ERG/201001

The challenge of meeting Canada's greenhouse gas reduction targets

Larry Hughes and Nikhil Chaudhry
Energy Research Group
Electrical and Computer Engineering, Dalhousie University
Halifax, Nova Scotia, Canada
larry.hughes@dal.ca

14 February 2010

The challenge of meeting Canada's greenhouse gas reduction targets

Larry Hughes and Nikhil Chaudhry
Energy Research Group
Electrical and Computer Engineering, Dalhousie University
Halifax, Nova Scotia, Canada
larry.hughes@dal.ca

Abstract

In 2007, the Government of Canada announced its medium and long-term greenhouse gas (GHG) emissions reduction plan entitled *Turning the Corner*, which proposed emission cuts of 20% below 2006 levels by 2020 and 60% to 70% below 2006 levels by 2050. A Canadian government advisory organization, the National Round Table on the Environment and the Economy (NRTEE), determined the feasibility of these targets and recommended both taxation and technical means to address them. NRTEE's technical report, *Achieving 2050: A carbon pricing policy for Canada*, presented a set of "fast and deep" pathways to emissions reduction through the large-scale electrification of the Canadian economy.

This paper examines the likelihood of the "fast and deep" pathways being met by considering the technical report's proposed energy systems, their associated energy sources, and the magnitude of the changes. The paper also questions the decision to omit non-electrical replacement solutions such as district heating, solar heating, and wind heating.

Keywords: Emissions reduction, Resource availability, Climate change

1 Introduction

In 2006, Canada's greenhouse gas emissions were 721 Mt CO_2e, 21.7% above 1990 levels and 29.1% above the country's Kyoto target (Environment Canada, 2009). The Canadian federal government, like many others around the world, realizing that achieving its Kyoto target was impossible, changed the rules and introduced new emissions reduction targets in 2007 (ecoAction, 2007). The new targets, described in a report entitled *Turning the Corner*, proposed cuts of 20% below 2006 levels by 2020 and 60% to 70% below 2006 by 2050 (ecoAction, 2009; ecoAction, 2008c; ecoAction, 2008b).

In response to these new targets, the National Round Table on the Environment and the Economy (NRTEE), an arms-length Canadian government environmental advisory organization, produced a series of reports outlining how the two proposed emission cuts could be met; NRTEE chose 65% as the 2050 target. The final two reports focused on implementation, with one report on carbon taxes and cap-and-trade (NRTEE, 2009a) and the second on a set of energy pathways with decadal targets culminating in 2050 (NRTEE, 2009b). The pathways resulted from an analysis of various non-carbon energy sources for the generation of electricity and their implementation between 2010 and 2050 (Nyboer, 2008).

Although NRTEE's analysis suggests that by 2050 the targets can be reached, there has been no published assessment of whether the targets are realistic, either in terms of the energy required to meet the expected demand or the time available to implement (and in some cases, develop) the necessary infrastructure. These omissions mean that a lack of energy or insufficient time in any of the proposed pathways could result in the 2050 reduction target not being reached. Furthermore, by focusing only on electricity to meet the end-use energy needs of most services, the technical analysis overlooks other technologies that could reduce greenhouse gas emissions at potentially lower costs.

This paper examines each of the energy sources in NRTEE's proposed "fast and deep" pathways, in terms of Canada's historic use of the energy source (that is, both supply and infrastructure), the planned growth in the source, and the energy required for the source. Crucial issues unique to each energy source are also discussed in order to explain any potential limitations or shortcomings. Economic issues are not considered as these have been discussed at length in the original reports. The objective of the paper is to examine the proposed pathways; alternatives to pathways are considered only in passing.

2 NRTEE's "Fast and Deep" pathways

In addition to carbon taxes and cap-and-trade as a means of encouraging a reduction in energy consumption, the report's "fast and deep" energy pathways recognized the need to replace existing, and restrict new, demand to non-carbon emitting energy sources (Hughes, 2009b). There are five energy pathways proposed: hydroelectricity, wind, other renewables, nuclear, and coal and natural gas with carbon capture and storage (CCS). These pathways are expected to grow over the four decades between 2010 and 2050, as non-electric energy sources are replaced with ones that are electric. Table 1 shows the historic (actual data for 2008) generation of electricity from each of the pathways in 2008 and the projected generation for each pathway every ten years, starting in 2020 and ending in 2050.

Table 1: NRTEE's pathways for electrical generation to 2050 (NRTEE, 2009b, p. 94)

Pathway	Historic (TWh)	Total Generation (TWh)			
	2008	2020	2030	2040	2050
Hydroelectricity	373.0	505	633	759	890
Wind	1.8	33	63	91	110
Other renewables	5.4	3	7	10	13
Nuclear	88.6	124	168	204	232
Coal and natural gas with CCS	0	62	193	328	456
Total generation	**468.8**	**868**	**1,166**	**1,445**	**1,712**

The pathways are based on the assumption that Canada will have an electric future with electricity coming from a limited number of generation sources, over 90% of which will be derived from hydroelectricity, coal and natural gas with CCS, and nuclear. The electricity produced is intended to replace existing demand from carbon-emitting energy sources such as fuel oil, natural gas, and biomass, as well as to ensure that new demand is restricted to electricity generated from non-carbon sources. By 2020, greenhouse gas emissions are to be 20% below 2006 levels and by 2050 they are to be 65% lower than 2006 levels.

Although not shown in this table, coal and natural gas continue to be used in the generation of electricity from non-CCS facilities. This is discussed in section 3.5, below.

3 An analysis of the pathways

Each of NRTEE's proposed energy pathways is now examined in detail. For each pathway, the historic growth rates and the necessary future growth rates to meet the short-term 2020 targets and long-term 2050 targets are considered. The analysis maintains the report's approach of referring to production (TWh) rather than capacity (MW).

3.1 Hydroelectricity

Hydroelectricity presently meets about 60 percent of Canada's electricity needs (Canadian Hydropower Association, 2003). According to NRTEE's projections, hydroelectricity will remain the largest contributor to electrical supply in Canada by 2050. Figure 1 shows both Canada's historical (1950 to 2008) and the report's projected hydroelectric production over four decades between 2010 and 2050.

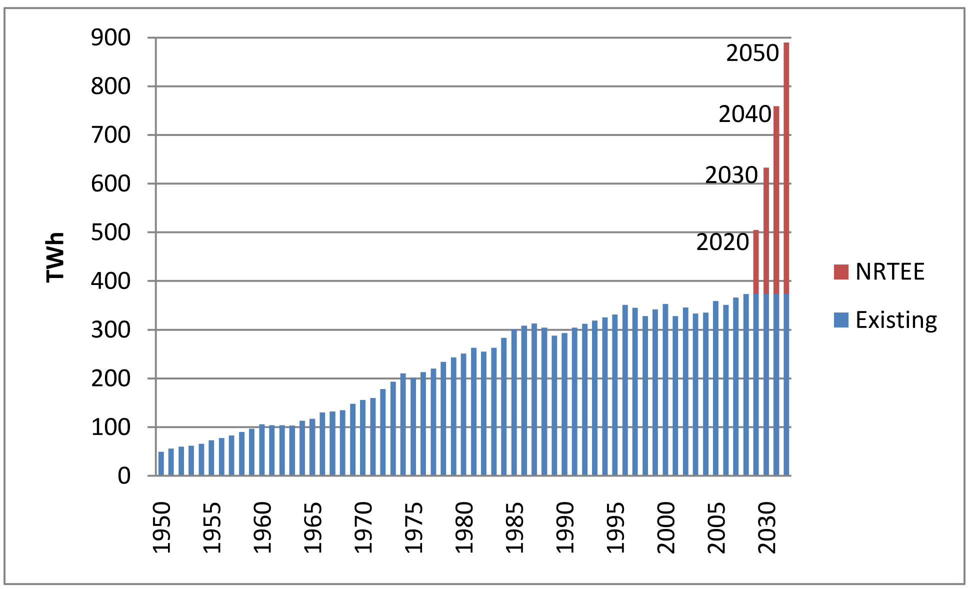

Figure 1: Historical and projected hydroelectric production (Statistics Canada, 2009a; Statistics Canada, 2009b)

In 2008, Canada produced 373 TWh from hydroelectricity; by 2050, the report expects Canada's hydroelectric production to reach 890 TWh per year, meaning that between 2010 and 2050, Canada's overall hydroelectric production must increase by 517 TWh. This falls within the Canadian Hydropower Association's "economically feasible" potential new hydroelectric facilities in Canada shown in Table 2.

