

# **Hydropower: A Response to Canada's Climate Change and Air Quality Challenges**

**Brief prepared by  
The Canadian Hydropower Association**

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## Executive Summary

Around the world, consumption of electricity is rapidly increasing, and as fossil fuels remain by far the most important source of power, this is having a major impact on air quality, climate change and the environment. According to the Energy Information Administration of the United States, the global electricity consumption will increase to 22000 TWh by the year 2020, three quarters more than the consumption in 1997. In Canada, electricity consumption increased by 2.2% in the year 2000 only, and the average projected increase is 1.3% per year over the next two decades. Electricity generation—more specifically the burning of fossil fuels to produce electricity—is responsible for 17% of greenhouse gas emissions in Canada, and 35% in the United States, as well as producing emissions causing smog and acid rain. It is thus imperative that we reduce our dependence on fossil fuels, and pursue clean and sustainable energy choices.

The following paper was prepared by the Canadian Hydropower Association (CHA), which was founded in 1998. The document summarizes the available information on greenhouse gases produced by hydropower reservoirs, assesses the greenhouse gas (GHG) emissions of hydropower facilities on a ton of CO<sub>2</sub> per TWh basis and compares these emissions with those of thermal electricity generation options. Positing various energy generation scenarios for the future, the paper analyses the impacts of our electricity choices on future greenhouse gas emissions and air quality, and illustrates the potential environmental impacts of future energy policies.

Canada's per capita GHG emissions are among the highest in the world. Natural Resources Canada has estimated that if no further action is taken to curtail emissions, they will continue to increase significantly. According to the most recent studies of the Intergovernmental Panel on Climate Change, man-made emissions of greenhouse gas (GHG), resulting mostly from the use of fossil fuels, are a major contributor to global warming, which in turn affects forests, fisheries, animals and humans. Another major environmental problem linked to fossil fuel combustion is air pollution and particularly smog and acid rain.

Hydropower produces virtually no air pollutants and very few greenhouse gases. In fact, hydropower plants per se do not produce GHG. Reservoirs, however, like natural lakes and rivers, emit small amounts of GHG mostly due to decomposing vegetation. As reservoirs modify ecosystems by replacing land and forests that may absorb GHG, as well as lakes and rivers that may emit GHG, it is important to compare the emissions of the watershed before and after the creation of a reservoir in order to assess the net effects of a hydropower project on GHG emissions.

Research on GHG emissions of reservoirs has been carried out since the early nineties in Canada, Finland and South America. The range of reservoirs studied goes from those that are deep and cold with a small amount of flooded vegetation to warm, shallow tropical reservoirs with greater quantities of flooded vegetation. GHG emissions in these reservoirs cover a relatively wide range. Results of studies of reservoirs in boreal

regions such as Canada show that emissions are much more consistent and always much lower than those produced by fossil fuel electricity generation—approximately 60 times less than coal-fired power plants and 20 times less than the least carbon intensive of the thermal generation options, the natural gas combined cycle. Life cycle emissions of hydropower generation are comparable to those of wind power.

Hydropower is the largest source of electricity in Canada, representing more than 60% of all electricity produced. If coal-fired power plants had produced that electricity, GHG emissions and emissions responsible for smog and acid rain would be between 50 to 77% higher than they are today. Or put in terms of the future, an increase in fossil fuel generated electricity, would increase existing risks to public health and the environment. On the other hand, favouring hydropower project development to meet our electricity needs would greatly reduce GHG emissions and air emissions causing smog and acid rain.

The position of the Canadian Hydropower Association is that Canada should favour the development of hydropower to continue providing reliable, and economic electricity to a growing economy while acting on its commitment to reduce GHG emissions and improve air quality. CHA considers that hydropower is the only competitive large-scale clean and renewable electricity generation option. In addition, the stability and operational flexibility of hydropower makes it a good partner for wind power by supplementing its irregular output.

Canada holds significant hydropower potential that can be developed with respect for the environment and in collaboration with local communities. In short, the Canadian government should not only encourage but also ensure the development of hydropower.

## **1 Introduction**

Around the world, energy and electricity consumption is growing rapidly. According to the Energy Information Administration of the United-States<sup>1</sup>, global electricity demand is forecast to increase to 22 000 TWh by the year 2020— three quarters more than in 1997. In Canada, electricity consumption is projected to increase by 1.3% per year, on average, over the next two decades<sup>2</sup>. According to the National Energy Board (NEB) case 1<sup>3</sup> scenario for the growth of the energy sector, 287 TWh of additional generating capacity will have to be built between 1997 and 2025 to satisfy this new demand. Since Canada has large hydropower and fossil fuel resources, a mix of these two electricity generation options will likely produce most of the new power. In fact, NEB scenario 1 includes 100 TWh of new hydropower (35% of the new capacity) and 173 TWh of new thermal power (60% of the new capacity). The actual future electricity generation mix will depend on energy and environmental policies, economic factors and project specific circumstances.

The environmental impacts of these electricity generation options differ significantly and the choices that will be made will have long lasting consequences regarding two of the most critical issues that Canadians are facing, climate change and air quality.

This paper summarizes the information available on greenhouse gas (GHG) emissions produced by hydropower reservoirs, compares these emissions with those of thermal power facilities and discusses the role that the development of hydropower could play in minimizing GHG emissions and air pollution. It shows that the emissions rates of the hydroelectric facilities that could be built in Canada in the foreseeable future are approximately 15 000 tonnes CO<sub>2</sub> eq/TWh. This is a very small amount when compared to 350 000 tonnes CO<sub>2</sub> eq/TWh for a leading-edge combined-cycle natural gas plant, the most efficient and least emitting thermal alternative. This difference is such that increasing the development of Canada's hydraulic resources and reversing the current trend towards more thermal electricity generation in our energy mix, would greatly reduce the growth of Canada's GHG emissions. It would also reduce emissions of sulphur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>2</sub>) and thus contribute to better air quality.

