3.22	3.09	2.56
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.22	0.16
Freight Energy Intensity (MJ/tkt)	0.98	0.85	0.79	0.64
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.06	0.06	0.05
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [1]	$60	$170	$147	$207
Increase in Gasoline Price (2003¢/L) [1]	7.5	15.0	15.0	25.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.64	2.55	2.64	2.79
GHG Intensity (t CO_2e/GJ Electricity)	0.15	0.08	0.04	0.02
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.78	7.50	7.18	7.01
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.46	0.38	0.29	0.26
Increase in Cost of Oil Sands Production (2003$/barrel) [1]	0.74	1.29	2.15	2.62
Increase in Cost of Gas Production (2003$/GJ) [1]	0.03	0.06	0.09	0.11

[1] Represents an increase over the reference case.

S2-CCS

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e) [1]	$15	$15	$15	$15

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	265	250	228	214
Demand Sectors				
Residential	9	9	9	7
Commercial	6	8	9	9
Transportation	35	40	46	49
Manufacturing Industry	16	14	11	8
Supply Sectors				
Crude Oil	124	123	112	109
Natural Gas	32	24	19	15
Coal Mining	1	1	1	2
Electricity Generation	36	27	18	12
Petroleum Refining	6	5	4	4
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,252	4,704	5,403	6,107
Demand Sectors				
Residential	204	209	206	186
Commercial	179	211	248	279
Transportation	489	558	644	686
Manufacturing Industry	341	400	438	468
Supply Sectors				
Crude Oil	1,934	2,140	2,322	2,503
Natural Gas	330	249	204	165
Coal Mining	11	11	12	15
Electricity Generation	638	754	1,090	1,509
Petroleum Refining	126	171	240	296
Ethanol	1	1	0	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	2,079	2,216	2,147	1,821
Coal	856	930	1,186	1,594
Petroleum Products	980	1,147	1,510	1,947
Electricity	210	248	339	462
Renewable	78	109	163	220
Other	50	54	58	63

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	629	1,284	3,316	3,864

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.51	0.45	0.40	0.33
Space Heating (t CO_2e/m^2 floorspace)	0.024	0.022	0.020	0.016
Hot Water Heating (GJ/household)	46	44	41	36
Hot Water Heating (t CO_2e/household)	2.3	2.2	2.0	1.7
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.5	13.2
Increase in Annual Energy Costs (2003$/household) [2]	$72	$38	$68	$154
Increase in Natural Gas Price (2003$/GJ) [2]	$0.00	$0.00	$0.00	$0.00
Increase in Electricity Price (2003¢/kWh) [2]	1.5	1.8	2.0	1.9
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.65	1.62	1.58	1.50
GHG Intensity (t CO_2e/m^2 floorspace)	0.06	0.06	0.05	0.05
Transportation				
Personal Energy Intensity (MJ/pkt)	2.03	1.94	1.87	1.70
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.14	0.13	0.12
Vehicle Energy Intensity (MJ/vkt)	3.40	3.31	3.23	2.91
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.24	0.23	0.20
Freight Energy Intensity (MJ/tkt)	1.01	0.98	0.98	0.91
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.07	0.07	0.07
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [2]	$0	$1	$2	$30
Increase in Gasoline Price (2003¢/L) [2]	0.0	0.0	0.0	0.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.66	2.57	2.67	2.83
GHG Intensity (t CO_2e/GJ Electricity)	0.15	0.09	0.05	0.02
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.83	7.53	7.20	7.03
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.46	0.40	0.32	0.28
Increase in Cost of Oil Sands Production (2003$/barrel) [2]	0.69	0.91	1.34	1.55
Increase in Cost of Gas Production (2003$/GJ) [2]	0.01	0.02	0.04	0.06

[1] Represents the shadow price on greenhouse gas emissions in the specified gas emitters framework.
[2] Represents an increase over the reference case.

S3-RBC

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e) [1]	$15	$15	$15	$15

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	310	328	352	387
Demand Sectors				
Residential	8	8	7	5
Commercial	6	7	7	6
Transportation	35	41	47	49
Manufacturing Industry	19	21	21	21
Supply Sectors				
Crude Oil	159	174	189	208
Natural Gas	32	25	19	15
Coal Mining	1	1	1	2
Electricity Generation	43	43	48	64
Petroleum Refining	7	9	12	15
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,055	4,351	4,679	5,095
Demand Sectors				
Residential	201	202	195	169
Commercial	178	208	241	267
Transportation	491	565	649	693
Manufacturing Industry	335	381	407	429
Supply Sectors				
Crude Oil	1,848	2,024	2,124	2,252
Natural Gas	330	248	200	159
Coal Mining	11	11	12	15
Electricity Generation	540	557	643	858
Petroleum Refining	122	156	207	253
Ethanol	1	1	1	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,948	1,967	1,732	1,311
Coal	802	836	926	1,164
Petroleum Products	1,001	1,197	1,587	2,040
Electricity	189	212	256	353
Renewable	66	85	119	164
Other	50	54	58	63

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	86	79	0	-83

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.48	0.41	0.35	0.27
Space Heating (t CO_2e/m^2 floorspace)	0.023	0.019	0.016	0.010
Hot Water Heating (GJ/household)	46	44	40	33
Hot Water Heating (t CO_2e/household)	2.3	2.2	1.9	1.4
Air Conditioning (GJ/household)	0.07	0.08	0.09	0.10
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.6	13.4
Increase in Annual Energy Costs (2003$/household) [2]	-$26	-$55	-$71	-$72
Increase in Natural Gas Price (2003$/GJ) [2]	$0.00	$0.00	$0.00	$0.00
Increase in Electricity Price (2003¢/kWh) [2]	0.0	0.0	0.0	0.0
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.64	1.59	1.53	1.43
GHG Intensity (t CO_2e/m^2 floorspace)	0.06	0.05	0.05	0.03
Transportation				
Personal Energy Intensity (MJ/pkt)	2.03	1.94	1.86	1.68
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.14	0.13	0.11
Vehicle Energy Intensity (MJ/vkt)	3.40	3.31	3.23	2.85
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.23	0.19
Freight Energy Intensity (MJ/tkt)	1.01	0.98	0.98	0.91
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.07	0.07	0.07
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [2]	$0	$0	$0	$0
Increase in Gasoline Price (2003¢/L) [2]	0.0	0.0	0.0	0.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.65	2.44	2.33	2.30
GHG Intensity (t CO_2e/GJ Electricity)	0.21	0.19	0.17	0.17
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.33	6.96	6.42	6.13
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.61	0.59	0.56	0.56
Increase in Cost of Oil Sands Production (2003$/barrel) [2]	0.00	0.00	0.00	0.00
Increase in Cost of Gas Production (2003$/GJ) [2]	0.00	0.00	0.00	0.00

[1] Represents the shadow price on greenhouse gas emissions in the specified gas emitters framework.
[2] Represents an increase over the reference case.

S4-NUC

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e) [1]	$15	$15	$15	$15

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	307	318	342	377
Demand Sectors				
Residential	9	9	8	6
Commercial	6	7	8	7
Transportation	35	41	47	49
Manufacturing Industry	19	21	21	21
Supply Sectors				
Crude Oil	159	174	189	209
Natural Gas	32	25	20	15
Coal Mining	1	1	1	2
Electricity Generation	39	32	37	53
Petroleum Refining	7	9	12	15
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,075	4,381	4,700	5,115
Demand Sectors				
Residential	206	211	204	178
Commercial	178	209	243	270
Transportation	491	565	650	694
Manufacturing Industry	335	381	408	430
Supply Sectors				
Crude Oil	1,848	2,023	2,122	2,251
Natural Gas	330	249	201	161
Coal Mining	11	11	12	15
Electricity Generation	555	577	651	864
Petroleum Refining	122	156	207	253
Ethanol	1	1	1	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,938	1,951	1,722	1,310
Coal	771	736	816	1,044
Petroleum Products	1,001	1,198	1,590	2,045
Electricity	188	203	240	336
Renewable	63	78	111	155
Other	49	53	57	61