Table 2: Canadian hydroelectric potential (Canadian Hydropower Association, 2003)

Hydroelectric potential	Production (TWh/year)
Gross theoretical	1,332
Technically feasible	981
Economically feasible	536

The largest post-war ten-year period of expansion in Canada's hydroelectric production was between 1965 and 1974, when about 93 TWh of hydroelectric production was added. Much of the significant growth ended in the early 1980s with the completion of projects started in the 1970s. Hydro Quebec's James Bay projects in the 1980s and 1990s saw other periods of decadal growth.

Between 1950 and 2008, the average increase in Canadian hydroelectric production was 50.6 TWh per decade; to meet the greenhouse emissions reduction targets described in its report, NRTEE requires production growth of about 130 TWh per decade. The difference in decadal growth, both historic and projected, is shown in Figure 2. The proposed increase of 130 TWh of new hydroelectric production per decade exceeds both the 1950-2008 decadal average and the 1965-74 increase of 93 TWh. Although adding 517 TWh of new hydroelectric production may be economically feasible, whether it can be achieved over four decades is unclear.

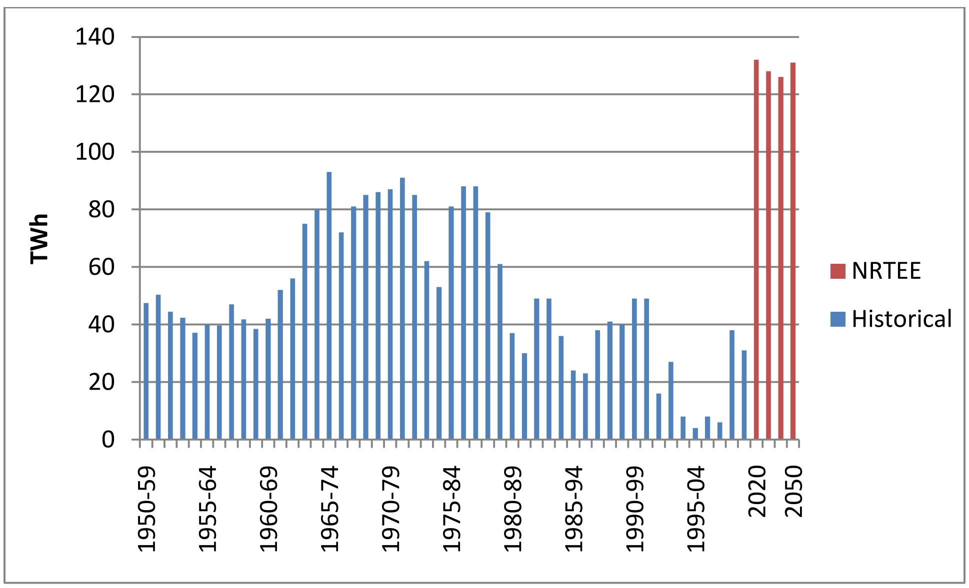

Figure 2: Decade-over-decade growth in Canadian hydroelectric production (Statistics Canada, 2009a)

It has been argued that since Canada is a wealthy nation and its GDP per capita has grown considerably since the Second World War, adding sufficient hydroelectric capacity to supply an additional 517 TWh over 40 years should be achievable (Dooley, 2010). This argument overlooks the rising cost of commodities required for the construction of new hydroelectric facilities and does not recognize the myriad of other financial pressures facing both federal and provincial Canadian governments, including rising health care costs, an ageing population, pensions, and increasing government debt.

A summary of the major hydroelectric projects in Canada intended for the 2010-20 timeframe is shown in Table 3. A total of over 59 TWh of new production from major hydroelectric projects is to be added this decade; the likelihood of a number of smaller projects in British Columbia and Ontario may bring the total to over 60 TWh (in its review of new Canadian energy sources to 2020, Canada's National Energy Board projects an increase of an additional 50 TWh from a number of hydroelectric projects, including those listed in Table 3 (NEB, 2007)).

Table 3: Major Canadian hydroelectric projects for 2010-20 ('*e*' – estimate)

Company and Projects	MW	TWh	Completion
BC Hydro (BC Hydro, n.d.)			
Site C	900	4.6	
Revelstoke Unit 5	500	2*e*	2010
G.M. Shrum	200	1*e*	2012-17
Mica Units 4 and 5	1,000	3.6*e*	2013-15
Manitoba Hydro (Adams, 2008)			
Keeyask	625	4.43	2017
Conawapa	1,250	7	2020
Wuskwatim	200	1.52	2011
Ontario Power Generation (OPG, 2009c)			
Beck tunnel		1.6	2010
Hydro Quebec (Hydro Quebec, 2009)			
Romaine	1,550	8	2009-20
Eastmain-1-A/Sarcelle/Rupert	918	8.7	2011-12
Newfoundland and Labrador Hydro (Newfoundland and Labrador, 2007)			
Lower Churchill	2,825	16.7	2015-17
Total		59.2	

NRTEE's 2020 target for new hydroelectric production in Canada is 132 TWh. If the projects listed in Table 3 can be achieved by their expected completion dates, an additional 60 TWh of production will be added, meaning that there is a shortfall of over 70 TWh. As a result, rather than requiring an average of 130 TWh of new hydroelectric production per decade between 2020 and 2050, each decade will require an average of 152 TWh of new production.

There are other issues that may limit the required growth in hydroelectricity to meet the planned greenhouse gas emission reduction targets. Perhaps the most serious are the expected changes in the hydrological cycle caused by climate change over the next 40 years (NRCan, 2004). Results from the Coupled Global Climate Model developed by Environment Canada show increases in average annual temperature across Canada, including those where hydroelectric dams are situated; rising temperatures will lead to increased evaporation, reducing the volume of water available for electrical generation. The model has projected that with a 2°C global warming, Ontario's Niagara and St. Lawrence hydropower generation would decline by 25% to 35%, resulting in annual losses of $240–350 million (CDN) at 2002 prices (Buttle, Muir, & Frain, 2004). In some locations, evaporation losses may be offset by increased precipitation; however, if winter precipitation falls as rain rather than snow, icepacks may diminish in size, leading to less water (from melting ice and snow) available during the summer months for electrical generation. Other studies suggest that drier and warmer conditions could result in lower electricity exports due to a decline in the availability of hydroelectricity for export and higher consumption of electricity for air conditioning during the summer (NEB, 2007).

Federal and provincial regulations subject energy projects to more intensive environmental scrutiny than in previous decades and, unlike in the past, require that Canada's First Nations be consulted. These regulations, though necessary, can delay the completion of projects and result in significant changes to their size and scope.

3.2 Wind

In addition to hydroelectricity, wind-generated electricity is seen by many as a way of reducing greenhouse gas emissions. To date, wind has made limited penetration in Canada and is confined to a few regions, most prominently southern Alberta, parts of eastern Quebec, and Prince Edward Island. Existing and projected electricity production from the wind since 1990 is shown in Figure 3.