## **2.0 Canada's Climate Change Challenge**

### **2.1 Evolution of the Climate**

Climate change is probably the most serious and challenging environmental problem that Canadians have ever faced. According to the most recent studies and forecasts of the Intergovernmental Panel on Climate Change<sup>4</sup>, man-made emissions of greenhouse gas (GHG), especially emissions resulting from the use of fossil fuels, are a major

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<sup>1</sup> Energy Information Administration of the United States. International Energy Outlook 2002

<sup>2</sup> Canada's Emissions Outlook: An Update, National Climate Change Secretariat, December 1999.

<sup>3</sup> Canadian Energy. Supply and Demand to 2025. NEB. 1999.

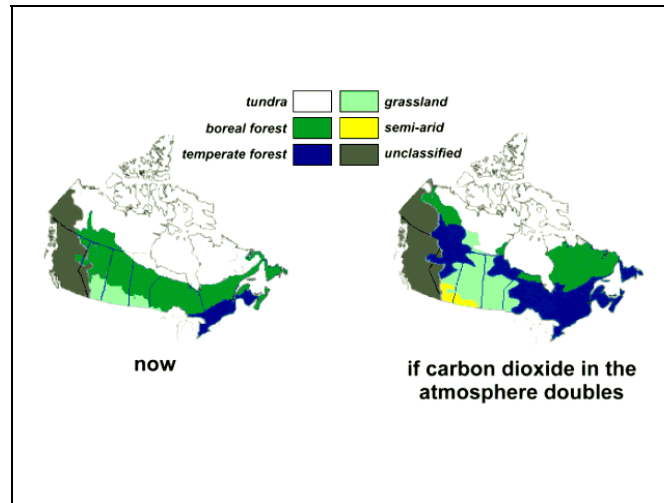
<sup>4</sup> Intergovernmental Panel on Climate Change. Third Assessment Report, 2001

contributor to global warming. These studies also show that global warming will bring large changes to the climate in temperate and arctic regions of the northern hemisphere.

The seriousness of the situation and the importance of taking action to reduce GHG emissions are well illustrated in the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (2001). Some of its key findings are listed hereafter:

- During the pre-industrial era, the atmospheric concentration of carbon dioxide (CO<sub>2</sub>) was approximately 275 ppm. The accumulation produced by the burning of fossil fuel and other activities is such that this concentration is now approximately 367 ppm and will likely continue to increase to a level within the 540-970 ppm range. The current level has likely not been exceeded during the past 20 million years. To stabilize CO<sub>2</sub> at 450 ppm, a level at which major climate changes would still occur, global anthropogenic emissions would have to be reduced to below 1990 levels within a few decades and to continue to decrease steadily thereafter.
- A significant warming of the Earth started around the middle of the 19th century and is continuing at an increasing rate. Over the period 1990 to 2100, the average surface temperature of the earth is projected to increase by 1.4 to 5.8°C (depending on GHG emissions scenarios). The average temperature in Northern Canada may increase by 8 °C .The projected rate of global warming is without precedent during at least the last 10 000 years.
- In the northern hemisphere, ice and snow are melting. As a result of the decrease in the quantity of water stored in snow and ice and of the thermal expansion of seawater, the sea level has increased by 10 to 20 cm during the 20th century. Ice and snow will continue to retreat during the 21<sup>st</sup> century and the sea level will rise by 0,1 to 0,9 m, resulting in severe flooding and erosion in low lying coastal areas, with catastrophic consequences in regions like Bangladesh, the Nile delta and small island states where population and infrastructures are concentrated in low coastal areas.
- In Canada the warming of the climate will:
  - Melt the permafrost, thus releasing more CO<sub>2</sub> and methane (CH<sub>4</sub>) and disrupting infrastructures in the North;
  - Change precipitation patterns and river flows. For example the level of the Great Lakes will drop. The flow of the St-Laurence River could be reduced by 34% at the end of the 21<sup>st</sup> century;
  - Cause a massive dieback of boreal forests and result in the loss of 40% of the tundra (see Figure 1);
  - Have major negative impacts on cold-water fisheries and threaten important northern species including Caribou, Polar bear, and Beluga whale;
  - Have severe negative socio-economic effects on aboriginal communities.

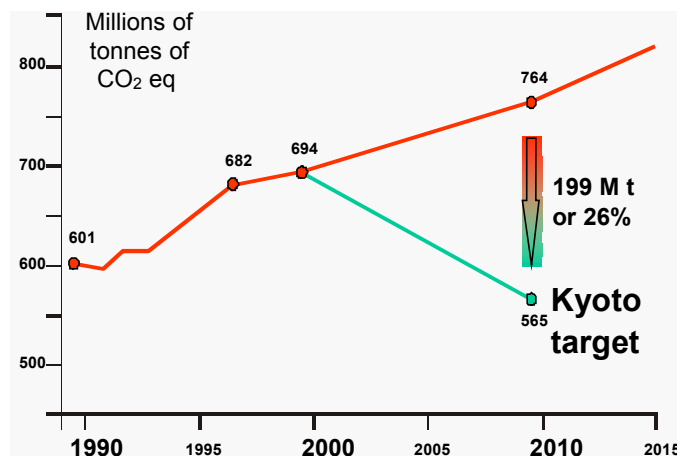
**Figure 1: Effects of Climate Change on Vegetation Zones**



## 2.2 Greenhouse Gas Emissions

The control of GHG emissions and the mitigation of the effects of climate change represent formidable challenges. In 1997, worldwide emissions of GHG were 33,100 Mt CO<sub>2</sub> eq. Canada's total was about 682 Mt CO<sub>2</sub> eq<sup>5</sup>. Canada's per capita emissions are among the highest in the world. Economic and demographic growth increases emissions of GHG. Natural Resources Canada has estimated that if no further action is taken to curtail emissions, they will increase from 682 Mt in 1997 to 764 Mt in 2010 and 845 Mt in 2020. This trend can be compared to Canada's objective of reducing its 2008-2012 emissions to 565 Mt (the 1990 level of 601 Mt minus 6%): the reduction that is needed to meet the target represents 26% of the emissions of the "business as usual scenario" and will require rapid and profound changes in many sectors of the economy<sup>6</sup> (Figure 2).

