Deep Reductions, Strong Growth:

An economic analysis showing that Canada can prosper economically while doing its share to prevent dangerous climate change

December 4, 2008

Introduction

If the world is to avoid a dangerous level of climate change, climate science shows that industrialized countries need to urgently reduce their emissions of greenhouse gases (GHGs) to 25–40% below the 1990 level by 2020.

Because of the extraordinary costs of uncontrolled global warming — for people, the environment and the economy — it is important to understand how emission reductions on this scale can be achieved. At the same time, the current economic downturn provides an opportunity to ensure that the private and public investments accompanying economic recovery are directed to clean energy solutions with much lower GHG emissions.

The Pembina Institute and the David Suzuki Foundation have therefore commissioned M.K.Jaccard and Associates Inc. (MKJA) to conduct an economic modelling study of government policies that will allow Canada to meet a GHG target consistent with climate science: 25% below the 1990 level by 2020.[*] In comparison, the Government of Canada's current GHG target for 2020 is a reduction of 3% below the 1990 level.[1]

To our knowledge, this is the first published study of a set of policies to meet the science-based 25% target for Canada.

The package of policies modelled reflects the expert consensus that an effective and economically efficient national plan to achieve substantial GHG reductions must combine

- a policy that puts a significant price on GHG emissions (a "carbon price") broadly across the economy
- complementary regulations and public investments to expand green infrastructure and the use of clean technology.

Below, we present initial modelling results showing projected economic effects of meeting the target. Two subsequent sections explain in more detail

[*] We are very grateful to TD Bank Financial Group for its generous support for this project. TD Bank is interested in promoting sound analysis of the interaction between the environment and the economy. TD Bank does not at this time advocate any particular GHG targets for Canada.

- the federal and provincial government policies that need to be implemented to reduce GHG pollution to the extent required, and those that we have modelled
- the origin and importance of science-based targets in Canadian and international efforts to fight climate change.

The detailed economic modelling report by MKJA[2] follows this summary document. This is the preliminary report from an ongoing economic modelling project in which the Pembina Institute and the David Suzuki Foundation will also study the policies that would be needed to meet the Government of Canada's current GHG target for 2020.

Economic modelling results

The analysis conducted by MKJA shows that with strong federal and provincial government policies, Canada can meet an ambitious science-based GHG reduction target in 2020 and still have a strong growing economy, a quality of life higher than Canadians enjoy today, and continued steady job creation across the country.

The analysis shows that a significant price on GHG emissions applied broadly across the entire economy, combined with strong complementary regulations and public investments, enables Canada to reduce its emissions to 25% below the 1990 level by 2020. The emissions price starts at $50 per tonne[3] in 2010 and rises in predictable annual increments to $125 per tonne by 2015 and $200 per tonne by 2020. (The anticipated emissions price after 2020 also affects decisions taken earlier; in this analysis the price continues to rise after 2020, reaching $300 per tonne by 2030.)

Continued strong economic growth

The analysis shows that with the package of policies modelled — including a fairly steep carbon price — Canada's economy is projected to continue growing strongly.

In a "business-as-usual" scenario, Canada's GDP is expected to grow 22.0% between 2011 and 2020. The implementation of our policy package is projected to slightly reduce GDP growth to 19.2–19.3% over the same period. Putting this another way, between 2011 and 2020 the economy would grow by an average of 2.2% annually under business-as-usual, and 2.0% if Canada were to meet a science-based GHG reduction target.

This modest reduction in the speed of economic expansion pales in comparison to projections of lost GDP under business-as-usual. In his 2006 review of the economics of climate change, former World Bank chief economist Sir Nicholas Stern estimated that the costs and risks of uncontrolled climate change are equivalent to a loss in global GDP of at least 5% and up to 20% or more.[4]

Under the policies modelled, most sectors see increases in output between 2005 and 2020 close to the increases projected under business-as-usual. Only two fossil fuel production sectors — petroleum refining and natural gas production — see reductions in output in absolute terms. In a subsequent stage of this project we intend to model policies designed to limit the unevenness of economic impacts among regions.

Continued employment growth

Substantial employment growth continues with our policy package in nearly all sectors of the Canadian economy. Under business-as-usual, the total labour force size is projected to grow by 6.4% between 2011 and 2020; under our policy package, the growth is projected to be 6.2–6.4% (the amount depends on assumptions about Canada's trading partners). In absolute terms, over 1.16 million net new jobs are projected to be created in Canada between 2011 and 2020 while meeting the science-based GHG reduction target. Only the fossil fuel production sectors (crude oil extraction, petroleum refining, natural gas production and coal mining), plus the electricity sector, see reductions in employment in absolute terms. Wages are projected to continue to rise under our policy package although somewhat more slowly than under business-as-usual.

Key emission reduction opportunities

The analysis reveals the key technologies that need to be deployed to achieve major reductions in Canada's GHG pollution. The most important of these are

- capture and storage of carbon dioxide from industrial facilities and power plants
- reduction of "fugitive" emissions from the oil and gas industry and from landfills
- increased energy efficiency throughout the economy (e.g., in vehicles and buildings)
- increased production of renewable energy (e.g., wind power accounts for 13% of electricity generated in 2020, compared to less than 1% now)
- replacement of fossil fuels by electricity (e.g., for heating buildings).

Besides the price on GHG emissions, our policy package includes several practical and sensible regulatory measures that will help to sustain our quality of life and economic prosperity. For instance, substantial emission reductions are achieved through something as simple as an alternative manner of dealing with our waste once it reaches the landfill. Instead of allowing landfill methane (a highly potent greenhouse gas) to enter the atmosphere, we include regulations to require the methane to be captured and potentially used for generating electricity. In our analysis, this simple yet effective measure cuts Canada's GHG emissions from landfills by 84%, relative to business-as-usual.

Another practical and readily available measure we've employed to reduce emissions accelerates the application of fuel efficient vehicle technology to the cars Canadians drive. By regulating a substantial decrease in tailpipe GHG emissions, Canadians will experience a considerable reduction in the amount of money they spend on fuel. In this analysis, by 2020 Canadians will save more than $5.6 billion each year at the pump, relative to business-as-usual. (In part this is also due to greater use of public transit and shorter commutes.)

International emission reduction opportunities

Investments by the federal government in emission reduction projects in less wealthy countries can help lower the cost of meeting a national GHG target, while simultaneously helping those countries address climate change. This can be done through the purchase of international emission credits, such as those currently available under the UN's Clean Development Mechanism. We have assumed a relatively high price for international credits ($100/tonne by 2020) to ensure Canada acquires credits that are of high environmental quality and represent real emission reductions.[5]

In this analysis Canada purchases 35–49 million tonnes of international reductions annually by 2020 (the exact amount depends on assumptions about Canada's trading partners). This means that Canada's *domestic* GHG emissions would be reduced to 17–19% below the 1990 level in 2020, with international reductions used to achieve the remainder of the 25% target.

Revenue

A price on GHG emissions would generate considerable government revenue. This analysis shows that setting the price at the level required to meet a science-based GHG target generates government revenue of $87–89 billion per year by 2020. However, most of this revenue is returned to Canadians in the form of reductions in income tax.

Two scenarios for Canada's trading partners

To take into account concerns about international competitiveness, the analysis looks at two different scenarios under which Canada could achieve the science-based GHG target in 2020. In the first scenario, Canada's OECD trading partners implement GHG emission reduction policies at least as strong as Canada's. If Canada's major trading partners implement similar policies, their costs of production will change by a similar amount to Canada's, reducing the likelihood that customers of Canadian goods will replace their purchases by foreign equivalents.

In the second scenario, the OECD (including the U.S.) does implement a price on GHG emissions, but Canada's GHG reduction policies are sufficiently stronger that the country can be considered to be "acting alone." In this scenario the analysis shows some shifting of GHG-intensive activities to other jurisdictions. For two significantly affected sectors, metal smelting and industrial minerals, we prevent a decline in activity by returning some emissions pricing revenue to producers in proportion to production levels.

In both of these scenarios, developing countries such as China, India and Brazil are assumed to have considerably weaker GHG reduction policies.

About the economic models used

This analysis uses the CIMS and DGEEM economic models. CIMS contains a detailed database of technologies relevant to GHG emissions. The model simulates firms' and individuals' choices of technologies based on studies of real-world behaviour. DGEEM is used to study "macroeconomic" measures such as GDP and employment. CIMS has been widely used by the governments of Canada, Alberta and other provinces.

Federal and provincial government policies modelled

There is a strong consensus among experts that an effective and economically efficient national plan to achieve substantial GHG reductions must combine

- a policy that puts a significant price on GHG emissions broadly across the economy — this can be a cap-and-trade system or an emissions tax
- regulations and public investments in sectors where the response to the emissions price is hampered by market barriers or market failures, or where emissions pricing cannot be easily implemented
- measures to protect people on low incomes

- measures to protect industry sectors where a significant portion of production and associated emissions would otherwise relocate to countries with weaker policies.[6]

We believe there is also a need for

- regulations and/or public investments to stimulate more rapid emission reductions during the transitional period when the emissions price is being gradually raised to the necessary level.[7]

The first table below shows the package of policies that we have modelled at the current stage of this project, with brief rationales provided for each one. All of the policies start in 2010.[8] Most of them could be either federal or provincial. However, we believe that the federal government has a responsibility to take a strong lead on climate change, in which case most of these policies should be implemented at the federal level. For policies that fall under exclusive provincial jurisdiction, we believe the federal government should make their implementation a condition for the transfer of revenue from emissions pricing.

Policy	Rationale
Carbon price: Emissions pricing policy (cap-and-trade system or emissions tax)[9] covering 80% of national emissions. In the case of cap-and-trade, emitters would have to pay for every tonne they emit, by purchasing emission permits auctioned by government. The price rises steadily over time.	Experts agree that an emissions price is the most important policy to achieve substantial GHG reductions. Auctioning all permits reflects the polluter-pays principle and generates revenues that can be used to finance other policies in the package. A steadily rising price allows the economy to adjust.
Agricultural offsets: Purchase by the federal government of "offset credits" representing emission reductions in the agriculture sector.	Agricultural emissions are administratively difficult to cover under a cap-and-trade system or emissions tax; purchase of credits is an alternative way to effectively price these emissions. Purchase by government, not the private sector, prevents any weakening of the price on industrial emissions.
Revenue recycling to targeted sectors: Recycling of emissions pricing revenue in proportion to production levels to industry sectors where a significant portion of production would otherwise relocate to countries with weaker GHG reduction policies.	There will be little or no environmental benefit if production and associated emissions simply relocate to other countries.
International investments: Investment by the federal government in emission reduction projects in less wealthy countries.[10]	This provides Canada with the option of meeting its GHG targets in part through international investments that are more cost-effective than domestic action, while also helping less wealthy countries address climate change.
Income tax reductions: Recycling of the remaining emissions pricing revenue to reduce income taxes on labour.	This will stimulate job creation and offset the increased cost of pollution.

Vehicle emission standards: GHG emission regulations for cars and light trucks initially in line with California standards and then gradually tightened.	Increased vehicle efficiency is hampered by significant market barriers. California standards are the strongest of those currently proposed by governments in North America.
Provincial regulations to prevent additional urban sprawl	Urban planning is not expected to respond efficiently to an emissions price. Higher-density urban development will significantly reduce emissions from transportation and buildings.
Building codes: Stronger energy efficiency requirements in building codes for new houses and commercial buildings: new houses 50% more energy efficient than current norms; new commercial buildings built to LEED Gold standard; no new fossil fuel heating in BC, Manitoba and Quebec.	Energy efficiency in buildings is hampered by significant market barriers/failures. BC, Manitoba and Quebec produce electricity that is nearly emissions-free and can be used to heat buildings using electric heating including the option of heat pumps.
Appliance efficiency standards: Energy efficiency regulations for major appliances set at the level of the most efficient commercially available models.	Appliance efficiency is hampered by significant market barriers.
Carbon capture requirement: Requirement to capture and store carbon dioxide from all new natural gas processors, coal-fired power plants and oil sands operations.	In the context of deep GHG reductions, we consider new fossil fuel developments to be acceptable only if they use carbon capture and storage. On its own the emissions price is too low to ensure this during the first few years.
Full cost pricing for nuclear power: Requirement that nuclear power producers pay the full estimated cost of waste management, decommissioning and insurance.	Major costs are not currently taken into account in decisions to invest in nuclear power, leading to economic inefficiency in addition to serious environmental and security issues. This measure requires nuclear power to compete fairly with other sources of electricity.
Venting and flaring regulations: Regulations to limit unnecessary venting and flaring emissions from oil and gas production.	These emissions are difficult to include in an emissions pricing policy because they are difficult to measure. Specific regulations are therefore preferred.
Regulations to require the capture of landfill gas	These emissions are difficult to include in an emissions pricing policy because they are difficult to measure. Specific regulations are therefore preferred.

In subsequent stages of this project, we intend to model the following additional policies:

Policy	Rationale
Revenue recycling to provinces: Federal-provincial transfers of emissions pricing revenue to reduce the unevenness of economic impacts among provinces.	This will smooth the economic transition.
Revenue recycling to people on low incomes: Recycling of emissions pricing revenue to ensure that people on low incomes are not worse off as a result of GHG reduction policies.	On its own, an emissions price is "regressive" (it will cost a greater percentage of the income of a typical person with a low income than of that of a typical person with a higher income). This is widely agreed to be unfair.
Government investments in public transit infrastructure	The level of transit investments is not expected to respond efficiently to an emissions price. More convenient transit services can significantly reduce emissions from transportation.
Retrofit grants: Grants for energy-saving retrofits in existing houses and commercial buildings.	Energy efficiency in buildings is hampered by significant market barriers/failures.
Green power incentives: Subsidies for low-impact renewable electricity production (e.g., wind and solar power).	The emissions price may not be high enough during the first few years to ensure adequate deployment of these technologies.
Corporate tax reductions: Recycling some emissions pricing revenue to reduce corporate income taxes in addition to labour income taxes.	Reducing labour income taxes alone biases benefits towards individuals and labour-intensive sectors, and away from corporations and capital-intensive sectors.

It should be noted that emission or absorption of carbon dioxide by forests has not been considered in this project. Reducing emissions from forests through conservation and, where appropriate, enhancing "sinks" (absorption of carbon dioxide from the air), could be important ways for Canada to reinforce its action on climate change, as the potential volumes of carbon dioxide involved are large.[11] However, the economic models we have used are not yet capable of including forests, and in most current discussions, GHG targets for Canada do not include them.

Science-based GHG targets for Canada and the industrialized world

The ultimate objective of the UN Framework Convention on Climate Change (UNFCCC), which has been ratified by virtually all countries in the world, is to "avoid dangerous anthropogenic interference with the climate system" — in other words, to avoid dangerous climate change. This objective should be the primary rationale for any country, Canada included, in setting targets for reducing GHG pollution.

There is now a broad consensus that more than 2ºC of average global warming above the pre-industrial level would constitute dangerous climate change. The Bali Climate Declaration by Scientists, signed in 2007 by over 200 of the world's leading climate scientists, states that staying within 2°C must be "the prime goal" of the next global climate agreement.[12] Many countries, including all of those in the EU, have set 2°C as the upper limit that should not be exceeded.

Prominent U.S. climate scientist James Hansen says that global warming above this threshold would be "exceedingly dangerous,"[13] given that the last time the world crossed it for a sustained period (3 million years ago), melting ice raised the sea level at least 15 metres higher than where it is now.[14] Scientists project sea levels to rise a metre or more this century alone if there is no action to cut GHG emissions[15] — enough to make 30 million Bangladeshis homeless.[16] Impacts like these would clearly be extraordinarily costly to people, the environment and the economy.

The Intergovernmental Panel on Climate Change (IPCC), the world's leading scientific body on climate change, has shown that to have a chance of not exceeding the 2ºC limit, industrialized countries' GHG emissions must fall to 25–40% below the 1990 level by 2020, if they are to make a fair contribution to the necessary cuts in global emissions.[17] Although industrialized countries as a whole could, in principle, meet a target within the 25–40% range even if Canada met only a weaker target, there are very good reasons why Canada's target should also be within this range. Notably, an analysis of various formulas for determining individual countries' fair share of emission reductions shows that Canada's percentage reduction target for 2020 should be very similar to the percentage reduction target for the industrialized world as a whole, whatever the year chosen as the starting point.[18,19]

Based on the IPCC's analysis, countries that are parties to the Kyoto Protocol agreed in 2007 that this range of emission reductions by industrialized countries should guide the current negotiations on a new global agreement to cut GHG emissions.[20] At the December 2008 UN climate conference in Poznan, Poland, countries will need to take the next step and start to consider specific targets within the 25–40% range, allowing negotiations to begin on national contributions to the aggregate target. This is a critical step towards a new global treaty for GHG reductions post-2012, which countries have agreed to finalize at the UN climate conference in Copenhagen, in December 2009.[21]

Overall, given the urgency underlined by the latest climate science and the need for Canada to do its fair share in tackling global warming, the Pembina Institute and the David Suzuki Foundation believe Canada should reduce its GHG emissions by at least 25% reduction below the 1990 level by 2020. As discussed in the preceding sections, Canada can if necessary meet this target by supplementing domestic action with investments in emission reductions in poorer countries.