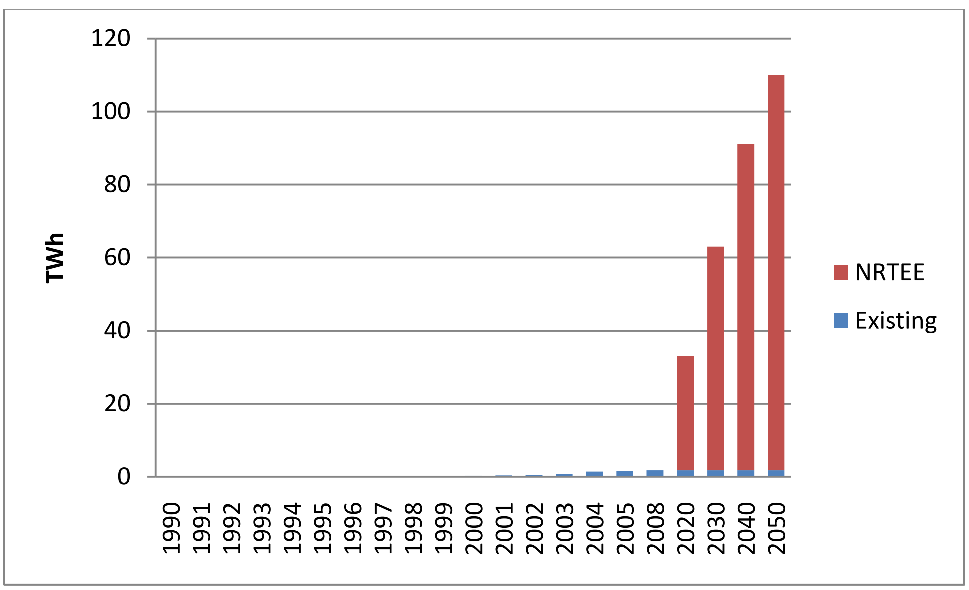

Figure 3: Historical and projected wind-electricity production (NationMaster, 2009; Statistics Canada, 2009b)

The historic and projected growth in wind-electricity production is shown in Table 4. The increase between 1990 and 2008 appears large because the starting production (and capacity) was slight; the growth between 2008 and 2020 is over 1,700% because of the small production base (about 1.77 TWh) and the large target production volume (over 31 TWh). From 2020 onwards, the growth appears modest in percentage terms but is still large in terms of production volume increases. Given that the expected life of most wind turbines is 20-25 years, it is likely that many of the turbines being installed early in this process will need to be replaced in later years; these numbers are not included in the totals, but will increase the number of turbines that will be required.

Table 4: Growth in wind-electricity production

Decade	Production increase (TWh)	Production increase (Percent)
1990-99	0.14	531%
2000-08	1.51	571%
2008-20	31.23	1,763%
2020-30	30.0	91%
2030-40	28.0	44%
2040-50	19.0	21%

NRTEE's proposed decadal growth in wind electricity production for Canada should be compared with wind's decadal increase in other countries in order to obtain an understanding of the size of the undertaking. Table 5 shows the decadal rise in wind production from various countries, the largest in Germany, followed by the United States and Spain; in all three of these countries, various financial incentives were in place to encourage the growth of wind electricity or the wind manufacturing industry, or both.

Table 5: Decadal growth in wind energy (UNData, 2009)

Country	Decade	Growth (TWh)
Canada	1997-2006	2.44
Denmark	1995-2004	5.41
Spain	1997-2006	22.29
United States	1997-2006	23.38
Germany	1997-2006	26.12

With increased demand for wind turbines around the world, it is unclear whether the projected growth in Canadian wind electricity production can be met, especially when it exceeds even that of Germany during the years it was creating its world-leading wind industry (which coincided with the rise in German wind production). However, CanWEA, a Canadian wind lobby group, is arguing for the installation of sufficient capacity to produce 163 TWh by 2025 (CanWEA, 2009), meaning that about 11 TWh of production would be added each year between 2010 and 2015; this annual value is about half of the decadal growth experienced by some of the best wind energy jurisdictions.

Whether such a large growth in wind can be accommodated in a grid is a question yet to be answered. This may not be an issue in regions with significant production volumes of hydroelectricity as it can act as a backup to wind (Luickx, Delarue, & D'haeseleer, 2008);

however, wind will probably be problematic in regions without adequate backup or some other means of integrating wind into the electricity mix (Blarke & Lund, 2008).

Another issue that has arisen recently with respect to wind-generated electricity is the effect of climate change on existing wind conditions (Moyer, 2009). If wind speeds do change significantly, either increasing, decreasing, or becoming more gusty, then existing or planned wind generation sites may be unusable.

3.3 Other renewables

NRTEE limits other renewables to a small amount of biomass for process heat in manufacturing. Biomass use in the residential sector for space and water heating is projected to decline to negligible amounts because it "produces methane emissions" (Nyboer, 2008, p. 22). Although this claim is referenced (see (Environment Canada, 2007, pp. 641-642)), the volume of methane produced is about 1% of CO_2 emissions for typical woodstoves and is less than 0.5% of CO_2 emissions for properly designed woodstoves. Rather than curtailing the use of biomass combustion for heating purposes because of methane emissions, a more politically acceptable solution would be to devise the necessary technology to reduce methane emissions below their present levels.

If used correctly, biomass can be a carbon-neutral renewable energy source; in fact, the government of Canada is promoting biomass energy research in areas such as wood pellets (Canmet, 2008). Whether it would be possible to expect that Canadians would not use wood for heating is questionable, as Canadians would probably turn to biomass in greater numbers since energy sources for residential space heating such as fuel oil and natural gas are expected to decline over the next 40 years.

Although solar thermal offers considerable potential in many areas of Canada as a replacement for some or all existing energy sources used for both residential and commercial space and water heating, it is never mentioned in the sectoral and regional analysis report. Similarly, solar photovoltaic, presently an extremely expensive form of electrical generation, is never mentioned.

3.4 Nuclear

Like many industrialized countries, Canada developed a nuclear-electricity program after the Second World War. A number of experimental reactors were built in Ontario in the 1950s, which led to the 600 MW heavy-water CANDU reactor design. The first of these came on-line in the early 1970s in Ontario; subsequently the reactor design was sold to various countries around the world as well as in Canada, with more reactors purchased by Ontario Hydro, Hydro Quebec, and NB Power. The electricity production from Canada's nuclear reactor fleet is shown in Figure 4.

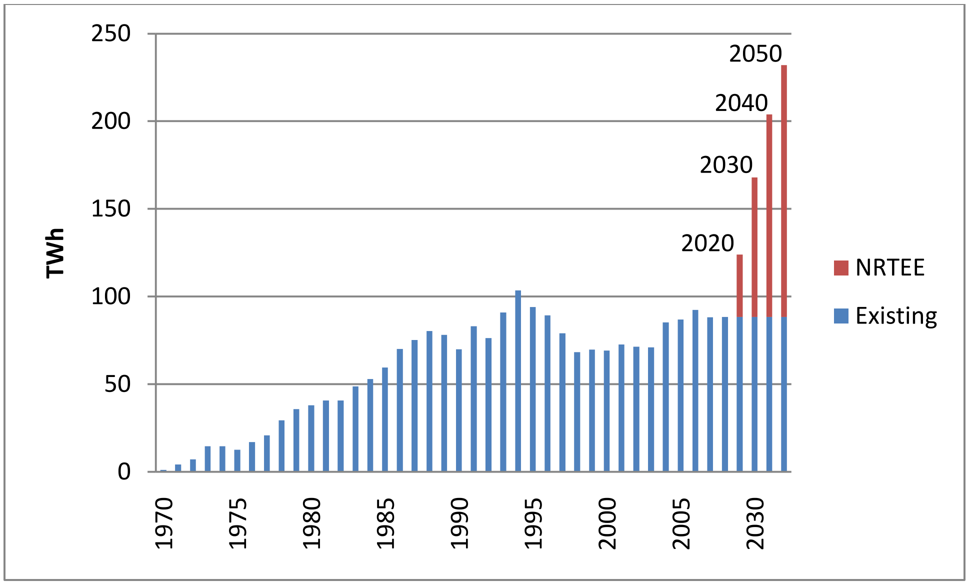

Figure 4: Existing and projected nuclear generation
(Brown, 2009; Statistics Canada, 2009b)

The decade-over-decade changes in nuclear-electricity production in Canada are shown in Figure 5. This reflects the growth in nuclear electricity throughout the 1970s and 1980s with the installation of all of Canada's reactor fleet taking place during this time. Technical problems with the CANDU design required the re-tubing of most, if not all, of Canada's reactors starting in the early 1990s; however, some reactors, such as units 2 and 3 at Pickering 'A' were deemed too expensive to repair and remain in a "safe shutdown state" (OPG, 2009a). Although Figure 5 suggests a growth in capacity between 1997-06 and 1999-08, this was not the case as it was simply refurbished reactors being brought back on-line (Nuclear Canada, 2004). NRTEE's projections for growth between 2010 and 2050 are well within the historical decadal growth patterns exhibited by Canada's nuclear industry.