**Figure 2: The GHG Challenge**



<sup>5</sup> Canada's Greenhouse Gas Inventory: 1997 Emissions and Removals with Trends. Environment Canada.

<sup>6</sup> Canada's Emissions Outlook: An Update. Analysis and Modelling Group. National Climate Change Process.

### 3.0 The Need for Further Reductions of Emissions of Air Pollutants

The reduction of smog and acid precipitation is another difficult environmental challenge. Smog is a major problem in the most heavily populated regions of the country, including the Fraser Delta (Vancouver) and the corridor extending from Windsor to Quebec City that includes Toronto, Ottawa and Montreal. It affects the health of the population of these regions, especially children, the elderly and those with respiratory and cardiac conditions. Federal studies show there are 5 000 deaths a year in Canada that can be attributed to air pollution<sup>7</sup>. According to the Ontario Medical Association,<sup>8</sup> air pollution annually costs Ontario citizens more than \$600 million in health care costs, \$560 million in direct costs to employers, and \$10 billion in total economic costs. Acid rain, which is due to NO<sub>x</sub> and SO<sub>2</sub> emissions, is having severe detrimental effects on fisheries and forests in wide ranging areas of Eastern Canada and New England.

One of the major causes of smog is nitrogen oxides (NO<sub>x</sub>) emission. The main source of NO<sub>x</sub> is the combustion of fuels in motor vehicles, residential and commercial furnaces, industrial and electrical-utility boilers and engines, and other equipment. In 1995, overall NO<sub>x</sub> emissions in Canada amounted to 2.46 million tonnes<sup>9</sup>. The largest contributor was the transportation sector, which accounted for approximately 53% of all emissions. Industry was second with 25% and thermal electricity generation third with 10% (Figure 3).

The main sources of SO<sub>2</sub> emissions are industries (particularly mines and metals, and oil and gas), and coal fired electricity generation (Figure 4). In 1995, overall SO<sub>2</sub> emissions in Canada amounted to 2.65 million tonnes<sup>5</sup>. The largest contributor was the industrial sector, which accounted for approximately 74% of all emissions, followed by thermal electricity generation (mostly coal fired power plants) with 20%. In the United States, where the majority of the electricity produced is thermal, electric generation is by far the biggest source of SO<sub>2</sub>.

Joint programs between Canada and the United States have brought reductions in SO<sub>2</sub> emissions. However, even with full implementation of these programs in 2010, almost 800 000 km<sup>2</sup> in South Eastern Canada will receive levels of acid rain well above critical load limits for aquatic systems. Acid rain scientists recently estimated that reductions in SO<sub>2</sub> and NO<sub>x</sub> emissions far beyond the targets of the current programs are required if forests and aquatic ecosystems are to recover.

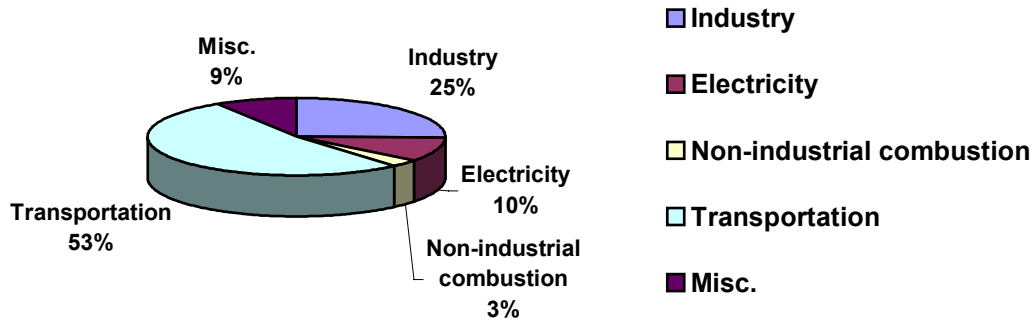
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<sup>7</sup> Report of the Commissioner of the Environment and Sustainable Development, 2000. Chapter 4: Smog: *Our Health at Risk*

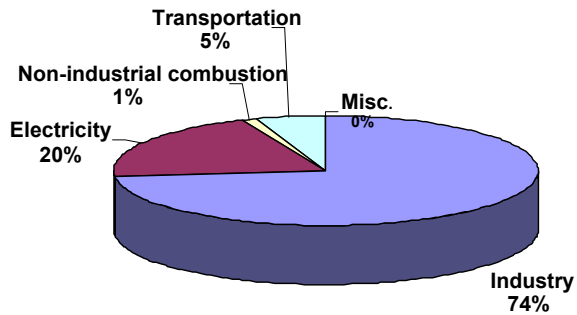
<sup>8</sup> Ontario Medical Association: The Illness Cost of Air Pollution. June 2000.

<sup>9</sup> 1995 Criteria Air Contaminant Emissions for Canada. Environment Canada, 1999.