Endnotes

[1] The Government of Canada expresses its 2020 target as 20% below the 2006 emission level (see Environment Canada, *Turning the Corner: Regulatory Framework for Industrial Greenhouse Gas Emissions* (Ottawa: Government of Canada, 2008), iii). This target can be re-expressed relative to the 1990 level based on emissions data from Environment Canada's *National Inventory Report*.

[2] MKJA, *Preliminary Report — Exploration of a policy package to reduce Canadian greenhouse gas emissions 25% from 1990 levels by 2020, December 3, 2008* (Vancouver, BC: MKJA, 2008).

[3] Of carbon dioxide equivalent.

[4] Short Executive Summary, available online at http://www.hm-treasury.gov.uk/stern_review_executive_summary.htm.

[5] For example, the Pembina Institute and the David Suzuki Foundation endorse credits from devoping countries that are registered to the Gold Standard. See http://www.cdmgoldstandard.org/.

[6] Clare Demerse and Matthew Bramley, *Choosing Greenhouse Gas Emission Reduction Policies in Canada* (Drayton Valley, AB: The Pembina Foundation, 2008). Also available online at http://climate.pembina.org/pub/1720.

[7] Ibid.

[8] In the model, the regulations listed begin in 2011, but this is only because the model uses fixed five-year periods for investments.

[9] In the MKJA report, the emissions pricing policy is referred to as a "carbon charge."

[10] In the MKJA report, this is referred to as "purchase of international emissions permits."

[11] See Canadian Forest Service, *Is Canada's Forest a Carbon Sink or Source?* (Ottawa, ON: Natural Resources Canada, 2007). Also available online at http://warehouse.pfc.forestry.ca/HQ/27501.pdf.

[12] Available online at http://www.climate.unsw.edu.au/bali/.

[13] James Hansen et al., "Climate change and trace gases," Phil. Trans. R. Soc. A 365: 1925 (2007). Also available online at http://pubs.giss.nasa.gov/docs/2007/2007_Hansen_etal_2.pdf.

[14] Eystein Jansen et al., "Paleoclimate," in S. Solomon et al., eds., *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, UK and New York, NY: Cambridge University Press, 2007), 440–442. Also available online at http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter6.pdf.

[15] See, for example, Stefan Rahmstorf, "A Semi-Empirical Approach to Projecting Future Sea-Level Rise," *Science* 315: 368 (2007). Also available online at http://www.pik-potsdam.de/~stefan/Publications/Nature/rahmstorf_science_2007.pdf.

[16] "U.N. chief urges climate change help despite slowdown," Reuter*s*, November 3, 2008, http://www.enn.com/climate/article/38556 (accessed November 26, 2008).

[17] Sujata Gupta et al., "Policies, Instruments and Co-operative Arrangements," in B. Metz et al., eds., *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, UK and New York, NY: Cambridge University Press, 2007), 776. Also available online at http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter13.pdf. The IPCC's analysis applied to stabilization of the atmospheric GHG concentration at 450 parts per million of CO_2e. This corresponds to about a 50% chance of limiting average global warming to 2ºC relative to the pre-industrial level. See Bill Hare and Malte Meinshausen, "How Much Warming Are We Committed to and How Much Can Be Avoided?," *Climatic Change* 75, nos. 1–2 (2006): 111. Also available online at http://www.springerlink.com/content/g5861615714m7381/fulltext.pdf.

[18] Niklas Höhne and Sara Moltmann, *Canada's emission reduction requirements under international climate policy approaches after 2012* (report for the National Round Table on the Environment and the Economy) (Cologne, Germany: ECOFYS, 2007)). The internationally accepted starting point for GHG reduction targets is 1990, because the IPCC's first Assessment Report alerted the world's governments to the dangers of climate change in that year, and the UNFCCC was adopted soon after in 1992.

[19] Also, the science is clear that emission reductions in the 25–40% range, accompanied by a fair share of reductions by developing countries, correspond to only about a 50% chance of keeping warming below 2ºC (see endnote 17). This is why Climate Action Network International has urged industrialized countries to strive for the upper end of the range, i.e., closer to a reduction of 40%.

[20] UNFCCC Secretariat, *Report of the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol on its resumed fourth session, held in Bali from 3 to 15 December 2007* (FCCC/KP/AWG/2007/5), 5. Also available online at http://unfccc.int/files/meetings/cop_13/application/pdf/awg_work_p.pdf.

[21] For more information on the Poznan conference and the countdown to Copenhagen, see Clare Demerse and Matthew Bramley, *UN Climate Negotiations in Poznan*, Poland (Drayton Valley, AB: The Pembina Institute, 2008). Also available online at http://climate.pembina.org/pub/1732.

PRELIMINARY REPORT

Exploration of a policy package to reduce Canadian greenhouse gas emissions 25% below 1990 levels by 2020

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Executive Summary

We reviewed the feasibility and cost of a 25% reduction in greenhouse gas (GHG) emissions below 1990 levels by 2020 (i.e., an absolute emissions target of 444 Mt) for the David Suzuki Foundation and the Pembina Institute. This analysis, completed using the CIMS hybrid technology simulation model and the DGEEM dynamic computable general equilibrium model, found the target is achievable, but only with a policy package of a stringency higher than that commonly discussed to date in Canada. Specifically, it includes:

- A carbon dioxide or equivalent (CO_2e) emissions charge, implemented as a full auction cap and trade or carbon tax on all combustion and almost all fixed process emissions equivalent to $50/tonne CO_2e in 2010 rising to $200/tonne CO_2e in 2020. If needed, non-fossil fuel sectors are refunded a sufficient amount of the carbon charge to maintain output at their 2008 level.
- A verifiably additive offset system to capture agricultural emissions reductions.
- A comprehensive suite of complementary regulations to address market failures, including:
    - Venting and flaring in the oil and gas sector is confined solely to safety purposes, with a carbon charge imposed for all registered safety emissions.
    - All new commercial buildings are built to LEED Gold standard or higher and residential buildings are required to be 50% more efficient than current standard practises. Both are also restrained from directly using fossil fuels in BC, Manitoba and Québec, including natural gas. All other options are allowed.
    - All new vehicles sold meet the California GHG emissions standards, with a gradually tightening standard due to become virtually zero by 2040.
    - As of 2011, white good appliance energy efficiency standards are raised to the most efficient commercially available versions of late 2008.
    - Almost all landfills are required to be covered, and the landfill gas flared or used to produce electricity and heat as the economics warrant.
    - A land use policy to encourage higher density urban form.

We also included a requirement to capture and store (CCS) all formation CO_2 from new natural gas processors, process CO_2 from new hydrogen production facilities, and all combustion CO_2 from all new coal fired electricity plants, oil sands facilities, and upgraders starting in 2011. This regulation, while not associated with a clear market failure, is meant to drive technological innovation and reduce costs associated with CCS use.

The carbon charge and most of the complementary polices are as strong as considered feasible. We tested their effect under two scenarios: one where the OECD countries impose policy as stringent as Canada ("OECD acts together"), and one where Canada goes further than its OECD trading partners ("Canada goes further"). To make up the difference between the target and domestic emissions reductions, purchases of international emissions permits are necessary in both scenarios. In the "OECD acts together" case purchases rising to 49.1 Mt per year in 2020 are necessary, while in the "Canada goes further" case 34.5 Mt of purchases are required.

Some key changes were made to nuclear generation costing in this analysis. Based on French government audits and literature, a 1.3¢/kwh waste and decommissioning charge was added to nuclear generation, as was a 4.0 ¢/kwh liability insurance charge. Nonetheless, the modeling scenario with these costing adjustments predicted the construction of new nuclear generation, a policy outcome with which the David Suzuki Foundation and the Pembina Institute disagree for various reasons, so nuclear generation was limited to existing capacity.

The policy package reduces long term GDP growth up to 3% below its business as usual path in the 2020s, i.e., GDP grows 19.3% instead of 22.1% from 2011 to 2020, and 43.4% instead of 47.4% from 2011 to 2030. Physical output in most sectors is relatively unaffected by the policy package, defined as a drop of less than 10% from business as usual 2020 output. The exceptions are the fossil fuel industries, freight transportation, and the cement and lime production sectors if fixed process emissions are included. Gross output, defined as the dollar value of sales, is significantly affected only in the fossil fuel sectors. The size of the labour force is relatively unchanged, but average salaries rise 11.4% from 2011 through 2020 instead of 18.1% in the business as usual case.

Nitric and adipic acid, solvents, consumption of halocarbons and forestry land-use change were not included in this analysis.

Introduction

In this report M.K. Jaccard and Associates Inc. (MKJA), at the request of the David Suzuki Foundation and the Pembina Institute, used two models of the Canadian energy economy — the CIMS hybrid technology simulation model and the DGEEM dynamic computable general equilibrium model — to explore the feasibility and cost of a 25% reduction in Canada's greenhouse gas (GHG) emissions from 1990 levels by 2020 (i.e., an emissions target of 444 Mt). This is a reduction schedule deeper and faster than most analyzed in the past, especially for Canada, and therefore is as much an exploration of the potential to achieve this kind of reduction as a detailed analysis of its costs and the necessary stringency of policy. This policy was explored under two contrasting global carbon policy scenarios; one where the OECD maintains the same level of carbon price as Canada, and one where Canada's policy is significantly more stringent. The developing countries are assumed to have non-existent or considerably reduced carbon emissions restrictions.

CIMS was used to explore the necessary emissions reductions and the sectoral technology, capital investment, energy, efficiency, and fuel switching implications, while DGEEM was used to explore the system-wide economic impacts, such as changes in GDP, employment, wages, and trade. Once a sufficient carbon price schedule combined with complementary regulations was found in CIMS to achieve the reduction target, DGEEM was run with the policy package to analyze the macroeconomic implications.

This report begins with descriptions of the CIMS and DGEEM models, followed by a description of the policy package and the scenario assumptions that were made. Finally, it concludes with results of the analysis. Appendices further describe CIMS and DGEEM. The last appendix describes the assumptions used to construct the reference case.

Method

Modeling Framework: CIMS

The CIMS model was originally designed as a predecessor to the NEMS model of the US Energy Information Administration, and has been subsequently developed for Canada by MKJA and the Energy and Materials Research Group at Simon Fraser University. It simulates the technological evolution of the energy-using capital stock in the Canadian economy (such as buildings, vehicles, and equipment) and the resulting effect on output, investment, labour and fuel costs, energy use, GHG and CAC emissions, and some material flows. The stock of energy-using capital is tracked in terms of energy service provided (m^2 of lighting or space heating) or units of physical product (metric tons of market pulp or steel). New capital stocks are acquired as a result of time-dependent retirement of existing stocks and growth in stock demand. Market shares of technologies competing to meet new stock demands are determined by standard financial factors as well as behavioral parameters from empirical research on consumer and business consumption and investment preferences. CIMS has three modules — energy supply, energy demand, and macro-economy — that 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 (e.g., it estimates the growth in total passenger travel demand or in airline passenger travel demand). The forecast adopted for this study is described in the reference case appendix.
2. In each time period, some portion of the 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 lifespan. The output of the remaining capital stocks is subtracted from the forecast energy service or product demand to determine the demand for new stocks in each time period.
3. Prospective technologies compete for new capital stock requirements based on financial considerations (capital cost, operating cost), technological considerations (fuel consumption, lifespan), and consumer preferences (perception of risk, status, comfort), as revealed by behavioral-preference research. The model allows both firms and individuals to project future energy and carbon prices with imperfect foresight when choosing between new technologies (somewhere between total myopia and perfect foresight about the future). Market shares are a probabilistic consequence of these various attributes.
4. A competition also occurs to determine whether technologies will be retrofitted or prematurely retired. This is based on the same type of considerations as the competition for new technologies.
5. The model iterates between the macro-economy, energy supply and energy demand modules in each time period until equilibrium is attained, meaning that energy prices, energy demand and product demand are no longer adjusting to changes in each other. Once the final stocks are determined, the model sums energy use, changes in costs, emissions, capital stocks and other relevant outputs.

The key market-share competition in CIMS can be modified by various features depending on 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 30 or more 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, biofuel, 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 move on to the next five-year time period.

The model was recently recalibrated to reflect EC's *National Inventory Report - Greenhouse Gas Sources and Sinks in Canada 1990-2006* as well as EC's online *Criteria Air Contaminant Emissions Summaries: 1990-2015.* We also updated the values from Natural Resources Canada's (NRCan) *Canada's Energy Outlook 2006 (CEO 2006)*, which provides the foundation of CIMS' physical output forecast to 2020, to reflect recently released output, energy and emissions data for 2005 from Natural Resources Canada's *Comprehensive Energy Use Database* and Statistics Canada's *Report on Energy Supply and Demand*. Details of the reference case are provided in an appendix. More on CIMS is also provided in an appendix.

CIMS Limitations and Uncertainties

Like all models, CIMS is a representation of the real world, not a perfect copy. Even though CIMS is very detailed compared to other models used for similar purposes, its broad scope (it represents almost all GHG emissions and 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, climate change or criteria air contaminant policy and to ensure that reference and policy scenarios are grounded in technological and economic reality, including realistic capital stock life and turnover. While care has been taken in representing the engineering and economic parameters of the many technologies in CIMS, including costs, uncertainty exists as to the appropriate cost and operating parameters of specific current and future technologies.

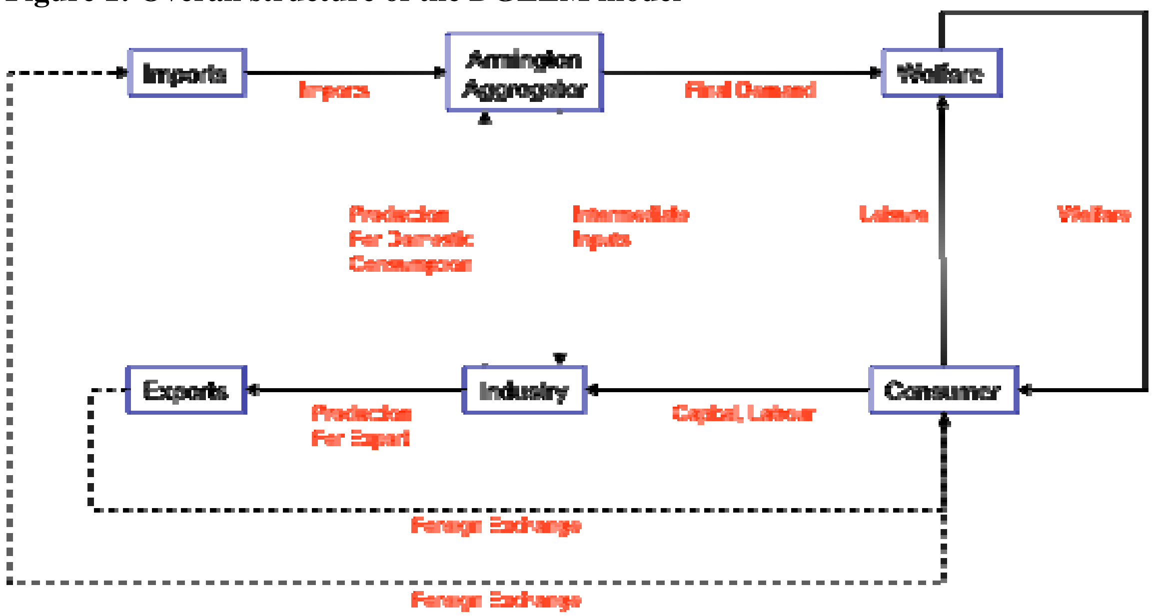
  While CIMS contains a representation of dynamic technological change that depicts how the costs of new technologies can be reduced through economies of scale and production experience based on historical experience, there is no guarantee that these relationships will hold in the future. In addition, CIMS only contains technological options that are known today (including those that are not yet commercialized). By definition, CIMS does not contain a depiction of new technologies that have not yet been invented and as a result, CIMS could miss technological substitution options in later years of the forecast. There are, however, only 12 years to 2020 — 12 years for brand new technologies not currently in CIMS to be invented, prototyped, commercialized and to enter the capital stock. Capital is mostly fairly longed-lived in buildings and industry, and there is simply not enough time for radical change to occur, other than by shutting industrial sectors down. This uncertainty becomes larger over time, but is of more concern after 2025-2030, which limits the concern for this analysis.

- **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; incorporating these 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.
- **External inputs:** CIMS requires external forecasts of macroeconomic activity in each sub-sector: population growth forecasts and starting 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 that are cited in the reference case appendix, and attempt to ensure consistency between various sources, but it is likely that the various inputs we use are not perfectly consistent with one another.
- **Equilibrium feedbacks:** Unlike most computable general equilibrium models (which do not generally contain technological detail), the current version of CIMS, while it does include direct responses of firms and consumers to increased input and final goods prices, does not equilibrate government budgets nor 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. For this reason, using the pricing results from CIMS, we use the DGEEM model of the Canadian economy to estimate the effect of the specified emissions reduction target.

