FINAL REPORT

Sensitivity and Uncertainty Analyses to Inform British Columbia's Interim Greenhouse Gas Targets

Final Report

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Prepared for:
British Columbia Climate Action Secretariat

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Introduction

The Climate Action Secretariat has retained MK Jaccard and Associates to inform the selection of 2012 and 2016 interim targets for greenhouse gas emissions. MK Jaccard and Associates uses a detailed energy-economy model called CIMS to evaluate energy and climate change policies and to determine the cost of reducing greenhouse gas emissions. A description of CIMS is provided as an appendix to this report.

In previous modeling of British Columbia's Climate Action Plan, we made many assumptions about uncertain parameters (e.g., energy prices, the cost of carbon capture and storage and the volume of natural gas production) to develop our forecast of greenhouse gas emissions. While these assumptions were informed by reliable sources, no amount of research enables perfect foresight into the future values for these parameters. The purpose of this report is to account for this uncertainty by analyzing the forecast's sensitivity to alternative assumptions.

This analysis forecasts greenhouse gas emissions under alternative assumptions about uncertain parameters in the Climate Action Plan (CAP) and additional policies recommended by the Climate Action Team (CAT). Details about these policies are available in previous reports.

The analysis involved a Monte Carlo analysis to account for uncertainty in a number of parameters. The Monte Carlo analysis involves performing multiple simulations, which draw the value of each uncertain parameter from a defined probability distribution. The resulting simulations provide insight into the probability of alternative forecasts for greenhouse gas emissions.

Methodology

Updates to the reference scenario

Since modeling the Climate Action Plan in June 2008, several industry working groups have been asked to help refine the analysis. The following updates were made to reflect input from these groups and other experts:

- **The model includes an upgrade to Alcan's aluminium smelter at Kitimat.** This retrofit is expected to increase capacity from between 275,000 tonnes per year to 400,000 tonnes per year. Additionally, the upgrade is expected to reduce the emission of perfluorocarbons from 500 kt CO_2e in 2007 to 70 kt CO_2e in 2012.[1]
- **The output of pulp and paper products was reduced to reflect recent changes in the industry.** The forecast for the pulp and paper sector used in the first analysis of the climate action plan was based on Natural Resources Canada's *Canada's Energy Outlook* (2006).[2] The pulp and paper working group has provided an alternative forecast that shows significantly lower output from the sector. This change has relatively little effect

[1] Rio Tinto Alcan, 2008, "Succeeding in a regulated carbon environment".
[2] Natural Resources Canada, 2006, "Canada's Energy Outlook: The Reference Case 2006", Analysis and Modelling Division, Natural Resources Canada.

on the overall emissions from British Columbia because the pulp and paper sector is projected to be a small contributor to greenhouse gas emissions.

- **The range of possible prices for natural gas was reduced to between $6.5 per mmBTU and $10 per mmBTU (2005$ US) based on recommendations by the natural gas industry.** The National Energy Board forecasts natural gas prices between $7 per mmBTU in their reference case and $12 per mmBTU in their "Fortified Islands" scenario. Members of the natural gas industry recommended a lower range for projected natural gas prices.

- **The production of natural gas from unconventional sources (i.e., tight gas and shale gas) was increased to reflect the most recent forecast from the Canadian Association of Petroleum Producers (CAPP).** The forecast of natural gas production has been significantly revised in the past months. The previous analysis showed a modest growth in natural gas production from approximately 2.6 billion cubic feet (Bcf) per day in 2005 to 2.9 Bcf per day in 2016. This forecast was largely based on the most recent forecast from the National Energy Board (2007).[3] However, the most recent forecast from the CAPP shows significantly greater production of natural gas, which reaches 4.4 Bcf of sales gas per day in 2016 in the base scenario. Most of the difference between the two forecasts is the result of increased optimism about the production of tight and shale gas in north eastern British Columbia.