**Figure 3: 1995 NO<sub>x</sub> Emissions  
(Total: 2.4 Mt)**



**Figure 4: 1995 SO<sub>2</sub> Emissions  
(Total: 2.65 Mt)**

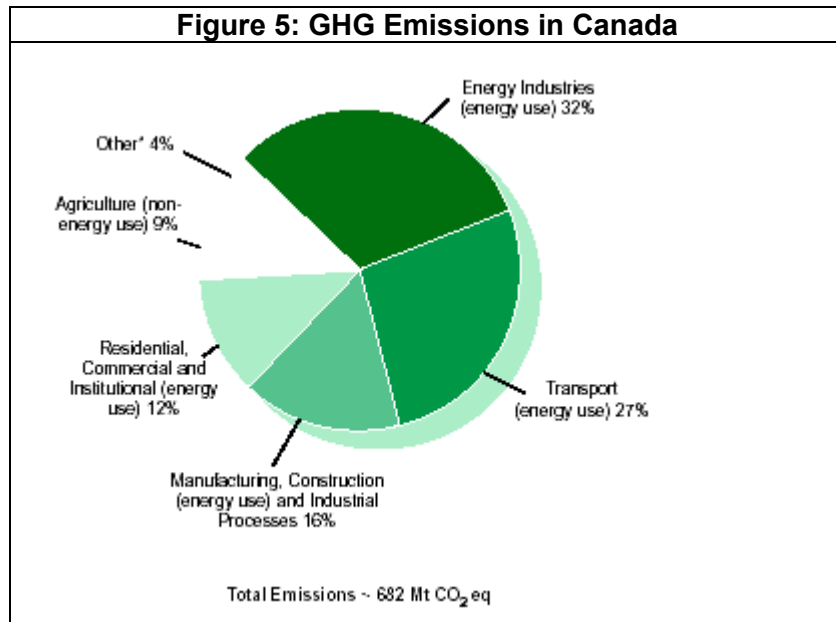


#### 4.0 GHG Emissions of Electricity Generation Options

Figure 5 provides an overview of the major economic areas' contributions to Canada's total GHG emissions. The two largest contributors are the energy industries (including

electricity generation and the coal, oil, and natural gas industries) that accounted for about 32% and transportation that accounted for 27%<sup>10</sup>.

In 1997, emissions from electricity generation were 111 Mt. This amount represents approximately 17% of Canada's total emissions<sup>11</sup>. The overwhelming proportion of the emissions of the electricity sector—84%—was from the use of coal. Natural gas and oil accounted for 9 and 7% respectively.



GHG emissions produced by the operation of thermal power plants burning fossil fuels can be calculated with a fair degree of accuracy on the basis of fuel consumption. The emissions of existing thermal power plants are therefore well known and included in the official inventories of GHG emissions.

Hydropower plants do not directly produce GHG, and until the early 1990s it was generally considered that hydropower did not emit GHG. Recent research however, has shown that hydroelectric reservoirs emit small amounts of CO<sub>2</sub> and methane (CH<sub>4</sub>). Although emissions of northern (boreal) reservoirs can now be estimated with a reasonable level of confidence, this is not the case in tropical regions where there are still major discrepancies between measurements made by various authors on different reservoirs. Because methods for estimating emissions of reservoirs are not yet standardized and not included in the current IPCC guidelines for inventories of GHG, emissions of hydropower facilities are not included in the 1990 baselines of the Kyoto

<sup>10</sup> Canada's Greenhouse Gas Inventory: 1997 Emissions and Removals with Trends. Environment Canada.

<sup>11</sup> Canada's Emissions Outlook: An Update. Analysis and Modelling Group. National Climate Change Process, December 1999.

Protocol and also not included in current GHG emissions inventories<sup>12</sup>. It should be noted that if these emissions were included, Canada's emissions growth between 1990 and 2008 (the beginning of the first commitment period of the Kyoto protocol) would likely not change significantly since between 1990 and 2008 there will have been only a modest increase in the total surface area of reservoirs, and this increase is likely counterbalanced by the slow decrease of emissions rates as reservoirs age.

#### **4.1 GHG Emissions of Hydropower Reservoirs**

Unlike synthetic pollutants such as BPC or DDT, the three most important greenhouse gases, carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) are products of natural biological or chemical reactions and have existed on the earth long before the beginning of our civilization. Climate change is occurring because their concentrations in the atmosphere are increasing as a result of man-made emissions that disrupt the balance between natural emissions and natural consumption of GHG.

Carbon dioxide is produced by the combustion of fuels (wood, peat, oil, natural gas, coal, etc.) and by the aerobic<sup>13</sup> biological degradation of organic matter. It is extracted from the atmosphere by plants through photosynthesis. Plants use the carbon contained in CO<sub>2</sub> to grow plant tissue (leaves, wood). When plants die, this carbon finds its way into soils. Some of the organic matter from plants and soils ends up in rivers and lakes, where it is decomposed by bacteria and other microorganisms that release part of its carbon in the form of CO<sub>2</sub> where oxygen is available, or CH<sub>4</sub> where oxygen is absent. As a result of these chemical and biological reactions of the carbon cycle and of other natural reactions involving nitrogen, many ecosystems naturally absorb or emit CO<sub>2</sub>, CH<sub>4</sub> and small quantities of N<sub>2</sub>O. For example, a growing boreal forest absorbs (traps) CO<sub>2</sub> and emits N<sub>2</sub>O; lakes and rivers emit CO<sub>2</sub> and CH<sub>4</sub>.

