



# Canada's Energy Outlook

CURRENT REALITIES AND IMPLICATIONS FOR A CARBON-CONSTRAINED FUTURE

## CHAPTER 3: ELECTRICITY CAPACITY, GENERATION AND RENEWABLE FUELS

Full report available at [energyoutlook.ca](http://energyoutlook.ca)

By J. David Hughes

MAY 2018



CCPA  
CANADIAN CENTRE  
for POLICY ALTERNATIVES  
BC Office



PARKLAND  
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CORPORATE  
MAPPING PROJECT

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#### PUBLISHING TEAM

Lindsey Bertrand, Shannon Daub, Alyssa O'Dell, Marc Lee, Terra Poirier

Copyedit: Lucy Trew

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Cover photo: Garth Lenz

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CCPA  
CANADIAN CENTRE  
for POLICY ALTERNATIVES  
BC Office

520 – 700 West Pender Street  
Vancouver, BC V6C 1G8  
604.801.5121 | [ccpabc@policyalternatives.ca](mailto:ccpabc@policyalternatives.ca)  
[www.policyalternatives.ca](http://www.policyalternatives.ca)



## ABOUT THE AUTHOR

J. DAVID HUGHES is an earth scientist who has studied the energy resources of Canada and the US for more than four decades, including 32 years with the Geological Survey of Canada (GSC) as a scientist and research manager.

His research focus with GSC was on coal and unconventional fuels, including coalbed methane, shale gas and tight oil. Over the past 15 years he has researched, published and lectured widely in North America and internationally on global energy and sustainability issues. Hughes is currently President of Global Sustainability Research Inc., a consultancy dedicated to research on energy and sustainability issues in the context of resource depletion and climate change. He is also a board member of Physicians, Scientists & Engineers for Healthy Energy, a Fellow of the Post Carbon Institute (PCI), and a research associate with the Canadian Centre for Policy Alternatives (CCPA).

Hughes has published widely in the scientific literature and his work has been featured in *Nature*, *The Economist*, *LA Times*, *Bloomberg*, *USA Today* and *Canadian Business*, as well as other press, radio and television outlets. Recent reports for CCPA and PCI include the following: *Will the Trans Mountain Pipeline and tidewater access boost prices and save Canada's oil industry?* (CCPA, May 2017); *Shale Reality Check* (PCI, February 2018); *Can Canada increase oil and gas production, build pipelines and meet its climate commitments?* (CCPA, June 2016); *A Clear View of BC LNG* (CCPA, May 2015); *Drilling Deeper* (PCI, October 2014); *Drilling California*; (PCI, December 2013) and *Drill, Baby, Drill* (PCI, February 2013).

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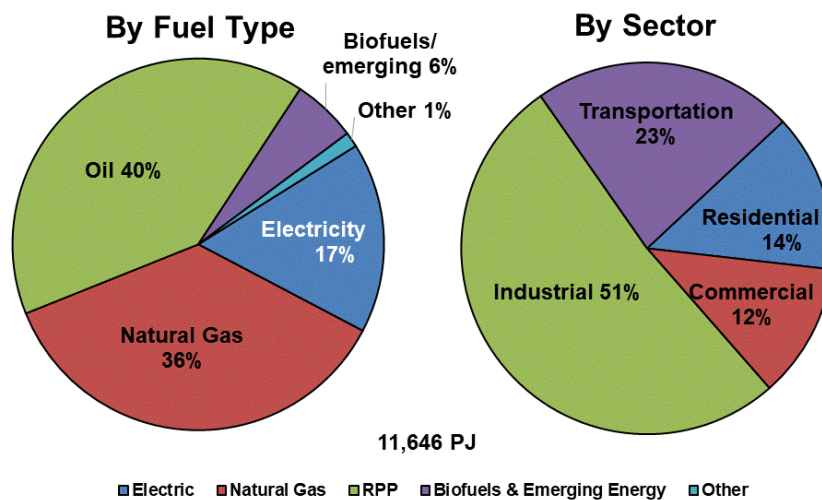
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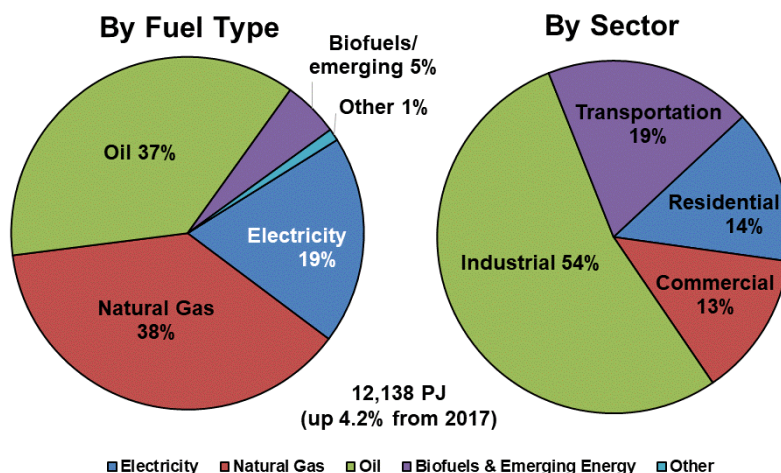
## Introduction to Part 3

Electricity is an energy carrier that provided only about 17% of the total delivered energy for end uses in Canada in 2017 (see Figure 105). The balance was provided by oil (40%); natural gas (36%); biomass, solid waste, coal and coke for thermal uses; and biofuels for transportation (7%). In its reference scenario, the NEB's projects that in 2040, oil and gas will still make up 75% of delivered energy, with electricity's share up slightly to 19% (see Figure 106). The industrial sector is the largest consumer of energy followed by the transportation, residential and commercial sectors.