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	357	641	529	465

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.51	0.45	0.39	0.31
Space Heating (t CO_2e/m^2 floorspace)	0.024	0.022	0.018	0.012
Hot Water Heating (GJ/household)	46	44	40	34
Hot Water Heating (t CO_2e/household)	2.3	2.2	2.0	1.4
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.6	13.4
Increase in Annual Energy Costs (2003$/household) [2]	$0	$16	$12	-$1
Increase in Natural Gas Price (2003$/GJ) [2]	$0.00	$0.00	$0.00	$0.00
Increase in Electricity Price (2003¢/kWh) [2]	0.3	0.5	0.3	0.2
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.64	1.60	1.54	1.45
GHG Intensity (t CO_2e/m^2 floorspace)	0.06	0.05	0.05	0.04
Transportation				
Personal Energy Intensity (MJ/pkt)	2.03	1.94	1.87	1.69
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.14	0.13	0.11
Vehicle Energy Intensity (MJ/vkt)	3.40	3.31	3.23	2.87
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.23	0.19
Freight Energy Intensity (MJ/tkt)	1.01	0.98	0.98	0.91
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.07	0.07	0.07
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [2]	$0	$0	$1	$6
Increase in Gasoline Price (2003¢/L) [2]	0.0	0.0	0.0	0.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.74	2.63	2.49	2.40
GHG Intensity (t CO_2e/GJ Electricity)	0.19	0.15	0.14	0.15
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.33	6.96	6.41	6.13
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.61	0.59	0.56	0.56
Increase in Cost of Oil Sands Production (2003$/barrel) [2]	0.00	0.00	-0.01	-0.01
Increase in Cost of Gas Production (2003$/GJ) [2]	0.00	0.01	0.01	0.01

[1] Represents the shadow price on greenhouse gas emissions in the specified gas emitters framework.
[2] Represents an increase over the reference case.

S5-VES

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e) [1]	$15	$15	$15	$15

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	309	325	350	385
Demand Sectors				
Residential	9	9	8	6
Commercial	6	7	7	7
Transportation	34	38	44	47
Manufacturing Industry	19	21	21	21
Supply Sectors				
Crude Oil	159	174	189	209
Natural Gas	32	25	20	15
Coal Mining	1	1	1	2
Electricity Generation	43	42	47	63
Petroleum Refining	7	9	12	15
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,038	4,314	4,642	5,063
Demand Sectors				
Residential	206	211	204	177
Commercial	178	208	242	268
Transportation	473	529	618	671
Manufacturing Industry	335	381	408	430
Supply Sectors				
Crude Oil	1,849	2,024	2,124	2,252
Natural Gas	330	248	200	160
Coal Mining	11	11	12	15
Electricity Generation	537	549	629	840
Petroleum Refining	120	152	203	250
Ethanol	1	1	1	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,960	1,977	1,744	1,320
Coal	801	831	917	1,151
Petroleum Products	975	1,157	1,553	2,021
Electricity	188	209	251	346
Renewable	66	86	119	163
Other	50	54	58	63

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	-273	-241	197	231

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.51	0.45	0.39	0.30
Space Heating (t CO_2e/m^2 floorspace)	0.024	0.021	0.018	0.012
Hot Water Heating (GJ/household)	46	44	40	34
Hot Water Heating (t CO_2e/household)	2.3	2.2	1.9	1.4
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.6	13.4
Increase in Annual Energy Costs (2003$/household) [2]	-$78	-$74	-$61	-$29
Increase in Natural Gas Price (2003$/GJ) [2]	$0.00	$0.00	$0.00	$0.00
Increase in Electricity Price (2003¢/kWh) [2]	0.0	0.0	0.0	0.0
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.64	1.60	1.53	1.44
GHG Intensity (t CO_2e/m^2 floorspace)	0.06	0.05	0.05	0.04
Transportation				
Personal Energy Intensity (MJ/pkt)	1.84	1.64	1.63	1.54
Personal Emissions Intensity (kg CO_2e/pkt)	0.13	0.12	0.11	0.10
Vehicle Energy Intensity (MJ/vkt)	3.05	2.63	2.67	2.50
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.22	0.19	0.19	0.17
Freight Energy Intensity (MJ/tkt)	1.01	0.98	0.98	0.91
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.07	0.07	0.07
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [2]	-$128	-$254	-$208	-$133
Increase in Gasoline Price (2003¢/L) [2]	0.0	0.0	0.0	0.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.66	2.44	2.33	2.30
GHG Intensity (t CO_2e/GJ Electricity)	0.21	0.19	0.17	0.17
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.34	6.96	6.42	6.13
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.61	0.59	0.56	0.56
Increase in Cost of Oil Sands Production (2003$/barrel) [2]	0.00	0.01	0.00	-0.01
Increase in Cost of Gas Production (2003$/GJ) [2]	0.00	0.00	0.00	0.01

[1] Represents the shadow price on greenhouse gas emissions in the specified gas emitters framework.
[2] Represents an increase over the reference case.

S6-LEED

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e) [1]	$15	$15	$15	$15

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	310	327	351	383
Demand Sectors				
Residential	9	9	8	6
Commercial	4	3	2	2
Transportation	35	41	47	49
Manufacturing Industry	19	21	21	21
Supply Sectors				
Crude Oil	159	174	189	209
Natural Gas	32	25	20	15
Coal Mining	1	1	1	2
Electricity Generation	44	45	51	64
Petroleum Refining	7	9	12	15
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,047	4,334	4,655	5,021
Demand Sectors				
Residential	206	211	204	178
Commercial	148	151	163	184
Transportation	493	566	651	691
Manufacturing Industry	335	381	408	430
Supply Sectors				
Crude Oil	1,849	2,024	2,124	2,251
Natural Gas	330	248	201	160
Coal Mining	11	11	12	15
Electricity Generation	554	585	686	860
Petroleum Refining	122	156	207	252
Ethanol	1	1	1	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,929	1,918	1,659	1,237
Coal	810	853	954	1,161
Petroleum Products	996	1,197	1,587	2,040
Electricity	195	224	274	355
Renewable	67	87	122	165
Other	50	54	58	63

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	341	744	1,169	1,108

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.51	0.45	0.39	0.30
Space Heating (t CO_2e/m^2 floorspace)	0.024	0.021	0.018	0.012
Hot Water Heating (GJ/household)	46	44	40	34
Hot Water Heating (t CO_2e/household)	2.3	2.2	1.9	1.4
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.6	13.4
Increase in Annual Energy Costs (2003$/household) [2]	-$73	-$75	-$62	-$28
Increase in Natural Gas Price (2003$/GJ) [2]	$0.00	$0.00	$0.00	$0.00
Increase in Electricity Price (2003¢/kWh) [2]	0.1	0.1	0.0	0.0
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.36	1.16	1.03	0.99
GHG Intensity (t CO_2e/m^2 floorspace)	0.04	0.03	0.01	0.01
Transportation				
Personal Energy Intensity (MJ/pkt)	2.03	1.94	1.86	1.68
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.14	0.13	0.11
Vehicle Energy Intensity (MJ/vkt)	3.40	3.31	3.23	2.86
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.23	0.19
Freight Energy Intensity (MJ/tkt)	1.01	0.98	0.98	0.91
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.07	0.07	0.07
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [2]	$2	$2	$1	$1
Increase in Gasoline Price (2003¢/L) [2]	0.0	0.0	0.0	0.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.64	2.43	2.33	2.29
GHG Intensity (t CO_2e/GJ Electricity)	0.21	0.19	0.17	0.17
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.33	6.96	6.41	6.13
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.61	0.59	0.56	0.56
Increase in Cost of Oil Sands Production (2003$/barrel) [2]	0.00	0.00	0.00	-0.01
Increase in Cost of Gas Production (2003$/GJ) [2]	0.00	0.00	0.00	0.01

[1] Represents the shadow price on greenhouse gas emissions in the specified gas emitters framework.
[2] Represents an increase over the reference case.