On a long-term basis, boreal forests slowly accumulate carbon. The average annual amount of carbon that is accumulated can be calculated by assuming that there was no soil and no biomass, and therefore no carbon accumulated at the end of the last ice age, about 10 000 years ago. The total amount that is found today in soil and biomass is the result of the slow accumulation over time of carbon removed from the atmosphere by trees. Boreal forests also absorb nitrogen from the atmosphere and reemit a small fraction of this nitrogen as N<sub>2</sub>O. The quantity of nitrous oxide that is emitted is too small to counterbalance the removal of CO<sub>2</sub>. In a long-term perspective boreal forests can therefore be considered as GHG "sinks". This example shows that to assess the "net" emissions of an ecosystem, a balance sheet approach has to be used: emissions and absorptions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O must all be taken into account<sup>14</sup>. These calculations

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<sup>12</sup> Since these emissions origin from the reservoirs and not from the hydropower plants, when they will be included, they will be accounted for in the land-use change category.

<sup>13</sup> Aerobic = in the presence of oxygen.

<sup>14</sup> In order to add or subtract quantities of different gases they are all converted into tonnes of "CO<sub>2</sub> equivalent" (t CO<sub>2</sub> eq) with factors that measure their respective warming potential. One tonne of CH<sub>4</sub> is deemed equivalent to 21 tonnes of CO<sub>2</sub> and 1 tonne of N<sub>2</sub>O is deemed equivalent to 310 tonnes of CO<sub>2</sub>.

show that some ecosystems, like forests are net sinks while others, like lakes and rivers, are net emitters.

Reservoirs are man-made lakes and like natural lakes they emit CO<sub>2</sub> and CH<sub>4</sub>. The main sources of the organic matter that is decomposed in reservoirs are:

- flooded soils and vegetation;
- the watershed upstream (carbon dissolved or suspended in rivers flowing into the reservoir).

When a dam is built, a reservoir replaces terrestrial ecosystems and natural lakes. In order to assess the effects of a hydropower development project on GHG emissions, the net emissions of the area before and after impoundment have to be compared. The difference between the net emissions after the construction and the net emissions before can be attributed to the development. For example, if a reservoir emitting 244 g CO<sub>2</sub> eq /m<sup>2</sup>.year has replaced a forest that was absorbing 6 g CO<sub>2</sub> eq/m<sup>2</sup>, the net emissions of the development are 250 g CO<sub>2</sub> eq per m<sup>2</sup>.year<sup>15</sup>. In order to simplify the discussion, in the following sections of this document, these emissions are called “net emissions of the reservoir” although they are really equal to the net emissions of the reservoir minus the net emissions before impoundment of the flooded land and flooded lakes.

Reservoirs trap some carbon through sedimentation of organic matter originating upstream in the watershed, and may thus conceivably reduce CO<sub>2</sub> emissions in rivers and estuaries downstream. In theory, this reduction in emissions should be taken into account in the assessment of the emissions of hydropower development projects. However, since there is not yet enough data to quantify this phenomenon, it has not been taken into account in the estimates that have been published to date.

Research on GHG emissions of reservoirs has been carried out since the early nineties in Canada, Finland and tropical South America<sup>16</sup>. The reservoirs that have been studied are quite diverse, ranging from relatively deep, cold, nutrient-poor boreal reservoirs in which the amount of biomass flooded is low, to warm, shallow tropical reservoirs with a much higher biomass content. GHG emissions per unit of area of these reservoirs cover a wide range of values<sup>17</sup>.

The data accumulated shows that there is much less diversity in results when only hydroelectric reservoirs located in boreal regions are considered. The mean net value

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<sup>15</sup> In fact, the boreal forest, besides being a CO<sub>2</sub> sink, is a N<sub>2</sub>O emitter. The complete calculation would show that the flooding also makes N<sub>2</sub>O emissions from the forest cease. However, emissions and sinks of flooded ecosystems in boreal regions are usually small in comparison to emissions from reservoirs.

<sup>16</sup> A list of references can be found in E. Duchemin's PhD dissertation. *Hydroélectricité et gaz à effet de serre: évaluation des émissions des différents gaz et identification des processus biogéochimiques de leur production*, 321 pages. Université du Québec à Montréal, 2000.

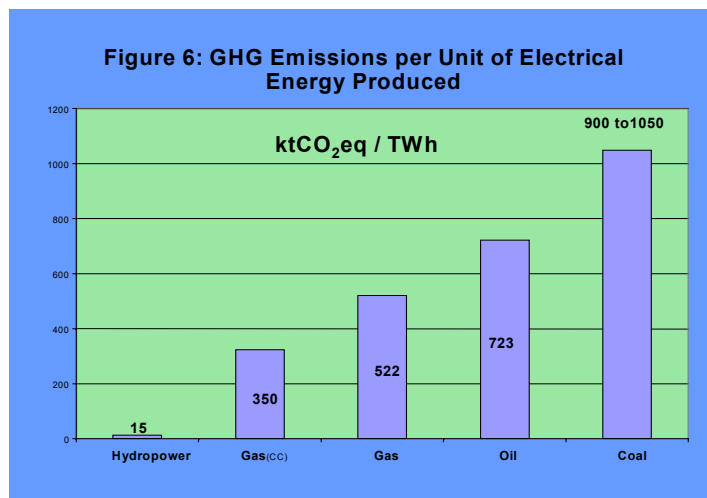
<sup>17</sup> The range is still wider when emissions are expressed as tonnes of equivalent CO<sub>2</sub> per TWh, since some of the reservoirs have a much lower energy output per unit of surface area than others.

for Canadian hydroelectric reservoirs is around 250 g CO<sub>2</sub> eq/m<sup>2</sup>.year. There are preliminary indications that this amount slowly decreases as reservoirs age.