**Figure 105: Delivered energy by fuel type and sector in Canada in 2017 (PJ = petajoules).<sup>1</sup>**



**Figure 106: Delivered energy by fuel type and sector in Canada in 2040 (PJ = petajoules).<sup>2</sup>**



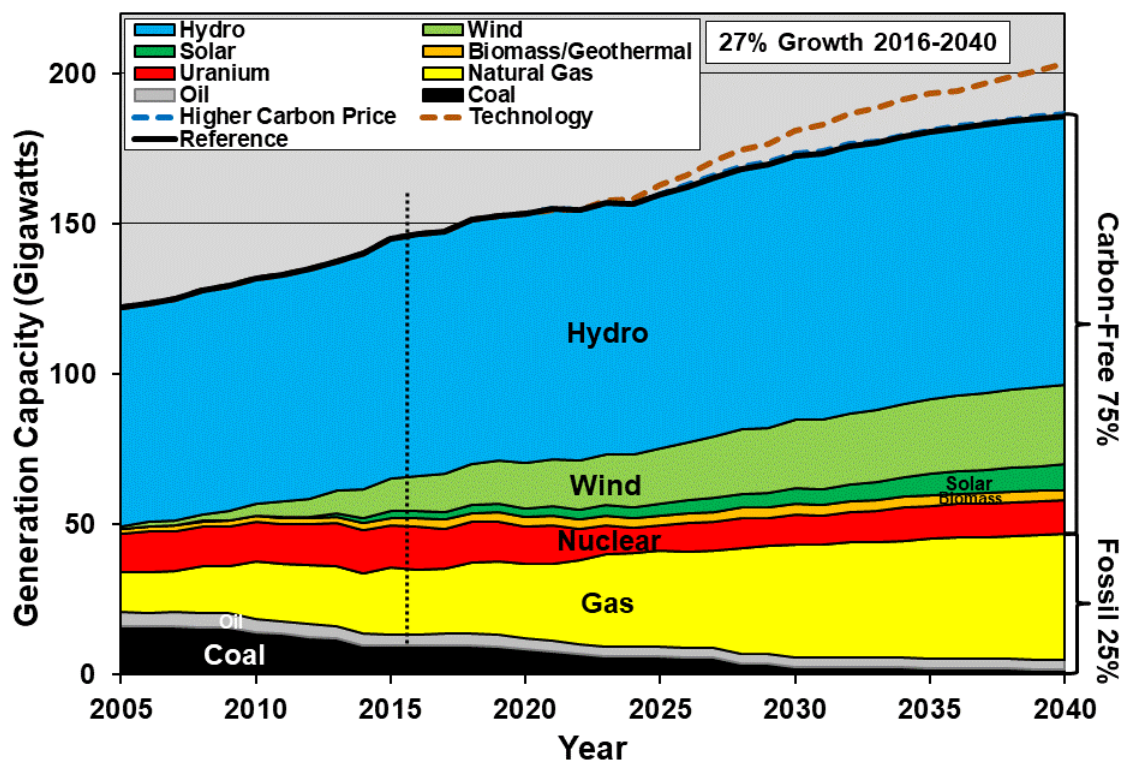
<sup>1</sup> National Energy Board Energy Future October 2017, <https://www.neb-one.gc.ca/nrg/ntgrtd/fttr/2017/2017nrgftr-eng.pdf>  
 appendices <https://apps.neb-one.gc.ca/fttrpndc/dflt.aspx?GoCTemplateCulture=en-CA>

<sup>2</sup> Op. cit.

The NEB's projection of electricity generating capacity under its reference case is illustrated in Figure 107, forecasting a 27% growth over 2016 levels by 2040. Wind, solar and natural gas are projected to increase substantially at the expense of coal, with the phase-out in Alberta and curtailment at the federal level, and nuclear. Large hydro, as outlined earlier, will remain the major source of generation capacity. Taken together, Canada's electricity generation capacity would be 75% carbon-free in 2040, about the same as it was in 2016.

**Figure 107: Electricity generation capacity in Canada from 2005 to 2040 according to the National Energy Board's reference case projection.**

*Also shown are the total capacities in the NEB's higher carbon price and technology scenarios.<sup>3</sup>*



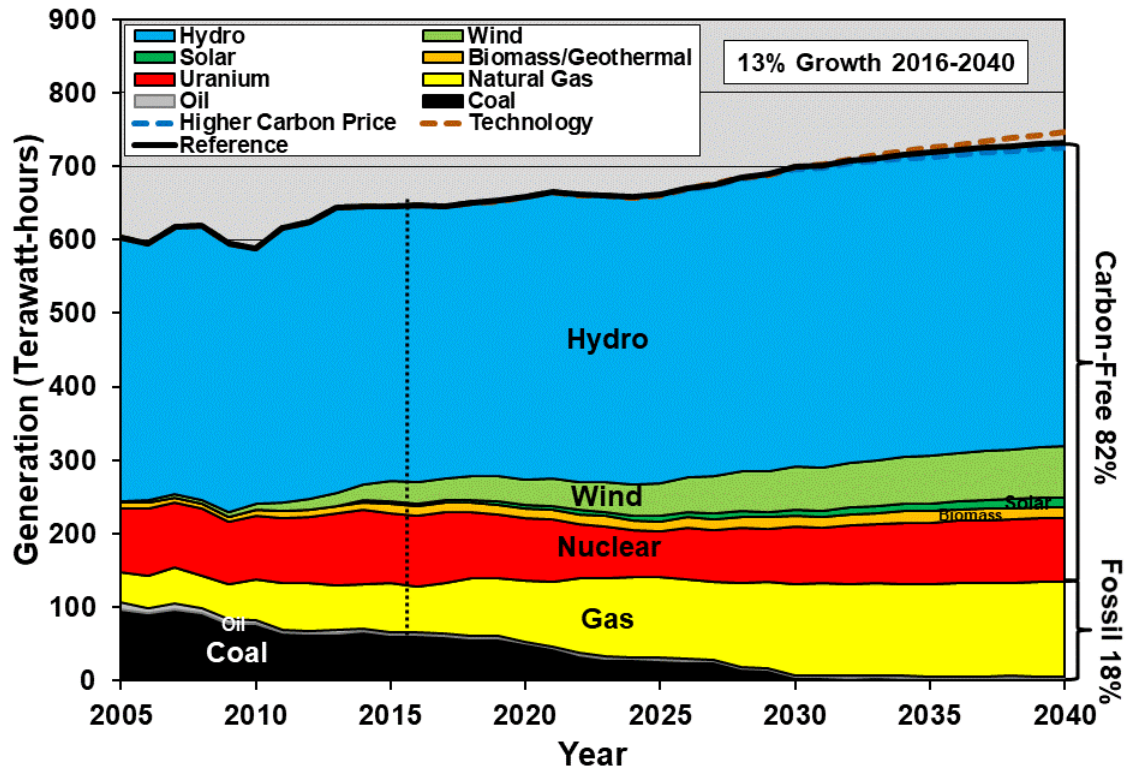
Actual electricity generation depends on the characteristics of the generation source. Nuclear, coal and combined-cycle gas typically are “base load” sources, as they can’t be easily ramped up and down to meet changing electricity demand. Gas turbines can be ramped up and down to meet variations in demand and hence can meet “peaking load,” although they are less efficient than combined-cycle natural gas. Hydro is a versatile source that can meet both base load and peaking load applications. Wind and solar are intermittent sources dependent on the vagaries of wind speed and solar insolation. Their output is prioritized (i.e., used first), but as they are unpredictable they must be backed up by a dispatchable generation source like natural gas or hydro.

<sup>3</sup> Op. cit.

Figure 108 illustrates the NEB's reference case projection for actual generation through 2040. Despite capacity additions of 27% over 2016 levels, actual generation grows only 13%, due to the addition of sources with lower capacity factors, such as solar and wind. In total, generation would be 82% carbon-free in 2040 according to this projection, about the same as it was in 2016.

