REPORT

Cost Curves for Greenhouse Gas Emission Reduction in Canada: The Kyoto Period and Beyond

Final Analysis Report
(Enhanced Costing Indicators)

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Executive Summary

Under the National Energy End-Use Database Standing Offer, MK Jaccard and Associates, Inc. (MKJA) began discussions with Natural Resources Canada in 2005 to complete a cost curves analysis and report that would build on previous studies, but would incorporate the most current energy price and growth forecasts from Natural Resources Canada (assumptions that are part of the forthcoming Canada's Energy Outlook Reference Case). A key objective was to extend the time period of the analysis so as to be capable of informing post-Kyoto discussions and/or future work on climate change and broader energy policy. MKJA was to develop cost curves for reducing greenhouse gas (GHG) emissions in 2010, 2015, 2020 and 2030.[1] Sectoral and regional disaggregation would be limited and there would be a specific focus on assumptions and definitions (primarily of costs) associated with the curves.

The CIMS Model

To conduct this analysis MKJA used CIMS, a hybrid energy-economy model that combines key characteristics of both the top-down and bottom-up approaches to energy modelling in order to maximize usefulness to policy makers. CIMS contains a detailed database representing most of the technologies in Canada that use energy and emit greenhouse gas emissions. It also simulates the manner in which consumers and businesses choose between different technologies – using behavioural parameters estimated from real-world evidence. CIMS is an integrated model in that energy supply and demand interact to reach an equilibrium of energy prices and quantities. It also includes macroeconomic feedbacks that adjust the demands for products and services to their prices, and that simulate the trade in energy and other products between Canada and other countries.

Costing Greenhouse Gas Emission Reduction

GHG emissions are reduced as a result of climate policy through two major categories of actions taken by business and consumers: actions to reduce GHG intensity, and changes in demand for a product or service. These two components were costed separately for this study. The costs associated with actions to reduce GHG intensity are represented using expected resource costs; these are derived from techno-economic costs and perceived private costs. To address the impact of demand feedbacks, loss of gross domestic product is provided for the goods producing sectors, while loss of consumer welfare is provided for the residential and personal transportation sectors.

There is considerable debate over the cost-effectiveness of actions to reduce the GHG intensity of production or end-use service provision. Estimates are especially dependant

[1] Natural Resources Canada made a specific request that results be provided for 2010 as well as for the later time periods. While MKJA has provided this information, care should be taken in interpreting the 2010 results. These will assume a GHG cost applied starting in the present year (2006) and may therefore overestimate the potential for change from the business-as-usual trend by the time action is taken.

on how a cost is defined by the analyst, with the opposing approaches frequently referred to as engineering (or bottom-up) analysis versus economic (or top-down) analysis. The bottom-up approach – usually associated with engineers, physicists and environmental advocates – focuses on the distinct characteristics of technologies. Those that provide the same service are assumed to be perfect substitutes except for differences in their financial costs. Using this methodology, many current and emerging technologies available for reducing GHG emissions appear to be profitable or just slightly more expensive relative to existing equipment. Bottom-up analyses often show, therefore, that substantial GHG reduction can be profitable or low-cost if these low-emission technologies were to increase from their small market share to achieve market dominance.

Many economists criticize the bottom-up approach for overlooking the fact that alternative equipment, buildings, industrial processes and urban forms are almost never perfect substitutes in the eyes of consumers and businesses. When consumers and businesses are asked, induced or forced to switch away from a technology they would otherwise have chosen, most economists say that the full cost of this switch is the difference in financial costs plus or minus the intangible costs related to option value (the expected gain from delaying or avoiding an irreversible, risky investment), consumer preference and marketplace heterogeneity. This perspective on decision making explains why low-emission technologies are not adopted more quickly and suggests that the full cost of societal adoption of these technologies is higher than presumed by bottom-up analysts.

CIMS has the flexibility to calculate the costs of actions to reduce GHG intensity according to alternative costing definitions, including those used in the bottom-up and top-down approaches. The bottom-up estimate is referred to as the *techno-economic cost* (TEC). This indicator expresses the financial costs associated with capital, labour and energy of actions to reduce GHG intensity. Up-front costs are amortized over the lifetime of each technology using a discount rate of 10%. GHG charges and other taxes are not included in the cost estimates as these are considered transfers internal to the Canadian economy – increased revenues from such charges will be redistributed in the form of government programs, tax credits or other benefits.

The top-down estimate provided in this report is called the *perceived private cost* (PPC). This indicator tends to be higher than the TEC because it includes the intangible costs related to option value, consumer preference and heterogeneity as embodied by the key behavioural parameters of CIMS. A caveat associated with the PPC is that it assumes all choices under the business-as-usual simulation were optimal and therefore assigns a cost to any reduction in GHG emissions that occurs as a result of policy. If consumers did not make perfect technology choices in the first place, the PPC can overestimate the perceived cost of GHG reduction.