When the net annual emissions of a hydropower reservoir are known they can be converted into tonnes of CO<sub>2</sub> equivalent per TWh, by dividing the annual GHG emissions by the energy output of the facility. In Canada, since the average surface area of reservoir per unit of energy, calculated for known large potential hydropower development projects<sup>18</sup>, is approximately 40 km<sup>2</sup>/TWh, the GHG emissions of these hydropower projects are approximately 15 000 tonnes of CO<sub>2</sub> eq/TWh on the average<sup>19</sup>.

#### 4.2 Compared GHG Emissions Factors of Electricity Generation Options

The emission factor of 15 000 tonnes of CO<sub>2</sub> eq/TWh for potential future Canadian hydroelectric reservoirs can be compared to typical values<sup>20</sup> of approximately 1 million tonnes/TWh for electricity from coal, 750 000 tonnes/TWh for electricity from oil or 500 000 tonnes/TWh for electricity from gas. These factors show that, in Canada, GHG emissions of future hydropower projects are approximately 20 times less than those of the least carbon intensive of all fossil fuel electricity generation technologies, the natural gas combined cycle, that emits approximately 350 000 tonnes of CO<sub>2</sub> per TWh (see Figure 6). These comparisons would give results even more favourable to hydropower, if GHG emissions of fuel extraction, treatment and transport were taken into account in assessing thermal options.



Notes: Emissions are for operation only. Emissions of upstream activities (fuel extraction, treatment and transportation) are not included. Emissions factors are from US EPA AP-42, Environment Canada, or recent projects in Canada. Hydropower emission factors are presented in Section 4 of this document.

<sup>18</sup> All projects listed in the appendices of the Electricity Table Report plus the Lower Churchill project.

<sup>19</sup> In order to simplify the discussion, the emissions shown in this document do not include emissions from construction activities. These emissions are small in comparison to the emissions from the operation phase and would not change the conclusions.

<sup>20</sup> US Environmental Protection Agency. AP-42 emission factors.

Since the risks and concerns about climate change make it all but certain that sooner or later we will live in a “carbon constrained” world, an interesting way of looking at the data shown on Figure 6 is to calculate how much electricity a generator could produce if there was a market for emission credits and the generator had acquired credits worth 1 Mt CO<sub>2</sub> eq. The results are as follows:

- 1 TWh of electricity can be produced from coal
- 1.4 TWh from oil
- 2.9 TWh from natural gas (combined cycle)
- 66.7 TWh from hydropower.

### **5.0 Role of Hydropower in Minimizing GHG and Air Pollutants Emissions**

The performance of hydropower in terms of GHG emissions is illustrated by the fact that, if coal-fired generation had produced the 342 TWh of electricity that were produced by hydropower facilities in 1997, Canada's total greenhouse gas emissions would have exceeded 1 000 Mt instead of being 682 Mt, an increase of approximately 50%. On the other hand, if the 551 TWh of electricity from all sources that were produced in Canada in 1997 had been produced by hydroelectric facilities, the emissions of the electricity sector would have been only a small fraction of the current 111Mt, and Canada's total GHG emissions would be 10 to 15% lower than they are.

The development of hydropower has avoided GHG emissions. It has also reduced emissions responsible for smog and acid precipitation. If coal-fired thermal power plants had been built instead of hydropower facilities to produce the 342 TWh of hydropower that were produced in 1997, the amount of NO<sub>x</sub> produced by the electricity sector would likely be more than 6 times higher than it actually is, increasing the overall Canadian total by 56%; similarly, the amount of SO<sub>2</sub> produced by the electricity sector would likely be close to 5 times higher than it actually is, increasing the overall Canadian total by more than 2 million tonnes or 77%<sup>21</sup>.

In order to illustrate the potential benefits of the future development of hydropower over the increased use of fossil fuels, emissions forecasts have been developed for three electricity generation scenarios<sup>22</sup>, for the period 1997-2025. These scenarios are based on NEB case 1<sup>23</sup> domestic generation forecasts. They all assume that domestic electricity generation will grow from 551 TWh to 838 TWh, but differ by the respective shares of hydropower and thermal power in the new capacity mix.

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<sup>21</sup> On the basis of Environment Canada 1995 Criteria Air Contaminant Emissions and assuming that the emission factors of the coal-fired facility would have been equal to the US average of 4023 g NO<sub>x</sub>/MWh and 5965 g SO<sub>2</sub>/MWh (Emission and Generation Resources Integrated Database, E-Grid, of the US EPA).

<sup>22</sup> These scenarios should not be considered as forecasts. They are simply coherent sets of data that have been used to illustrate the potential impacts of future energy policies on trends in emissions of GHG and air pollutants.

<sup>23</sup> Canadian Energy. Supply and Demand to 2025. NEB. 1999

Scenario A assumes that there will be obstacles to hydropower development that will reduce new hydroelectric generation to zero. A mix of natural gas and coal-fired facilities will replace the projected increase in hydropower. Scenario B is simply NEB case 1; it includes 100TWh of new hydropower generation. Scenario C assumes that aggressive policies favouring low GHG emissions generation will be put in place, and that 186,5 TWh of new hydroelectric generation will be built. The details of the three scenarios are provided in Table1.

In order to estimate future emissions it has been assumed that the removal of CO<sub>2</sub> from flue gas will not become economically feasible, and that SO<sub>2</sub> and NO<sub>x</sub> emissions rates of new gas-fired and coal-fired plants will be below current Environment Canada Guidelines<sup>24</sup>, but not as low as the levels that can be reached with the best available technologies. The emissions factors that have been used are shown in Table 2. The results of the emissions forecasts for the 3 scenarios are summarized in Table 3. Figure 7 shows the growth of GHG emissions.