**Figure 108: Electricity generation in Canada from 2005 to 2040 according to the National Energy Board's reference case projection.**

Also shown is the total generation in the NEB's higher carbon price and technology scenarios, which are little different from the reference case.<sup>4</sup>

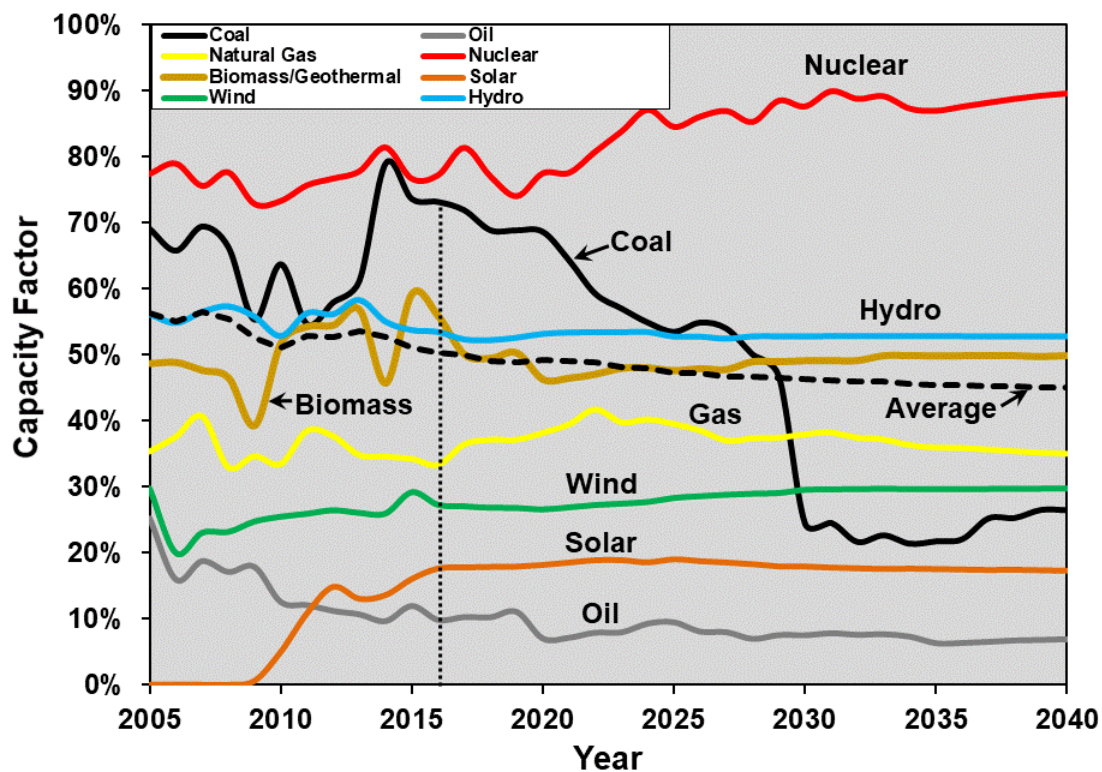


<sup>4</sup> Op. cit.



The ratio of generation capacity to actual generation is termed “capacity factor.” Base load sources like hydro, nuclear, coal and combined-cycle natural gas can generally run at capacity factors of more than 50%, and nuclear typically runs at 80% or more. The trade-off between coal and combined-cycle natural gas has historically depended on fuel price, and in future carbon pricing will likely reduce the use (and hence capacity factor) of any remaining coal plants after the phase-out. Gas turbines are only used when needed to meet peak demand as they are less efficient and therefore more expensive compared to combined-cycle natural gas. Wind and solar, due to their intermittency, have much lower capacity factors. In a very good location wind may have a capacity factor of 30–35%, and solar in a good location at the latitude of Southern Canada may have a capacity factor of 15–20% (higher in the summer and lower in winter). Therefore, for a given amount of generation, several times the amount of solar and wind capacity must be installed compared to dispatchable sources like hydro or natural gas. Figure 109 illustrates the capacity factors of various generation sources assumed in the NEB’s reference case through 2040.

**Figure 109: Capacity factors for various electricity generation sources in the National Energy Board’s reference case from 2005 to 2040.<sup>5</sup>**

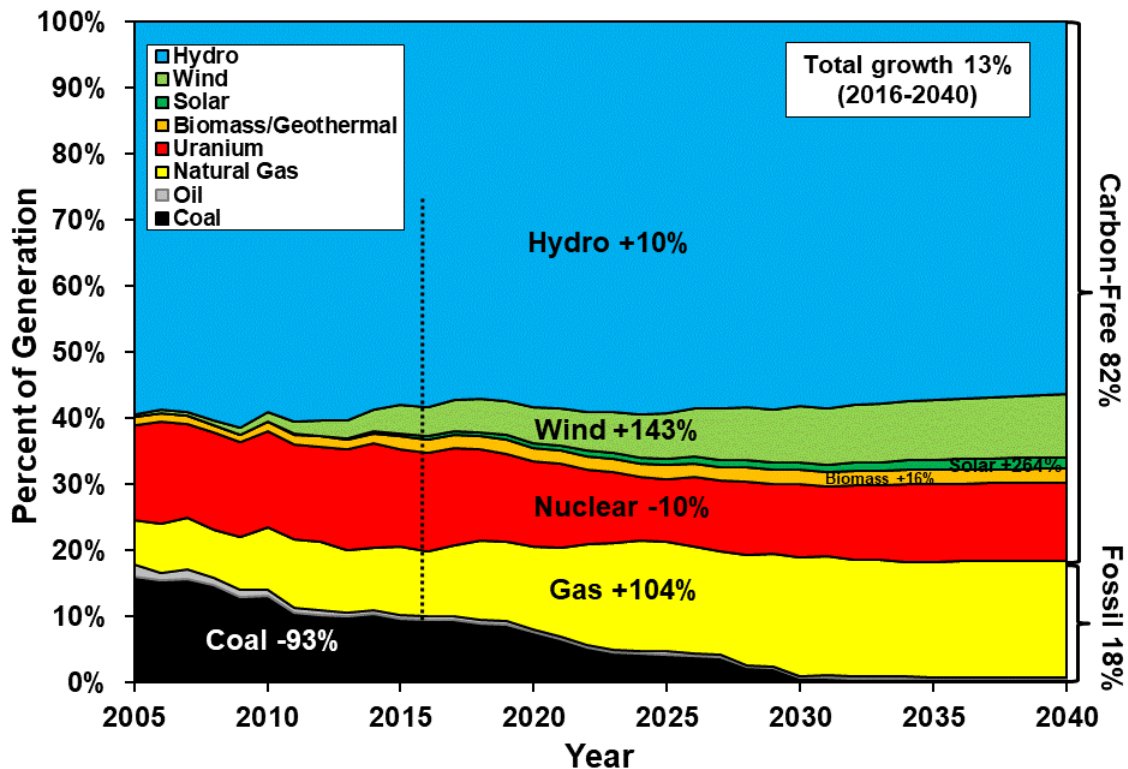


<sup>5</sup> Op. cit.

Figure 110 illustrates the percentage share of Canadian generation through 2040 in the NEB's reference case. The share of fossil fuel generation declines slightly from 2015 to 2040 and overall generation increases by 13%. Wind, solar and biomass increase substantially but are offset by a decline in nuclear generation. Fossil fuel generation is projected to decline only slightly despite the phase-out of coal, which is offset by the increase in gas-fired generation.