In order to provide information that is relevant to decision makers, the TEC and PPC costing indicators have been used to derive an estimate of the *expected resource cost* (ERC) of actions to reduce GHG intensity. To calculate the ERC, the TEC is adjusted upward to account for real financial risks associated with premature failure and longer payback periods (option value), as well as diversity in technological opportunities. The intangible cost associated with switching away from preferred technologies is not part of the ERC, even though a loss of welfare occurs. The ERC is estimated by adding to the TEC 75% of the difference between the TEC and the PPC. This method of calculating the ERC was the result of careful review on the part of MKJA and the Energy and Materials Research Group at Simon Fraser University during the AMG roll-up analysis carried out as part of the National Climate Change Implementation Process.

Results of the GHG Emission Charge Simulations

To generate cost curves for GHG abatement in Canada, MKJA used CIMS to simulate the economy's response to different levels of a GHG charge implemented in the year 2006: $10, $20, $30, $40, $50, $75, $100, $150, $200 and $250 per tonne CO_2e. For this exercise, the GHG charge was applied across all sectors and regions modelled by CIMS as an adder to fuel prices based on their carbon content. The charge could represent an emission tax or the permit price in an emission permit-trading scheme. The GHG charge associated with a given level of emission reduction is indicative of the marginal cost of reaching that emission reduction target. For all the simulations, CIMS was run with both its energy supply-demand and macroeconomic feedbacks activated. Changes in emission reductions, energy consumption and costs presented below are relative to a business-as-usual simulation.

Table 1 shows the contribution of each sector to the national emission reductions estimated for the year 2020. The electricity generation and petroleum crude sectors tend to have higher emission reductions under the GHG charges than would be expected given business-as-usual emission levels. The transportation sector, on the other hand, tends to have lower than expected levels of emission reduction under the GHG charges.

Table 1: Contribution to National Emission Reductions by Sector, 2020

	10	20	30	40	50	75	100	150	200	250
Commercial	4%	4%	4%	4%	4%	3%	3%	4%	4%	5%
Residential	7%	7%	7%	7%	7%	6%	6%	6%	7%	7%
Transportation	6%	8%	8%	12%	12%	11%	11%	12%	12%	13%
Industry	18%	19%	19%	19%	19%	17%	17%	16%	16%	17%
Electricity	25%	23%	22%	19%	20%	22%	21%	21%	22%	22%
Natural Gas	18%	13%	12%	10%	10%	9%	9%	8%	9%	9%
Petroleum Crude	21%	24%	27%	28%	30%	30%	34%	32%	30%	28%

Table 2 shows the contribution of each region to the national emission reduction for the year 2020. Up to half of the emission reductions observed at the national level in 2020 occur in Alberta.

Table 2: Contribution to National Emission Reductions by Region, 2020

	10	20	30	40	50	75	100	150	200	250
British Columbia	12%	11%	11%	11%	11%	10%	9%	9%	9%	10%
Alberta	39%	40%	42%	41%	43%	47%	51%	50%	49%	47%
Saskatchewan	6%	5%	5%	6%	6%	7%	6%	6%	6%	6%
Manitoba	2%	2%	2%	2%	2%	1%	1%	1%	1%	2%
Ontario	22%	22%	21%	21%	20%	19%	18%	19%	19%	20%
Québec	12%	13%	12%	12%	12%	10%	9%	9%	9%	9%
Atlantic	7%	7%	7%	7%	6%	6%	5%	6%	6%	6%