Modeling Framework: DGEEM

DGEEM is a multi-sector, open-economy computable general equilibrium model of the Canadian economy. In the model, a representative consumer is the owner of the primary factors (labour and capital). The consumer rents these factors to producers, who combine them with intermediate inputs to create commodities. These commodities can be sold to other producers (as intermediate inputs), to final consumers, or sold to the rest of the world as exports. Commodities can also be imported from the rest of the world. DGEEM is a small open-economy model – Canada is assumed to be a price taker for internationally traded goods. The key economic flows in DGEEM are captured schematically in Figure 1.

Figure 1: Overall structure of the DGEEM model



DGEEM assumes that all markets clear – prices adjust until supply equals demand. All markets are assumed to be perfectly competitive, such that producers never make excess profits and that supply equals demand. Likewise, factors of production are completely employed, so that there is no involuntary unemployment and no non-productive capital.

Previous versions of DGEEM have used a static framework. In a static framework, the accumulation and depreciation of capital is not modeled explicitly, so the model cannot capture the implications of changes in policy on investment and capital accumulation. Instead, investment capital is modeled as a fixed stock whose overall level does not change in response to changes in economic or environmental policy.

The version of DGEEM used for this project adopts a dynamic framework. In a dynamic framework, consumers are assumed to maximize utility over multiple time periods by choosing an appropriate rate of investment and consumption in each time period. In this approach, investment is directly influenced by changes in policy. Changes in investment cause changes in the level of capital stock that can be employed by firms, which influences overall economic growth and other variables.

Like most computable general equilibrium models, DGEEM imposes the restriction of constant returns to scale on producers to make the model more tractable.[1] Likewise, it imposes the assumption that consumer preferences are homothetic.[2]

The data underlying the model is derived primarily from the Statistics Canada System of National Accounts. We use the S-Level Input, Output, and Final Demand tables to populate the model, and aggregate these to focus on sectors of primary interest.[3] Energy consumption is disaggregated using data from the CIMS model and from the Natural Resources Canada publication *Canada's Energy Outlook: The Reference Case to 2006*.

DGEEM is implemented in GAMS, using the MPS/GE substructure.

An appendix with more information is provided for DGEEM.

DGEEM limitations and uncertainties, and how they interact with CIMS

Like CIMS, DGEEM is a representation of the real world, not a perfect copy. DGEEM is designed to capture the economy as a whole, and especially to integrate consumer demand, labour and capital supply, and the markets for all key inputs and outputs. This comes at the cost of simplifying assumptions. The main uncertainties and limitations in the model are:

- **Depiction of technological and technology dynamics:** Like most CGE models DGEEM makes use of production functions to depict technology and production, which assume a smooth substitution between all inputs at a given rate, depicted as an elasticity. In certain industries, such as services, there does seem to be a relatively smooth substation frontier between capital, labour, energy and materials. In other industries, such as electricity production or the iron and steel industry, this is not the case since fundamentally different technologies can produce the final end product. This phenomenon is not confined to industry; natural gas furnaces or electric resistance heaters can both be used to heat buildings, but have completely different capital and operating cost, energy use, and emissions profiles. It is for these reasons that bottom-up models initially conceived, including the one that evolved into CIMS.
- **Calibration of the social accounting matrix:** Like all calibrated as opposed to estimated CGE models, DGEEM must be calibrated to a given year's input and output of primary factors, goods and services.[4] This creates a base structure from which the model adjusts to policy shocks. If the chosen year is unrepresentative,

[1] Constant returns to scale implies that if all inputs to a firm are doubled, then all outputs are likewise doubled.

[2] Homothetic preferences imply that as consumer income doubles, demand for all goods and services doubles.

[3] The benchmark year for the model is 2000. Data for the year 2000 are based on a three year average of data from 1999, 2000, and 2001 in order to reduce the dependence of the model on statistical quirks from a single year.

[4] Calibrated CGE models operate from a single input output matrix from a given year, where all inputs and outputs are balanced. Estimated CGE models operate from parameters estimated from historical time series.

or economic or technology structure is changing quickly, the outputs of the model may be biased.

- **Forecasts of population, labour-force participation and labour productivity.**

How CIMS and DGEEM relate to each other and the analysis

In sum, DGEEM and CIMS are two different ways of modeling the Canadian energy economy, each with strengths and weaknesses. In this analysis we have treated CIMS as the lead model for emissions responses, capital investment, and fuel and technology choices, and DGEEM as the lead model for macroeconomic responses. DGEEM's production function structure has been calibrated to CIMS' emissions pricing response to ensure the macroeconomic consistency, but we provide CIMS' results for all energy, emissions, and changes in sector output, unit cost, and expenditures on capital, energy and labour. In turn, we have provided DGEEM's responses for changes in GDP, employment and trade.

Modeling the Target

The purpose of this project was to investigate the feasibility and cost of reducing GHG emissions by 25% from 1990 levels by 2020. Given the depth of the emissions target, we have assumed a full auction cap and trade or carbon tax of the necessary stringency to hit the target in 2020, starting with a price of $50/tonne in 2010 with complementary regulations as listed after Table 1. The GHG price path, which also assumes a steady rise to $300/t by 2030, is shown in Table 1.

Table 1: Projected emissions prices ($/tonne CO_2e $2005) for covered emissions

2010	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*
50	65	80	95	110	125	140	155	170	185	200
2021	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*	*2031->*
210	220	230	240	250	260	270	280	290	300	300

The complementary regulations, based on market failures, were as follows:

- Venting and flaring in the oil and gas sector are confined solely to safety purposes, with a carbon charge imposed for all safety orientated emissions.
- To simulate urban sprawl containment, the urban footprint of single-family homes was constrained to its forecast 2010 level, and all new housing growth is redirected to higher density housing. This policy is a proxy for a more sophisticated land use planning policy to reduce GHG emissions through reduced transportation and buildings emissions.
- All new commercial buildings are built to LEED Gold standard or higher, and are restrained from directly using fossil fuels, including natural gas, in BC, Manitoba and Québec. All other options, including heat pumps, ground source heat pumps, and electric resistance heating are allowed.
- All new residential housing is built to an energy efficiency standard 50% higher than today's norm for new housing, and are restrained from directly using fossil

fuels, including natural gas, in BC, Manitoba and Québec. All other options, including heat pumps, ground source heat pumps, and electric resistance heating are allowed.

- All new vehicles sold meet the California GHG emissions standards, with expectation of a gradually tightening standard due to become virtually zero beyond the horizon of this analysis.
- As of 2011, white good appliance energy efficiency standards are raised to the most efficient commercially available versions of late 2008.
- Almost all landfills are required to be covered, and the captured landfill gas emissions flared to reduce the CO_2 forcing potential or used to produce some combination of electricity and heat as the economics warrant.

We also included a requirement to capture and store (CCS) all formation CO_2 from new natural gas processors, and all combustion CO_2 from all new coal fired electricity plants, oil sands facilities, and upgraders starting in 2011. This regulation, while not associated with a clear market failure is meant to drive technological innovation and reduce costs associated with CCS use.

To prevent undue economic dislocation, a rule was also followed for the non-fossil fuel sectors whereby sufficient carbon revenue was returned to a sector to at least maintain production at 2008 levels, i.e., to maintain employment and investment already in place. Two sectors - metal smelting and industrial minerals - required this support in the "Canada goes further" scenario.

We have assumed the same package of carbon pricing and complementary regulations under two opposing "bookend" scenarios: one where Canada's OECD trading partners maintain a carbon policy as strict as Canada's ("OECD acts together"), and one where "Canada goes further" and Canada's carbon pricing policy is significantly more stringent than that of its trading partners. Because of the uncertainty surrounding future OECD and developing world climate policy, these two contrasting scenarios should be thought of as learning tools and not strict predictions of future events – they provide our best estimate of the bounds of the effect of carbon competitiveness effects. As will be seen, these effects are potentially significant for a couple of sectors, but not for the economy as a whole.

Emissions reductions from the policy package were not quite large enough in either scenario to hit the target in 2020, even given the carbon price path and the regulations. The price and regulations are considered as strong as they may realistically be, so a further 49.1 Mt of international permit purchases are made in 2020 in the "OECD acts together" case, an amount sufficient to hit the target once added to the domestic reductions; the detailed permit purchase schedule from 2010 through 2020 is provided in the results section. In the "Canada goes further" case, 34.5 Mt of permits were required in 2020.

Scenario Assumptions

In order to determine the GHG abatement opportunities in the Canadian economy over time, we use the concept of a reference scenario and a policy scenario. The reference scenario shows how the Canadian economy might evolve in the absence of specific new policies to reduce GHG emissions, while the policy scenario shows how the economy might evolve under the policy package. The difference between the two scenarios is due to the effect of the policy. When doing this type of analysis, many assumptions need to be made. Some key overall conditions include:

- *In the "OECD acts together" scenario we have assumed that Canada's OECD trading partners impose GHG policy at least as stringent as Canada's.* This assumption has important impacts on how the policy affects Canada's trade in industrial goods, and is realized in CIMS' macroeconomic module. CIMS simulates international trade by using Armington substitution elasticities to proxy the demand for traded goods. These elasticities were calculated for use in the Finance Canada CASGEM model, and we use them to operate as price elasticities in CIMS.[5][6] These elasticities represent how the domestic and foreign demand for Canadian products might change in response to changes in the cost of domestic production, and are a composite of domestic and foreign demand for Canadian traded goods, i.e., if the elasticity is -1, and price goes up 1%, demands fall 1%. The Armington formulation is a composite of the propensity of customers of Canadian goods to substitute foreign equivalents and the end-use demand for a given good. If Canada's major trading partners have similar climate policies, their costs of production would presumably change in a similar magnitude to Canada, reducing the propensity of customers of Canadian goods to substitute foreign equivalents because the relative prices remain the same (i.e., they go up in all regions). It does not, however, reduce the propensity for them to substitute low carbon equivalents (i.e., to replace high carbon cement with lower carbon building materials); because the price of carbon intense goods has gone up in all regions, demand falls in all regions subject to its own price elasticity. We use our best judgement to reduce the Armington elasticities to remove the effect of the first component, and preserve the end-use demand effect. *In the second "Canada goes further" scenario we have assumed that while the OECD and the US in particular could impose carbon pricing, Canada imposes sufficiently stronger carbon pricing (approximately 50-100% greater) that it can be considered to be "acting alone",* and the Armington elasticities were adjusted accordingly.

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[5] The Armington elasticities in CIMS are from Wirjanto, T. (1999)."Estimation of Import and Export Elasticities: A report prepared for the Economic and Fiscal Policy Branch at the Department of Finance." Department of Economics, University of Waterloo

[6] For details of CIMS' macroeconomic mechanics see Bataille, C., M. Jaccard, J. Nyboer and N. Rivers. (2006). "Towards General Equilibrium in a Technology-Rich Model with Empirically Estimated Behavioral Parameters." In *Hybrid Modeling: New Answers to Old Challenges, Special Issue of the Energy Journal*, 27:93-112.

- *We have assumed the carbon pricing and complementary regulations are at least as stringent following 2020 as they are in 2020.* Firms and consumers in CIMS make investment and consumption decisions with limited foresight of future emissions prices. The carbon price is assumed to rise to \$300/tonne CO_2e by 2030. As a result, consumers factor this in to some degree in decisions made prior to 2021.
- *NRCan's "Canada's Energy Outlook 2006" was considered to be the starting point for output and energy data* because of its comprehensiveness and status as Canada's national energy use forecast. *EC's GHG Inventory was considered the starting points for all emissions intensity data* because of its comprehensiveness and status as Canada's national emissions forecast, as are EC's emissions coefficients for fuel combustion. When NRCan's energy use is calculated by EC's emissions coefficients, the results do not always match, but we have attempted to reconcile them as best as possible. The differences are most significant in the upstream oil and gas sector, specifically the combustion coefficients associated with upstream and transmission oil and gas fugitives. All forecast values have been updated for the most recent official historical data.
- *We have allowed domestic and export demand for crude oil to fluctuate in response to the cost of producing it.* While there are substantial economic rents associated with crude oil when prices are high (>\$50/barrel), in the long run its output is sensitive to the cost of producing oil and long run expectations of demand and prices. In our analysis we have assumed minimal rents; as domestic demand rises and falls, and as export demand rises and falls, we assume changes in the cost of production translate into changes in price, with appropriate responses in demand. *We have also allowed natural gas production to fluctuate based on its cost of production, and how this affects the price and demand.* There is substantial uncertainty what will happen to Canadian gas production in a carbon limited North America. Domestic consumption of natural gas drops significantly under both scenarios, but if the United States imposes any sort of carbon restrictions, as we have assumed, it will need to make significant efforts to decarbonize its electricity system. This will likely involve a substantial switch from coal to natural gas generation, which will likely require some combination of more LNG imports, shale gas production, and Mexican and Canadian gas imports. Given there are pressures to both increase and reduce gas production in a carbon limited world, we experimented with both fixed and flexible NG production, and finally chose flexible production for harmonization with the macroeconomic analysis.
- *The emissions charge policy simulated here is based on a cap and trade with full auction, or a carbon tax, with any revenue attained from the emissions charge recycled to households and labour taxes.* The revenue recycling worked as follows:
  (1) Permit/tax revenues are collected by government.

(2) Sufficient revenues were returned to non-fossil fuel production sectors to maintain 2005 BAU output (i.e., 50% of carbon revenues were returned to industrial minerals and metal smelting in the “Canada goes further” scenario).
(3) Government uses these revenues, along with all other tax receipts, to finance purchases of public goods (health care, defence, education, roads, etc.). The quantity of provision of public goods remains the same in the policy and BAU cases (even though the price of provision may change in response to a policy).
(4) Government transfers enough of the total tax revenues back to households to maintain transfers between government and households at the same level in BAU and under the policy package.
(5) If there is still money left over, it is used to lower the labour tax rate, until the government budget is balanced. Labour income taxes are lowered, not transfer mechanisms like Employment Insurance and Canada Pension Plan.

- Agricultural emissions reductions, which rise to 7.3 Mt in 2020, are assumed to be strictly additional and verifiable with adequate government enforcement to ensure additionality and verifiability. The agricultural emissions model in CIMS was designed to incorporate only those emissions reductions that are highly likely to be additional, verifiable and resistant to free-ridership, and its estimate of emissions reductions is used for this analysis. Further, it is assumed government purchases these emissions reductions, not industry, with the appropriate monetary flows.

Results

We provide first emissions reductions, key emission reduction actions, changes in physical output, and capital, labour and energy costs from CIMS. We then provide the changes in GDP, wages, employment, and trade from DGEEM.

CIMS – Sector, emissions, investment and energy impacts

Table 2 provides the annual reductions in emissions by sector and for the whole economy under the influence of the policy package.

Table 2: Annual reduction of all GHG emissions (Mt CO_2e) from BAU to Policy

	2010		*2015*		*2020*	
	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further
Residential	7.1	7.2	18.9	18.9	28.5	28.5
Commercial	3.1	3.1	12.0	12.0	22.5	22.5
Personal Trans.	3.6	3.6	11.9	11.9	28.3	28.3
Freight Trans.	12.8	12.9	36.7	37.0	60.4	61.2
Chemical Products	0.1	0.3	2.6	3.3	4.3	5.0
Industrial Minerals	0.6	1.2	3.1	4.4	6.4	7.5
Iron and Steel	0.2	0.2	0.6	1.2	0.8	2.0
Metal Smelting	0.1	0.3	0.4	0.6	0.7	1.0
Mineral Mining	0.2	0.3	0.6	1.2	1.0	1.9
Paper Manufacturing	0.1	0.2	0.2	0.4	0.2	0.4
Other Manufacturing	2.1	2.2	4.4	4.6	7.1	7.4
Agriculture	0.8	0.8	4.6	4.6	7.2	7.3
Waste	1.6	1.6	24.9	24.9	25.7	25.7
Electricity	6.8	7.0	24.1	24.9	38.3	39.3
Petroleum Refining	1.4	1.4	5.4	5.5	10.3	10.3
Petroleum Crude Extr.	6.3	6.7	56.0	59.0	94.9	99.1
Natural Gas Extraction	3.5	3.5	18.5	20.9	21.5	25.1
Coal Mining	0.1	0.1	0.3	0.4	0.5	0.5
Ethanol	0.0	0.0	-0.3	-0.3	-0.4	-0.4
Biodiesel	0.0	0.0	-1.3	-1.2	-2.4	-2.4
Total	**50.5**	**52.5**	**223.7**	**234.2**	**355.8**	**370.3**

Emissions reductions were 14.5 Mt greater in the "Canada goes further" scenario in 2020, a small (3.9%) portion of the overall reduction of 370.3 Mt. The differences between the two scenarios, mainly increased reduction in output, were significant only for a few sectors: industrial minerals, chemical products, metal smelting and natural gas and petroleum crude extraction. Only two sectors, metal smelting and industrial minerals, qualified for carbon revenue returns to keep output at its 2008 level; each was returned 50% of its carbon charges after the sectors made their investment decisions.