**Figure 110: Electricity generation in Canada from 2005 to 2040 as a percentage of total generation according to the National Energy Board's reference case projection.<sup>6</sup>**

*Hydro and carbon-free energy sources maintain their share through 2040, although overall generation increases by 13%. The percentage change of each generation source from 2016 to 2040 is also shown.*



<sup>6</sup> Op. cit.

The breakdown in electricity generation capacity, actual generation and capacity factor by source for Canada in 2015 is given in Table 16. Of carbon-free emissions sources, large hydro provides roughly 59%, followed by nuclear at 15%. Although wind and solar make up 6% of capacity, they generate less than 3% of total generation due to their low capacity factors. Carbon-emitting thermal sources made up 22% of 2015 generation.

**Table 16: Canada's electricity generation capacity, actual generation and capacity factor by source in 2015.<sup>7</sup>**

*Also shown is the National Energy Board's reference case change in generation from 2016 to 2040.*

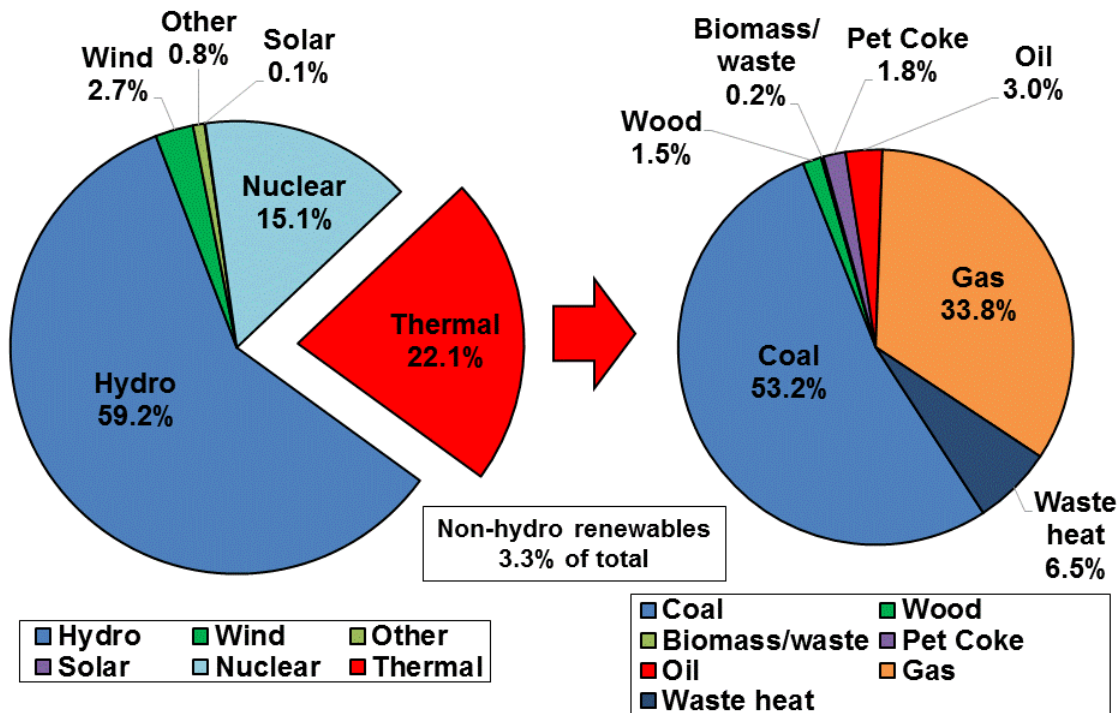
Source	Capacity		Generation		Capacity factor	2016–2040 generation change
	Gigawatts	%	TWh	%	%	
Hydro	79.23	58.57%	373.84	59.18%	53.86%	12.50%
Wind	7.64	5.65%	17.11	2.71%	25.57%	101.74%
Solar	0.19	0.14%	0.34	0.05%	20.27%	108.34%
Nuclear	14.03	10.37%	95.68	15.15%	77.84%	-27.39%
Thermal	34.15	25.25%	139.46	22.08%	46.62%	40.90%
<b>Total</b>	<b>135.27</b>	<b>100.00%</b>	<b>631.68</b>	<b>100.00%</b>	<b>53.31%</b>	<b>13.70%</b>

<sup>7</sup> Statcan CANSIM tables 127-0007 and 127-0009 accessed March 8, 2017. Note that there are discrepancies between Statcan data for solar compared to other sources. IRENA reports 2015 capacity as 2.44 GW vs .19 GW for Statcan. In 2014 both IRENA and NRCAN report 1.84 GW vs .19 GW for Statcan. For 2014 generation Statcan reports .33 TWh vs 1.78 TWh for IRENA and NRCAN. BP reports 1.9 TWh in 2015 vs .34 TWh for Statcan. If alternate data are used solar would be 0.3% of total generation and 1.8% of capacity. Wind capacity for 2015 is also understated by Statcan at 7.64 GW vs 11.2 GW for IRENA and the Canadian Wind Energy Association.

A detailed breakdown of thermal generation sources in 2015 is illustrated in Figure 111. Wood, other biomass and waste are renewable, and are by definition carbon-free (although they emit carbon when burned, in theory regrowth will remove these emissions); they amounted to 1.7% of thermal generation and less than .5% of total generation in 2015.

**Figure 111: Canada's electricity generation by source in 2015, illustrating a breakdown of thermal generation sources.<sup>8</sup>**

*Pet coke is petroleum coke derived from upgrading operations, and waste heat is energy captured from industrial operations.*



<sup>8</sup> Statcan 2017, CANSIM Tables 127-0006 and 127-0007 accessed March 10, 2017.



Environment and Climate Change Canada (ECCC) has developed a “Mid-Century Long-Term Low-Greenhouse Gas Development Strategy” (mid-century strategy),<sup>9</sup> which presents six scenarios for meeting a goal of approximately 80% emissions reduction by 2050. Three of these were developed by ECCC using its Global Change Assessment Model (GCAM), two by the Trottier Energy Futures Project<sup>10</sup> and one by the Deep Decarbonization Pathways Project (DDPP).<sup>11</sup> All of these scenarios call for greatly increased generation of electricity, ranging from 86% to 245% above 2015 levels. Table 17 illustrates these scenarios compared to the NEB's reference case projection through 2040.

New generation capacity required in these scenarios for growth in electricity generation is explored for each energy source in the following section. One thing that is clear, however, is that the NEB's projections of modest growth in electricity generation and essentially the same proportion of delivered energy supplied by electricity in 2040 as today are unlikely to result in the emissions reductions needed when compared to the scenarios in ECCC's mid-century strategy.