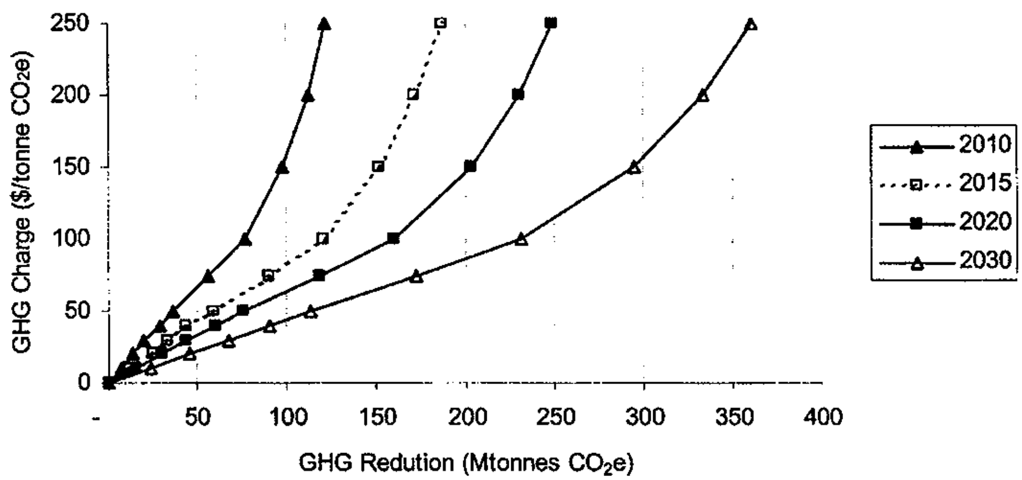
Table 3 and Figure 1 provide emission reductions estimated at the national level under the GHG charges. The year 2010 results suggest that it will be very difficult to attain emission reductions in the 100 Mt range from the sectors modelled by CIMS within the Kyoto timeframe. There are few opportunities offered by the natural turnover of existing capital stocks in this timeframe, with further reductions requiring premature stock replacement. Including opportunities for GHG reduction associated with sectors not modelled in CIMS – municipal landfill gas, actions in the agricultural sector, and incremental (from business-as-usual) agricultural and forest sinks – would increase the emission reduction potential from what is shown here.[2]

Table 3: Emission Reductions under GHG Charges, National Total (Mt CO_2e, annual)

	10	20	30	40	50	75	100	150	200	250
2010	7.5	13.7	19.9	28.6	36.3	56.4	77.0	97.4	111.8	122.0
2015	11.6	24.6	33.2	44.0	58.9	90.9	120.4	151.9	171.9	186.8
2020	15.7	30.1	43.8	60.4	76.3	118.6	160.0	203.6	230.5	249.4
2030	23.8	45.3	67.0	90.9	113.6	172.5	231.4	295.0	333.6	360.3

[2] The potential for beyond business-as-usual agriculture and forest sinks is estimated in the order of 15 to 20 Mt. The cost of reductions from incremental agriculture and forest sinks, agricultural emission reductions and landfill gas has been estimated at $10 per tonne of carbon dioxide equivalent by the Government of Canada (2005).

Figure 1: Cost Curves for GHG Emission Reduction, National Total



In later time periods, the curves become less steep as natural capital stock turnover and endogenous technical change (declining capital costs) afford opportunities for lower cost emission reduction. However, all four curves assume a GHG charge is initiated in 2006. If a consistent signal discouraging GHG emissions is not provided early on, targets further into the future are not necessarily easier to achieve than near term targets.

Even over the medium-term (2015 and 2020), the results indicate a significant GHG charge would be required to achieve GHG emission reductions in the 200 Mt range. It is important to note that CIMS represents energy efficiency and GHG intensity improvements in terms of the real or anticipated technology options that are available for meeting energy service demands. Over a longer simulation period it is not always possible to anticipate future new technology options or process improvements. However, it is also possible for new technologies and energy service categories to develop which will increase energy use and GHG emissions in the future. Along with associates at the Energy and Materials Research Group at Simon Fraser University, MKJA will continue to research this issue.

In the long-term, to 2030 and beyond, there is increasing evidence of the prospects for zero-emission uses of fossil fuels, in which natural gas, plentiful coal and perhaps oil are converted without combustion into electricity, hydrogen and cleaner-burning synthetic fuels, while potentially harmful byproducts like acid compounds, toxins and greenhouse gases are separated and safely stored in geological formations. Since the required technologies are already applied in fertilizer production, refineries, electricity generation, enhanced oil and gas recovery, and coal-to-liquid-fuel conversion, this zero-emission fossil fuel strategy appears to be technologically and economically feasible, although scale-up would face various challenges.

The components of a zero-emission fossil fuel energy system are being integrated into CIMS. The version of the model used in this analysis included lower cost carbon capture and storage opportunities available in the electricity and petroleum crude supply sectors, and significant uptake of these options was observed during the simulations. Work is underway to more fully represent carbon capture and storage, and to introduce additional hydrogen and electric technologies as part of a zero-emission energy system. Once this work is complete, the cost curve for 2030 estimated using CIMS is expected to be less steep, perhaps significantly, with zero-emission fossil fuels complementing energy efficiency and renewables to provide greater emission reductions at the intermediate and high GHG charges. However, some capital stocks, such as hydrogen distribution infrastructure will take a long time to develop and might not be available by 2030 even given the assumption that GHG charges are initiated in 2006. Simulations out to 2040 and 2050 would capture more of the impact of these long-term technological shifts.