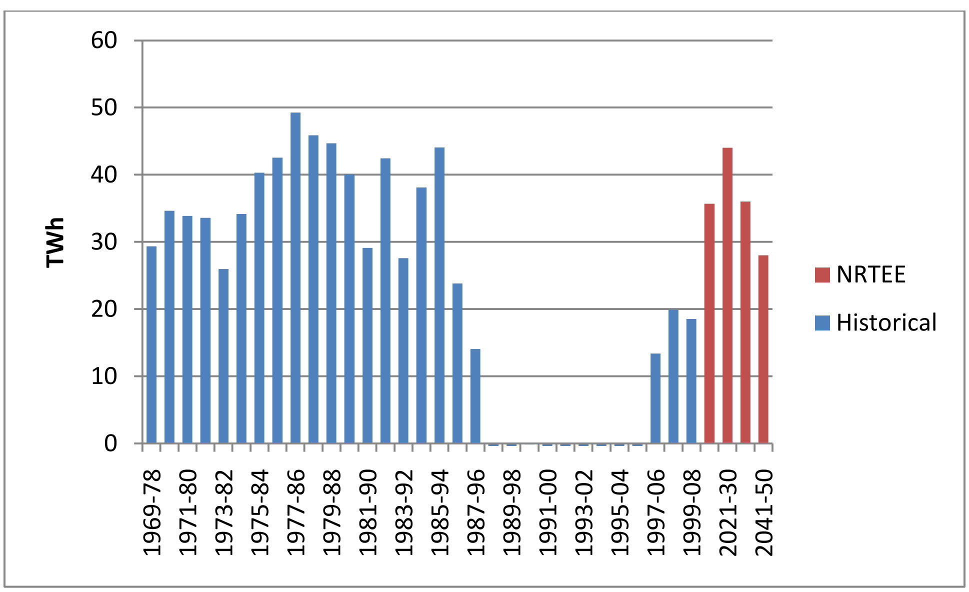

Figure 5: Decade-over-decade growth in Canadian nuclear electricity production

The proposed replacement and refurbishment of some of Ontario's existing nuclear reactors will not reduce greenhouse gas emissions unless there is an increase in electrical production from the reactors.

The Ontario government is planning to add a number of reactors to its existing fleet. The first tranche is for 4,800 MW of nuclear capacity to be added to Ontario Power Generation's existing Darlington site which presently houses four CANDU reactors with a total capacity of 3,524 MW (OPG, 2009; CNSC, 2009). The new capacity is expected to produce about 36 TWh per year; if completed before 2020, it would mean that the 2020 target for nuclear production between 2010 and 2020 would be met. There are a number of issues that need to be addressed before any of the nuclear production targets can be achieved, including the cost of new reactors, the state of new reactor technology, and objections from the anti-nuclear lobby.

Since nuclear reactors are essentially thermal power stations with nuclear-fuel supplying the heat, nuclear stations require access to dry cooling towers or bodies of water to condense its prime mover, steam. Most, if not all, of Canada's reactors are located near bodies of water for this reason. However, the same issues confronting Canada's hydroelectric facilities—specifically increasing temperatures and changing precipitation patterns caused by climate change—may also affect nuclear stations. If water levels recede or water temperatures increase, reactors may not be able to operate at full capacity, as has been seen across Europe in recent years (Boselli, Eckert, & Kahn, 2009). This type of problem would probably occur during the summertime, when demand for air conditioning would be at its greatest because of rising temperatures.

3.5 Coal and natural gas with carbon capture and storage

After hydroelectricity, NRTEE expects that the most significant supplier of electricity will be thermal generation from coal and natural gas using carbon capture and storage (CCS). As electrical generation from CCS facilities increases, generation from non-CCS coal and natural gas facilities is expected to decrease. These changes are shown in Table 6.

Table 6: Changes in electrical production from coal and natural gas (TWh) (Nyboer, 2008)

	2020	2030	2040	2050
Coal without CCS	112	86	43	5
Natural Gas without CCS	26	15	9	6
Carbon Capture and Storage	62	193	328	456

The historic and projected decline in thermal generation and the concomitant increase in CCS is shown in Figure 6. Unlike the projected use of hydroelectric and nuclear, the generation of electricity from non-CCS thermal facilities is expected to decrease significantly over time. The growth in CCS replaces electricity demand from thermal sources, while policies restrict new electricity demand from fossil energy to CCS generation sources.

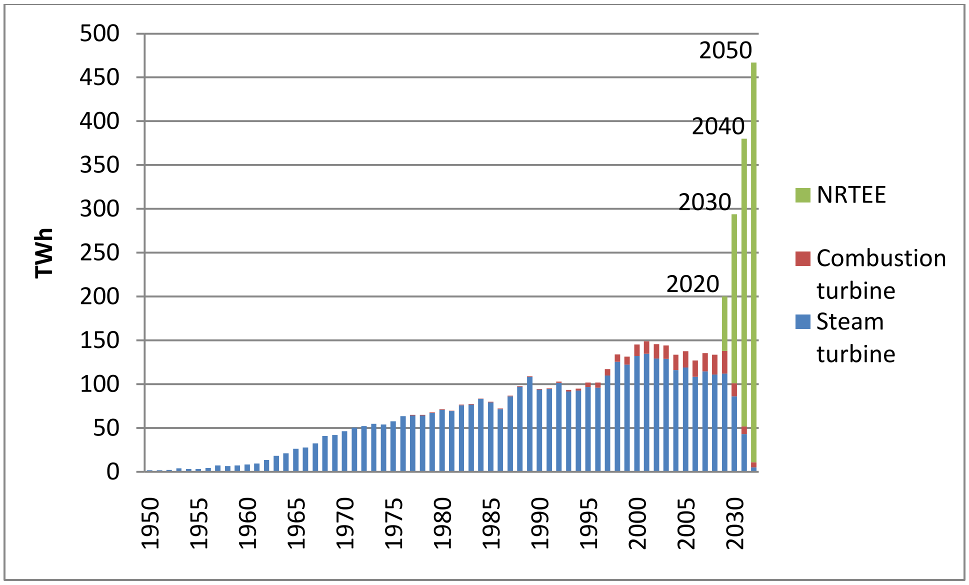

Figure 6: Existing and projected coal and natural gas generation (Statistics Canada, 2009b; Statistics Canada, 2009e)

The proposed use of CCS is optimistic, given the state of the technology and its associated costs. NRTEE's report recognizes this, projecting annual production of 62 TWh at the end of the first decade (2010-20) and increasing by an average of 131.3 TWh at the end of each decade thereafter. At the end of each decade over the 40 year period (2010 to 2050), there is a CCS production target (shown in Table 6). Figure 7 shows the annual production increase if the growth in CCS over each decade is uniformly distributed. The cumulative production is also shown in this figure; over the 40 year period, CCS produces a total of 8,338 TWh of electricity (this ignores the electricity produced from non-CCS coal and natural gas).

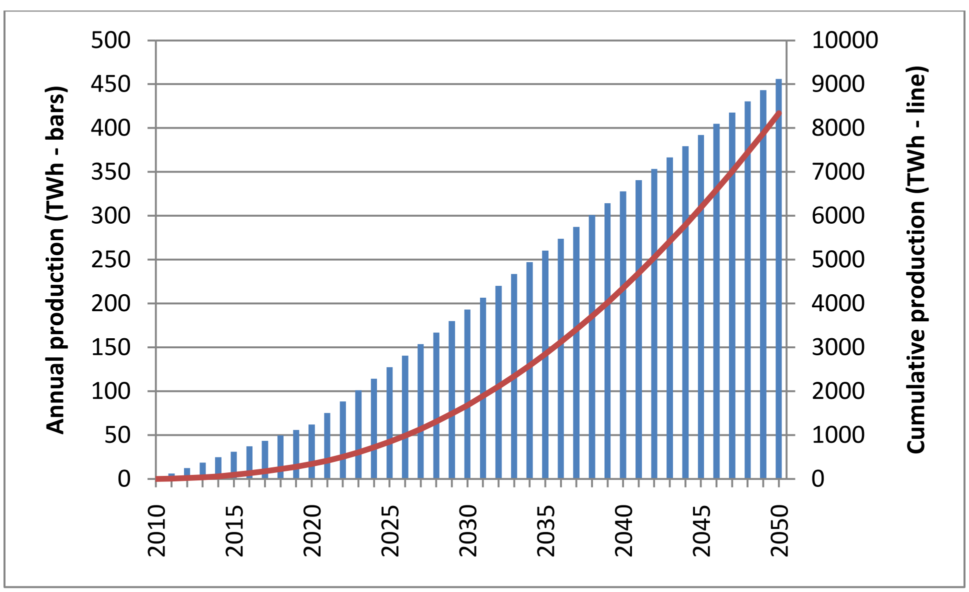

Figure 7: NRTEE's annual and cumulative production from CCS facilities

CCS is parasitic, meaning it requires more energy to produce a kilowatt-hour of electricity than does a typical non-CCS, thermal power station (Jensen, Musich, Ruby, Steadman, & Harju, 2005; USDOE, 2007). The expected costs associated with CCS are making some countries with limited supplies of coal and natural gas question the justification of the expenses associated with these facilities (de Coninck, et al., 2009).