**Table 17: Generation of electricity in Environment and Climate Change Canada's mid-century strategy scenarios compared to current generation and to the National Energy Board's reference case 2040 projection.**

*Also shown is the percentage of final delivered energy supplied by electricity in 2050.<sup>12</sup>*

Scenario	TWh	% growth from 2015 levels	% of delivered energy
NEB 2015 Generation	646	-	16.8%
DDPP 2050	1477	129%	48.5%
Trottier Current Tech 2050	2257	249%	65.3%
Trottier New Tech 2050	1622	151%	58.4%
ECCC High Nuclear 2050	1648	155%	57.0%
ECCC High Hydro 2050	1648	155%	57.0%
ECCC High Demand Response 2050	1215	88%	33.1%
NEB Reference in 2040	732	13%	19.1%

<sup>9</sup> Environment and Climate Change Canada, 2016, Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, [http://unfccc.int/files/focus/long-term\\_strategies/application/pdf/canadas\\_mid-century\\_long-term\\_strategy.pdf](http://unfccc.int/files/focus/long-term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf)

<sup>10</sup> Trottier Energy Futures Project Final Report, 2016, [https://www.cae-acg.ca/wp-content/uploads/2013/04/3\\_TAFP\\_Final-Report\\_160425.pdf](https://www.cae-acg.ca/wp-content/uploads/2013/04/3_TAFP_Final-Report_160425.pdf)

<sup>11</sup> Bataille, C. et al. 2015, Pathways to Deep Decarbonization in Canada. Retrieved from [http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP\\_CAN.pdf](http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_CAN.pdf)

<sup>12</sup> Environment and Climate Change Canada, 2016, Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, see Figures 2 and 7, [http://unfccc.int/files/focus/long-term\\_strategies/application/pdf/canadas\\_mid-century\\_long-term\\_strategy.pdf](http://unfccc.int/files/focus/long-term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf)

## 3.1 Nuclear

Canada has 19 operating reactors, which amounted to 14% of Canada's total generating capacity and 15% of actual generation in 2015 (see Table 16). Four reactors in Ontario and Quebec are being decommissioned and two, Pickering A2 and A3, are idle and listed as permanently shut down.<sup>13</sup> Table 18 illustrates the operating reactors, their capacity and their currently planned closure dates.

**Table 18: Nuclear reactors currently operating in Canada, their capacity and planned closure date.**

*The date of the plants' first power, and the date of commissioning of refurbished plants is also shown.<sup>14</sup> (OPG = Ontario Power Generation; MWe net = net generation capacity in megawatts)*

Reactor	MWe net	Operator	First power	Refurbishment first power	Planned close, or licensed to
Pickering A1	515	OPG	1971	2005	2022
Pickering A4	515	OPG	1972	2003	2018
Pickering B5	516	OPG	1982		2018
Pickering B6	516	OPG	1983		2019
Pickering B7	516	OPG	1984		2018
Pickering B8	516	OPG	1986		2018
Bruce A1	750	Bruce Power	1977	2012	2035
Bruce A2	750	Bruce Power	1976	2012	2035
Bruce A3	750	Bruce Power	1977	2004	2036
Bruce A4	750	Bruce Power	1978	2003	2036
Bruce B5	825	Bruce Power	1984		2024 <sup>a</sup>
Bruce B6	825	Bruce Power	1984		2024 <sup>a</sup>
Bruce B7	825	Bruce Power	1986		2026 <sup>a</sup>
Bruce B8	825	Bruce Power	1987		2027 <sup>a</sup>
Darlington 1	881	OPG	1990		2025
Darlington 2	881	OPG	1990		2025
Darlington 3	881	OPG	1992		2025
Darlington 4	881	OPG	1993		2025
Point Lepreau 1	635	NB Power	1982	2012	2037
<b>Total</b>	<b>13,553</b>	<sup>a</sup> - closure date assuming a 40-year life without refurbishment			

<sup>13</sup> IAEA, 2017, Power Reactor Information System, <https://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=CA>

<sup>14</sup> World Nuclear Association, November, 2016, Nuclear Power in Canada, <http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/canada-nuclear-power.aspx>

The World Nuclear Association provides a good overview of nuclear power in Canada, including its recent history and future outlook.<sup>15</sup> Given the closure and/or “licensed to” dates in Table 18, which would see all plants closed by 2037, major investments in refurbishing existing reactors and/or building new ones will be required just to maintain output or stem the decline. Table 19 illustrates the nuclear capacity lost with the closure of reactors according to the schedule in Table 18. By 2025, 61% of capacity would be lost and by 2037 all plants would be closed.

**Table 19: Decline in nuclear generating capacity through 2040 given the World Nuclear Association's closure dates given in Table 18.**

Closure date	Number closed	Capacity lost MWe net	% of total	Total % lost
2018–2019	5	2,579	19.0%	19.0%
2020–2025	7	5,689	42.0%	61.0%
2026–2030	2	1,650	12.2%	73.2%
2031–2035	2	1,500	11.1%	84.2%
2035–2040	3	2,135	15.8%	100.0%
<b>Total</b>	<b>19</b>	<b>13,553</b>	<b>100.0%</b>	<b>100.0%</b>

Clearly this is unlikely to happen, but it points out the vulnerability of Canada's aging fleet of reactors. Ontario Power Generation (OPG) has announced plans to refurbish the four Darlington reactors at a cost of \$12.8 billion over the next decade, extending their life by perhaps another 20 years when complete in 2026.<sup>16</sup> As part of this plan, OPG plans to keep the Pickering reactors running until 2024, which is six years beyond their current closure date, when they will be decommissioned. Refurbishments of the four Bruce B reactors have been announced by Bruce Power over the 2020–2033 period, along with further work on the Bruce A3 and A4 reactors, at a cost of \$13 billion.<sup>17,18</sup> If the Darlington and Bruce B refurbishments go ahead as announced, that would extend 50% of existing capacity beyond the current 2037 closure dates for all plants. If the life of the older Bruce A3 and A4 reactors is also significantly extended, that would preserve 61% of existing capacity.

Even with the expenditure of \$26 billion on refurbishments of the Bruce and Darlington reactors, Canadian nuclear power is set to decline by about 39% over the next two decades unless new reactors are constructed. The NEB's reference case projection of a 10% decline in nuclear power from 2016 levels by 2040 shown in Figure 109 is therefore optimistic, as it would require four new 1,000-megawatt reactors to be built.

Globally, 447 reactors are operational, with 99 in the US and 58 in France, the top two nuclear-powered countries.<sup>19</sup> Permanently shut down reactors total 160 worldwide, with 34 of those in the US and 12 in France. Some 56 reactors are under construction, with 20 of those in China, seven in Russia and six in India. Although they are currently the top two users of nuclear power, the US and France have just three reactors under construction between them (two for the US and one for France). Given that two-thirds of the world's nuclear reactors were built prior to 1990, it remains to be seen if new construction can keep up with retirements as older plants reach the end of their design life. Construction of nuclear power plants is

<sup>15</sup> Op. cit.