S7-REN

	2020	2030	2040	2050
Carbon Charges (2003\$/tonne CO_2e) [1]	\$15	\$15	\$15	\$15

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	306	324	349	382
Demand Sectors				
Residential	9	9	8	6
Commercial	6	7	7	6
Transportation	35	41	47	49
Manufacturing Industry	19	21	21	21
Supply Sectors				
Crude Oil	159	174	189	209
Natural Gas	32	25	19	15
Coal Mining	1	1	1	2
Electricity Generation	39	39	44	59
Petroleum Refining	7	9	12	15
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,025	4,324	4,652	5,057
Demand Sectors				
Residential	206	211	204	176
Commercial	178	208	241	267
Transportation	491	565	649	693
Manufacturing Industry	335	381	408	429
Supply Sectors				
Crude Oil	1,849	2,024	2,124	2,252
Natural Gas	330	248	200	159
Coal Mining	11	11	12	15
Electricity Generation	504	520	606	813
Petroleum Refining	122	156	207	253
Ethanol	1	1	1	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,935	1,954	1,719	1,299
Coal	765	802	892	1,111
Petroleum Products	994	1,195	1,586	2,042
Electricity	188	211	256	355
Renewable	92	110	143	192
Other	49	53	55	58

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	149	170	212	285

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.51	0.45	0.39	0.30
Space Heating (t CO_2e/m^2 floorspace)	0.024	0.021	0.018	0.011
Hot Water Heating (GJ/household)	46	44	40	33
Hot Water Heating (t CO_2e/household)	2.3	2.2	1.9	1.4
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.11
Appliance Energy Consumption (GJ/household)	15.3	15.0	14.6	13.4
Increase in Annual Energy Costs (2003$/household) [2]	-$82	-$75	-$65	-$44
Increase in Natural Gas Price (2003$/GJ) [2]	$0.00	$0.00	$0.00	$0.00
Increase in Electricity Price (2003¢/kWh) [2]	-0.2	-0.2	-0.2	-0.2
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.64	1.59	1.53	1.43
GHG Intensity (t CO_2e/m^2 floorspace)	0.06	0.05	0.05	0.03
Transportation				
Personal Energy Intensity (MJ/pkt)	2.03	1.94	1.86	1.68
Personal Emissions Intensity (kg CO_2e/pkt)	0.14	0.14	0.13	0.11
Vehicle Energy Intensity (MJ/vkt)	3.40	3.31	3.23	2.85
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.24	0.23	0.23	0.19
Freight Energy Intensity (MJ/tkt)	1.01	0.98	0.98	0.91
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.07	0.07	0.07
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [2]	$2	$2	$1	-$3
Increase in Gasoline Price (2003¢/L) [2]	0.0	0.0	0.0	0.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.49	2.29	2.20	2.17
GHG Intensity (t CO_2e/GJ Electricity)	0.19	0.17	0.16	0.16
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.34	6.96	6.42	6.13
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.61	0.58	0.56	0.56
Increase in Cost of Oil Sands Production (2003$/barrel) [2]	0.00	0.01	0.01	0.00
Increase in Cost of Gas Production (2003$/GJ) [2]	0.00	0.00	0.00	0.00

[1] Represents the shadow price on greenhouse gas emissions in the specified gas emitters framework.
[2] Represents an increase over the reference case.

S8-PKG

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e) [1]	$15	$15	$15	$15

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	260	242	219	206
Demand Sectors				
Residential	8	8	8	7
Commercial	4	4	3	2
Transportation	34	38	44	47
Manufacturing Industry	16	14	11	8
Supply Sectors				
Crude Oil	124	123	112	109
Natural Gas	32	24	19	15
Coal Mining	1	1	1	2
Electricity Generation	35	26	18	12
Petroleum Refining	6	5	4	4
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,245	4,674	5,408	6,153
Demand Sectors				
Residential	199	200	197	178
Commercial	148	152	163	184
Transportation	472	524	609	665
Manufacturing Industry	341	400	438	468
Supply Sectors				
Crude Oil	1,935	2,141	2,323	2,502
Natural Gas	330	249	204	165
Coal Mining	11	11	12	15
Electricity Generation	685	831	1,228	1,683
Petroleum Refining	124	166	235	292
Ethanol	1	1	1	0

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	1,985	2,088	2,002	1,691
Coal	804	885	1,182	1,601
Petroleum Products	961	1,109	1,467	1,914
Electricity	216	265	366	489
Renewable	68	101	160	221
Other	49	53	58	63

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	1,476	3,313	5,889	7,497

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.48	0.41	0.36	0.30
Space Heating (t CO_2e/m^2 floorspace)	0.023	0.020	0.017	0.014
Hot Water Heating (GJ/household)	46	44	41	36
Hot Water Heating (t CO_2e/household)	2.3	2.2	2.0	1.7
Air Conditioning (GJ/household)	0.07	0.08	0.09	0.10
Appliance Energy Consumption (GJ/household)	15.3	15.1	14.5	13.2
Increase in Annual Energy Costs (2003$/household) [2]	-$19	-$76	-$55	$35
Increase in Natural Gas Price (2003$/GJ) [2]	$0.00	$0.00	$0.00	$0.00
Increase in Electricity Price (2003¢/kWh) [2]	1.7	2.0	2.0	1.9
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.37	1.17	1.04	0.99
GHG Intensity (t CO_2e/m^2 floorspace)	0.04	0.03	0.02	0.01
Transportation				
Personal Energy Intensity (MJ/pkt)	1.84	1.65	1.64	1.55
Personal Emissions Intensity (kg CO_2e/pkt)	0.13	0.12	0.11	0.11
Vehicle Energy Intensity (MJ/vkt)	3.05	2.63	2.68	2.54
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.22	0.19	0.19	0.17
Freight Energy Intensity (MJ/tkt)	1.01	0.97	0.98	0.91
Freight Emissions Intensity (kg CO_2e/tkt)	0.07	0.07	0.07	0.07
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [2]	-$131	-$252	-$204	-$109
Increase in Gasoline Price (2003¢/L) [2]	0.0	0.0	0.0	0.0
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.78	2.66	2.73	2.85
GHG Intensity (t CO_2e/GJ Electricity)	0.14	0.08	0.04	0.02
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.88	7.64	7.44	7.36
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.45	0.37	0.26	0.21
Increase in Cost of Oil Sands Production (2003$/barrel) [2]	0.68	0.90	1.33	1.55
Increase in Cost of Gas Production (2003$/GJ) [2]	0.02	0.02	0.04	0.06

[1] Represents the shadow price on greenhouse gas emissions in the specified gas emitters framework.
[2] Represents an increase over the reference case.

S9-DEEP

	2020	2030	2040	2050
Carbon Charges (2003$/tonne CO_2e)	$100	$300	$300	$300

GHG Emissions (Mt CO_2e)

	2020	2030	2040	2050
Alberta Total	189	140	114	115
Demand Sectors				
Residential	7	4	2	1
Commercial	5	4	2	1
Transportation	29	20	15	15
Manufacturing Industry	14	10	7	5
Supply Sectors				
Crude Oil	68	59	54	61
Natural Gas	28	19	14	12
Coal Mining	1	1	1	1
Electricity Generation	30	19	16	18
Petroleum Refining	6	5	2	2
Ethanol	0	0	0	0

Energy Consumption (PJ)

	2020	2030	2040	2050
Alberta Total	4,243	4,615	5,302	6,270
Demand Sectors				
Residential	187	154	127	111
Commercial	162	168	173	189
Transportation	414	328	334	399
Manufacturing Industry	341	397	433	462
Supply Sectors				
Crude Oil	1,937	2,166	2,354	2,574
Natural Gas	307	215	167	137
Coal Mining	11	11	12	15
Electricity Generation	770	1,046	1,526	2,158
Petroleum Refining	113	130	173	223
Ethanol	1	1	1	2

Energy Consumption by Fuel Type (PJ)

	2020	2030	2040	2050
Natural Gas	2,154	2,389	2,525	2,282
Coal	823	859	1,080	1,577
Petroleum Products	818	689	714	1,109
Electricity	269	397	580	791
Renewable	128	223	337	437
Other	51	58	67	75

Increase in GDP in sectors covered by CIMS (2003$ Million)