Table 4: Reduction in Energy Consumption under GHG Charges, National Total (PJ, annual)

	10	20	30	40	50	75	100	150	200	250
2010	75	136	196	287	354	509	651	880	1,071	1,219
2015	108	241	307	398	533	759	959	1,259	1,490	1,687
2020	136	264	377	527	643	919	1,155	1,509	1,801	2,025
2030	204	372	540	733	885	1,230	1,510	1,952	2,323	2,593

The costs presented in this report are always cumulative (representative of costs incurred in all years from 2006 up to and including the year in question) and are provided for the years 2010, 2015, 2020 and 2030. All costs have been converted to net present value by discounting at a rate of 10% up to the first day of 2004. Cost inputs to CIMS have been maintained in $1995 Canadian, so outputs are also in $1995.

Expected resource costs for actions to reduce GHG intensity are provided at the national level in Table 5. Most sectors show small reductions in expected resource costs at the lower GHG charges as actions take place that reduce financial expenditure without imposing significant intangible costs. Sometimes cost reductions even become greater as the GHG charge increases because the higher charges stimulate more actions that reduce financial expenditure. Eventually, however, the lower cost actions are overwhelmed by actions with greater techno-economic costs and greater intangible costs, and as a result higher expected resource costs are observed as the GHG charge increases. Once the GHG charge reaches $100 per tonne CO_2e expected resource costs are observed at the national level across all time periods.

Table 5: Expected Resource Costs of Actions to Reduce GHG Intensity, National Total ($1995 millions, cumulative)

	10	20	30	40	50	75	100	150	200	250
2010	-641	-1,116	-1,438	-1,811	-1,803	-812	1,444	3,302	5,044	6,238
2015	-804	-1,487	-1,569	-1,423	-1,089	2,042	7,283	13,583	19,204	24,004
2020	-980	-1,576	-1,683	-1,494	-628	4,282	12,373	22,831	31,844	39,673
2030	-1,237	-1,922	-1,906	-1,418	-74	7,106	19,208	35,647	49,263	61,213

Table 6 provides the total loss of gross domestic product (GDP) estimated under the GHG charges. GDP, also known as value added, is the sum of expenditures on capital, labour, and natural resources, the three "primary factors" of production, to produce a given good or service. This measure, which addresses changes in demand as well as intensity effects, was estimated for the industry sectors as well as the commercial and freight transportation sectors.

It should be noted that because value added is based on the cost of production, if the cost of goods rise but their consumption falls relatively less, GDP may go up under the influence of GHG pricing. In this analysis, the most significant changes in GDP are due to a reallocation of national productive capacity away from direct goods and services production and into reducing the GHG intensity of energy production (e.g., through carbon capture and storage or renewable electricity generation). As the GHG price rises, GDP in the non-energy supply sectors progressively falls, while it increases for the aforementioned energy supply sectors. At higher GHG charges, the GDP gains occurring in energy supply are outweighed by the losses occurring in other sectors; however, at lower GHG charges, the gains outweigh the losses and negative numbers are expressed in the table below.

Table 6: Loss of GDP under GHG Charges, National Total ($1995 millions, cumulative)

	10	20	30	40	50	75	100	150	200	250
2010	-1,789	-449	971	3,390	4,773	7,831	10,865	18,617	26,921	35,485
2015	-4,053	-1,081	-677	1,757	4,889	8,823	12,853	23,129	34,228	45,806
2020	-6,024	-2,746	-2,335	1,146	4,551	8,994	13,141	24,210	36,692	49,530
2030	-8,596	-4,989	-4,468	119	3,829	8,739	12,416	23,483	36,674	50,017

Table 7 provides the loss of consumer welfare estimated under the GHG charges. The core measure of a national welfare in economic theory is "personal welfare," based on the summed population's willingness to pay for consumption goods, and the amount they actually consume. Based on the financial standard of living, it rises with more consumption and services, and falls with less; however, each additional unit of consumption adds a declining amount of welfare. This measure, which is based solely on the change in demand for goods and services and not intensity, was estimated for the residential sector and for personal transportation. It is the sum of the losses in these two areas that is shown in Table 7.

Table 7: Loss of Consumer Welfare under GHG Charges, National Total ($1995 millions, cumulative)

	10	20	30	40	50	75	100	150	200	250
2010	2,498	4,954	7,362	9,708	11,999	17,637	23,279	34,548	45,805	57,096
2015	3,849	7,623	11,292	14,861	18,354	27,011	35,678	52,958	70,215	87,541
2020	4,627	9,153	13,546	17,822	22,016	32,412	42,789	63,447	84,079	104,814
2030	5,302	10,479	15,503	20,392	25,188	37,057	48,887	72,436	95,970	119,674