A recent report from the Canadian government proposes the installation of CCS facilities to capture 5 Mt CO_2 per year starting in 2015 (ecoAction, 2008a). The report gives an example of a typical western-Canadian 600 MW coal-fired thermal electrical-generation station which produces about 3.8 Mt CO_2 per year. To capture 5 Mt of CO_2 per year would require 789 MW of coal capacity with CCS; assuming a 90% capacity factor and 100% CO_2 capture efficiency, the annual electrical production would be 6.2 TWh. If this capacity could be added starting in 2015, by 2020, a total of 37.2 TWh would be produced by CCS. This is 60% of NRTEE's 2020 target. Since the technology is in its infancy and can be expected to be subject to delays, achieving 60% of the 2020 target may be optimistic.

The amount of natural gas and coal needed to meet these targets will depend upon the technology associated with the different CCS systems. For the purposes of this paper, it is assumed that electricity is used to capture and store the carbon; this electricity is in addition to the total production expected from the CCS systems. These parasitic losses increase the electricity requirements of the CCS systems by 10%, 20%, and 30%, from 8,338 TWh to 9,172 TWh, 10,006 TWh, and 10,839 TWh, respectively. The percentage of the energy within the natural gas or coal that is converted to electricity varies from 25% to 45%.

3.5.1 Natural gas

The volume of natural gas necessary to produce 8,338 TWh over the 40 years is shown in Table 7. In the best case, parasitic losses are 10% and the efficiency of the conversion process is 50%, meaning that only 1,782 billion cubic metres (BCM) are required. At the other extreme, 30% parasitic losses and 30% conversion efficiency calls for 3,509 BCM.

Table 7: Natural gas requirements to produce 8,338 TWh (in BCM)

Conversion Efficiency	Parasitic losses		
	10%	20%	30%
30%	2,969	3,239	3,509
35%	2,545	2,777	3,008
40%	2,227	2,430	2,632
45%	1,980	2,160	2,340
50%	1,782	1,944	2,106

Table 7 refers to the volume of natural gas needed to produce electricity from CCS. However, since NRTEE requires continued electrical production from non-CCS natural gas facilities between 2010 and 2050 (see Table 6), an additional 150 BCM of natural gas will be necessary (assuming a linear decline in non-CCS natural gas demand).

In 2007, Canada's natural gas reserves were estimated to be about 1,534 BCM (Statistics Canada, 2009d). Although the reserves have been holding steady at this level for about a decade (see Figure 8), the long-term trend shows a marked decline to at least 2030 and probably beyond (NEB, 2007). The report expects Canadian natural gas production to peak at about 200 BCM in 2015, declining to less than 150 BCM in 2050. Not only are these numbers optimistic, they omit the fact that Canada exports more than half its natural gas production to the United States and will continue to do so well into the future because of its NAFTA obligations (Laxer & Dillon, 2008).

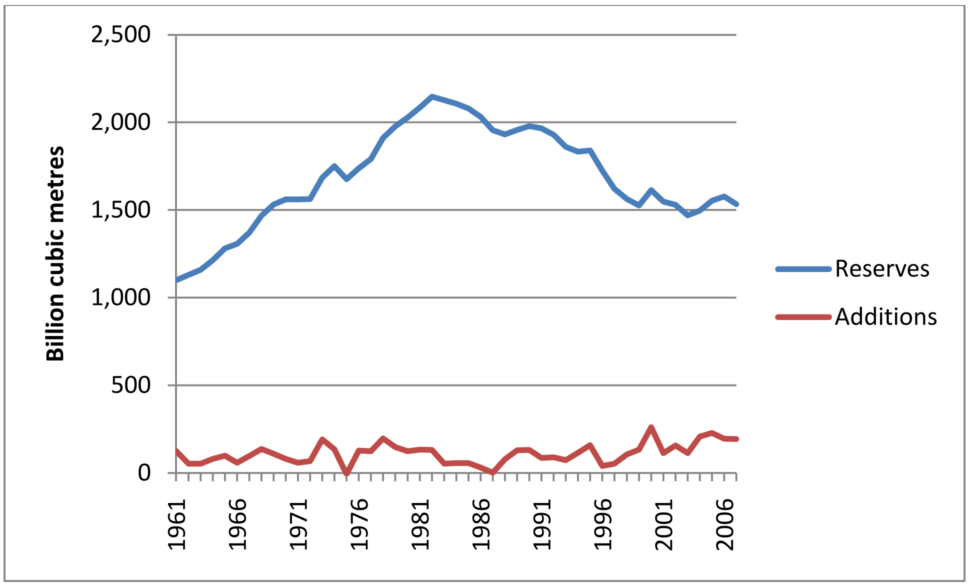

Figure 8: Canadian natural gas reserves (Statistics Canada, 2009d)

The report assumes that most of the natural gas presently used for heating purposes in the residential and commercial-institutional sectors is to be used for electrical generation (this is discussed in more detail in section 4, below, on end-use demand). However, declining reserves, trade commitments, and other possible uses of natural gas (for example, plastics and fertilizers) suggests that coal will have to be employed if the projected electrical supply from CCS is to be met.

3.5.2 Coal

The method used to determine the amount of natural gas required to meet the 8,338 TWh from CCS can be applied to coal. There are two categories of coal, bituminous and sub-bituminous (which includes lignite); for the purposes of this paper, their energy contents are 27.6 GJ/t and 18.8 GJ/t, respectively (NEB, 1999)). As with natural gas, the same three parasitic losses are considered, as are a range of conversion efficiencies.

Table 8 shows the amount of coal needed to produce 8,338 TWh of electricity from different CCS plants with diverse efficiencies and parasitic losses. The higher the coal's energy content, the less coal required. The amount of bituminous coal necessary ranges from 2.66 to 5.66 gigatonnes, while the amount of sub-bituminous coal (including lignite) varies from 3.90 to 8.31 gigatonnes.

Table 8: Coal requirements to produce 8,338 TWh (in gigatonnes)

Conversion Efficiency	Bituminous			Sub-bituminous		
	Parasitic losses			Parasitic losses		
	10%	20%	30%	10%	20%	30%
25%	4.79	5.22	5.66	7.03	7.67	8.31
30%	3.99	4.35	4.72	5.86	6.39	6.92
35%	3.42	3.73	4.04	5.02	5.48	5.93
40%	2.99	3.27	3.54	4.39	4.79	5.19
45%	2.66	2.90	3.14	3.90	4.26	4.61

As with natural gas, it is important to put the amount of coal required by the CCS systems into context. In 2008, the total stock of bituminous coal (both steam and metallurgical) in Canada was 2.25 gigatonnes, while that of sub-bituminous coal was 2.08 gigatonnes (see Figure 9). About 98% of the metallurgical (i.e., coking) coal and over 75% of the steam bituminous coal was exported in 2008; in total, about 5% of Canada's bituminous coal was consumed in Canada (Statistics Canada, 2009c). If these export markets are to remain active into the future, Canada will have very little in the way of bituminous coal to use for CCS. If considered separately, Canada does not have sufficient reserves of bituminous or sub-bituminous coal to meet the CCS electricity production target.