	2020	2030	2040	2050
Alberta Total	893	2,293	3,643	6,585

Detailed Sectoral Results

	2020	2030	2040	2050
Residential				
Space Heating (GJ/m^2 floorspace)	0.45	0.31	0.20	0.16
Space Heating (t CO_2e/m^2 floorspace)	0.020	0.009	0.002	0.000
Hot Water Heating (GJ/household)	44	34	26	21
Hot Water Heating (t CO_2e/household)	2.1	1.3	0.7	0.3
Air Conditioning (GJ/household)	0.08	0.09	0.10	0.10
Appliance Energy Consumption (GJ/household)	15.2	14.8	14.0	12.5
Increase in Annual Energy Costs (2003$/household) [1]	$552	$953	$335	-$6
Increase in Natural Gas Price (2003$/GJ) [1]	$5.01	$15.02	$15.02	$15.02
Increase in Electricity Price (2003¢/kWh) [1]	3.1	3.3	2.8	2.5
Commercial				
Energy Intensity (GJ/m^2 floorspace)	1.50	1.30	1.10	1.01
GHG Intensity (t CO_2e/m^2 floorspace)	0.05	0.03	0.01	0.01
Transportation				
Personal Energy Intensity (MJ/pkt)	1.69	1.29	1.20	1.18
Personal Emissions Intensity (kg CO_2e/pkt)	0.12	0.09	0.07	0.05
Vehicle Energy Intensity (MJ/vkt)	3.06	2.45	2.15	1.89
Vehicle Emissions Intensity (kg CO_2e/vkt)	0.22	0.17	0.12	0.07
Freight Energy Intensity (MJ/tkt)	0.85	0.50	0.41	0.45
Freight Emissions Intensity (kg CO_2e/tkt)	0.06	0.03	0.01	0.01
Increase in Annual Vehicle Fuel Costs (2003$/vehicle) [1]	$243	$650	$405	$261
Increase in Gasoline Price (2003¢/L) [1]	25.0	74.9	74.9	74.9
Electricity Generation				
Energy Intensity (GJ Fuel/GJ Electricity)	2.51	2.33	2.36	2.51
GHG Intensity (t CO_2e/GJ Electricity)	0.10	0.04	0.02	0.02
Upstream Oil and Gas				
Oil Sands Energy Intensity (GJ/m^3 crude)	7.83	7.61	7.30	7.19
Oil Sands GHG Intensity (t CO_2e/m^3 crude)	0.32	0.25	0.20	0.19
Increase in Cost of Oil Sands Production (2003$/barrel) [1]	3.39	3.68	4.34	4.68
Increase in Cost of Gas Production (2003$/GJ) [1]	0.16	0.28	0.33	0.37

[1] Represents an increase over the reference case.