  Due to the recent turmoil in international credit markets and declines in natural gas prices, the development of tight and shale gas is assumed to be delayed by 2 years from the CAPP forecast. For example, the production of tight and shale gas in 2016 matches the production forecasted by CAPP in 2014. This assumption was developed in consultation with the Climate Action Secretariat and the Ministry of Energy, Mines and Petroleum Resources.

- **The cost of carbon capture and storage (CCS) was increased by 70%.** The cost estimates for CCS used in the initial analysis were based on the Intergovernmental Panel on Climate Change's special report on carbon capture and storage, and a report by David Keith for Environment Canada.[4] The cost of capturing formation carbon dioxide from natural gas processing, which is of particular importance in British Columbia, was based on Keith.[5] Various members of the gas industry in British Columbia believe the costs are too low, and have recommended a 70% increase based on recent increases in construction costs.[6]

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[3] National Energy Board, 2007, "Canada's Energy Future: Reference Case and Scenarios to 2030", National Energy Board.

[4] Intergovernmental Panel on Climate Change, 2005, "Carbon Dioxide Capture and Storage". Keith D., 2002, "Towards a strategy for implementing CO2 capture and storage in Canada", *Environment Canada*.

[5] The cost of applying CCS to formation carbon dioxide is assumed to be significantly lower than other applications of CCS, because separating the carbon dioxide from the gas stream occurs regardless of whether the carbon dioxide is vented or sequestered (i.e., the costs of separating carbon dioxide are considered to be "sunk" costs).

[6] In the modeling, we assume a 20% discount rate for carbon capture and storage. The discount rate assumed by Keith (2002) is not discussed, but we assume it to be 10%. The higher discount rate increases the price for greenhouse gas emissions at which carbon capture and storage of formation CO_2 becomes economically viable to around $50 / tonne CO_2e.

Monte Carlo analysis

Modellers typically use Monte Carlo simulation analysis to characterize the overall uncertainty in the model outputs. The Monte Carlo analysis includes a large number of simulations where multiple assumptions are varied simultaneously, to identify potential interactive effects among uncertain parameters. The Monte Carlo analysis enables us to define a “prediction interval”, which approximates the upper and lower limit for future greenhouse gas emissions with a prescribed probability.

For each uncertain parameter in the Monte Carlo analysis, we assign a normal distribution with a mean (i.e., the value assumed to be the most likely outcome) and a standard deviation, which measures the assumed variability in the outcome. For a rough rule of thumb, 95% of all outcomes for an uncertain parameter will fall within two standard deviations of the mean. For example, if the most likely scenario for the price for oil is assumed to be $85 per barrel and the standard deviation is assumed to be $17.5 per barrel, approximately 95% of random draws for the price for oil will be between $50 and $120 per barrel.

The Monte Carlo analysis includes the following:

- **Uncertainty in the price for key energy commodities.** The most likely price for oil in the medium-term (from 2010 to 2016) is assumed to be $85 per barrel (2005$ USD), and we assign a 95% probability that the price for oil will range from $50 per barrel to $120 per barrel. In other words, the standard deviation for the price for oil is assumed to be $17.5 per barrel. The price for natural gas is correlated with the price for oil, but may also vary independently because natural gas prices are set in continental markets whereas oil prices are set globally. Overall, approximately 95% of draws for the price of natural gas range from $6.5 per mmBTU (2005$ USD) to $10 per mmBTU.
- **Uncertainty in the production of natural gas.** One of the key uncertainties in the modeling is the extent of the natural gas development in British Columbia. The Canadian Association of Petroleum Producers has produced three forecasts that show low, medium and high growth for tight and shale gas production. The updated CAPP base scenario is assumed to be the most likely scenario to 2016. In 2016, the 95% predictive interval represents the low and high estimates provided by CAPP which are 3.3 and 5.8 Bcf of sales gas per day respectively.
- **Uncertainty in the cost of carbon capture and storage.** The base cost for carbon capture and storage is assumed to be 70% greater than the costs reported by the Intergovernmental Panel on Climate Change (2005) and Keith (2002). The costs of carbon capture range from 30% greater than the costs reported by the IPCC and Keith to 110% above these costs in the 95% prediction interval.
- **The development of shale gas in British Columbia is a function of the price for natural gas and the cost of carbon capture and storage.** The production of shale gas in British Columbia is marginal, and we assume a break-even price with current production methods of between $7.25 and $8.25 per mmBTU ($2005 USD). If the price for natural gas is below the break-even price, the development of shale gas does not occur. Alternatively, if the sector adopts carbon capture and storage, a greater price for natural gas is required to break-even.