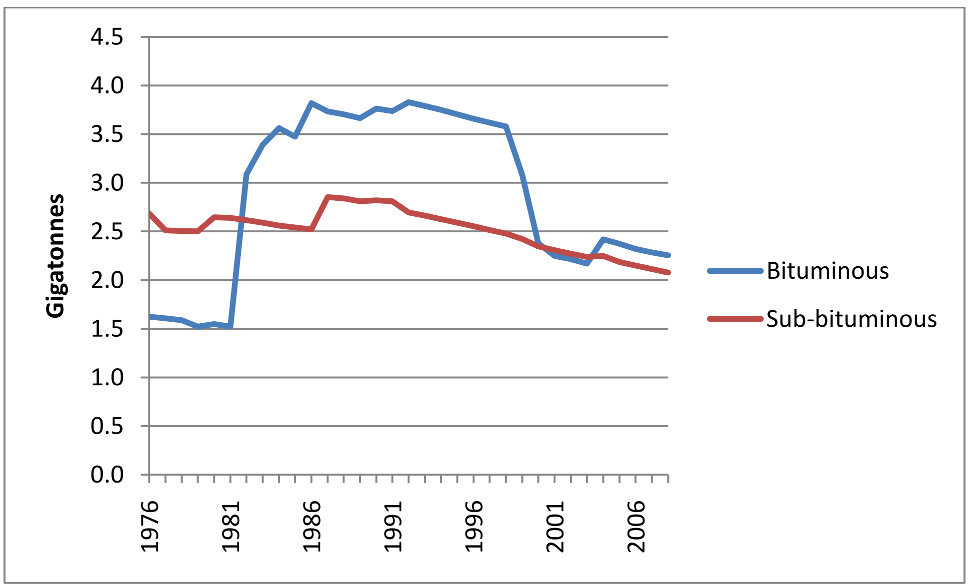

Figure 9: Canadian coal reserves (Statistics Canada, 2008a; Statistics Canada, 2008b)

However, this is only part of the problem as the report projects a continued use of coal for non-CCS electrical production between 2010 and 2050. Assuming a linear decline in consumption, the demand for coal during this period will be 1.95 gigatonnes—this is almost equal to Canada's present reserves of sub-bituminous coal.

4 End use demand

NRTEE proposes a future that relies on electrical production from a growth in hydroelectricity, CCS, and nuclear, resulting in a reduction in greenhouse gases. Why and where these reductions take place will depend upon the state of electrical generation in each province:

- In provinces already relying on hydroelectricity for most of their electricity supply, the model projects very little reduction in greenhouse gas emissions from electrical generation. Instead, decline will occur by having energy services either replace existing demand for carbon-intensive fuels (such as fuel oil, natural gas, or biomass) with electricity or restrict new demand to electricity (Nyboer, 2008). This also holds true for provinces that intend to expand their nuclear fleet.
- Those provinces relying on coal and natural gas generation for electricity supply (typically with little or no hydroelectric expansion capability) are expected to replace existing thermal facilities with, and restrict new facilities to, CCS. In these cases, emissions reduction is expected to occur because of CCS and the replacement and restriction of demand to non-carbon electricity.

For example, by 2050, NRTEE's model projects that electricity will meet 97% of residential space heating, as described in the following paragraph and shown in Table 9 (Nyboer, 2008):

> *The main action to reduce greenhouse gas emissions in the residential sector is the adoption of electric space heating systems – by 2050 in the policy scenario, over 97% of installed heating systems use electricity (see Table 16). The installation of electric baseboards and ground source heat pumps account for the majority of installations, while air source heat pumps account for the remainder.*

Table 9: Penetration of electric space heating systems (from Table 16 (Nyboer, 2008))

System	2020	2030	2040	2050
Electric baseboards	46%	51%	51%	51%
Air source heat pumps	19%	31%	21%	13%
Ground source heat pumps	0%	6%	22%	33%
Space heating total	65%	88%	94%	97%

What is perhaps most surprising about the projected adoption of electric heating systems is the overwhelming use of electric baseboard heating. Although it is simple to install, electric baseboard heating is one of the worst ways to heat with electricity because it typically adds to the winter peak, requiring more generation capacity than the electricity supplier may be able to provide economically. There are viable alternatives to electric baseboard heating; for example, electric thermal storage systems can be charged during the off-peak hours and allowed to discharge throughout the day without adding to the day-time load on system or to the evening peak.

Ground source heat pumps can operate with a horizontal field of heat-exchange tubing placed below the frost line, often requiring considerable area to achieve the expected results. They are best suited to low-density housing developments where the space exists for the field. Another approach is to place the tubing vertically, ideally encountering an aquifer which can act as a heat reservoir. Without an underground source of heat, the field may freeze as heat is extracted faster than it can be replaced; to counter this, it may be necessary to store heat underground throughout the summer months (Dincer, 2002).

The report also projects an increase in the use of electric water heating, as shown in Table 10.

Table 10: Penetration of electric hot water heating systems (from Table 17 (Nyboer, 2008))

	2020	2030	2040	2050
Electric water heating	60%	83%	89%	93%

This level of electricity usage for water heating, like the proposed use of electricity for space heating, may add unnecessary load to the system, potentially requiring the construction of expensive facilities to handle winter peak demand if brownouts and blackouts are to be avoided. Again, viable alternatives such as solar thermal, which can offset some or all of a building's need for electrically heated water, have been overlooked.

In a country like Canada, space and water heating are essential services for the residential, commercial, and institutional sectors. Collectively, they are responsible for about 21% of Canada's final energy demand, second only to transportation at about 34% (NRCan, 2006). Meeting Canada's heating demand primarily with electricity and electric baseboard heaters, even if derived from renewable sources, will put unnecessary demands on the electrical system.

Existing carbon-based energy sources can be replaced by, and future demand can be restricted to, non-carbon sources that are more appropriate than the continuous supply of electricity required by electric baseboard heaters; these include:

- District heating in locations where there is sufficient heat density to warrant the development of a district heating network.
- Solar thermal in individual buildings and communities; these can be diurnal systems or if the storage exists, seasonal systems.
- Wind heating as a means to overcome intermittency by using wind directly for space and water heating or indirectly as a means to use excess wind (Hughes, 2009a).

These are important replacement and restriction energy sources; had NRTEE pursued them, less new generation capacity would have been required resulting in lower greenhouse gas emissions.

5 Discussion

NRTEE's vision of an electric future demands a marked increase in electric production by 2020 and 2050, as shown in Table 11.

Table 11: NRTEE's required growth in electrical production by 2020 and 2050

	Demand (TWh)			Growth (TWh)	
	2008	**2020**	**2050**	**2008-20**	**2008-50**
Hydroelectricity	373	505	890	132	517
Wind	2	33	110	31	108
Other renewables	6	3	13	-3	7
Nuclear	89	124	232	35	143
Coal without CCS	111	112	5	1	-106
Natural gas without CCS	23	26	6	3	-17
Coal and gas with CCS	0	62	456	62	456

The previous sections have showed that by 2020, hydroelectricity and CCS will not be able to reach these targets in large part because the projects being considered over the next decade are of insufficient capacity to produce the required volume of electricity. On the other hand, Ontario's proposed nuclear new-build, if completed on time, will meet the 2020 nuclear target. Despite the optimism of both NRTEE and CanWEA, the likelihood of wind satisfying its 2020 production target is unlikely when compared to the growth rates seen in other countries.

If the 2020 target cannot be met, the targets in subsequent decades will have to increase. For example, the number of hydroelectric projects to be completed by 2020 is expected to add about 60 TWh of production, a shortfall of 70 TWh from the 2020 target. This will increase the average hydroelectric target from 130 TWh per decade to over 152 TWh per decade.

The 2050 targets appear optimistic as well. If the impact of climate change is as great as Canadian government projections suggest, existing or planned hydroelectricity may produce less electricity in the future because of decreased snowfall to serve as a reservoir during the spring and summer (NEB, 2009).

CCS, like existing thermal generating stations, consumes natural gas or coal to produce electricity. NRTEE's plans for CCS require supplies of natural gas and coal that do not appear to exist in Canada. About half of Canada's natural gas supplies are destined for the United States to satisfy its NAFTA obligations. Moreover, although the remainder should be kept for the production of fertilizers and other non-energy products, NRTEE proposes that it should be used for electrical generation with CCS.