Appendix C – Sectoral Wedge Diagrams

Figure 49: Sectoral Wedge Diagrams for P1-F15

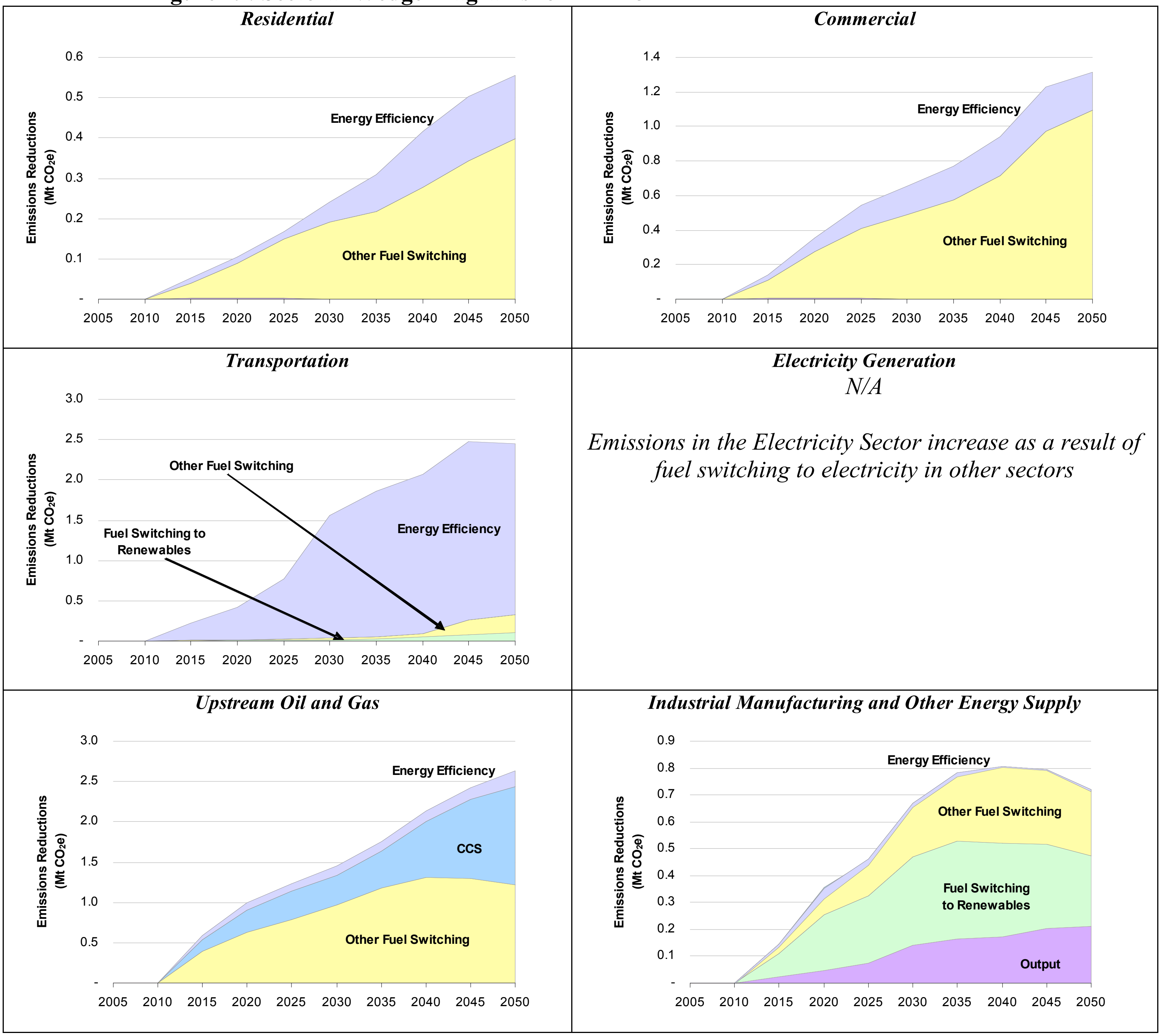


Figure 50: Sectoral Wedge Diagrams for P2-F30

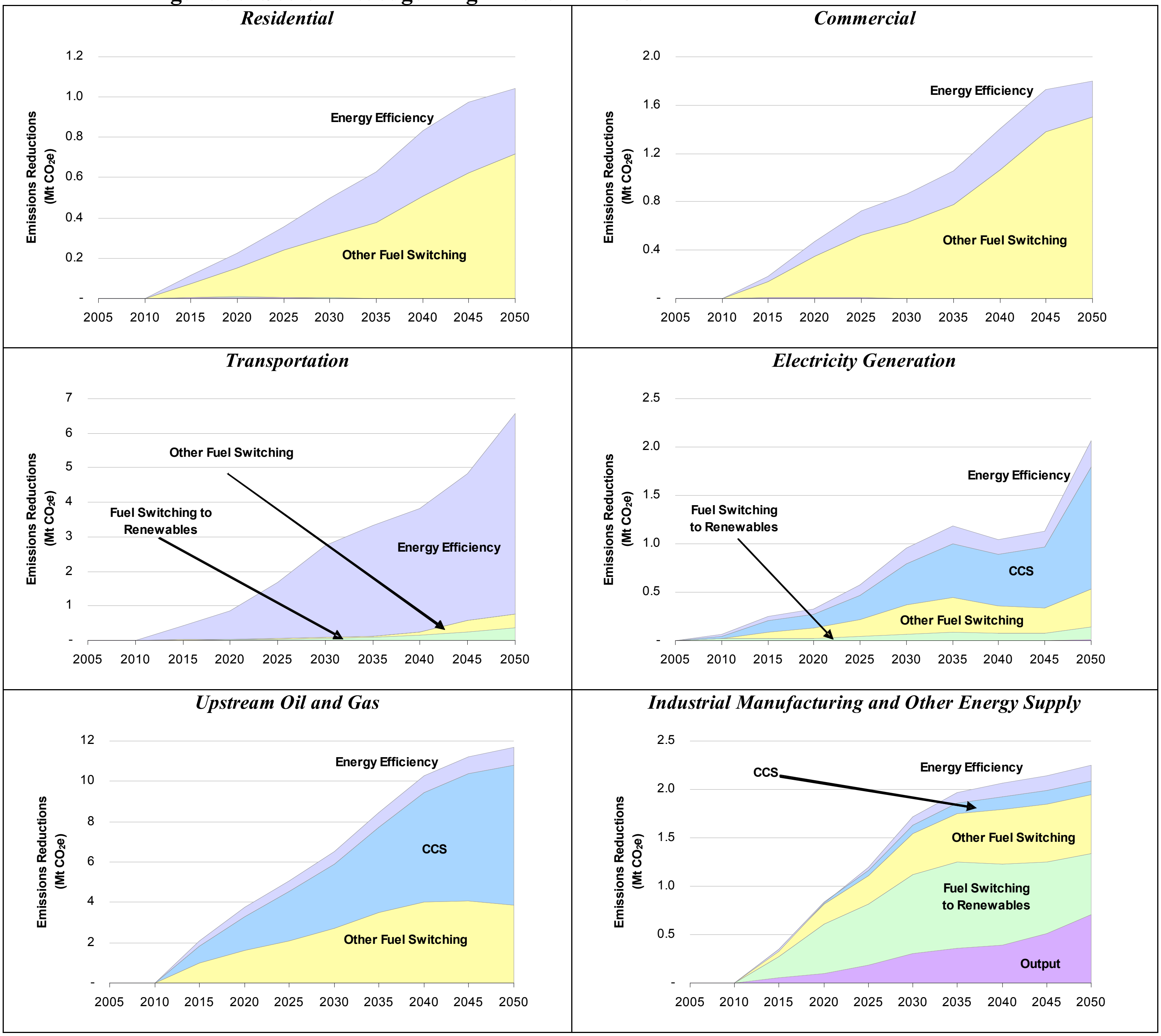


Figure 51: Sectoral Wedge Diagrams for P3-F60

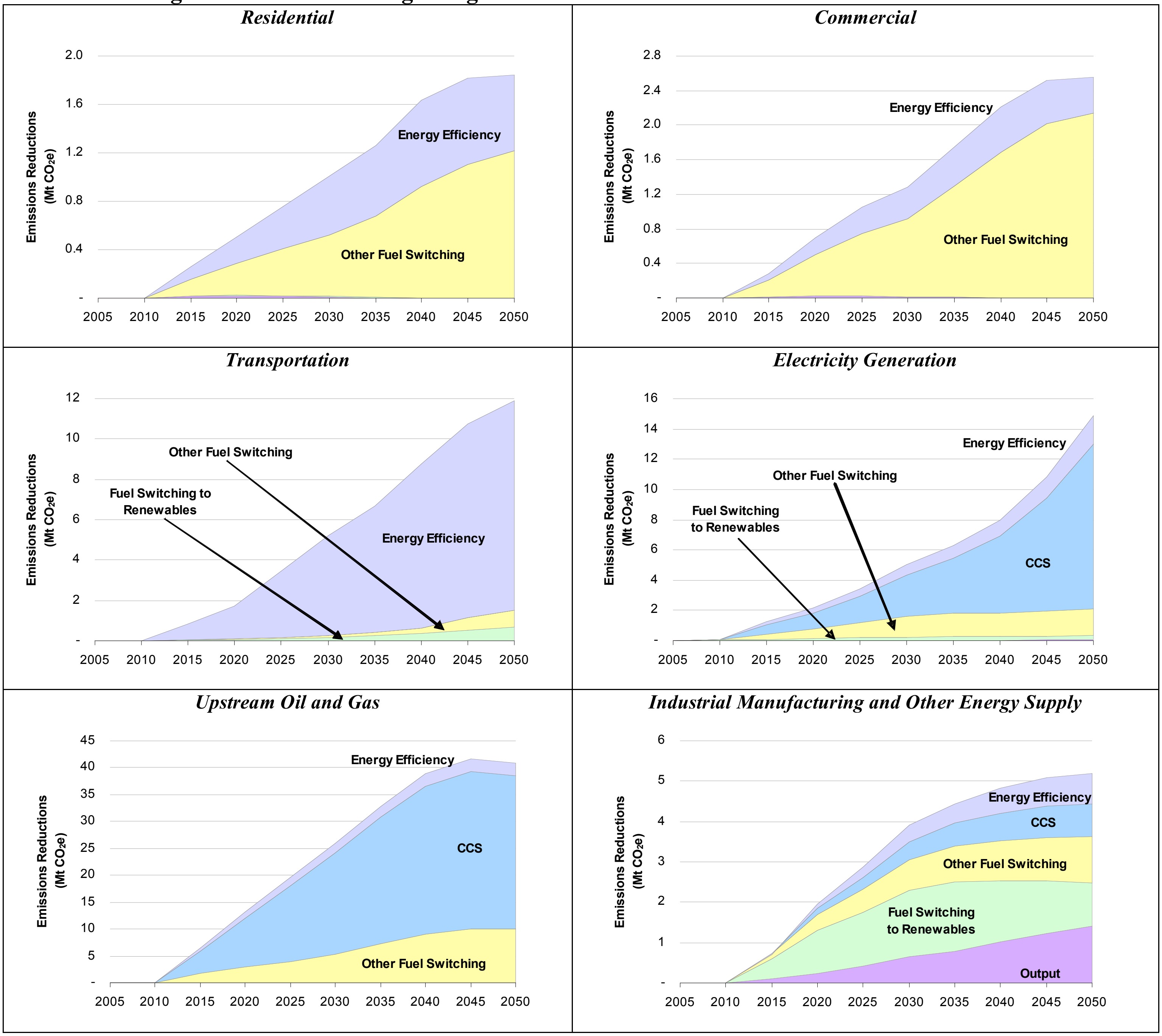