The biggest reductions come from petroleum crude extraction (94.9 to 99.1 Mt in 2020 depending on the scenario), freight transportation (60.4 to 61.2 Mt), electricity (38.3 to 39.2 Mt), personal transportation (28.3 Mt), residential and commercial buildings (28.5 to 22.5 Mt), natural gas extraction (21.5 to 25.1 Mt) and the landfill waste sector (25.7 Mt). These reductions are due to capital investment in energy and GHG efficiency measures (e.g., CCS), fuel switching, and output reductions in a couple of key sectors. The overall reductions are 34.5 to 49.1 Mt short of the target in 2020, and it is assumed this is made up through international permit purchases – the cost and foreign exchange requirements associated with this are included in the DGEEM macroeconomic analysis.

Table 3 provides the annual reductions expressed as percentages compared to the reference case (i.e., BAU 2020 is compared to Policy 2020). Again, there are very small differences between the scenarios. The very large percentage increases in biodiesel and ethanol are due to the very low starting values.

Table 3: Annual % reduction of all GHG emissions (Mt CO_2e) from BAU to Policy

	2010		*2015*		*2020*	
	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further
Residential	18%	19%	49%	49%	72%	72%
Commercial	9%	9%	32%	32%	55%	55%
Personal Trans.	3%	3%	11%	11%	24%	24%
Freight Trans.	13%	13%	33%	33%	47%	48%
Chemical Products	1%	2%	21%	27%	35%	40%
Industrial Minerals	4%	7%	17%	24%	33%	38%
Iron and Steel	1%	2%	5%	9%	5%	14%
Metal Smelting	1%	3%	4%	7%	9%	12%
Mineral Mining	4%	6%	12%	23%	18%	37%
Paper Manufacturing	1%	3%	3%	7%	6%	11%
Other Manufacturing	10%	11%	19%	20%	27%	28%
Agriculture	2%	2%	10%	10%	15%	15%
Waste	6%	6%	84%	84%	84%	84%
Electricity	6%	6%	21%	22%	35%	36%
Petroleum Refining	7%	7%	25%	25%	42%	43%
Petroleum Crude Ext.	7%	7%	41%	44%	58%	61%
Natural Gas Ext.	5%	6%	29%	33%	39%	45%
Coal Mining	4%	4%	14%	16%	19%	22%
Ethanol	-247%	-248%	-2323%	-2342%	-2088%	-2102%
Biodiesel	-62%	-60%	-1024%	-1010%	-1560%	-1529%
Total	**7%**	**7%**	**28%**	**29%**	**42%**	**44%**

Table 4 provides the emissions reductions by sector and region for the "OECD acts together" scenario, and Table 5 describes them for the "Canada goes further" scenario. Most reductions occur in Alberta (168.5 Mt / 45%) and Ontario (81.9 Mt / 22%), with 25% (93.2 Mt) of all reduction occurring in the Alberta Petroleum Crude sector.

Emissions reductions are greatest in the petroleum crude sector (27%), freight transportation (17%) and electricity (11%).

Table 4: Emissions reductions in 2020 by sector and region (Mt CO_2e) from BAU to Policy "OECD acts together"

	BC	AB	SK	MB	ON	PQ	ATL	∑	%
Residential	2.1	5.6	0.8	0.6	15.3	3.0	1.1	28.5	8%
Commercial	2.1	3.6	0.9	0.7	11.3	2.3	1.6	22.5	6%
Personal Trans.	4.0	3.0	0.8	0.8	10.6	7.0	2.0	28.2	8%
Freight Trans.	10.2	10.7	2.3	1.3	20.6	9.7	5.6	60.4	17%
Chemicals	0.1	3.5	0.0	0.0	0.4	0.3	0.0	4.3	1%
Ind. Minerals	0.7	0.8	0.0	0.0	3.9	0.9	0.0	6.3	2%
Iron and Steel	0.0	0.0	0.0	0.0	0.7	0.0	0.1	0.8	0%
Metal Smelting	0.1	0.0	0.0	0.0	0.1	0.5	0.0	0.7	0%
Mineral Mining	0.1	0.0	0.4	0.0	0.1	0.2	0.1	0.9	0%
Paper Mnftg	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0%
Other Mnftg	2.0	0.7	0.0	0.2	2.4	1.5	0.3	7.1	2%
Agriculture	0.3	1.5	1.1	1.5	1.6	1.0	0.3	7.3	2%
Waste	4.8	2.6	0.9	0.9	7.1	7.1	2.4	25.8	7%
Electricity	0.3	26.1	8.5	-1.3	1.4	0.6	2.8	38.4	11%
Pet. Refining	1.3	1.9	0.3	0.0	4.2	1.6	1.0	10.3	3%
Pet. Crude Ext.	0.4	90.3	4.0	0.0	0.0	0.0	0.1	94.8	27%
NG Ext.	6.9	11.5	1.5	0.1	0.6	0.0	0.8	21.4	6%
Coal Mining	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.5	0%
Ethanol	-0.1	0.0	0.0	0.0	-0.1	-0.1	0.0	-0.3	0%
Biodiesel	-0.2	-0.5	-0.2	0.0	-0.9	-0.3	-0.3	-2.4	-1%
Total	**35.4**	**161.5**	**21.4**	**4.8**	**79.3**	**35.41**	**17.9**	**355.7**	**100%**
%	10%	45%	6%	1%	22%	10%	5%	100%	

Table 5: Emissions reductions in 2020 by sector and region (Mt CO_2e) from BAU to Policy "Canada goes further"

	BC	AB	SK	MB	ON	PQ	ATL	∑	%
Residential	2.1	5.6	0.8	0.6	15.3	3.0	1.1	28.5	8%
Commercial	2.1	3.6	0.9	0.7	11.3	2.3	1.6	22.5	6%
Personal Trans.	4.1	3.0	0.8	0.8	10.6	7.0	2.0	28.3	8%
Freight Trans.	10.5	10.7	2.4	1.3	20.9	9.8	5.7	61.3	17%
Chemicals	0.1	4.1	0.0	0.0	0.5	0.3	0.0	5.0	1%
Ind. Minerals	1.0	1.0	0.0	0.0	4.1	1.2	0.2	7.5	2%
Iron and Steel	0.0	0.0	0.0	0.0	2.0	0.0	0.0	2.0	1%
Metal Smelting	0.1	0.0	0.0	0.1	0.1	0.7	0.1	1.1	0%
Mineral Mining	0.1	0.0	1.3	0.0	0.1	0.2	0.2	1.9	1%
Paper Mnftg	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.3	0%
Other Mnftg	2.1	0.8	0.0	0.2	2.5	1.5	0.3	7.4	2%
Agriculture	0.3	1.5	1.1	1.5	1.6	1.0	0.3	7.3	2%
Waste	4.8	2.6	0.9	0.9	7.1	7.1	2.4	25.8	7%
Electricity	0.3	26.8	8.7	-1.3	1.5	0.6	2.8	39.4	11%
Pet. Refining	1.3	1.9	0.3	0.0	4.2	1.6	1.0	10.3	3%
Pet. Crude Ext.	0.4	93.2	5.3	0.0	0.0	0.0	0.1	99.0	27%
NG Ext.	7.3	13.9	1.8	0.1	1.0	0.1	0.9	25.1	7%
Coal Mining	0.2	0.3	0.1	0.0	0.0	0.0	0.0	0.6	0%
Ethanol	-0.1	0.0	0.0	0.0	-0.1	-0.1	0.0	-0.3	0%
Biodiesel	-0.2	-0.5	-0.2	0.0	-0.9	-0.2	-0.3	-2.3	-1%
Total	**36.6**	**168.5**	**24.2**	**4.9**	**81.9**	**36.2**	**18.4**	**370.7**	**100%**
%	10%	45%	7%	1%	22%	10%	5%	100%	

Table 6 and Figure 2 describe the actions taken to reduce GHGs out to 2020 in the "OECD acts together" scenario, assuming the policy package remains at the same stringency out to 2030 (i.e., complementary regulations plus \$300/tonne CO_2e). Figure 3 and Table 7 provide the same for when "Canada goes further". In the short to medium run out to 2020, the most important actions are:

- Carbon capture and storage (105 Mt in 2020 in "OECD acts together" and 94 Mt in "Canada goes further"). In early years this is primarily from relatively pure CO_2 sources, such as formation CO_2 from natural gas processing and CO_2 from steam reformation of methane to produce hydrogen.
- Energy efficiency (62 Mt in 2020 in "OECD acts together" and 63 Mt in "Canada goes further"), primarily in the personal and freight transportation sectors.
- Other GHG control (55 Mt in 2020 in "OECD acts together" and 60 Mt in "Canada goes further"), which includes control of fugitives in upstream oil and gas, and capping, flaring and cogeneration of landfill gas
- International permit purchases (49 Mt in 2020 in "OECD acts together" and 35 Mt in "Canada goes further")
- Switching to electricity in all sectors, including buildings (48 Mt in 2020 in "OECD acts together" and 47 Mt in "Canada goes further")

- Switching to renewables in electricity production (43 Mt in 2020 in “OECD acts together” and 42 Mt in “Canada goes further”). This is largely hydro and wind.
- Output reductions (24 Mt in 2020 in “OECD acts together” and 48 Mt in “Canada goes further”), mostly reduced output in the entire fossil fuel industry.

Table 6: Actions taken to reduce emissions "OECD acts together", Mt CO_2e

	2005	*2010*	*2015*	*2020*
Baseline emissions	711*	738	797	849
Policy Emissions	711	688	574	493
Emissions reductions				
Carbon Capture And Storage	0	1	59	105
Energy Efficiency	0	21	42	62
Other GHG Control (waste and oil &gas fugitives)	0	8	47	55
Fuel Switching to Electricity	0	9	26	48
Fuel Switching to Renewables	0	5	21	43
Output Reduction	0	4	18	24
CCS Energy Efficiency Penalty	0	0	6	12
Fuel Switching to Other Fuels	0	0	5	8
Fuel Switching to Nuclear	0	0	0	0
International Permit purchases	0	5	27	49
Target = Baseline - policy emissions – reduction actions - permit purchases				444

*Note: Does not match EC GHG inventory because it includes BAU carbon sequestration in agriculture. Land use change in forestry is not included, and neither are nitric and adipic acid production, solvents or HFCs.

Figure 2: Emission reduction actions "OECD acts together"

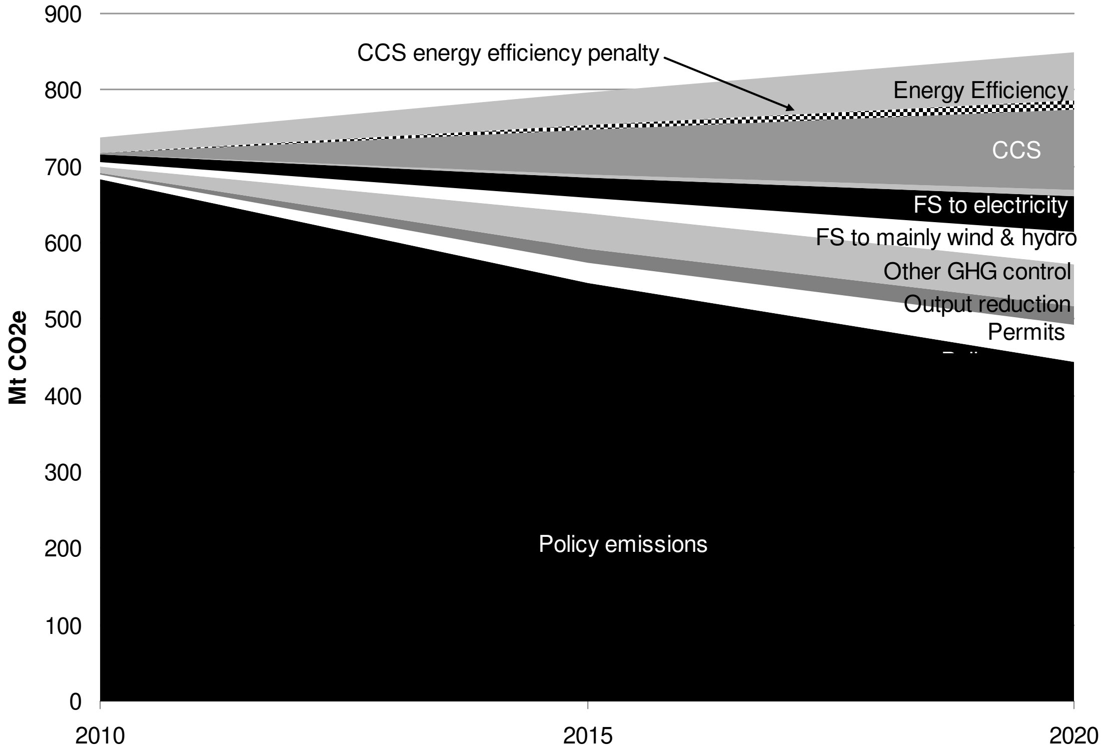
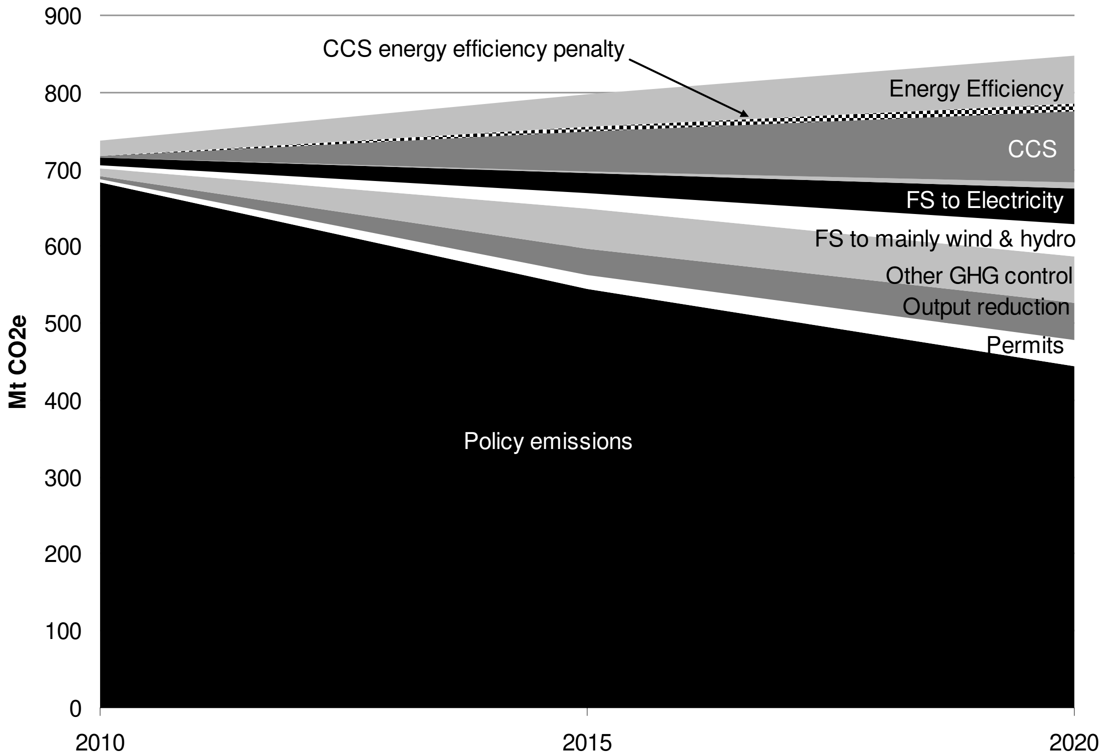


Table 7: Actions taken to reduce emissions "Canada goes further"

	2005	*2010*	*2015*	*2020*
Baseline emissions	711*	738	797	849
Policy Emissions	710	686	563	479
Emissions reductions				
Carbon Capture And Storage	0	1	52	94
Energy Efficiency	0	21	42	63
Other GHG Control (waste and oil &gas fugitives)	0	9	50	60
Output Reduction	5	5	34	48
Fuel Switching to Electricity	0	10	26	47
Fuel Switching to Renewables	0	5	20	42
CCS Energy Efficiency Penalty	0	0	5	10
Fuel Switching to Other Fuels	-4	0	4	7
Fuel Switching to Nuclear	0	0	0	0
International Permit purchases	0	3	19	35
Target = Baseline - policy emissions – reduction actions - permit purchases				444

*Note: Does not match EC GHG inventory because it includes BAU carbon sequestration in agriculture

Figure 3: Emission reduction actions "Canada goes further" , Mt CO_2e



The necessary capital investment, operations, and fuel switching changes in each sector engender changes in capital, energy, labour and emissions costs. Output impacts, which are included in these values, will be discussed later. Table 8 through to Table 11 document, by sector:

- the changes in capital expenditure for energy using and producing capital stock;
- changes in labour related to energy using and producing capital stock;
- changes in energy costs; and
- payments for emissions (which are transfers within the economy).