Canada has reserves of bituminous metallurgical and steam coal, most of which is exported; given the importance of metallurgical coal, it would make little sense to consume it for electrical generation. Canada also has reserves of sub-bituminous coal which could be used with CCS. However, regardless of the coal type, NRTEE's plans to gradually reduce non-CCS coal consumption means that there will be insufficient supplies for use in the generation of electricity from CCS sources.

Admittedly, coal could be imported to augment Canada's supply; however, as the world's demand for energy increases, sources that were once available may disappear from the market or rising prices may make imported coal unaffordable.

The nuclear production targets appear achievable as they are in keeping with the decadal growth experienced throughout the 1970s and 1980s when nuclear new-build was at its height in Canada. The wind production numbers seem optimistic when compared with the rate of construction in other countries and the fact that as wind grows in popularity, adding new capacity could be a challenge as equipment may become more difficult to obtain. As with hydroelectricity, changes in the climate might impact water levels, water temperatures, and wind patterns—all things that nuclear and wind rely on to allow them to function.

NRTEE's decision to downplay the use of non-traditional renewables (i.e., wind, solar, and modern biomass) in favour of the "traditional" modern renewable, hydroelectricity, will adversely impact the electrical system. The decision to adopt a future that relies on electric baseboards and electric domestic hot water will put additional pressures on the overall system. There are some energy services that do not need access to continuous supplies of electricity, these include space and water heating. Renewables such as biomass, solar, and wind could all make a significant contribution to reducing greenhouse gas emissions and decreasing the need for some of NRTEE's proposed new electrical supply.

Canada exports energy to the United States. At present, electricity exports amount to about 10% of Canadian electrical production, this is expected to increase over the coming years; for example, the National Energy Board projects net electricity exports to increase from 29.4 TWh in 2008 to 73.4 TWh in 2020 (NEB, 2009). If electricity exports do increase, it will mean less production available for Canadian consumption.

6 Concluding remarks

In 2007, the Government of Canada announced its long-term greenhouse gas emissions reduction targets plan entitled *Turning the Corner*, which proposed cuts 20% below 2006 levels by 2020 and 65% by 2050. Subsequently, the National Round Table on the Economy and Environment produced a report explaining how these targets could be met using a "fast and deep" approach. This assumes a marked decline in greenhouse gas emissions through an expansion of electrical production in three areas: hydroelectricity, carbon capture and storage, and nuclear. However, a number of assumptions were made that highlight the challenges associated with energy replacement and restriction strategies for greenhouse gas reduction targets.

Hydroelectricity is the cornerstone of NRTEE's greenhouse gas emission reduction plan, with production increasing from 373 TWh in 2008 to 505 TWh in 2020 and rising to 890 TWh in 2050. In the case of the 2020 target, the number of hydroelectric projects planned for completion by 2020 will produce less than half the 132 TWh required. The shortfall in production by 2020 will increase the requirement for new production between 2020 and 2050 from an average of 130 TWh per decade to over 152 TWh per decade. Meeting this level of production increase in such a short period may be a challenge, not only because it is three times the average decadal increase in hydroelectric production achieved in Canada between 1950 and 2008, but because it is expected to occur during a time a rising costs in commodities, pensions, and health care. Even if these targets could be met, the impact of climate change over the next 40 years is expected to reduce hydroelectric production in all parts of Canada.

CCS relies on supplies of natural gas and coal. It would appear that Canada does not have adequate supplies of either to justify the construction of the large-scale CCS facilities envisaged by NRTEE. The 2020 target of 62 TWh is optimistic, given the state of CCS technology, while the 2050 target will be limited by supplies of natural gas and coal. Without coal imports, it is unclear how coal-based CCS is possible in Canada.

Of the three major areas of expansion envisaged by NRTEE, only nuclear has the potential to meet its 2020 and 2050 targets. However, like hydroelectricity, nuclear may be affected by climate change in 2050 as rising temperatures make it more difficult to operate reactors that rely on lakes and rivers for cooling.

Wind and other renewables, the non-traditional energy sources considered by NRTEE, play a limited role in helping reduce greenhouse gas emissions. This reflects, in part, the fact that many of these sources when generating electricity are intermittent. There are ways of handling intermittency: storage will be central to a renewable future as it will allow energy to be stored as heat or electricity.

It is generally agreed that there are three major energy services (transportation, heating and cooling, and applications requiring access to a continuous supply of electricity). Given the importance of electricity, it is necessary to find other sources of energy for heating. Renewables such as modern biomass, solar thermal, and wind heating can make significant contributions to Canada's space and water heating needs. By reducing electrical demand for heating, the need for new capacity (such as hydroelectric, CCS, or nuclear) is also lowered, thereby making greenhouse gas emission targets that much easier to achieve.

NRTEE's proposed approach to addressing climate change illustrates the difficulty in decreasing greenhouse gas emissions and why the effort should have started decades ago. If anything, NRTEE's work has highlighted the challenges facing countries such as Canada as they attempt to implement climate change policies. However, as this paper has shown, climate change isn't the only complication—access to secure sources of energy will become more difficult and may become the dominant issue between now and 2050. Every effort must be made to reduce energy consumption and replace existing insecure, high-emission sources and restrict new demand to energy sources that are secure, sustainable, and environmentally benign.

Acknowledgements

The authors would like to thank Mark Gardner, Anirudh Muralidhar, Jim Parsons, Dave Ron, and Sandy Cook for their comments and assistance on this paper.

References

Adams, K. (2008, April 17). *Northern Hydro Development in Manitoba*. Retrieved December 3, 2009, from http://dnr.wi.gov/environmentprotect/gtfgw/documents/MeTF20080417.pdf

BC Hydro. (n.d.). *Re-investing for generations.* Retrieved January 4, 2010, from BChydro for generations: http://www.bchydro.com/etc/medialib/internet/documents/appcontent/your_account/Reinvesting_for_Generations.Par.0001.File.policies55154.pdf

Blarke, M. D., & Lund, H. (2008). The effectiveness of storage and relocation options in renewable energy systems. *Renewable Energy , 33* (7), pp. 1499–1507.

Boselli, M., Eckert, V., & Kahn, M. (2009, June 30). *Heatwaves can crimp power output across Europe.* (J. Jukwey, Ed.) Retrieved December 1, 2009, from Reuters: http://www.reuters.com/article/ELECTU/idUSLU67986320090630?pageNumber=1&virtualBrandChannel=0

Brown, M. (2009, November 24). Canadian nuclear electrical generation data. *Personal communication* .

Buttle, J., Muir, J. T., & Frain, J. (2004). Economic impacts of climate change on the Canadian Great Lakes hydro-electric power producers: a supply analysis. *Canadian Water Resources Journal , 29*, pp. 89-109.

Canadian Hydropower Association. (2003). *Current and planned hydro development in Canada*. Retrieved November 19, 2009, from Canadian Hydropower Association: http://www.canhydropower.org/hydro_e/pdf/Canada%20Current%20and%20Planned%20Hydro%202003.pdf

Canmet. (2008, November 14). *Bioenergy Systems - Biofuels and Solid Biofuels*. (Natural Resources Canada) Retrieved November 29, 2009, from Canmet Enregy: http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/bioenergy/biofuels/solid_biofuels.html

CanWEA. (2009). *Windvision 2025 - Powering Canada's Future.* Retrieved December 5, 2009, from Canadian Wind Energy Association: http://www.canwea.ca/images/uploads/File/Windvision_summary_e.pdf

CNSC. (2009, November 16). *Status: Ontario Power Generation Darlington New Nuclear Power Plant Project.* Retrieved December 4, 2009, from Canadian Nuclear Safety Commission: http://www.cnsc-ccsn.gc.ca/eng/readingroom/newbuilds/opg_darlington/#3

de Coninck, H., Flach, T., Curnow, P., Richardson, P., Anderson, J., Shackley, S., et al. (2009, May). The acceptability of CO2 capture and storage (CCS) in Europe: An assessment of the key determining factors: Part 1. Scientific, technical and economic dimensions. *International Journal of Greenhouse Gas Control , 3* (3), pp. 333-343.