**Table 1: Electricity Generation Scenarios**

TWh	1997	2025 <sup>1</sup>		
		Scenario A	Scenario B (NEB case 1)	Scenario C
		No new hydropower NEB 1	100 TWh of new hydropower	186.5 TWh of new hydropower
Hydropower	342	342	442	528.5
Nuclear	78	91	91	91
Coal	91	152	127	109
Other thermal	40	252	177	108.5
Wind	0.1	1	1	1
Total	551	838	838	838

1) The new thermal generation is projected to be approximately 78% from gas and 22% from coal

**Table 2: Emissions factors for New Thermal Generation**

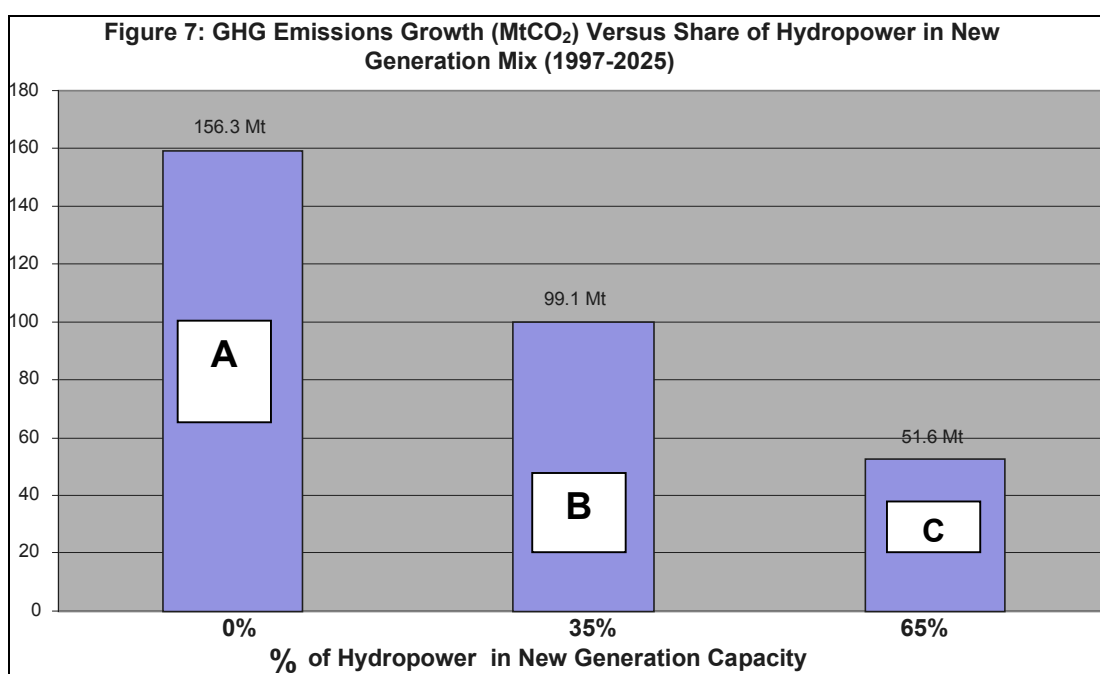
Tonnes/ TWh	Coal fired generation	Other thermal (1)	Hydro
GHG	1000 000	450 000	15 000
SO <sub>2</sub>	600	15	0
NO <sub>x</sub>	400	100	0

1) Since this category is 98,5% natural gas, emission factors for a mix of gas turbines and combined cycle plants are used.

<sup>24</sup>Thermal Power Generation Emissions-National Guidelines for New Stationary Sources. Environment Canada, 1999.

**Table 3: Incremental Emissions of Electricity Generation, 1997 to 2025**

Scenario	A	B	C	Avoided emissions with increased (+186.5 TWh) hydro development (C minus A)
Emissions	No new hydro	NEB Case1: 100 TWh of new Hydro:	186.5 TWh of new hydro	
GHG	156.3 Mt	99.1 Mt	51.6 Mt	104.7Mt
SO <sub>2</sub>	39.8 kt	23.7 kt	11.8 kt	28 kt
NO <sub>x</sub>	45.6 kt	28.1 kt	14 kt	31.6 kt



The analysis shows that favouring the development of hydropower would greatly reduce GHG emissions, and that if hydropower is not developed there will be a large additional increase of GHG emissions and significant negative impacts on air quality. For example, if in 2025 the 100 TWh of new hydroelectricity that are included in NEB case 1 are displaced by thermal power, annual GHG emissions will likely increase by approximately 57 Mt. This amount represents approximately 8% of Canada's current total. By contrast, if new hydropower generation is increased to 186,5 TWh, the avoided GHG emissions will be 48 Mt in comparison to NEB case 1 and 105 Mt in comparison to scenario A (no new hydropower).

Similarly, the scenario with increased hydropower development (C) would reduce sulphur oxides (SO<sub>2</sub>) emissions by 28 000 t and nitrogen oxides (NO<sub>x</sub>) emissions by

31,600 t in comparison to the scenario with no new hydropower (A). Although these amounts of SO<sub>2</sub> and NO<sub>x</sub> may look relatively small in comparison to Canada's total emissions which are approximately 2.5 millions tonnes for each of these pollutants, they are important when assessed in the context of a growing economy in which we have to make room for new sources of SO<sub>2</sub> and NO<sub>x</sub> while we need to simultaneously reduce total emissions further to protect public health and the environment.

Technological advances can bring new reductions in emissions of NO<sub>x</sub> and SO<sub>2</sub> of thermal power plants, but these changes will not completely eliminate acid emissions in the foreseeable future and, on average, power plants that will be built in the coming years will likely have emissions rates at least equal to those used to develop the scenarios presented here. Once these plants are built, their retrofitting with more advanced technologies will be expensive and is not likely to be required by legislation.