Table 8: Increase in annual capital costs ($2005 millions) from BAU to policy case

	2010		*2015*		*2020*	
	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further
Residential	196	204	1,132	1,151	122	118
Commercial	-1,413	-1,399	-524	-473	566	560
Personal Trans.	-2,107	-2,106	-7,827	-7,825	-6,084	-6,084
Freight Trans.	-1,939	-1,981	-4,547	-4,682	-3,480	-3,892
Chemical Products	-23	-82	53	-112	59	-91
Industrial Minerals	-18	-66	-12	-88	168	21
Iron and Steel	0	-12	-50	-152	-36	-140
Metal Smelting	-22	-70	-59	-119	-30	-60
Mineral Mining	-25	-93	-181	-576	-99	-384
Paper Manufacturing	-124	-472	-104	-438	-14	-147
Other Manufacturing	-22	-52	-7	-36	1	-20
Agriculture	-13	-13	-83	-83	-43	-43
Waste	11	11	204	204	51	50
Electricity	7,353	6,951	10,658	9,279	12,081	11,268
Petroleum Refining	-115	-116	-64	-74	-209	-213
Petroleum Crude Ext.	72	-1	3,436	628	2,821	1,626
Natural Gas Ext.	-594	-643	-885	-1,460	-781	-1,169
Coal Mining	-87	-89	-50	-81	-43	-61
Ethanol	1	1	41	41	330	332
Biodiesel	25	24	880	867	1,194	1,147
Total	**1,158**	**-3**	**2,008**	**-4,028**	**6,570**	**2,817**

The capital investment patterns differ significantly between the two scenarios. In general, more capital is required in the "OECD acts together" case than the "Canada goes further" case. Output falls less, and therefore more capital is required to decarbonise electricity generation equipment, buildings, industrial machinery, rolling stock, etc.

Differences between the sectors are evident, with the largest impacts on the transport and electricity sectors. Just under $10 billion less capital is invested and spent annually in the transport sector in 2020, mainly because more efficient vehicles tend to be smaller. There is also significant mode shifting in both personal and freight transportation, both of which reduce capital expenditure. There may be disagreement as to whether these reductions should be directly construed as benefits as consumers and firms are induced to use different vehicles and modes than they would have chosen in the reference case, implying a reduction in welfare and profits. It is beyond the scope of this analysis to fully analyze the costs and benefits of mode switching and the use of smaller, more efficient vehicles, as it would require discussion of the welfare impacts of urban form and its amenability to transit, impacts on local air quality, and host of other issues.

Another sector with significant changes in capital investment is the electricity sector whose requirements for capital have risen by $11-$12 billion annually by 2020. This is due to across-the-board fuel switching to electricity, further impelled by regulations prohibiting direct use of fossil fuels for space and water heating for all new buildings in commercial and residential in BC, Manitoba, and Québec. Electricity production is one of the lowest cost areas to achieve low and zero GHG energy production, and its use goes up markedly across the economy.

Table 9 describes the changes in labour or equivalent time expenditures (e.g., in transportation) directly associated with energy using capital in the economy. A wider picture of the impacts on labour will be provided in the DGEEM macroeconomic section following the CIMS results. The labour results roughly match the impact of the capital results.

Table 9: Increase in annual operating & maintenance costs ($2005 million) from BAU to policy case

	2010		*2015*		*2020*	
	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further
Residential	-4	-4	-20	-20	-33	-33
Commercial	-3	-3	-16	-16	-28	-28
Personal Trans.	-980	-980	-3,041	-3,041	-4,849	-4,849
Freight Trans.	-2,503	-2,511	-5,595	-5,640	-8,128	-8,260
Chemical Products	-4	-16	4	-51	13	-70
Industrial Minerals	-1	-8	12	-6	29	-3
Iron and Steel	-10	-24	-79	-217	-117	-374
Metal Smelting	-7	-23	-32	-62	-52	-89
Mineral Mining	-5	-17	-40	-138	-60	-208
Paper Manufacturing	-40	-122	-57	-227	-62	-258
Other Manufacturing	-3	-9	-3	-15	-2	-18
Agriculture	33	33	116	116	158	158
Waste	5	5	103	102	125	125
Electricity	763	721	1,745	1,566	2,857	2,597
Petroleum Refining	-124	-125	-277	-283	-495	-505
Petroleum Crude Ext.	-227	-286	-775	-2,569	-1,025	-3,601
Natural Gas Ext.	-230	-244	-766	-1,267	-1,288	-2,087
Coal Mining	-22	-22	-33	-41	-44	-56
Ethanol	5	5	61	62	544	543
Biodiesel	52	51	1,921	1,892	4,351	4,228
Total	**-3,305**	**-3,580**	**-6,774**	**-9,855**	**-8,106**	**-12,787**

Table 10 describes the changes in annual energy expenditures by sector. There are significant differences between the sectors. Both scenarios have considerable savings in early years, but these continue only in the tighter “Canada goes further” scenario where $6.0 to $7.0 billion is saved annually. The residential and commercial sectors spend more due to the enforced switch away from direct fossil fuel use in Québec, BC and

Manitoba. Considerable amounts are saved in the transport sector due to efficiency and mode shifting.

Table 10: Increase in annual fuel costs ($2005 million) from BAU to policy case

	2010		*2015*		*2020*	
	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further
Residential	165	120	2,802	2,684	4,473	4,397
Commercial	-142	-178	1,407	1,294	1,732	1,644
Personal Trans.	-1,601	-1,602	-3,702	-3,705	-5,645	-5,650
Freight Trans.	-4,672	-4,709	-6,323	-6,483	-5,724	-6,263
Chemical Products	25	-22	296	-10	379	-118
Industrial Minerals	25	5	52	-2	35	-51
Iron and Steel	-31	-39	-48	-94	-66	-172
Metal Smelting	100	61	188	98	205	95
Mineral Mining	22	-21	206	-54	252	-165
Paper Manufacturing	-6	-112	234	-27	226	-42
Other Manufacturing	47	-11	487	348	576	395
Agriculture	30	27	383	375	659	656
Waste	-7	-7	-203	-202	-325	-325
Electricity	-121	-152	-470	-691	-744	-1,109
Petroleum Refining	-103	-106	-183	-210	-384	-421
Petroleum Crude Ext.	46	-7	1,651	302	2,984	1,028
Natural Gas Ext.	-240	-271	-269	-733	-620	-1,215
Coal Mining	-14	-15	38	26	58	41
Ethanol	4	4	28	28	61	60
Biodiesel	13	12	481	471	1,057	1,018
Total	**-6,463**	**-7,023**	**-2,945**	**-6,584**	**-811**	**-6,197**

Table 11 shows the direct average annual payments made for emissions by all sectors. These revenues are recycled as described earlier. The amounts involved are considerable, rising from $30.4 billion in the "OECD acts together" case and $30.5 billion in the "Canada goes further" case in 2010, to $89.5-86.6 billion in 2020. Half of the sector specific revenue is returned in the cases of the industrial minerals and metals smelting sectors in the "Canada goes further" scenario.

Table 11: Average annual emissions charge costs that are recycled as reduced labour taxes ($2005 million)

	2010		*2015*		*2020*	
	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further
Residential	1,573	1,572	2,504	2,503	2,229	2,228
Commercial	1,620	1,620	3,225	3,226	3,643	3,643
Personal Trans.	5,016	5,016	12,126	12,125	17,878	17,879
Freight Trans.	4,133	4,128	9,514	9,475	13,652	13,495
Chemical Products	580	572	1,202	1,110	1,613	1,474
Industrial Minerals	793	763	1,870	1,715	2,632	2,429
Iron and Steel	713	710	1,665	1,589	2,664	2,410
Metal Smelting	527	520	1,141	1,114	1,562	1,510
Mineral Mining	254	250	585	509	866	671
Paper Manufacturing	295	292	595	571	723	687
Other Manufacturing	926	920	2,358	2,332	3,842	3,790
Electricity	5,600	5,587	11,073	10,973	14,044	13,829
Petroleum Refining	943	942	2,073	2,069	2,801	2,787
Petroleum Crude Ext.	4,427	4,410	9,903	9,531	13,488	12,643
Natural Gas Ext.	3,013	3,009	5,535	5,226	6,851	6,123
Coal Mining	106	105	255	250	416	401
Ethanol	1	1	36	37	78	78
Biodiesel	6	6	172	170	512	502
Total	**30,525**	**30,422**	**65,831**	**64,524**	**89,494**	**86,581**

Table 12 describes the impact of the increased production costs on physical output in each sector (note this is physical output, not gross output in dollar terms). The most heavily impacted sectors are industrial minerals (-8 to 19%, limited by revenue recycling sufficient to maintain estimated 2008 production), petroleum refining (-30 to 31%), petroleum crude extraction (-9 to -20%), and natural gas extraction (-21 to -30%). Electricity production rises 18-20% by 2020 to accommodate fuel switching. These results do not include any form of border tax adjustment to value imports according to their GHG content; these would alleviate the impacts, but also increase emissions.

Table 12: Projected annual % reduction in physical output from the business as usual case to the policy case

	2010		*2015*		*2020*	
	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further
Residential	-2%	-2%	-4%	-4%	-4%	-4%
Commercial	-1%	-1%	-6%	-6%	-8%	-8%
Personal Trans.	0%	0%	-2%	-2%	-2%	-2%
Freight Trans.	-6%	-6%	-9%	-10%	-11%	-12%
Chemical Products	0%	-1%	-2%	-5%	-2%	-7%
Industrial Minerals	-2%	-6%	-6%	-14%	-8%	-19%
Iron and Steel	0%	-1%	-2%	-5%	-2%	-9%
Metal Smelting	-1%	-2%	-2%	-6%	-3%	-8%
Mineral Mining	0%	0%	-1%	-3%	-2%	-5%
Paper Manufacturing	-1%	-5%	-2%	-8%	-3%	-9%
Other Manufacturing	0%	-1%	-1%	-2%	-1%	-2%
Electricity	6%	6%	13%	11%	20%	18%
Petroleum Refining	-7%	-7%	-18%	-18%	-30%	-31%
Petroleum Crude Ext.	-2%	-3%	-7%	-16%	-9%	-20%
Natural Gas Ext.	-3%	-4%	-12%	-18%	-21%	-30%
Coal Mining	-10%	-10%	-14%	-17%	-17%	-21%
Ethanol	252%	253%	1900%	1910%	11910%	11881%
Biodiesel	77%	75%	1631%	1606%	2834%	2754%
Total	-2%	-2%	-4%	-4%	-4%	-4%

To provide perspective, **Table 13** provides the change in physical output from 2005 to 2020 in the policy cases. Except for the refining and natural gas sectors, which fall 18% and 28% respectively, and the metal smelting and industrial minerals sectors, which receive rebates of 50% of their carbon charge costs in the "Canada goes further" scenario, no sector actually reduces output from 2005 levels in 2020.[7]

In an environment where all of North America is reducing emissions, there is some uncertainty that Canada's natural gas output will fall. The price of NG, based on its relatively low GHG intensity and utility for making electricity, could stay high enough to maintain Canadian production. We will further explore the impacts on this sector in the next version of this analysis.

Table 13: Projected increase in physical output from 2005 to 2020 in the policy case

	2010		*2015*		*2020*	
	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further
Residential	5%	5%	9%	10%	16%	16%
Commercial	10%	10%	16%	17%	29%	29%
Personal Trans.	20%	20%	34%	34%	50%	50%
Freight Trans.	11%	11%	19%	19%	29%	27%
Chemical Products	6%	5%	11%	7%	17%	11%
Industrial Minerals	6%	2%	12%	3%	18%	4%
Iron and Steel	4%	3%	8%	4%	13%	5%
Metal Smelting	5%	3%	3%	0%	4%	0%
Mineral Mining	6%	6%	9%	6%	10%	6%
Paper Manufacturing	0%	-3%	3%	-3%	7%	0%
Other Manufacturing	13%	12%	27%	25%	42%	40%
Electricity	13%	12%	26%	24%	42%	39%
Petroleum Refining	-4%	-4%	-10%	-10%	-18%	-18%
Petroleum Crude Ext.	28%	27%	54%	39%	71%	50%
Natural Gas Ext.	0%	0%	-1%	-7%	-18%	-28%
Coal Mining	-4%	-5%	1%	-3%	7%	1%
Ethanol	1765%	1771%	17326%	17415%	151663%	151304%
Biodiesel	360%	356%	7748%	7637%	17220%	16748%
Total	5%	5%	9%	10%	16%	16%

One of the key emissions reduction actions is decarbonization of electricity, and fuel switching to electricity from other fuels, requiring more electricity be made. Figure 4 provides the BAU and policy electricity generation mix for "OECD acts together", and Figure 5 for "Canada goes further".

There were some key changes in the electricity sector for this analysis compared to previous analyses done with CIMS.

[7] One exception is the pulp and paper sector, which reduce output below 2005 levels in 2010 through 2015. We will explore carbon revenue returns to this sector in the next version of this study.

- It is the stated policy of the David Suzuki Foundation that no new nuclear capacity be built in Canada. Given this, we explored a restriction on nuclear generation based on full societal cost measure that would include waste, decommissioning and liability insurance. New nuclear energy was required to pay a 1.3 ¢/kwh waste and decommissioning charge, based on recent French legal decisions regarding the cost of waste disposal and decommissioning of France's existing fleet, as well as a 4.0 ¢/kwh liability insurance charge to capture the implicit government insurance subsidy on nuclear power.[8] These charges did not make nuclear sufficiently expensive to prevent new capacity from being purchased in the policy case, so total nuclear capacity was limited to existing 2005 capacity. Nuclear generation is 5 TWh greater under policy than BAU, but this is because the fleet is retired less quickly than it would have been in BAU. BAU included the waste, decommissioning and insurance charges as well; on the premise that politicians and regulatory bodies are aware of these costs.
- CCS costs were raised significantly to reflect recent estimate of costs (i.e., post combustion CCS has been raised from prices starting at \$50/tonne CO_2e to \$75-\$100+ /tonne CO_2e).
- Reflecting recent experience with wind power in other jurisdictions (e.g., Spain, Portugal, Germany and Denmark), we reduced near term constraints on wind to a maximum of 15% of generation by 2020. The policy drove the share of wind to 13.3% of total generation in 2020.

In the "OECD acts together" scenario (Figure 4) total generation increases 140 TWh compared to BAU, while in the "Canada goes further" scenario (Figure 5) total generation rises 124 TWh. Of the increase in 2020 production of 140 to 124 TWh, small and large hydro took 69 to 62 TWh, wind and other renewables 76 to 70 TWh, nuclear 5 TWh, and coal and NG with CCS 32 to 30 TWh. Coal and NG without CCS lost 43-42 TWh of generation share.

[8] The waste and decommissioning charge is from « Le démantèlement des installations nucléaires et la gestion des déchets radioactifs », Rapport Public Particulier, Cour des Comptes, Janvier 2005. The insurance charge is from Heyes, A. and C. Heyes, "An empirical analysis of the Nuclear Liability Act (1970) in Canada" *Resource and Energy Economics* 2000, 22(1):91-101.

Figure 4: Electricity production and mix "OECD acts together"

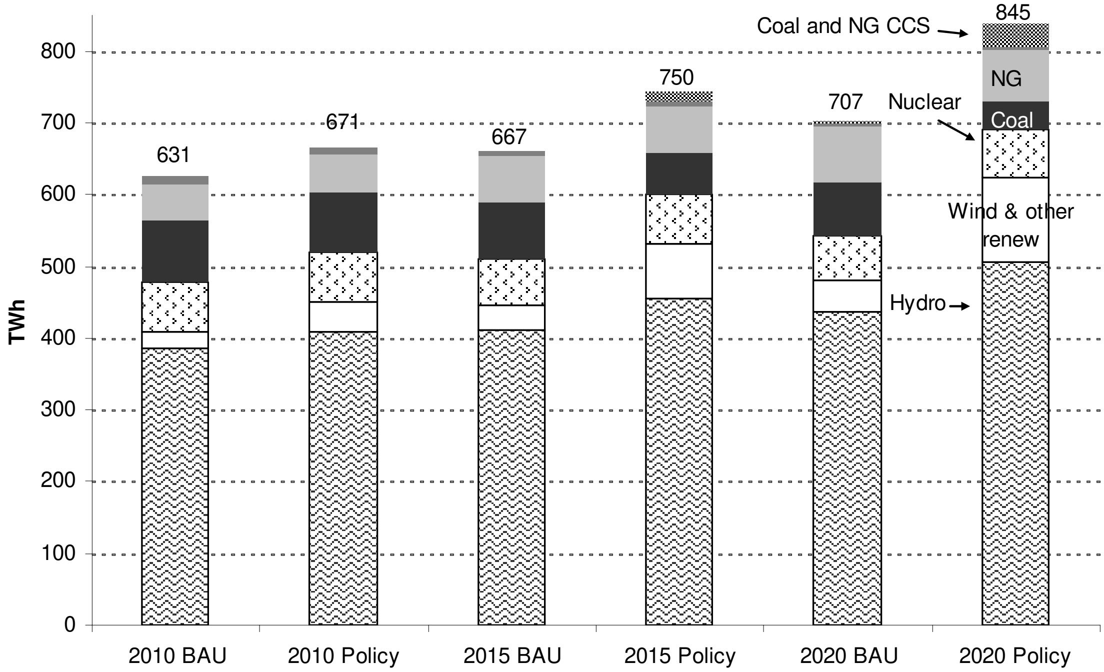


Figure 5: Electricity production and mix "Canada goes further"

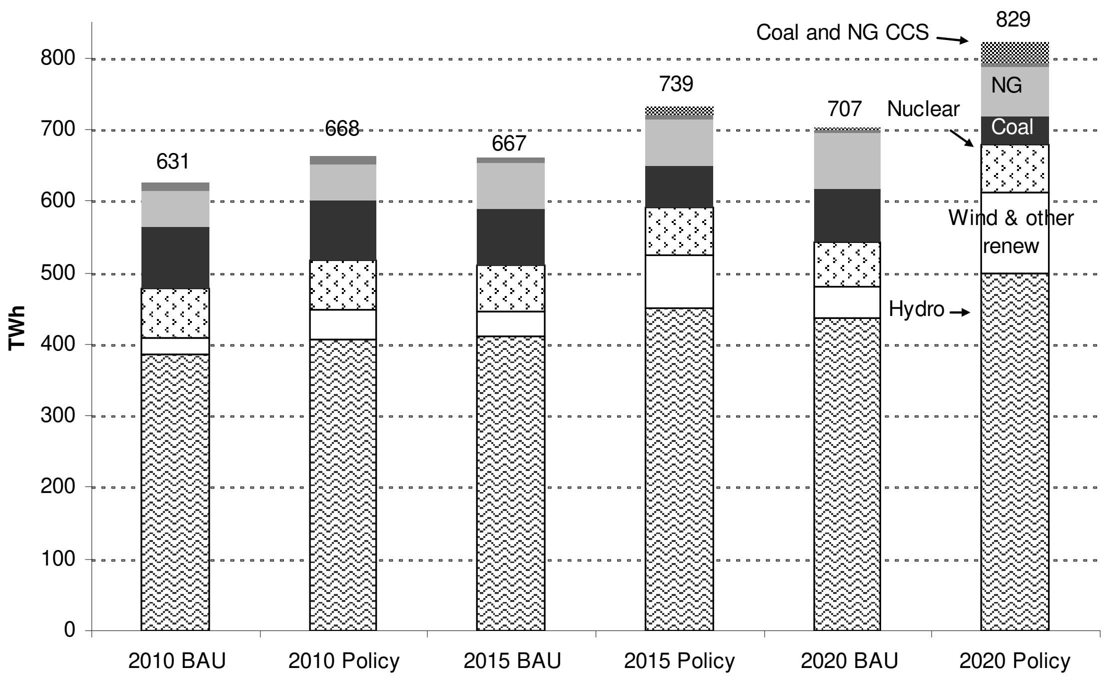


Table 14 summarizes the net financial effects that come out of CIMS. It adds the changes in annual capital, energy, and labour costs. Emissions costs are not included as they are transfers to the rest of the economy.