Dincer, I. (2002). On thermal energy storage systems and applications in buildings. *Energy and Buildings* , doi:10.1016/S0378-7788(01)00126-8.

Dooley, J. (2010, January 18). Email communication.

ecoAction. (2008a, January 9). *Canada's fossil energy future - The way forward on carbon capture and storage.* Retrieved December 6, 2009, from EcoAction Task Force on Carbon Capture and Storage: http://www.nrcan-rncan.gc.ca/com/resoress/publications/fosfos/fosfos-eng.pdf

ecoAction. (2007, April 26). *Canada's New Government Announces Mandatory Industrial Targets to Tackle Climate Change and Reduce Air Pollution .* Retrieved December 5, 2009, from EcoAction - Government of Canada: http://www.ec.gc.ca/default.asp?lang=En&n=714D9AAE-1&news=4F2292E9-3EFF-48D3-A7E4-CEFA05D70C21

ecoAction. (2008b, March 10). *Government Delivers Details of Greenhouse Gas Regulatory Framework.* Retrieved December 5, 2009, from EcoAction - Government of Canada: http://www.ecoaction.gc.ca/news-nouvelles/20080310-eng.cfm

ecoAction. (2008c, March). *Turning the corner - Taking action to fight climate change.* Retrieved December 5, 2009, from EcoAction - Government of Canada: http://www.ec.gc.ca/doc/virage-corner/2008-03/pdf/572_eng.pdf

ecoAction. (2009, December 3). *Turning the corner: An action plan to reduce greenhouse gases and air pollution.* Retrieved December 5, 2009, from Government of Canada: http://www.ecoaction.gc.ca/turning-virage/index-eng.cfm

Environment Canada. (2007). *National Inventory Report: 1990–2005, Greenhouse Gas Sources and Sinks in Canada.* Ottawa: Greenhouse Gas Division.

Environment Canada. (2009). *National Inventory Report: 1990-2006, Greenhouse Gas Sources and Sinks in Canada.* Ottawa: Greenhouse Gas Division.

Hughes, L. (2009a, November). Meeting residential space heating demand with wind-generated electricity. doi:10.1016/j.renene.2009.11.014.

Hughes, L. (2009b, June). The four 'R's of energy security. *Energy Policy , 37* (6), pp. 2459-2461.

Hydro Quebec. (2009). *Construction Projects' Home Page*. Retrieved December 3, 2009, from http://www.hydroquebec.com/projects/index.html

Jensen, M. D., Musich, M. A., Ruby, J. D., Steadman, E. N., & Harju, J. A. (2005, June). *Carbon separation and capture.* Retrieved January 4, 2010, from Plains CO2 reduction partnership: http://www.netl.doe.gov/technologies/carbon_seq/partnerships/phase1/pdfs/CarbonSeparationCapture.pdf

Laxer, G., & Dillon, J. (2008). *Over a Barrel: Exiting from NAFTA's Proportionality Clause.* Edmonton, Alberta: Parkland Institute and Canadian Centre for Policy Alternatives.

Luickx, P. J., Delarue, E. D., & D'haeseleer, W. D. (2008, September). Considerations on the backup of wind power: Operational backup. *Applied Energy , 85* (9), pp. 787-799.

Moyer, M. (2009, October). Climate Change May Mean Slower Winds. *Scientific American* .

NationMaster. (2009). *Energy Statistics - Electricity - Wind - Production - Public - Canada (historical data).* Retrieved October 10, 2009, from NationMaster.com: http://www.nationmaster.com/time.php?stat=ene_ele_win_pro_pub&country=ca

NEB. (2009). *2009 Reference Case Scenario: Canadian energy demand and supply to 2020.* Calgary, Alberta: National Energy Board.

NEB. (2007). *Canada's Energy Future: Reference Case and Scenarios to 2030.* Calgary: National Energy Board.

NEB. (1999). *Canadian Energy: Supply and Demand to 2025.* Calgary: National Energy Board.

Newfoundland and Labrador. (2007). *Focusing Our Energy - Provincial Energy Plan.* Retrieved December 4, 2009, from Natural Resource - Goverment of Newfoundland and Labrador: http://www.nr.gov.nl.ca/energyplan/EnergyReport.pdf

NRCan. (2006). *Canada's Energy Outlook: The Reference Case 2006.* Ottawa: Natural Resources Canada.

NRCan. (2004, June 7). *Climate Warming*. (Natural Resources Canada) Retrieved November 27, 2009, from The Atlas of Canada: http://atlas.nrcan.gc.ca/site/english/maps/climatechange/scenarios

NRTEE. (2009a). *Achieving 2050: A Carbon Pricing Policy for Canada (Advisory Note).* National Round Table on the Environment and the Economy.

NRTEE. (2009b). *Achieving 2050: A Carbon Pricing Policy for Canada (Technical Report).* National Round Table on the Environment and the Economy.

Nuclear Canada. (2004, January 9). Bruce Unit 3 reconnects to grid after five year layup. *Canadian Nuclear Association Electronic Newsletter , 5* (1), p. 1.

Nyboer. (2008). *Technology Roadmap to Low Greenhouse Gas Emissions in the Canadian Economy: A sectoral and regional analysis - FINAL REPORT.* Surrey, British Columbia: J & C Nyboer and Associates.

OPG. (2009). *Darlington Nuclear.* Retrieved December 4, 2009, from Ontario Power Generation: http://www.opg.com/power/nuclear/darlington/

OPG. (2009a). *Pickering Nuclear.* Retrieved December 4, 2009, from Ontario Power Generation: http://www.opg.com/power/nuclear/pickering/

OPG. (2009c). *The new Niagara tunnel project.* Retrieved December 4, 2009, from Ontario Power Generation: http://www.opg.com/power/hydro/new_projects/ntp/index.asp

Statistics Canada. (2009a). *Table 127-0001 - Electric power generation, by class of electricity producer, monthly (megawatt hour).* Retrieved July 15, 2009, from CANSIM (database), Using E-STAT (distributor): http://estat.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&EST-Fi=EStat/English/CII_1-eng.htm

Statistics Canada. (2009b). *Table 127-0002 - Electric power generation, by class of electricity producer, monthly (megawatt hour).* Retrieved July 15, 2009, from CANSIM (database), Using E-STAT (distributor): http://estat.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&EST-Fi=EStat/English/CII_1-eng.htm

Statistics Canada. (2009c, July 2). *Table 135-0002 - Production and exports of coal, monthly (tonnes).* Retrieved January 7, 2010, from CANSIM (database), Using E-STAT (distributor): http://estat.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&EST-Fi=EStat/English/CII_1-eng.htm

Statistics Canada. (2009d, September 12). *Table 153-0014 - Established natural gas reserves, annual (cubic metres).* Retrieved January 7, 2010, from CANSIM (database), Using E-STAT (distributor): http://estat.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&EST-Fi=EStat/English/CII_1-eng.htm

Statistics Canada. (2008a, September 12). *Table 153-0017 - Recoverable reserves of bituminous coal, annual (tonnes).* Retrieved January 7, 2010, from CANSIM (database), Using E-STAT (distributor): http://estat.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&EST-Fi=EStat/English/CII_1-eng.htm

Statistics Canada. (2008b, September 12). *Table 153-0018 - Recoverable subbituminous coal and lignite reserves, annual (tonnes).* Retrieved January 7, 2010, from CANSIM (database), Using E-STAT (distributor): http://estat.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&EST-Fi=EStat/English/CII_1-eng.htm

Statistics Canada. (2009e). *Table 3030026 - Electric power statistics, monthly.* Retrieved November 9, 2009, from CANSIM (database), Using E-STAT (distributor): http://estat.statcan.gc.ca/cgi-win/cnsmcgi.exe?Lang=E&EST-Fi=EStat/English/CII_1-eng.htm

UNData. (2009). *Wind electricity.* Retrieved December 4, 2009, from UN Data - Energy Statistics Database - United Nations Statistics Division: http://data.un.org/Data.aspx?d=EDATA&f=cmID%3aEW

USDOE. (2007, September 6). *Carbon Capture Research.* Retrieved January 4, 2010, from U.S. Department of Energy: http://fossil.energy.gov/programs/sequestration/capture/