<sup>16</sup> Ontario Power Generation, press release January 11, 2016, [http://www.opg.com/news-and-media/news-releases/Documents/20160111\\_DarlingtonRefurb.pdf](http://www.opg.com/news-and-media/news-releases/Documents/20160111_DarlingtonRefurb.pdf)

<sup>17</sup> CBC, December 3, 2015, <http://www.cbc.ca/news/canada/toronto/bruce-power-1.3348633>

<sup>18</sup> Bruce Power, March, 2017, BPRIA backgrounder refurbishment schedule, <http://www.brucepower.com/bpria-backgrounder/refurbishment-schedule/>

<sup>19</sup> World Nuclear Association, August 2017, World Nuclear Power Reactors and Uranium Requirements, <http://www.world-nuclear.org/info/Facts-and-Figures/World-Nuclear-Power-Reactors-and-Uranium-Requirements/> Note that two US reactor construction projects were shut down in late July, 2017, which reduces the actual number under construction to 56, rather than 58 as noted in this reference.

also expensive compared to other forms of generation, costing over five times more than gas, three times more than onshore wind and two times more than utility-scale solar (see Table 20). Cost overruns in construction are also common, and decommissioning costs are 10% to 15% of the original construction cost.

**Table 20: Power plant capital costs for construction, and fixed and variable operating and maintenance (O&M) costs.<sup>20</sup>**

*All figures are in 2016 US dollars.*

Power plant type	Plant size capacity (MW)	Overnight capital cost (\$US2016/KW)	Fixed O&M (\$/KW-year)	Variable O&M (\$/MWh)
Ultra supercritical coal	650	3,636	42	4.6
Ultra supercritical coal with ccs	650	5,084	70	7.1
Natural gas combined cycle	702	978	11	3.5
Natural gas combustion turbine	100	1,101	18	3.5
Advanced nuclear	2,234	5,945	100	2.3
Biomass fluidized bed	50	4,985	110	4.2
Onshore wind (wn)	100	1,877	40	0
Photovoltaic – fixed	20	2,671	23	0
Photovoltaic – tracking	20	2,644	24	0
Photovoltaic – tracking	150	2,534	22	0
Battery storage	4	2,813	40	8

Aside from the expense of construction, nuclear power poses the additional problem of long-term disposal of high- and low-level radioactive wastes. Despite decades of research and some promising repositories, permanent disposal at scale has not yet been achieved. Repositories such as Yucca Mountain in Nevada have been ruled out after many years and billions of dollars of investment. The additional risk of infrequent but very costly accidents such as Fukushima and Chernobyl have caused countries such as Germany to phase out nuclear power, and Japan has vastly curtailed nuclear generation.

<sup>20</sup> EIA, November 2016, Capital Cost Estimates for Utility Scale Electricity Generating Plants, [https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capcost\\_assumption.pdf](https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capcost_assumption.pdf)



Notwithstanding these environmental and cost issues, ECCC's mid-century strategy requires growth of up to 733% in nuclear generation by 2050 from 2015 levels (see Table 21), when nuclear power would make up to 48% of total generation. The lowest nuclear scenario (DDPP) would see a decline of 15% in generation by 2050, but would still require construction of three new reactors to replace decommissioned reactors. This would be at a cost of US\$17.8 billion, assuming advanced nuclear reactors at a cost of US\$5,945 per kilowatt and a capacity factor of 77.8% (see Table 20). In the high nuclear case, 108 new reactors at a cost of US\$642 billion would be required. In all scenarios, the refurbishment of eight existing reactors at a cost of \$26 billion is assumed to maintain nuclear generation at 39% below existing levels through 2050.

**Table 21: Generation of electricity by nuclear power in Environment and Climate Change Canada's mid-century strategy scenarios compared to current generation and to the National Energy Board's reference case 2040 projection.**

*Also shown is the percentage of 2050 generation from nuclear power, the number of new reactors required and their estimated cost assuming "advanced nuclear reactors" per Table 20.<sup>21</sup>*

Scenario	TWh	% growth from 2015 levels	% of total generation	New 1GW reactors needed	New reactor cost (US2016\$B)
NEB 2015 Generation	96	-	14.8%	-	-
DDPP 2050	81	-15%	5.5%	3	17.8
Current Tech Trottier 2050	797	733%	35.4%	108	642.1
New Tech Trottier 2050	656	586%	40.6%	87	517.2
High Nuclear 2050	797	733%	48.4%	108	642.1
High Hydro 2050	281	194%	17.1%	32	190.2
High Demand Response 2050	163	70%	13.4%	15	89.2
NEB Reference in 2040	87	-9%	11.9%	4	23.8

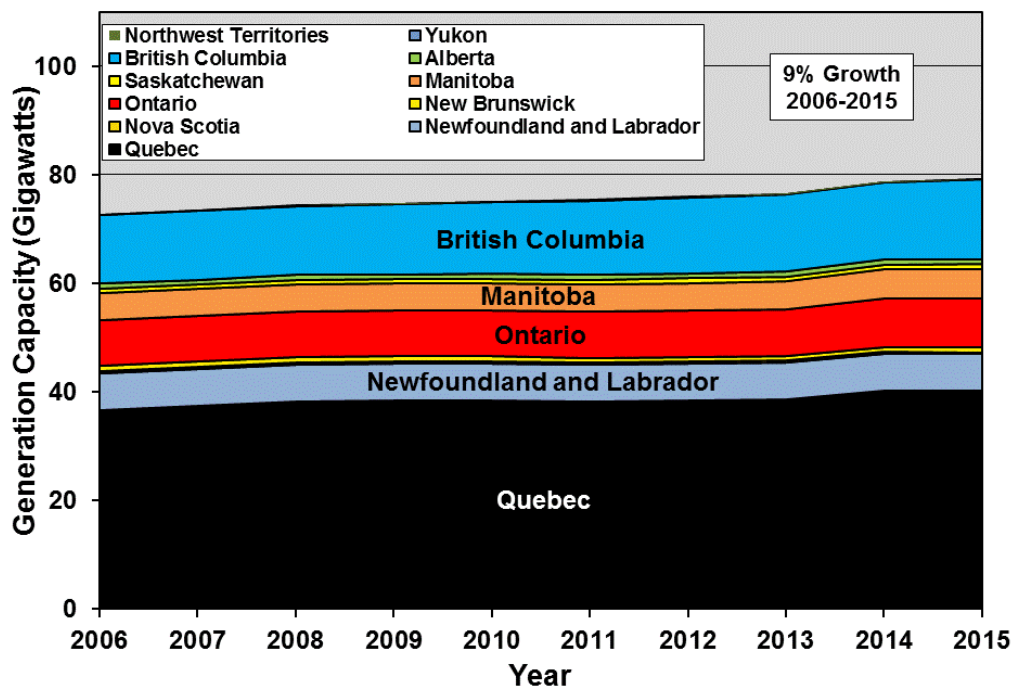
<sup>21</sup> Environment and Climate Change Canada, 2016, Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, see Figures 2 and 7, [http://unfccc.int/files/focus/long-term\\_strategies/application/pdf/canadas\\_mid-century\\_long-term\\_strategy.pdf](http://unfccc.int/files/focus/long-term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf)

## 3.2 Hydro

Hydro comprises 58% of Canada's electricity generating capacity and 59% of total generation (Table 16). Some 55% of Canada's 79 gigawatts of hydro capacity is contained in 22 facilities rated at more than one gigawatt each, although there are 576 hydro facilities rated at more than 0.8 megawatts.<sup>22</sup> Generation capacity has increased by 9% over the 2006–2015 period, as illustrated in Figure 112. Quebec has 51% of total capacity followed by BC (18%) and Ontario (11%).