- **Uncertainty in the selling price of emissions permits.** The base scenario for the price of emissions is assumed increase from \$25/tCO_2e in 2012 to \$50/tCO_2e in 2016, with a 95% predictive interval of +/- 40%.
- **The output forecasts for all sectors (e.g., number of households, production of cement) are assumed to be uncertain.**
- **Uncertainty in key behavioral parameters.** For each behavioral parameter, we assume that the value used in the first estimate of the climate action plan was the most likely outcome, and the standard deviation is 10% of the original value. The uncertain behavioral parameters included in this analysis include:
  - The implicit discount rate that households and firms appear to use when purchasing technologies;
  - The parameters that represent the heterogeneity of household and business choices;
  - The Progress Ratio that measures the rate at which the cost of a technology declines with accumulating experience;
  - Intangible costs, which reflect consumer's and firm's non-financial preferences;
  - The elasticities of supply for different commodities or services.

Quantitative Results

Monte Carlo analysis

Table 1 shows the 95% prediction intervals for greenhouse gas emissions under the Climate Action Plan (CAP) in 2012, and with the additional recommendations of the Climate Action Team (CAT) in 2016. The prediction interval indicates that approximately 95% of the forecasts for greenhouse gas emissions are contained between the upper and lower bounds. The probability distribution of greenhouse gas emissions in 2012 and 2016 are shown in Figure 1 and Figure 2. The key findings are:

- A key source of variability in the analysis is the production of natural gas.
- In the policy scenarios, greenhouse gas emissions are forecasted to decline to:
  - between 61.4 Mt CO2e and 64.8 Mt CO2e by 2012 (based on a 95% prediction interval), and
  - between 52.0 Mt CO2e and 55.9 Mt CO2e by 2016 (based on a 95% prediction interval).

Table 1: 95% prediction intervals for greenhouse gas emissions, including land-use changes (Mt CO_2e)

	2012		*2016*	
	Reference	*CAP*	*Reference*	*CAP + CAT*
Lower Bound	67.2	61.4	73.9	52.0
Mean	69.7	63.1	78.0	54.0
Upper Bound	72.3	64.8	82.0	55.9

Figure 1: Percentage of simulations with emissions below candidate 2012 reduction targets