Table 14: Annual net financial costs by sector ("+" = costs, "-" = gains, $2005 millions (Sum of annual capital, labour related to energy use, and energy costs)

	2010		*2015*		*2020*	
	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further	OECD trading partners act together	Canada goes further
Residential	357	321	3,914	3,816	4,562	4,483
Commercial	-1,559	-1,579	866	806	2,270	2,176
Personal Trans.	-4,687	-4,688	-14,570	-14,571	-16,578	-16,582
Freight Trans.	-9,114	-9,202	-16,465	-16,805	-17,332	-18,415
Chemical Products	-2	-120	353	-174	451	-279
Industrial Minerals	5	-69	51	-96	231	-33
Iron and Steel	-40	-75	-177	-464	-220	-687
Metal Smelting	71	-32	97	-83	123	-55
Mineral Mining	-8	-132	-15	-768	93	-757
Paper Manufacturing	-171	-706	73	-693	150	-447
Other Manufacturing	21	-72	476	297	575	357
Agriculture	49	47	415	408	773	770
Waste	9	9	104	104	-150	-150
Electricity	7,995	7,519	11,933	10,154	14,194	12,756
Petroleum Refining	-341	-347	-525	-566	-1,088	-1,138
Petroleum Crude Ext.	-109	-294	4,312	-1,638	4,779	-946
Natural Gas Ext.	-1,064	-1,158	-1,920	-3,460	-2,689	-4,472
Coal Mining	-123	-126	-46	-96	-29	-76
Ethanol	9	10	130	131	934	935
Biodiesel	90	88	3,282	3,230	6,601	6,393
Total	**-8,610**	**-10,605**	**-7,711**	**-20,467**	**-2,348**	**-16,167**

Table 15 interpolates the financial impacts of "OECD acts together" between 2010, 2015 and 2020, and adds net foreign permit purchases. Table 16 shows the assumed schedule of foreign permit purchases, which rise in price from $25/tonne in 2010 to $100/tonne in 2020. Total payments are $22.1 billion by 2020; the annual payment in 2020 is $.9 billion. Domestic emissions costs are not included as they are transfers to the rest of the economy. The summed impacts over time in the "OECD acts together" scenario, *which are not discounted*, are a net *reduction* in expenditure on capital, labour and energy of $49.3 billion. If the transportation impacts are removed, the summed impacts are a net *increase* in expenditure of $249.0 billion. In the "Canada goes further" scenario (Table 17) the total including transportation is a reduction in expenditure of $167.1 billion, while excluding transportation the net increase in financial costs is $136.4 billion. These values do not necessarily represent net benefits to society; these are usually calculated as changes in consumer surplus or welfare.

Table 15: Annual net financial costs by sector ("+" = costs, "-" = gains, $2005 billions (Sum of annual capital, labour related to energy use, and energy costs) ("OECD acts together")

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	∑
Residential	0.4	1.1	1.8	2.5	3.2	3.9	4.0	4.2	4.3	4.4	4.6	34.3
Commercial	-1.6	-1.1	-0.6	-0.1	0.4	0.9	1.1	1.4	1.7	2.0	2.3	6.5
Trans. Personal	-4.7	-6.7	-8.6	-10.6	-12.6	-14.6	-15.0	-15.4	-15.8	-16.2	-16.6	-136.6
Trans. Freight	-9.1	-10.6	-12.1	-13.5	-15.0	-16.5	-16.6	-16.8	-17.0	-17.2	-17.3	-161.7
Chem. Products	0.0	0.1	0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.5	3.1
Ind. Minerals	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	1.0
Iron and Steel	0.0	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-1.7
Metal Smelting	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.1
Mineral Mining	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2
Paper Man.	-0.2	-0.1	-0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.3
Other Man.	0.0	0.1	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.6	0.6	4.2
Agriculture	0.0	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.6	0.7	0.8	4.5
Waste	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	-0.1	-0.1	0.1
Electricity	8.0	8.8	9.6	10.4	11.1	11.9	12.4	12.8	13.3	13.7	14.2	126.2
Pet. Refining	-0.3	-0.4	-0.4	-0.5	-0.5	-0.5	-0.6	-0.8	-0.9	-1.0	-1.1	-6.9
Crude Oil Ext.	-0.1	0.8	1.7	2.5	3.4	4.3	4.4	4.5	4.6	4.7	4.8	35.6
NG Ext.	-1.1	-1.2	-1.4	-1.6	-1.7	-1.9	-2.1	-2.2	-2.4	-2.5	-2.7	-20.9
Coal Mining	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	-0.7
Ethanol	0.0	0.0	0.1	0.1	0.1	0.1	0.3	0.5	0.6	0.8	0.9	3.5
Biodiesel	0.1	0.7	1.4	2.0	2.6	3.3	3.9	4.6	5.3	5.9	6.6	36.5
International Permit Payments	0.1	0.3	0.5	0.8	1.2	1.7	2.2	2.8	3.4	4.1	4.9	22.1
Total	**-8.5**	**-8.1**	**-7.7**	**-7.2**	**-6.7**	**-6.0**	**-4.5**	**-2.8**	**-1.1**	**0.7**	**2.6**	**-49.3**

Table 16: Schedule of international permit payments ($2005 millions).

		OECD acts together		Canada goes further	
	Price ($/tonne CO_2e)	Mt	Payments	Mt	Payments
2010	25	4.5	$ 112	3.1	$ 78
2011	32.5	8.9	$ 290	6.3	$ 204
2012	40	13.4	$ 536	9.4	$ 376
2013	47.5	17.9	$ 848	12.5	$ 596
2014	55	22.3	$ 1,228	15.7	$ 863
2015	62.5	26.8	$ 1,674	18.8	$ 1,176
2016	70	31.2	$ 2,187	22.0	$ 1,537
2017	77.5	35.7	$ 2,767	25.1	$ 1,945
2018	85	40.2	$ 3,415	28.2	$ 2,399
2019	92.5	44.6	$ 4,129	31.4	$ 2,901
2020	100	49.1	$ 4,910	34.5	$ 3,450
Total			$ 22,095		$ 15,525

Table 17: Annual net financial cost ("+" = costs, "-" = gains, $2005 billion). Sum of annual capital, labour related to energy use, & energy costs ("Canada goes further")

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	∑
Residential	0.3	1.0	1.7	2.4	3.1	3.8	3.9	4.1	4.2	4.3	4.5	33.5
Commercial	-1.6	-1.1	-0.6	-0.1	0.3	0.8	1.1	1.4	1.6	1.9	2.2	5.8
Trans. Personal	-4.7	-6.7	-8.6	-10.6	-12.6	-14.6	-15.0	-15.4	-15.8	-16.2	-16.6	-136.7
Trans. Freight	-9.2	-10.7	-12.2	-13.8	-15.3	-16.8	-17.1	-17.4	-17.8	-18.1	-18.4	-166.9
Chem. Products	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3	-0.3	-2.1
Ind. Minerals	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0	-0.8
Iron and Steel	-0.1	-0.2	-0.2	-0.3	-0.4	-0.5	-0.5	-0.6	-0.6	-0.6	-0.7	-4.6
Metal Smelting	0.0	0.0	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.7
Mineral Mining	-0.1	-0.3	-0.4	-0.5	-0.6	-0.8	-0.8	-0.8	-0.8	-0.8	-0.8	-6.5
Paper Man.	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.6	-0.6	-0.5	-0.5	-0.4	-6.9
Other Man.	-0.1	0.0	0.1	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.4	2.3
Agriculture	0.0	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.6	0.7	0.8	4.5
Waste	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	-0.1	-0.1	0.1
Electricity	7.5	8.0	8.6	9.1	9.6	10.2	10.7	11.2	11.7	12.2	12.8	111.6
Pet. Refining	-0.3	-0.4	-0.4	-0.5	-0.5	-0.6	-0.7	-0.8	-0.9	-1.0	-1.1	-7.3
Crude Oil Ext.	-0.3	-0.6	-0.8	-1.1	-1.4	-1.6	-1.5	-1.4	-1.2	-1.1	-0.9	-11.9
NG Ext.	-1.2	-1.6	-2.1	-2.5	-3.0	-3.5	-3.7	-3.9	-4.1	-4.3	-4.5	-34.2
Coal Mining	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-1.1
Ethanol	0.0	0.0	0.1	0.1	0.1	0.1	0.3	0.5	0.6	0.8	0.9	3.5
Biodiesel	0.1	0.7	1.3	2.0	2.6	3.2	3.9	4.5	5.1	5.8	6.4	35.6
International Permit Payments	0.1	0.2	0.4	0.6	0.9	1.2	1.5	1.9	2.4	2.9	3.5	15.5
Total	**-10.5**	**-12.4**	**-14.2**	**-15.9**	**-17.6**	**-19.3**	**-18.1**	**-16.8**	**-15.5**	**-14.1**	**-12.7**	**-167.1**

DGEEM - Macroeconomic impacts

The policies used in CIMS to meet the -25% from 1990 levels by 2020 were also analyzed in DGEEM to understand possible macroeconomic implications. Due to the technical complexity of the complementary regulations simulated in CIMS, it was not possible to directly model them in DGEEM. However, most of the regulations are designed to mimic the carbon price in sectors and situations where there is likely to be a carbon market failure. The one exception is the CCS regulation; this is unlikely to bias the results, however, as many fewer facilities are built in the crude oil and NG sectors.[9] Table 18 provides some selected macroeconomic impacts of the two scenarios.

Table 18: Selected macroeconomic impacts in real dollars

	BAU 2011 to 2020 growth	OECD acts together Policy 2011 to 2020 growth	Canada goes further Policy 2011 to 2020 growth
Gross domestic product	+22.03%	+19.27%	+19.21%
Consumption	+24.25%	+19.97%	+19.84%
Average salary (2020, $2003 CAD) 2010 =$43,831	$51,753	$48,839	$49,044
Labour force size	+6.36%	+6.15%	+6.35%
Returns to labour (wage rate * labour force)	+9.68%	+4.08%	+4.83%
Imports	+20.18%	+18.62%	+18.55%
Exports	+19.67%	+20.23%	+20.54%

The model suggests that in the "OECD acts together" scenario GDP will grow 19.3% instead of 22.0% in the BAU over 2011-2020. Imports grow slightly less (18.6 vs. 20.2%), and exports slightly more (20.2 vs. 19.7%), partly to help pay for international permits. The "OECD acts together" and "Canada goes further" scenarios are largely similar from a macroeconomic perspective, with the latter experiencing slightly higher GDP losses and consumption reductions.

The 2010 BAU average salary is $43,831 ($2003), and 18.452 million people are working. In the BAU scenario 1.188 million jobs are created from 2011 to 2020, and the 2020 average salary is $51,753. In the "OECD acts together" scenario 1.164 million jobs are created, and the average 2020 salary is $48,839. As a result, the labour force grows 6.2% instead of 6.4%. In the "Canada goes further" scenario, 1.179 million jobs are created, and the average salary is $49,044.

Table 19 provides changes in gross output and employment by sector in 2020 for the "OECD acts together" scenario. Overall employment increases 19% instead of 26%

[9] Our modelling shows a drop in NG production and consumption, largely because of fuel switching in the electricity production, commercial and residential buildings sectors, as well as lower exports due to increased production costs. These results have some uncertainty in them in regards to US demand for Canadian natural gas. Conventional natural gas reserves in Canada are being depleted faster than they are being replaced, but a significant amount of shale and tight gas is available, at production cost of $4+/GJ. If North American retail natural gas prices rise and stay in the $7/GJ range in the policy case, Canada is likely to produce significant amounts of shale and tight gas. Shale gas tends to have significant amounts of formation CO_2 in it, and CCS will be required to capture and store this CO_2 if any significant emissions reductions targets are to be met.

between 2011 and 2020 as a result of the policy package. Fossil fuel industries bear most of the reduction. The reader should note that the labour columns are in total expenditure, not people employed as in Table 18.

Table 19: Changes in gross output and employment by sector in 2020 "OECD acts together", expressed as % change in total expenditures

	BAU 2011 to '20 increase in gross output ($)	Policy 2011 to '20 increase in gross output ($)	BAU 2011 to '20 increase in labour expenditures ($)	Policy 2011 to '20 increase in labour expenditures ($)
Agriculture	21%	22%	27%	24%
Pet. Crude Extraction	18%	-11%	25%	-15%
Natural Gas Extraction	11%	-16%	19%	-25%
Coal Mining	2%	-35%	7%	-36%
Other Mining	18%	13%	23%	14%
Electricity	41%	51%	-1%	-7%
Construction Industry	18%	17%	21%	17%
Other Manufacturing	21%	24%	26%	25%
Pulp and Paper	21%	22%	27%	23%
Petroleum Refining	13%	4%	20%	2%
Chemicals	21%	22%	28%	21%
Industrial Mineral	18%	19%	23%	20%
Iron and Steel	20%	22%	25%	21%
Warehousing	23%	18%	26%	19%
Freight Transport	21%	20%	27%	19%
Services	22%	17%	27%	19%
Government	23%	19%	26%	19%
Total	21%	18%	26%	19%

Labour expenditure in electricity drops significantly in BAU and Policy in the model simulations. Coal and natural gas electricity generation employ significantly more people per unit of generation than hydroelectricity. In both BAU and policy coal production is significantly reduced, and hydroelectricity increases. In the policy case coal and NG production are significantly reduced, while hydroelectricity gains yet more market share of a larger generation base. The per unit generation labour requirements of nuclear, wind and other renewables are also less than that of coal and natural gas, but to a lesser degree than hydro.

Figure 6 shows the forecasted over time impacts of the policy package on gross domestic product. 0.0% represents the BAU growth path. While overall GDP continues to increase, the policy package increasingly slows the economy out to 2027, and then the growth path starts to return to potential. These are contrasted against overall GDP in Figure 7. GDP is $36 billion less than BAU in 2020.