Figure 52: Sectoral Wedge Diagrams for P4-F100

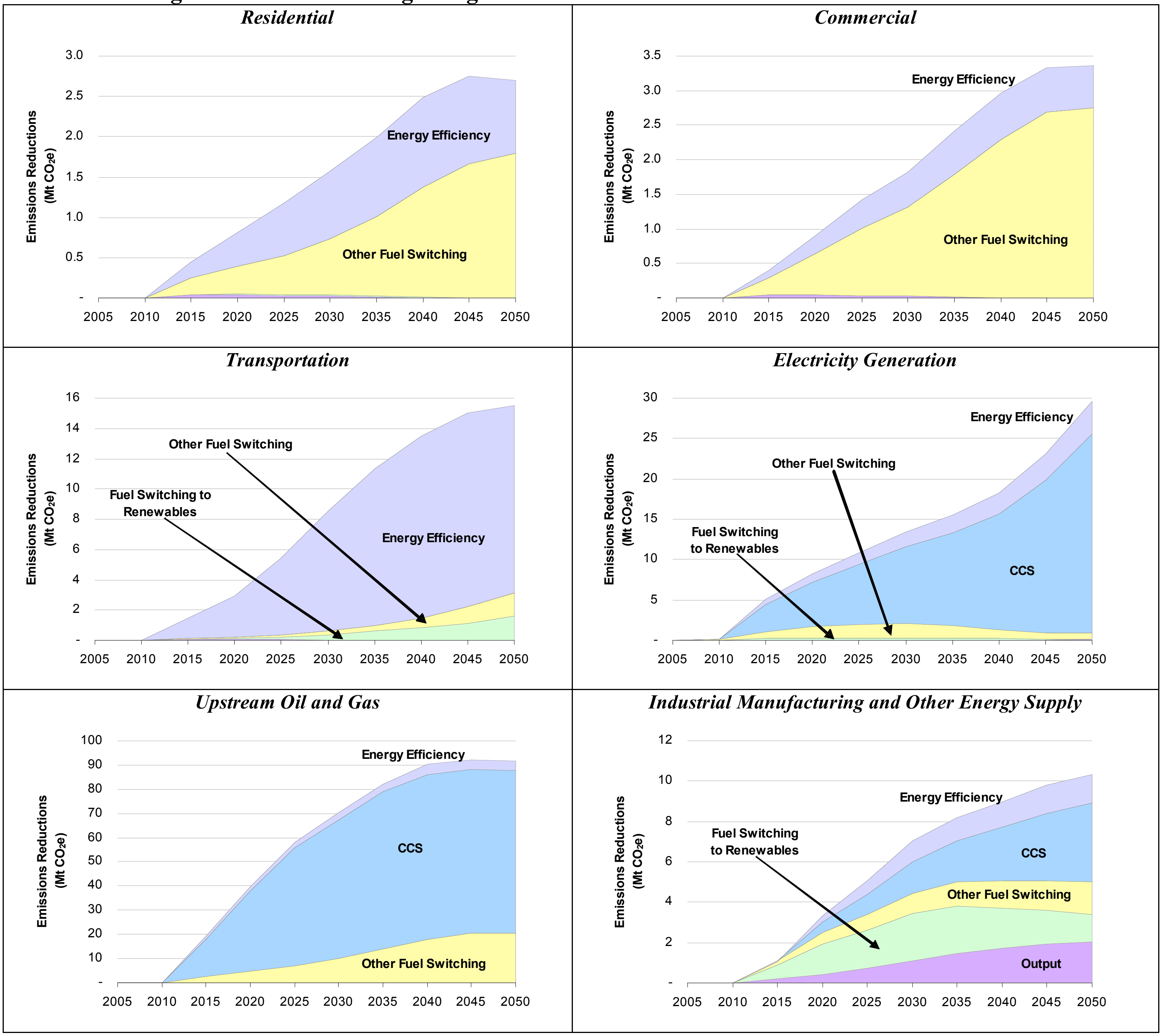


Figure 53: Sectoral Wedge Diagrams for P5-Ea

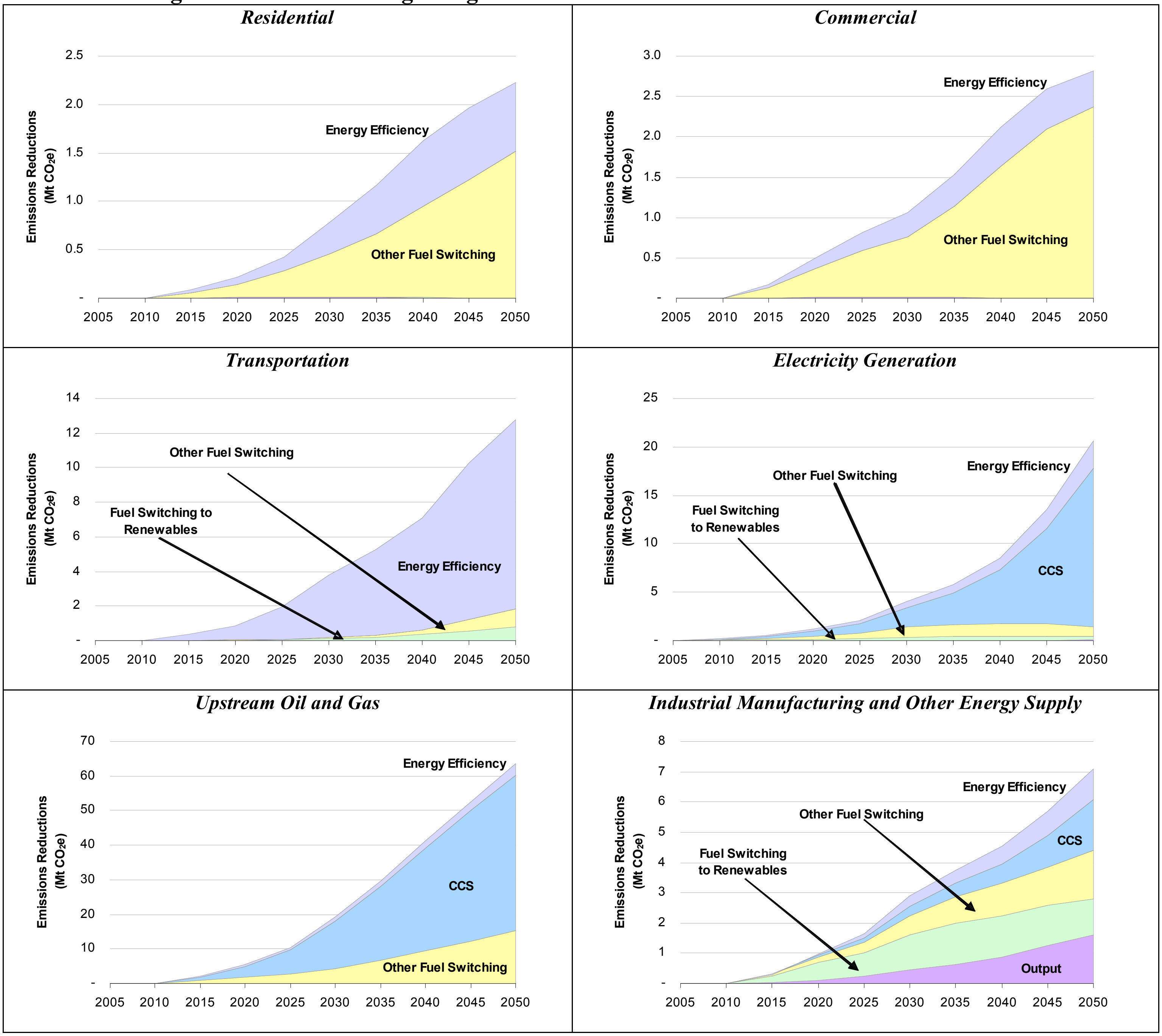


Figure 54: Sectoral Wedge Diagrams for P6-Eb

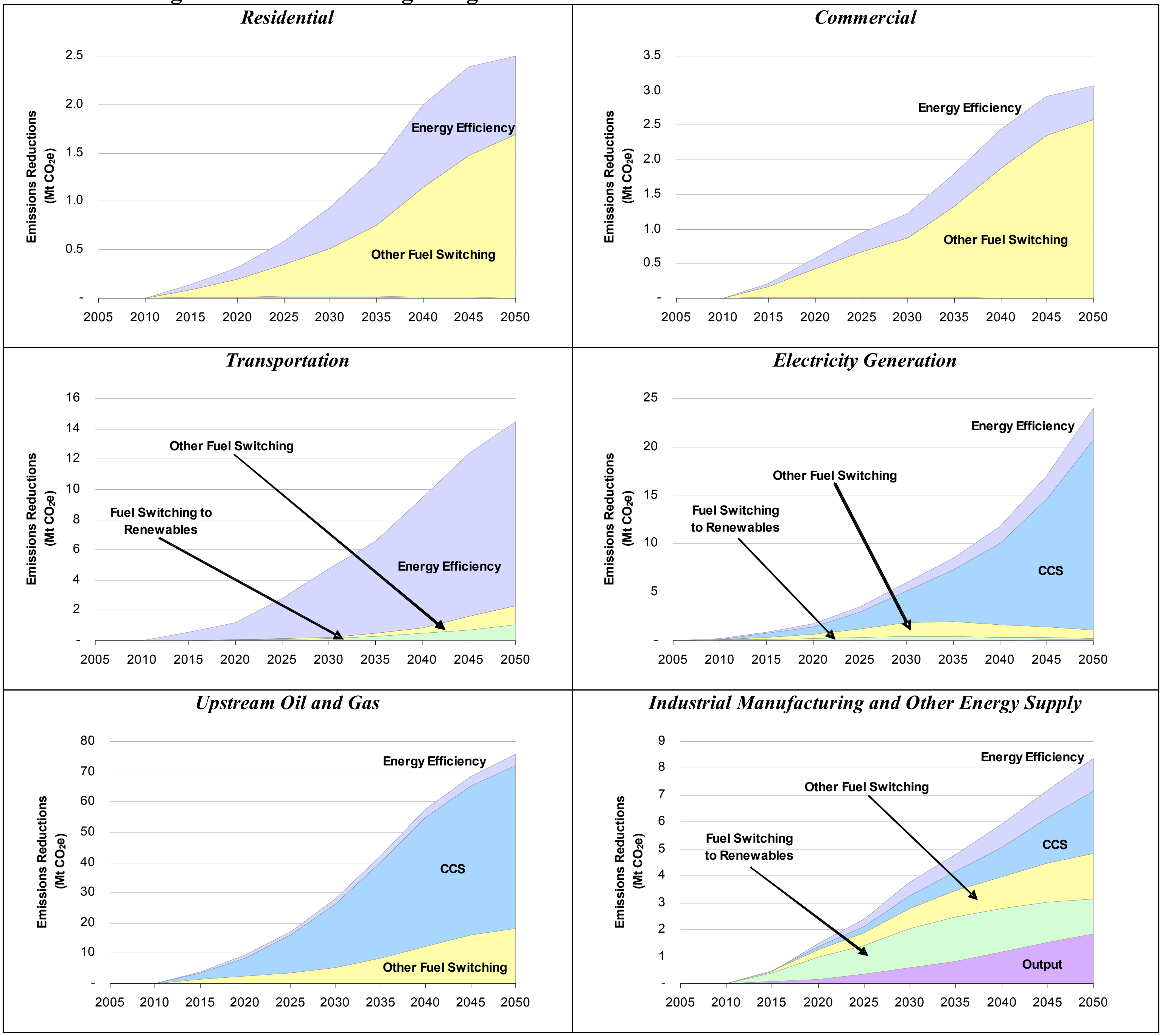


Figure 55: Sectoral Wedge Diagrams for P7-Ec