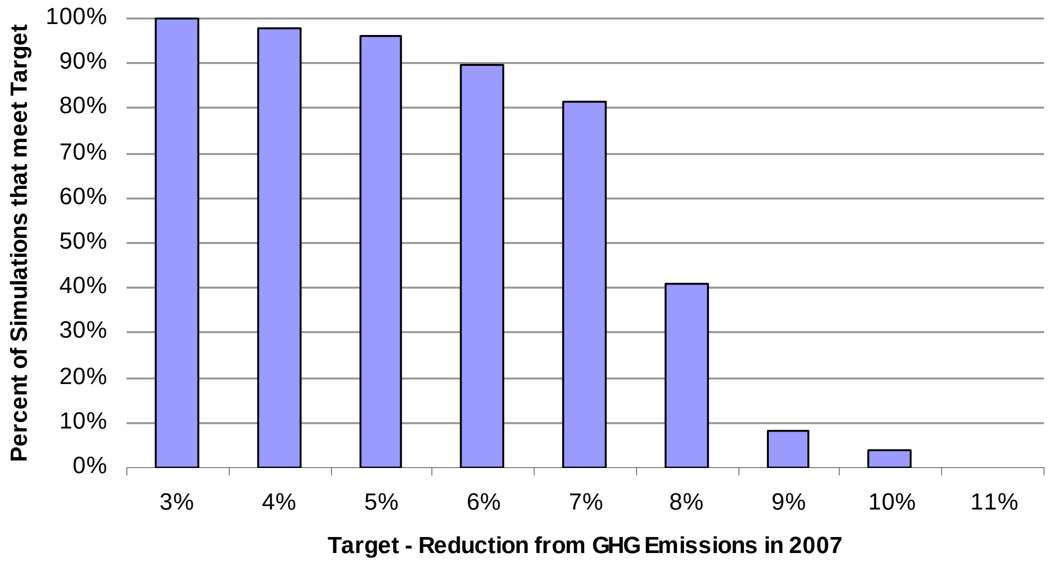
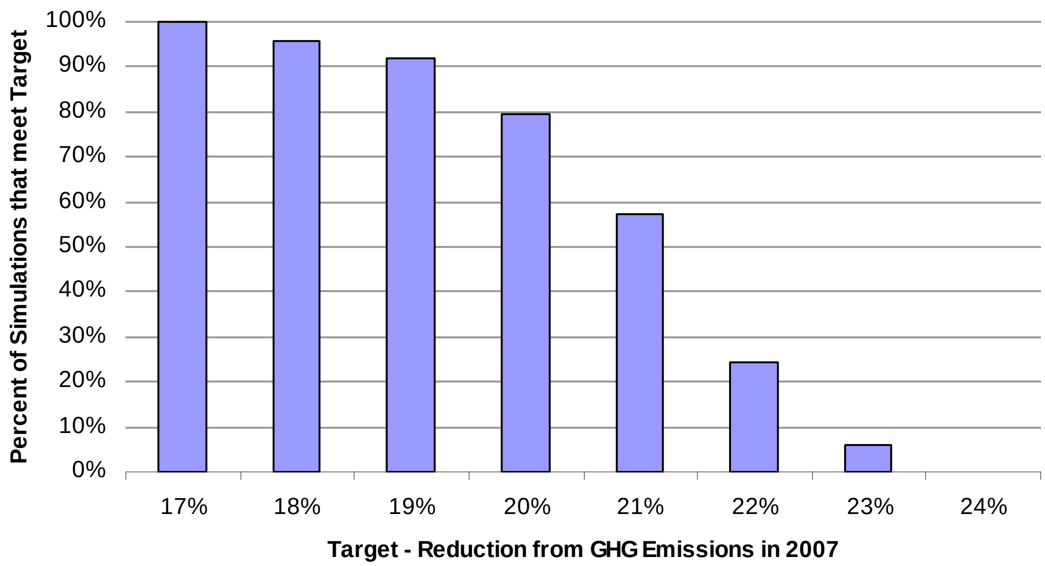


Figure 2: Percentage of simulations with emissions below candidate 2016 reduction targets



Appendix – The CIMS Model

Introduction to the CIMS model

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

CIMS simulations reflect the energy, economic and physical output, greenhouse gas emissions, and CAC emissions from its sub-models as shown in Table 2. CIMS does not include solvent, or hydrofluorocarbon (HFC) emissions. CIMS covers nearly all CAC emissions in Canada except those from open sources (like forest fires, soils, and dust from roads).

Table 2: Sector Sub-models in CIMS

Sector	*BC*	*Alberta*	*Sask.*	*Manitoba*	*Ontario*	*Quebec*	*Atlantic*
Residential	■	■	■	■	■	■	■
Commercial/Institutional	■	■	■	■	■	■	■
Transportation	■	■	■	■	■	■	■
Personal	■	■	■	■	■	■	■
Freight	■	■	■	■	■	■	■
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	■	■	■		■	■	■
Ethanol	■	■	■	■	■	■	■
Biodiesel	■	■	■	■	■	■	■
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