Figure 6: Annual impact of policy package on gross domestic product "OECD acts together" compared to BAU growth path

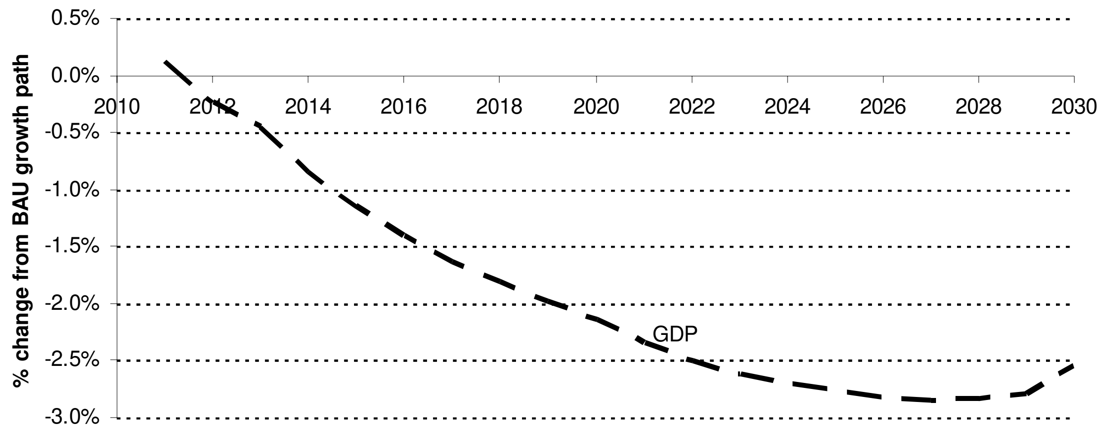
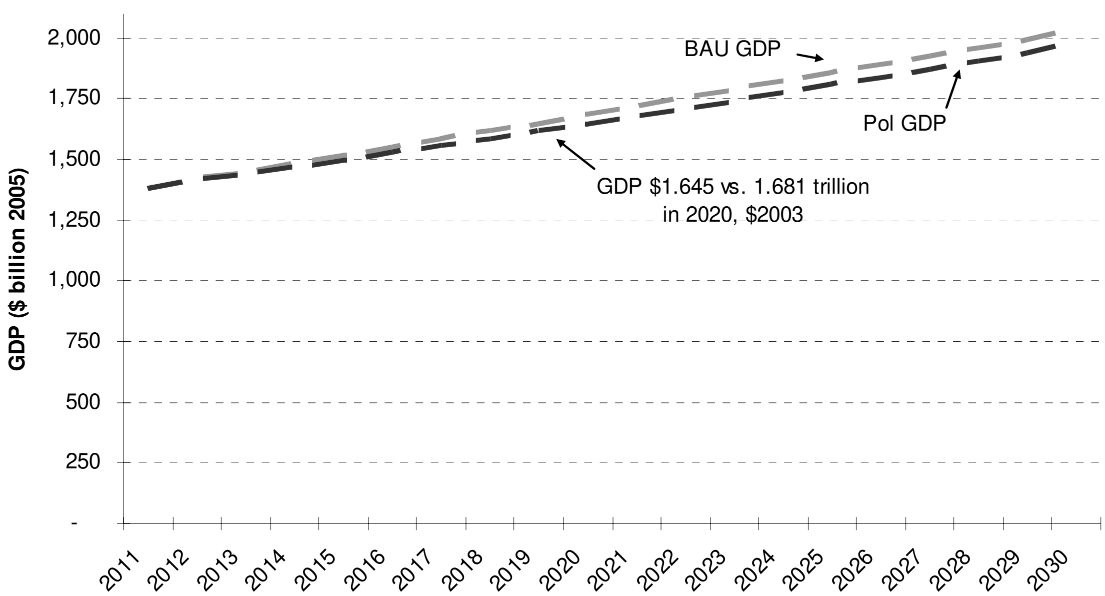


Figure 7: Absolute GDP under BAU and Policy, "OECD acts together"



Appendix – CIMS

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 20. CIMS does not include adipic and nitric acid, solvents or hydrofluorocarbon (HFC) emissions. CIMS covers nearly all CAC emissions in Canada except those from open sources (e.g., forest fires, soils, and dust from roads).

Table 20: Sector Sub-models in CIMS

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

* Metal smelting includes Aluminium.

Model structure and simulation of capital stock turnover

As a technology vintage model, CIMS tracks the evolution of capital stocks over time through retirements, retrofits, and new purchases, in which consumers and businesses make sequential acquisitions with limited foresight about the future. This is particularly important for understanding the implications of alternative time paths for emissions reductions. 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.

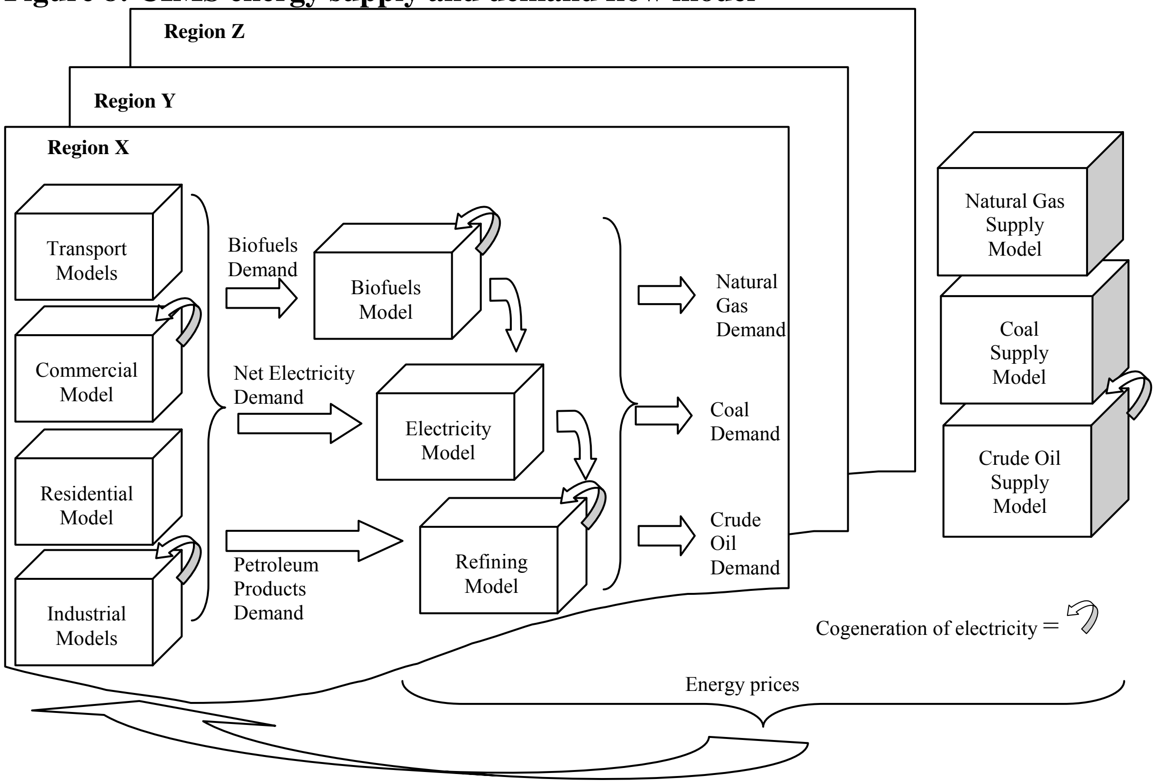
CIMS simulates the competition of technologies at each energy service node in the economy based on a comparison of their life cycle cost (LCC) and some technology-specific controls, such as a maximum market share limit in the cases where a technology is constrained by physical, technical or regulatory 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 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 8 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 8: 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).[10] 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

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

(especially smaller units), these must be estimated from surveys at different levels of technological detail and by calibrating the model's simulated energy consumption to real-world aggregate data for a base year.

Fuel-based GHGs emissions are calculated directly from CIMS' estimates of fuel consumption and the GHG coefficient of the fuel type. Process-based GHGs emissions are estimated based on technological performance or chemical stoichiometric proportions. CIMS tracks the emissions of all types of GHGs, and reports these emissions in terms of carbon dioxide equivalents.[11]

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.

Behavioral parameters are estimated through a combination of literature review, judgment, supplemented with the use of discrete choice surveys for estimating models whose parameters can be transposed into behavioral 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.

Please see the following list of publications for further information on CIMS:

Bataille, C., M. Jaccard, J. Nyboer and N. Rivers. (2006). "Towards General Equilibrium in a Technology-Rich Model with Empirically Estimated Behavioral Parameters." *Hybrid Modeling: New Answers to Old Challenges, Special Issue of the Energy Journal.*

Jaccard, M., J. Nyboer, C. Bataille, and B. Sadownik (2003). "Modeling the Cost of Climate Policy: Distinguishing Between Alternative Cost Definitions and Long run Cost Dynamics." *The Energy Journal* 24(1): 49-73.

Rivers, N. and M. Jaccard. (2005) "Combining Top-Down and Bottom-Up Approaches to Energy-Economy Modeling Using Discrete Choice Methods." *The Energy Journal* 26(1): 83-106.

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

Appendix - DGEEM

The model is a single-region Ramsey-type dynamic putty-clay general equilibrium model of the Canadian economy. It is calibrated to the input, output, and final demand tables produced by Statistics Canada. Data for these tables is based on an average of 1999-2001 data, and updated to a 2010 reference year according to sectoral and overall growth rate forecasts produced by Natural Resources Canada (2006), using the so-called RAS algorithm (Robinson, Cattaneo, and El-Said, 2001).

Household

The representative household maximizes intertemporal utility, where utility is given by a constant elasticity of intertemporal substitution function:

$$\max U = \sum_{t=1}^{T}\left(\frac{1}{1+\rho}\right)^{t} u(c_t) \tag{1}$$

where T is the time horizon of the model, ρ is the rate of pure time preference, c_t is consumption, and $u(c_t)$ is the instantaneous utility of consumption, given by:

$$u(c_t) = \frac{c_t^{1-\theta} - 1}{1-\theta} \tag{2}$$

Where $\sigma_t = 1/\theta$ is the elasticity of intertemporal substitution.

Instantaneous consumption is based on a nested constant elasticity of substitution function, in which consumption of leisure (l) and goods (g) are substitutes with constant elasticity of substitution, $\sigma_{cl} = 1 / (1 - \gamma_{cl})$, and where the time subscripts have been dropped for clarity of exposition:

$$c = \left(\alpha_{cl} l^{\gamma_{cl}} + (1-\alpha_{cl}) g^{\gamma_{cl}}\right)^{1/\gamma_{cl}} \tag{3}$$

Utility from consumption of individual goods, g, is a nested constant elasticity of substitution function in the consumption-leisure function:

$$g = \left(\begin{array}{l} \alpha_{ene} \left(\left(\alpha_{ht} \left(\left(\alpha_{eg} q_{ng}^{\gamma_{eg}} + (1-\alpha_{eg}) q_{el}^{\gamma_{eg}} \right)^{1/\gamma_{eg}} \right)^{\gamma_{ht}} + (1-\alpha_{ht}) q_t^{\gamma_{ht}} \right)^{1/\gamma_{ht}} \right) \\ +(1-\alpha_{ene}) \left(\left(\sum \alpha_{ne} q_{ne}^{\gamma_{ne}} \right)^{1/\gamma_{ne}} \right)^{\gamma_{ene}} \end{array} \right)^{1/\gamma_{ene}} \quad (4)$$

Where q_{ng} is household natural gas consumption, q_{el} is electricity consumption, q_t is petroleum product consumption, q_{ne} is non-energy product consumption, and each γ is related to an elasticity of substitution σ by $\gamma = 1 - 1/\sigma$, where σ_{eg} is the elasticity of substitution between natural gas and electricity, σ_{ht} is the elasticity of substitution between the electricity-gas aggregate and petroleum products, σ_{ne} is the elasticity of substitution between non-energy products, and σ_{ene} is the elasticity of substitution between the energy aggregate and the non-energy aggregate. The α parameters in the above equations are all determined through calibration with the benchmark data set.

The consumer maximizes intertemporal utility subject to an intertemporal budget balance:

$$\sum_{t=1}^{T} \sum p_{gt} g_t (1 + tc_{gt}) = \sum_{t=1}^{T} \left(\frac{(L_t - l_t) w_t}{1 + td_{lt}} \right) + TRN_t + \frac{K_0 r_0}{1 + td_{k0}} - \frac{K_{T+1} r_{T+1}}{1 + td_{kT+1}} \quad (5)$$

Where p_{gt} is the price of good g in period t, tc_{gt} is the ad valorem tax on final consumption of good g in period t, TRN_t represents lump sum transfers from government to households in period t, L_t is the exogenous labour endowment, l_t is the endogenous leisure demand, w_t is the gross wage rate, td_{lt} is the direct tax on labour income, td_{kt} is the direct tax on capital income, r_t is the rental rate on capital, and K_t is the capital stock. The final two terms on the right hand side represent the value of the initial capital stock and the post-terminal capital stock, respectively.

Production

Production of goods in each sector j in each time period is given by a constant returns to scale constant elasticity of substitution function, where an energy-value added aggregate is combined with intermediate material inputs to produce output (time subscripts have again been dropped for clarity of exposition):

$$Y_j = \left(\alpha_{s,j} eva_j^{\gamma_{s,j}} + (1 - \alpha_{s,j}) in_j^{\gamma_{s,j}} \right)^{1/\gamma_{s,j}} \quad (6)$$

Energy products are subsequently nested to represent differing ease of substitutability between alternative energy types:

$$eva_j = \left(\alpha_{eva,j} va_j^{\gamma_{eva,j}} + (1-\alpha_{eva}) en_j^{\gamma_{eva,j}}\right)^{1/\gamma_{eva,j}} \tag{7}$$

$$en_j = \left(\alpha_{ef,j} f_j^{\gamma_{ef,j}} + (1-\alpha_{ef,j}) el_j^{\gamma_{ef,j}}\right)^{1/\gamma_{ef,j}} \tag{8}$$

$$f_j = \left(\alpha_{cgl,j} gl_j^{\gamma_{cgl,j}} + (1-\alpha_{cgl,j}) co_j^{\gamma_{cgl,j}}\right)^{1/\gamma_{cgl,j}} \tag{9}$$

$$gl_j = \left(\alpha_{gl,j} ng_j^{\gamma_{gl,j}} + (1-\alpha_{gl,j}) rpp_j^{\gamma_{gl,j}}\right)^{1/\gamma_{gl,j}} \tag{10}$$

Capital and labour form a value-added aggregate, and intermediate material inputs form an intermediate aggregate:

$$va_j = \left(\alpha_{kl,j} k_j^{\gamma_{kl,j}} + (1-\alpha_{kl,j}) l_j^{\gamma_{kl,j}}\right)^{1/\gamma_{kl,j}} \tag{11}$$

$$in_j = \left(\sum \alpha_{in,j} i_j^{\gamma_{in,j}}\right)^{1/\gamma_{in,j}} \tag{12}$$

Producers maximize profits, and profits for each sector are zero in each time period in equilibrium (time subscripts are suppressed):

$$\pi_j = p_j Y_j - rK_j(1+tf_k) - wl_j(1+tf_l) - \sum p_{in} in_j \tag{13}$$

Where p_j is the price of output, tf_f is the net input tax rate on factors of production, p_{in} is the price of inputs, and in_j is the quantity of inputs. The α terms in the above equations represent calibrated distribution parameters, and the γ parameters are exogenously specified parameters that relate to substitution elasticities via the relationship $\gamma = 1 - 1/\sigma$. Substitution elasticities are as follows: σ_s = elasticity of substitution between energy/value added aggregate and intermediate input aggregate; σ_{eva} = elasticity of substitution between energy and value added, σ_{ef} = elasticity of substitution between electricity and fuels, σ_{cgl} = elasticity of substitution between coal and other fuels, σ_{gl} = elasticity of substitution between natural gas and petroleum products, σ_{kl} = elasticity of substitution between capital and labour, σ_{in} = elasticity of substitution between intermediate inputs.

Government

One government agent represents all three levels of Canadian government. Government collects net tax revenue (less subsidies), including both direct and indirect taxes. Taxes included in the model are (1) a direct labour income tax and (2) a direct corporate income tax, (3) an indirect factor input tax/subsidy on producers, (4) a consumption tax on final consumption and investment, and (5) import tariffs. The rates of all indirect taxes and subsidies are calibrated to the input output data, while the rates for direct taxes are derived from separate data on direct income taxation. All taxes are assumed to remain constant throughout the simulation unless endogenously modified (as described in the text). When a carbon price is applied, government is considered the owner of emission permits (or the collector of tax receipts, in the case of a carbon tax).

Government expenditures finance provision of an aggregate public good (health, education, etc.). In all simulations, provision of the aggregate public good remains constant at reference case levels. Remaining government budget is transferred to households in lump sum unless otherwise specified. Government is subject to an intertemporal budget constraint such that all net tax revenue is balanced by expenditures and transfers.

Trade

To allow for cross-hauling, the model uses an Armington formulation for international trade in which domestically and internationally produced goods are treated as imperfect substitutes. In particular, each domestic consumption good *i* is a constant elasticity of substitution aggregate of domestic and foreign goods:

$$g_i = \left(\alpha_{hf,i} h_i^{\gamma_{hf,i}} + (1-\alpha_{hf,i}) f_i^{\gamma_{hf,i}}\right)^{1/\gamma_{hf,i}} \tag{14}$$

Where h_i and f_i are the quantities of domestic and foreign good, respectively, and where $\sigma_{hf,i} = 1 / (1 - \gamma_{hf,i})$ is the Armington elasticity for commodity *i*. For exports, a similar constant elasticity of transformation is applied to each domestic production industry:

$$Y_j = \left(\alpha_{dx,i} d_i^{\gamma_{dx,i}} + (1-\alpha_{dx,i}) x^{\gamma_{dx,i}}\right)^{1/\gamma_{dx,i}} \tag{15}$$

Where d_i and x_i are the quantities of domestically produced good for domestic and export markets, respectively, and where $\sigma_{dx,i} = 1 / (1 - \gamma_{dx,i})$ is the Armington elasticity for commodity *i*.