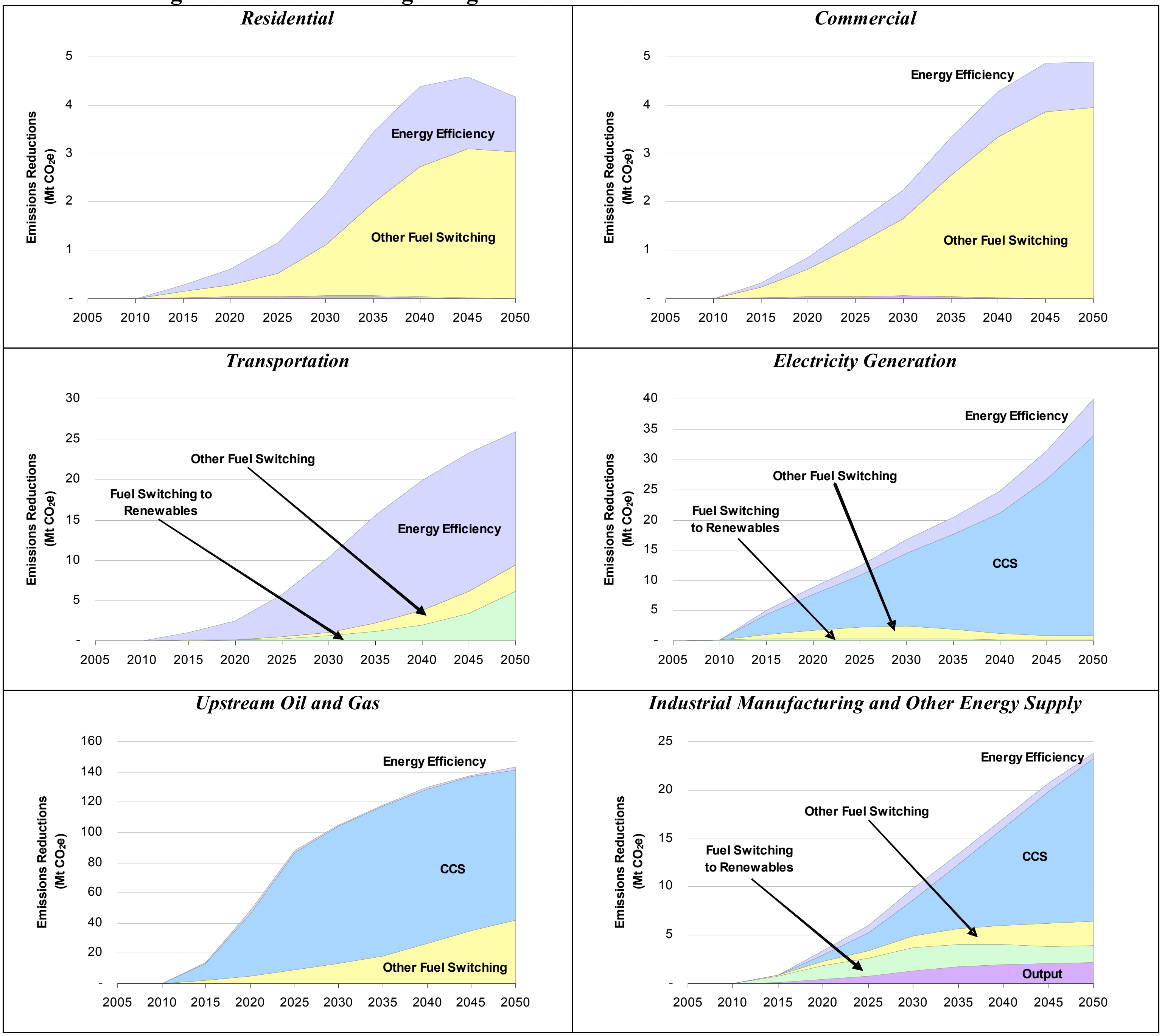


Figure 56: Sectoral Wedge Diagrams for S1-EaCCS

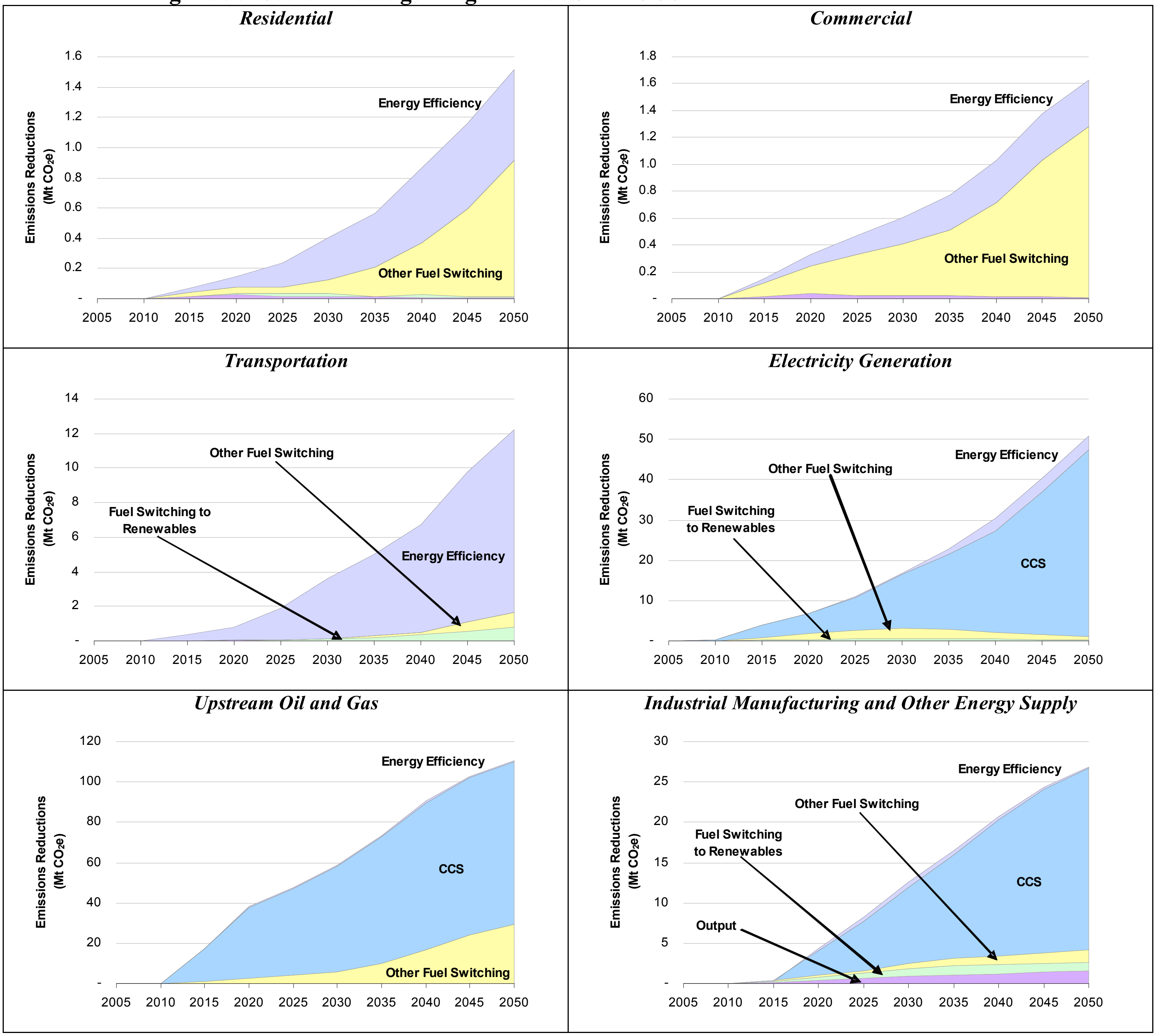
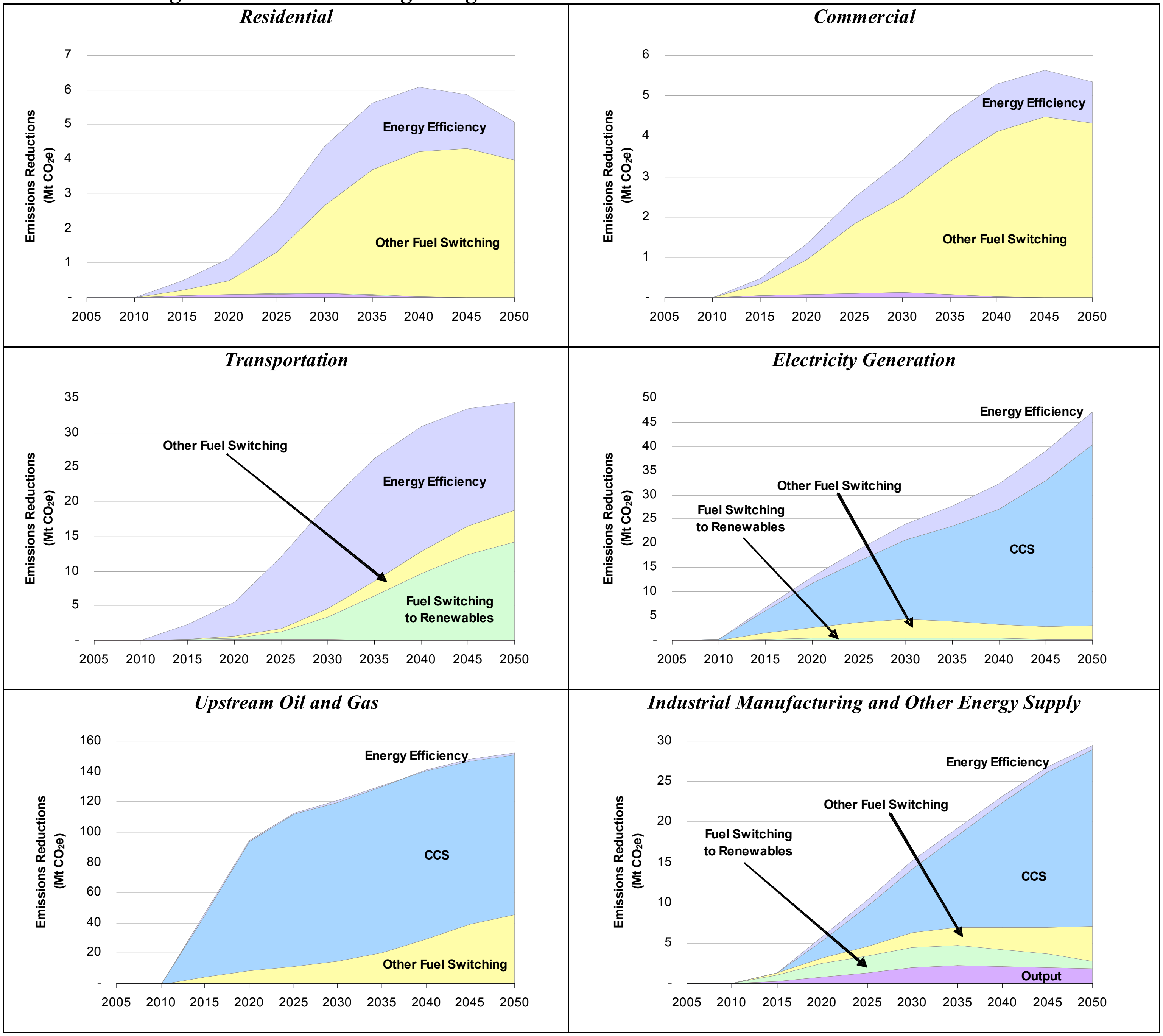
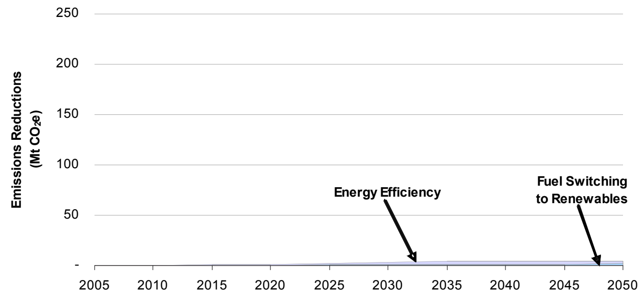


Figure 57: Sectoral Wedge Diagrams for S9-DEEP