**Figure 112: Hydroelectricity generation capacity in Canada by province from 2006 to 2015.**<sup>23</sup>

*Total capacity increased by 9% over this period.*



Hydro is a reliable, renewable and carbon-free source of electricity (if emissions from the construction of dams and the flooding of reservoirs, which occur in the early years of projects, are not considered). Hydro also provides dispatchable power, meaning it can be ramped up and down to follow demand. This makes hydro a better match for intermittent renewable energy sources like wind and solar than primarily base load generation from nuclear, coal and combined-cycle gas, which are best suited to constant output.

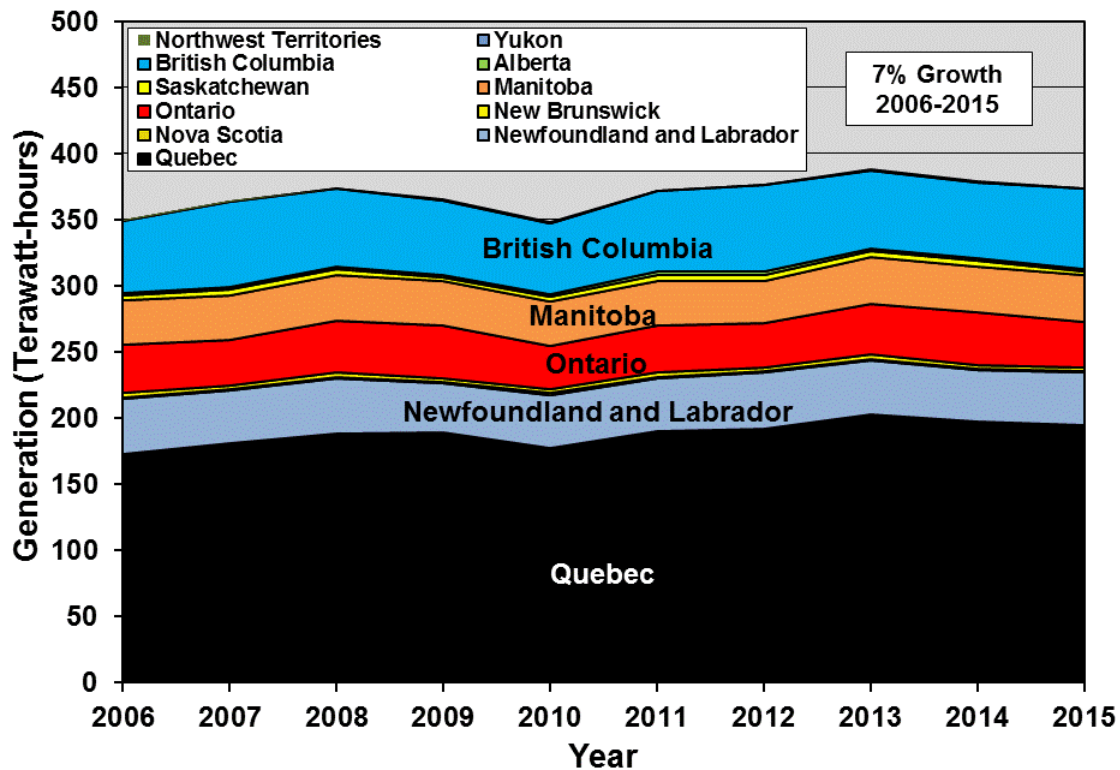
<sup>22</sup> NRCAN, 2016, Energy Fact Book 2016–2017, [https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/EnergyFactBook\\_2016\\_17\\_En.pdf](https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/EnergyFactBook_2016_17_En.pdf)

<sup>23</sup> Statistics Canada, 2017, CANSIM Table 127-0009, retrieved March 8 2017.

Actual generation from hydro facilities depends on seasonal variations in rainfall and water supply, and variations in demand. Climate change may impose additional constraints on water supply and variability. The average capacity factor for hydro in Canada is 54% of maximum rated output (see Table 16). Figure 113 illustrates hydro generation by province, which has increased overall by 7% from 2006 through 2015.

**Figure 113: Hydroelectricity generation in Canada by province from 2006 to 2015.<sup>24</sup>**

*Total generation increased by 7% over the period.*



<sup>24</sup> Statistics Canada, 2017, CANSIM Table 127-0007, retrieved March 8 2017.

Five additional projects were under development in 2016, which would add 4.6 gigawatts, or 5.8%, to total hydro capacity by 2024 (see Table 22).<sup>25</sup> The NEB's reference case projects a growth in hydro generation of 10.4% over 2015 levels by 2040, which would require eight new hydro projects of the size of the Site C dam in BC.

**Table 22: Hydro projects under construction in Canada as of 2016.**

Project	Province	Capacity (MW)	Expected in-service date
Site C	BC	1,100	2024
La Romaine Complex	Quebec	1,550	2017–2020
Muskrat Falls	Newfoundland–Labrador	824	2018
Keeyask	Manitoba	695	2021
Lower Mattagami Complex	Ontario	438	2016
<b>Total</b>		<b>4,607</b>	

Development of new large hydro projects is controversial, as evidenced by protests of the Site C project in BC and Muskrat Falls in Labrador. Site C's critics cite, among other things, the following:

- Flooding of high-value agricultural land.
- Disruption of traditional land use and values of First Nations.
- Downstream impacts, including to the Peace River delta.
- Impacts on wildlife and fish.
- Emissions of methane from flooded land.
- Emissions during the construction process.

Similarly, there have been protests against less invasive “run-of-river” hydro projects in BC as they involved roads and transmission lines constructed in pristine wilderness in addition to the actual hydro infrastructure itself. These projects are also high-cost, with Site C amounting to \$8.335 billion,<sup>26</sup> or \$7,577 (US\$5,683) per kilowatt, which is at the high end of the cost scale, roughly the same as nuclear (see Table 19). Site C is forecast to produce 5,100 GWh per year, meaning that it will have a capacity factor of 53%—much higher than renewables like wind and solar but lower than nuclear.