Trade in commodities is mediated through the foreign exchange market, which allows Canadian currency to appreciate or depreciate relative to foreign currencies. In each period, the model requires balance in the foreign exchange market relative to the reference case scenario (in which there is a balance of trade surplus).

Dynamics

The model is a Ramsey-type growth model, in which consumers endogenously choose how much of total output to invest in a given period. The capital stock evolves subject to these investments:

$$K_{t+1} = K_t \cdot (1-\delta) + I_t \tag{16}$$

Where k_t is the total capital stock in time t, δ is the rate at which the capital stock depreciates, and I_t is the total investment in period t. Overall investment is an aggregate of investment goods (time subscripts are suppressed):

$$I = (\sum_g \alpha_{Ig} g^{\gamma_I})^{1/\gamma_I} \tag{17}$$

Where the elasticity of substitution between alternative investment goods is $\sigma_I = 1/(1-\gamma_I)$.

Investment is a 'zero-profit' activity:

$$r(1+\phi)I - \sum_i p_i g(1+ti_i) = 0 \tag{18}$$

Where ϕ is the interest rate, and ti_i is the tax on investment demand for good i.

Because the model has a finite horizon, a constraint is needed for final period investment. Following Lau et al. (2002), the following constraint is used:

$$\frac{I_T}{I_{T-1}} \geq \sum_J \frac{Y_{j,T}}{Y_{j,T-1}} \tag{19}$$

Parameters

Parameter	***Description***	***Value***
	Household utility function elasticities	
σ_t	Elasticity of intertemporal substitution	0.5
σ_{cl}	Elasticity of substitution between consumption and leisure	0.8
σ_{eg}	Elasticity of substitution between electricity and natural gas in residential consumption	0.65
σ_{ht}	Elasticity of substitution between gas-electricity aggregate and petroleum products	0.3
σ_{ne}	Elasticity of substitution between non-energy goods	0.25
σ_{ne}	Elasticity of substitution between non-energy aggregate and energy aggregate	0.15
	Production function elasticities	
$\sigma_{s,j}$	Elasticity of substitution between energy-value-added aggregate and material aggregate	0
$\sigma_{va,j}$	Elasticity of substitution between energy and value added aggregate	0.27 – 1.8
$\sigma_{ef,j}$	Elasticity of substitution between electricity and fuels	0.2 – 1.8
$\sigma_{cgl,j}$	Elasticity of substitution between coal and other fuels	0.3 – 0.8
$\sigma_{gl,j}$	Elasticity of substitution between natural gas and petroleum products	0.1 – 2.69
$\sigma_{kl,j}$	Elasticity of substitution between capital and labour	1.1
$\sigma_{in,j}$	Elasticity of substitution between intermediate non-energy material inputs	0.05 – 0.5
	Trade elasticities	
$\sigma_{hf,i}$	Elasticity of substitution between home and foreign goods (Armington elasticity)	0.9 – 3.5
$\sigma_{dx,i}$	Elasticity of transformation between domestic and export markets	0.9 – 3.5
	Dynamic parameters	
ϕ	Interest rate	0.039
δ	Depreciation rate	0.05

Appendix - 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 12 years to 2020 (CIMS typically simulates out to 2050, but we have not reported 2021 onward for this project). 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. Credible sources have been used 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, another for the amount of cement produced in the province, and another for amount of natural gas produced as applicable. These forecasts can be internally adjusted when a policy is applied.

For all energy demand sectors, the external forecast through 2020 is based on the same data used by NRCan to develop the national energy outlook in 2006.[12]

Table 21: Canada economic and demographic forecast

	Units	*2005*	*2010*	*2015*	*2020*
Gross Domestic Product	*Billion 1997$ [a]*	1,083.7	1,237.5	1,383.9	1,552.2
Population	*Millions*	32.2	33.5	34.7	35.8

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

While the residential, commercial and transportation sectors are not the direct subject of policy in this analysis, their demand for electricity, processed natural gas and refined petroleum products set the stage for many of the industrial sectors subject to the *Regulatory Framework*. The CIMS models for each of these sectors were updated with 2005 data to ensure their demand for energy end use commodities fits history, is reasonable, and adjusts in a credible fashion with population, economic growth and technology.

Physical output in each of the industrial sectors was also updated to reflect recently released 2005 statistics. Energy use for each sector was also checked against Statistics Canada's *Report on Energy Supply and Demand 2005*, as well as NRCan's *Comprehensive Energy Use Database*. 2005 emissions of GHGs and CACs were

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

calibrated against the aforementioned energy use statistics and EC's draft *GHG Inventory for 2005*.[13]

Table 22 summarizes the reference case economic output forecast that is adopted for this forecast. As has been emphasized throughout, this forecast reflects historic and anticipated future trends, but is highly uncertain, particularly in the later years of the forecast.

Table 22: Reference case forecast of physical output[14]

	Units	*2005*	*2010*	*2015*	*2020*
Demand Sectors					
Residential	*thousands of households*	12,607	13,545	14,416	15,222
Commercial	*million m^2 of floorspace*	653.4	729.2	810.9	911.1
Transportation					
Passenger	*billion passenger-km*	617	742	839	944
Freight	*billion tonne-km*	865	966	1,083	1,198
Manufacturing Industry					
Chemical Products	*thousand tonnes* [a]	18,369	19,468	20,777	21,979
Industrial Minerals	*thousand tonnes* [b]	16,623	17,951	19,751	21,393
Pulp and Paper	*thousand tonnes* [c]	20,103	20,466	21,296	22,114
Iron and Steel	*thousand tonnes*	14,200	14,740	15,564	16,403
Metal Smelting	*thousand tonnes*	4,577	4,838	4,839	4,916
Mining	*thousand tonnes*	246,385	262,005	270,985	274,301
Other Manufacturing	*million $2005*	181,806	205,184	231,403	260,052
Waste	*million tonnes of waste in place*	670	696	722	747
Supply Sectors					
Crude Oil (CAP report)					
Conventional Light	*thousand barrels/day*	580	513	428	351
Conventional Heavy	*thousand barrels/day*	475	438	392	322
Synthetic	*thousand barrels/day*	495	878	1,539	2,075
Blended Bitumen	*thousand barrels/day*	436	880	1,246	1,437
Natural Gas (CIMS)	*billion cubic feet/day*	16.78	17.27	18.85	17.26
Coal Mining	*million tonnes*	67.5	72.3	80.2	88.2
Electricity Generation	*TWh*	545.3	576.8	610.0	646.8
Petroleum Refining	*million m^3*	99.8	101.6	107.8	115.8
Ethanol	*TJ*	30.51	163.06	268.14	388.85

[13] Environment Canada, "National Inventory Report: 1990-2005. Greenhouse Gas Sources and Sinks in Canada." November 2007.

[14] 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 coal bed methane

Energy prices

CIMS also requires an external forecast for energy prices. As for sectoral output, fuel prices can change while a policy scenario is running if the policy induces changes in the cost of fuel production. Reference case prices for most fuels through 2020 are derived from the recent energy outlook published by NRCan (the industrial and electricity coal price forecasts were derived from forecasts by the U.S. Environmental Protection Agency), with some modification based on the latest NEB forecasts. Table 23 shows the fuel price forecast that was used to develop the reference case forecast in this report – the values differ slightly by province depending on supply costs and taxation; the values for Ontario are provided. 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 23: Ontario reference case price forecast for key energy commodities

	Units	*2005*	*2010*	*2015*	*2020*
Crude Oil (WTI)	*2003$ / barrel*	62.45	46.84	46.84	46.84
Natural Gas					
Industrial	*2005$ / GJ*	10.64	9.63	8.56	8.71
Residential	*2005$ / GJ*	13.85	12.62	11.43	11. 30
Commercial	*2005$ / GJ*	12.22	11.01	9.90	9.87
Electricity Generation	*2005$ / GJ*	10.03	9.00	8.63	8.89
Coal					
Market	*2005$ / GJ*	2.87	3.36	3.36	3.36
Electricity Generation	*2005$ / GJ*	2.57	3.00	3.00	3.00
Gasoline	*2005$ / GJ*	25.27	31.07	25.98	23.33
Diesel (Road)	*2005$ / GJ*	21.89	28.25	23.36	20.87
Electricity					
Industrial	*2005$ / GJ*	17.73	18.03	19.12	19.37
Residential	*2005$ / GJ*	24.04	24.72	25.48	27.39
Commercial	*2005$ / GJ*	20.74	21.41	23.15	25.41

Note: All prices in Canadian dollars.

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 GHG and CAC emissions through 2020. 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 24, while Tables 26 through 28 show natural gas, refined petroleum product, and electricity consumption, respectively. The residual energy consumption of other fuel types (total minus natural gas, refined petroleum products, and electricity) is not explicitly shown in this report.

Table 24: Reference case total energy consumption

	Units	2005	2010	2015	2020
Demand Sectors					
Residential	*PJ*	1,399.10	1,417.00	1,488.03	1,567.41
Commercial	*PJ*	1,126.56	1,197.71	1,293.12	1,412.71
Transportation	*PJ*	2,617.73	2,787.72	3,103.38	3,451.61
Manufacturing Industry	*PJ*	2,298.77	2,352.33	2,436.57	2,526.78
Waste	*PJ*	85.28	88.41	91.54	94.42
Agriculture	*PJ*	208.51	201.28	196.13	197.10
Supply Sectors					
Crude Oil	*PJ*	591.86	1,033.54	1,608.55	1,990.11
Natural Gas	*PJ*	704.72	691.84	686.28	607.01
Coal Mining	*PJ*	21.47	22.09	23.11	24.14
Utility Electricity Gen.	*PJ*	3,708.22	3,745.23	3,805.08	3,887.52
Petroleum Refining	*PJ*	337.68	352.27	385.50	427.50
Ethanol	*PJ*	0.03	0.14	0.24	0.34
Total	***PJ***	***13,100.36***	***13,890.51***	***15,118.89***	***16,189.12***

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.[15]

Table 25: Reference case natural gas consumption

	Units	2005	2010	2015	2020
Demand Sectors					
Residential	*PJ*	632.97	644.99	704.85	736.83
Commercial	*PJ*	568.08	616.71	676.42	745.77
Transportation	*PJ*	13.23	7.57	3.29	2.31
Manufacturing Industry	*PJ*	745.25	762.11	796.19	820.30
Waste	*PJ*	0.00	0.00	0.00	0.00
Agriculture	*PJ*	26.86	26.57	26.31	26.01
Supply Sectors					
Crude Oil	*PJ*	282.12	543.72	824.05	955.79
Natural Gas	*PJ*	639.04	624.44	609.83	535.65
Coal Mining	*PJ*	2.51	2.63	2.89	3.16
Electricity Generation	*PJ*	354.75	416.44	495.83	582.85
Petroleum Refining	*PJ*	73.51	80.94	95.22	111.46
Ethanol	*PJ*	0.02	0.13	0.21	0.29
Total	***PJ***	3,338.37	3,726.36	4,235.42	4,520.91

[15] 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 26: Reference case refined petroleum product consumption

	Units	2005	2010	2015	2020
Demand Sectors					
Residential	*PJ*	105.29	65.93	31.62	18.42
Commercial	*PJ*	77.86	58.64	48.43	40.56
Transportation	*PJ*	2,601.21	2,772.18	3,088.24	3,434.88
Manufacturing Industry	*PJ*	157.19	146.60	149.71	161.00
Waste	*PJ*	0.00	0.00	0.00	0.00
Agriculture	*PJ*	144.74	137.59	132.50	133.54
Supply Sectors					
Crude Oil	*PJ*	76.74	74.01	74.57	88.27
Natural Gas	*PJ*	25.19	25.26	26.83	24.38
Coal Mining	*PJ*	6.10	6.16	6.83	7.72
Electricity Generation	*PJ*	130.39	105.32	80.90	56.99
Petroleum Refining	*PJ*	95.60	92.54	91.80	93.08
Ethanol	*PJ*	0.00	0.01	0.02	0.03
Total	***PJ***	3,420.45	3,484.62	3,732.10	4,059.72

Table 27: Reference case electricity consumption

	Units	2005	2010	2015	2020
Demand Sectors					
Residential	*PJ*	578.37	637.60	688.84	749.17
Commercial	*PJ*	480.61	522.35	568.27	626.38
Transportation	*PJ*	3.15	6.75	8.58	9.85
Manufacturing Industry	*PJ*	691.59	705.96	708.13	715.98
Waste	*PJ*	-0.27	-0.49	-0.68	-0.93
Agriculture	*PJ*	36.92	37.12	37.30	37.51
Supply Sectors					
Crude Oil	*PJ*	44.95	59.69	79.39	91.20
Natural Gas	*PJ*	40.50	42.14	49.62	46.98
Coal Mining	*PJ*	4.04	4.06	4.31	4.56
Electricity Generation	*PJ*	0.00	0.00	0.00	0.00
Petroleum Refining	*PJ*	16.90	15.00	14.64	14.83
Ethanol	*PJ*	0.00	0.00	0.00	0.01
Total	***PJ***	1,896.79	2,030.27	2,158.61	2,295.87

Based on total energy consumption as well as on process emissions in the industrial sector and supply sectors, we calculate the GHG emissions associated with the reference case forecast (Table 28). In the absence of new policies to control GHG emissions, emissions are expected to grow in all sectors of the Canadian economy. Especially strong growth is expected in the crude oil sector as a result of rapidly expanding output.

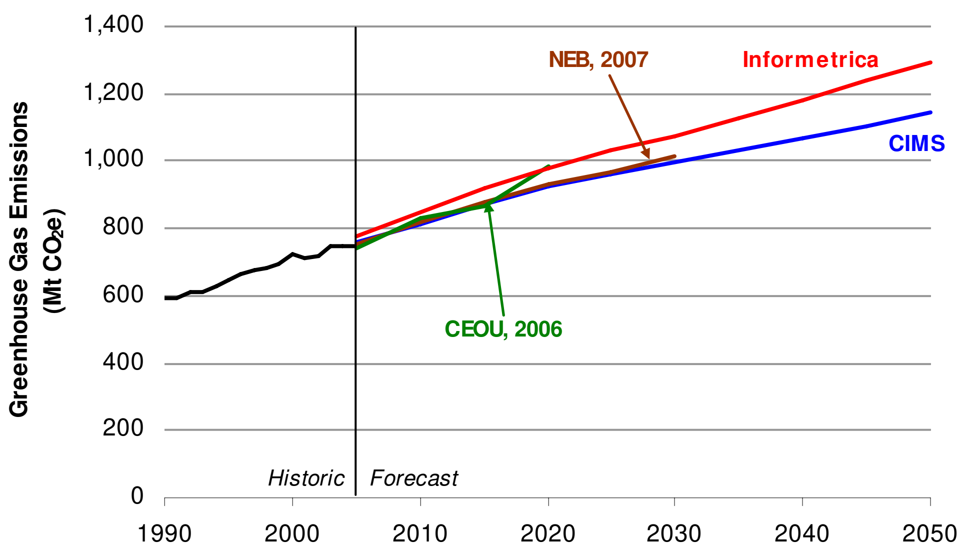
Table 28: Reference case GHG emissions

	Units	2005	2010	2015	2020
Demand Sectors					
Residential	*Mt of CO_2e*	41.18	38.60	38.97	39.61
Commercial	*Mt of CO_2e*	34.51	35.54	37.80	40.71
Transportation	*Mt of CO_2e*	187.43	199.37	221.66	246.34
Manufacturing Industry	*Mt of CO_2e*	83.94	85.16	87.21	89.99
Waste	*Mt of CO_2e*	27.48	28.51	29.54	30.52
Agriculture	*Mt of CO_2e*	58.81	51.73	46.99	48.21
Supply Sectors					
Crude Oil	*Mt of CO_2e*	65.53	94.86	135.20	162.36
Natural Gas	*Mt of CO_2e*	64.91	63.72	62.75	55.71
Coal Mining	*Mt of CO_2e*	2.22	2.20	2.37	2.55
Electricity Generation	*Mt of CO_2e*	126.26	118.77	112.71	108.48
Petroleum Refining	*Mt of CO_2e*	19.40	20.22	22.00	24.27
Ethanol	*Mt of CO_2e*	0.00	0.01	0.01	0.02
Total	***Mt of CO_2e***	711.70	738.76	797.32	848.92

Note: CIMS does not include nitric and adipic acid production, consumption of halocarbons, "other and undifferentiated production", and solvents.

Figure 9 compares the total GHG emissions reported in this reference case to those in the NRCan reference case, a recent forecast by Informetrica Ltd. prepared for the federal government, and the recently released NEB 2007 forecast. All show Canada's energy-related GHG emissions increasing over time from 734 Mt in 2005 to between 900 and 1000 Mt by 2020. Forecasting emissions for Canada is a highly uncertain process, especially given the rapidly changing forecasts for oil sands production.

Figure 9: Reference case GHG emissions (all adjusted to include nitric and adipic acid production, solvents, halocarbons, and "other & undifferentiated emissions").



Note: Historic emissions in this chart are from Environment Canada's 2005 Greenhouse Gas Inventory.