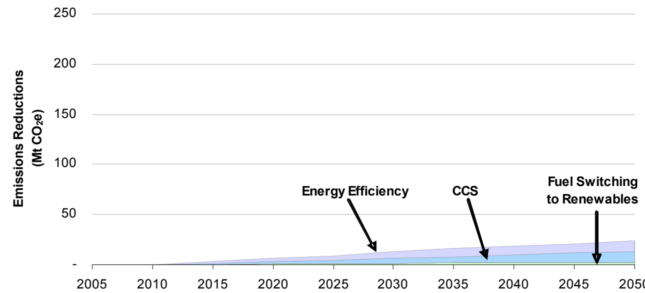


Appendix D – GHG Reduction Wedge Diagrams

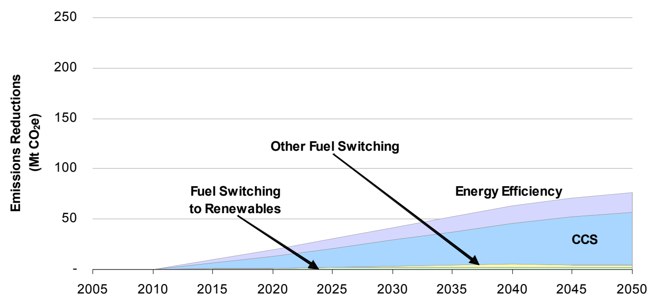
P1-F15



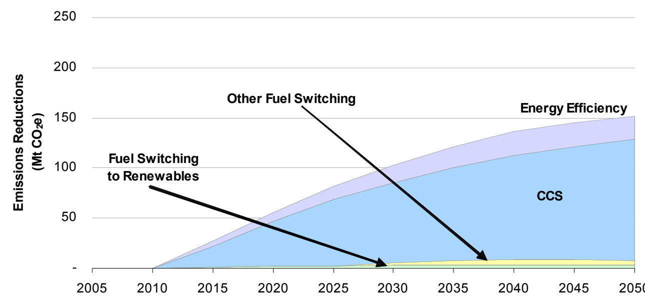
P2-F30



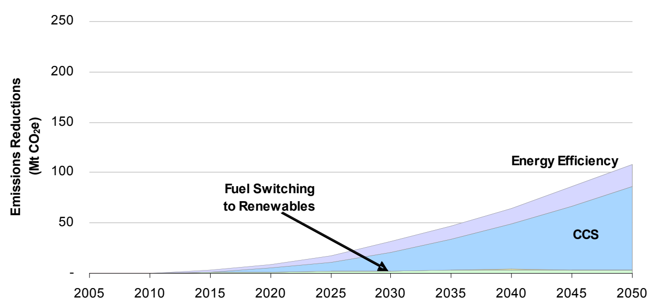
P3-F60



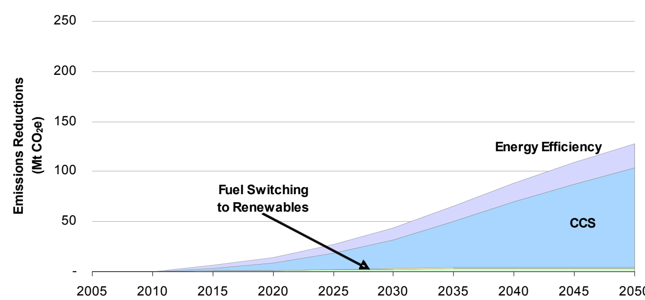
P4-F100



P5-Ea



P6-Eb



P7-Ec