Hydropower appears to be the only alternative to thermal power that can be developed on a large scale. Wind power can also play a role in the reduction of emissions, but at a much smaller scale. On a life-cycle basis GHG emissions of wind power are comparable to those of hydropower (the materials, manufacturing and construction of wind generation facilities require energy and thus result in emissions). The International Energy Agency estimates<sup>25</sup> that worldwide, the average life-cycle emissions of wind power are 7 000 to 9 000 tonnes of CO<sub>2</sub> eq/TWh, whereas those of hydropower are 4 000 to 15 000 tonnes of CO<sub>2</sub> eq/TWh. Wind power, however, is intermittent and needs backup electricity production such as oil or gas-fired turbines or hydropower with a reservoir, thus making emission comparisons with other energy options difficult except in the context of a specific power grid. The current installed wind generation capacity in Canada is small. Taking into account the natural wind potential, cost and other constraints, it appears that the maximum amount of wind power that can realistically be developed in the foreseeable future, assuming a favourable energy policy environment, is of the order of 10TWh. This amount of energy is small when compared to the probable growth of electricity demand in Canada (287 TWh) and to the role that hydropower can play in fulfilling this demand.

## **6.0 Conclusion**

Canada is currently facing the difficult challenge of continuing to provide a relatively cheap and reliable source of electricity to a growing economy, while meeting its commitments regarding the reduction of greenhouse gas emissions and improving air quality to minimize smog and acid precipitation.

Scientific evidence showing that the use of fossil fuels plays an important role in climate change is mounting. Canadians are increasingly aware of climate issues. There is little doubt that we will see a "carbon constrained future" and should, as a country, plan for such a situation.

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<sup>25</sup> Benign Energy? The Environmental Implications of Renewables. International Energy Agency, 1998.

Unfortunately Canada's GHG emissions are now increasing quickly, pushed up by a growing economy and a shift away from hydropower and nuclear power, to fossil fuel electricity generation. Simultaneously the efforts that have been made to reduce smog have not been sufficient and smog remains a major problem in the most heavily populated regions of the country. Recent data show that the impacts of poor air quality on the health of Canadians are severe and will increase unless further reductions in air pollutants emissions are implemented. Acid rain is still having wide-ranging impacts despite the reductions in SO<sub>2</sub> and NO<sub>x</sub> emissions that have been achieved in Canada and the United States, and sensitive ecosystems are not recovering. Scientific evidence now indicates that SO<sub>2</sub> and NO<sub>x</sub> reductions, beyond those that will take place when the current Canada-United States Agreement will be fully implemented in 2010, are required to ensure that acid lakes, rivers and forests return to normal.

When compared to other sources of electricity that can be expected to play a significant role in Canada's generation mix in the foreseeable future, hydropower produces only very small amounts of GHG. Scientific research carried out since 1992 in Canada and to a lesser extent in other countries, has shown that boreal reservoirs emit small quantities of methane and CO<sub>2</sub>. These gases are produced by the decomposition of flooded biomass and natural organic compounds drained from the upstream part of the watershed. In Canada, emissions of hydroelectric reservoirs are approximately 15 000 t CO<sub>2</sub> eq/TWh on the average. This compares to more than 1 million t CO<sub>2</sub> eq/TWh for coal-fired generation and 350 000 t CO<sub>2</sub> eq/TWh for a state-of-the-art natural gas combined cycle plant, the most efficient of thermal electricity generation options. This comparison would be even more favourable to hydropower if the emissions of fossil fuel extraction, treatment and transportation were taken into account.

If the obstacles that currently hinder the development of hydropower had existed in the past, coal-fired generation would likely have produced the vast majority of the 342 TWh of electricity that were produced by hydropower facilities in 1997. As a consequence, Canada's total annual greenhouse gas emissions would have exceeded 1 000 Mt instead of being 682 Mt, an increase of approximately 50%, and Canada's total NO<sub>x</sub> and SO<sub>2</sub> emissions would likely be approximately 56% and 77% higher than they are.

In Canada, electricity consumption is projected to increase by 1.3% per year, on average, over the next two decades<sup>26</sup>. This growing demand makes it essential to favour power generation options that minimize GHG and air pollutants emissions. In fact, if more carbon intensive, polluting options are selected to satisfy the majority of our electricity needs in the coming years, more drastic action to curb emissions will be required later or will have to be imposed upon other industries, and the cost of reducing total emissions to acceptable levels will increase sharply.

Canada has large undeveloped hydropower resources. The Canadian Electricity Industry Table suggests that another 118 000 MW of hydropower could be developed, twice the amount currently in operation. Comparative analyses of electricity generation

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<sup>26</sup> Canada's Emissions Outlook: An Update, National Climate Change Secretariat, December 1999.

options show that increased development of hydropower can greatly contribute to reducing emissions of GHG, smog and acid compounds. For example, a scenario for 1997 to 2025 with no significant additional hydropower generation capacity would likely result in additional annual emissions of 57 MT of GHG, 16 kt of SO<sub>2</sub> and 17.5 kt of NO<sub>x</sub>, when compared to a scenario with 100 TWh of additional hydropower.

Unfortunately the development of hydropower has slowed down since the early nineties. It is currently facing serious obstacles including excessive delays and uncertainties caused by the Canadian Environmental Assessment Act (CEAA) and the Canadian Fisheries Act (CFA) and their current interpretation. Since hydropower projects are long to develop, action should be taken now to improve the CEAA and the CFA, and to implement policies that will favour the development of the cleaner and least intensive GHG emitter of Canada's major energy resources.