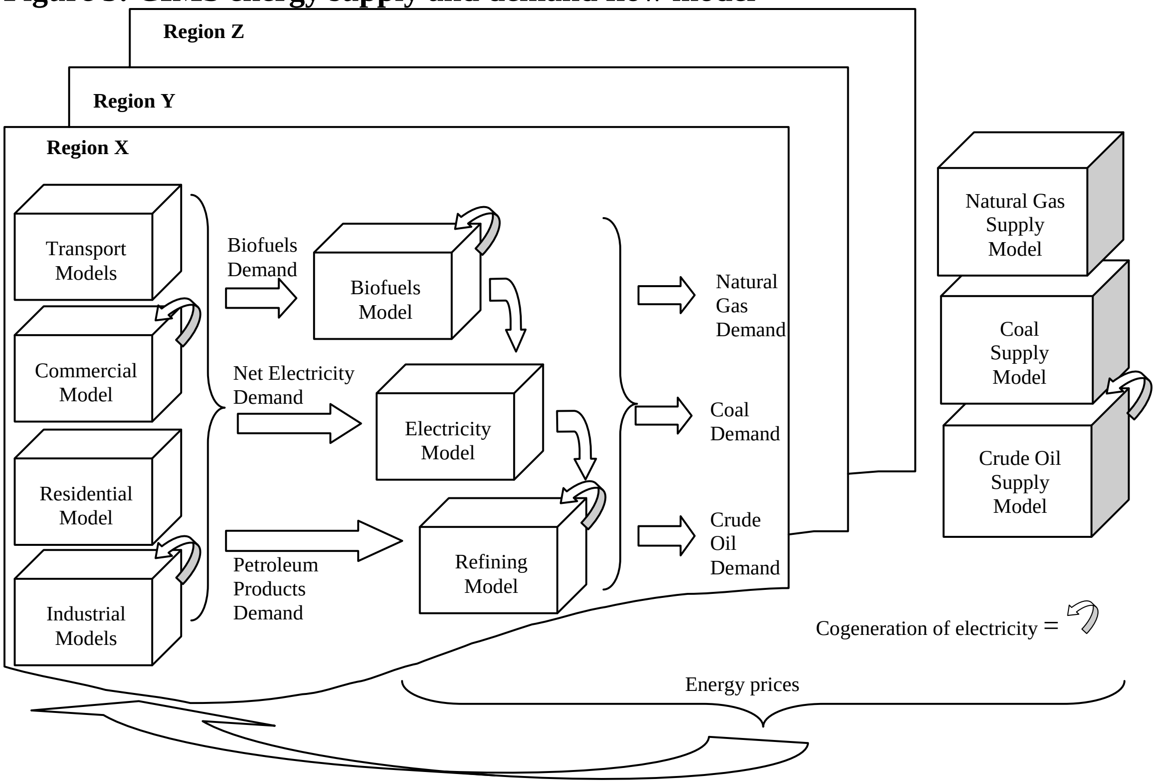
CIMS is an integrated, energy-economy equilibrium model that simulates the interaction of energy supply-demand and the macroeconomic performance of key sectors of the economy, including trade effects. Unlike most computable general equilibrium models, however, the current version of CIMS does not equilibrate government budgets and the markets for employment and investment.[7] 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 3 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

[7] The recent economic downturn has been incorporated into the analysis by adjusting the forecasted output of the industrial sectors.

remained at exogenously forecast levels (described later in this section), since Canada is assumed to be a price-taker for these fuels.

Figure 3: 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).[8] 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

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

Technical and market literature provide the conventional bottom-up data on the costs and energy efficiency of new technologies. Because there are few detailed surveys of the annual energy consumption of the individual capital stocks tracked by the model (especially smaller units), these must be estimated from surveys at different levels of technological detail and by calibrating the model's simulated energy consumption to real-world aggregate data for a base year.

Fuel-based greenhouse gas emissions are calculated directly from CIMS' estimates of fuel consumption and the greenhouse gas coefficient of the fuel type. Process-based greenhouse gas emissions are estimated based on technological performance or chemical stoichiometric proportions. CIMS tracks the emissions of all types of greenhouse gas emissions, and reports these emissions in terms of carbon dioxide equivalents.[9]

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

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

Simulating endogenous technological change with CIMS

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

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