Although many of the best hydropower sites in Canada within proximity to large population centres have been developed, the question remains: How much undeveloped hydropower capacity exists in Canada? The Canadian Hydropower Association claims there are 160 gigawatts (GW) in addition to the 80 GW already developed, but offers no evidence to support this claim.<sup>27</sup> Canada's National Research Council (NRC) prepared a report in 2014 on the total hydrokinetic energy of all Canadian rivers, which projected very large numbers, but noted “that most locations would potentially be infeasible for energy extraction for a host of reasons.”<sup>28</sup> The NRC estimated a mean hydrokinetic energy potential of 344 GW with a 95% probability interval of 29 GW to 5,530 GW. When asked what proportion of this potential would be technically feasible to develop, an NRC representative replied, “to my knowledge the practical or technical resource remains undetermined.”<sup>29</sup>

<sup>25</sup> NRCan, 2016, Energy Fact Book 2016–2017, [https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/EnergyFactBook\\_2016\\_17\\_En.pdf](https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/EnergyFactBook_2016_17_En.pdf)

<sup>26</sup> BC Hydro, Site C Fact Sheet, March 2017, [https://www.sitecproject.com/sites/default/files/site-c-fact-sheet-march-2017\\_2.pdf](https://www.sitecproject.com/sites/default/files/site-c-fact-sheet-march-2017_2.pdf)

<sup>27</sup> Canadian Hydropower Association, retrieved April 6, 2017, cites a 2007 report it commissioned that is not publicly available hence cannot be evaluated, <https://canadahydro.ca/hydropower-potential/>

<sup>28</sup> National Research Council, 2014, Assessment of Canada's Hydrokinetic Power Potential, Phase III Report, Resource Estimation, see page 39.

<sup>29</sup> Personal communication, Andrew Cornett, National Research Council, March 28, 2017.



In 2015, Canada ranked a distant second in the world to China in terms of total hydropower generation (374 TWh versus 1,163 TWh).<sup>30</sup> It seems unlikely that Canada will significantly ramp up large-scale hydropower generation beyond projects under construction over the next few decades, given environmental considerations and opposition along with cost.

Notwithstanding this, the ECCC projects in its mid-century strategy scenarios that hydropower capacity will have to increase on average by 107% by 2050. Table 23 illustrates new hydro capacity required for each scenario.

**Table 23: Projected increases in hydropower by scenario in Environment and Climate Change Canada's mid-century strategy<sup>31</sup> and under the National Energy Board's reference scenario.<sup>32</sup>**

*Also shown is total cost (assuming US2016\$5,683 per kilowatt of capacity, which is the estimated construction cost of Site C), and number of new Site C-sized dams required (given Site C capacity of 1.1 GW).*

Scenario	TWh	% growth from 2015 levels	% of total generation	New capacity needed (GW)	New dam cost (US2016\$B)	New Site C-sized dams required
NEB 2015 Generation	374		57.9%			
DDPP 2050	786	110%	53.2%	102	576.8	92
Current Tech Trottier 2050	828	121%	36.7%	111	630.8	101
New Tech Trottier 2050	824	120%	50.8%	111	630.8	101
High Nuclear 2050	526	41%	31.9%	36	204.6	33
High Hydro 2050	967	158%	58.7%	130	738.8	118
High Demand Response 2050	865	131%	71.1%	108	613.8	98
NEB Reference in 2040	413	10.4%	56.4%	8.3	47.0	8

Developing this much additional hydropower in just 33 years would require up to 118 new dams the size of Site C at a cost of up to US\$739 billion. This would likely involve multiple dams on the last remaining undammed rivers, including the Fraser, Skeena, Mackenzie and Yukon, as well as major investments in new transmission lines. The environmental costs of doing this would be substantial, to put it mildly.

<sup>30</sup> BP Statistical Review of World Energy 2017.

<sup>31</sup> National Energy Board Energy Future October 2017, <https://www.neb-one.gc.ca/nrg/ntgrtd/fttr/2017/2017nrgftr-eng.pdf> appendices <https://apps.neb-one.gc.ca/fttrpndc/dflt.aspx?GoCTemplateCulture=en-CA>

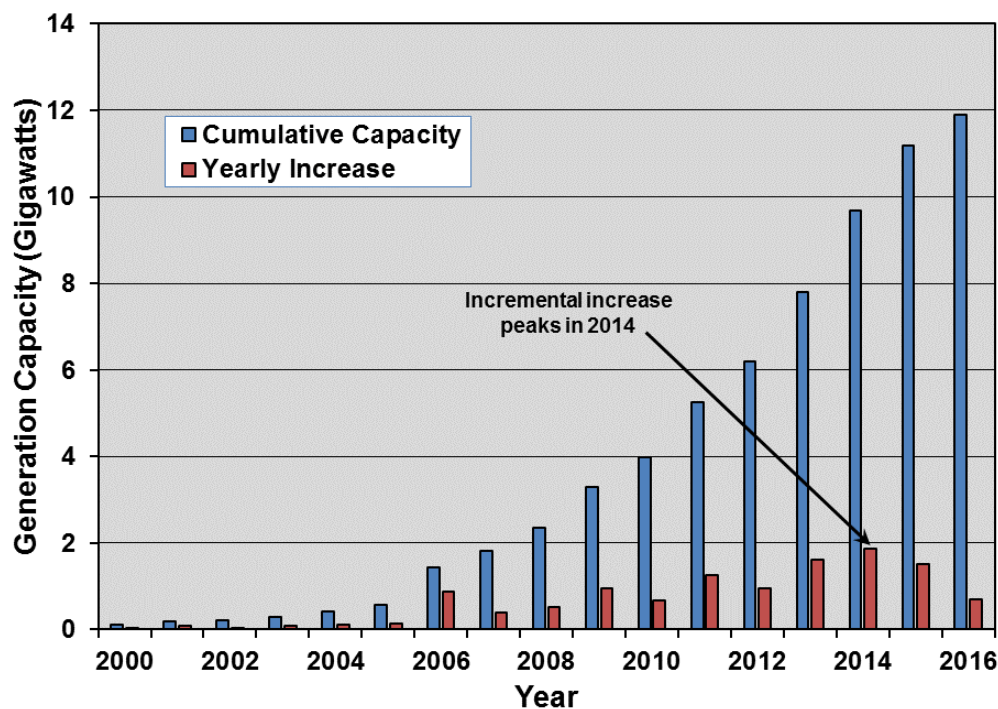
<sup>32</sup> Environment and Climate Change Canada, 2016, Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, see Figures 2 and 7, [http://unfccc.int/files/focus/long-term\\_strategies/application/pdf/canadas\\_mid-century\\_long-term\\_strategy.pdf](http://unfccc.int/files/focus/long-term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf)

### 3.3 Wind

Wind electricity generation capacity has grown from less than one gigawatt in 2005 to nearly 12 gigawatts in 2016 (see Figure 114) according to the Canadian Wind Energy Association (CANWEA).<sup>33</sup> This represents about 9% of 2016 Canadian capacity, although Statistics Canada reported that wind was just 5.65% of Canadian capacity in 2015 (see Table 16—CANWEA notes all wind projects and is believed to be more complete and accurate than Statistics Canada). Yearly additions of wind capacity have declined since peaking in 2014. At the time of writing, an additional 22 wind projects worth US\$4.8 billion were either under construction, under review, approved or planned. If completed, these would add 2.6 gigawatts, increasing Canada's capacity by 22% to 14.5 gigawatts.<sup>34</sup>

**Figure 114: Incremental and cumulative wind generation capacity in Canada from 2000 to 2016.**

*Yearly growth in capacity peaked in 2014.*<sup>35</sup>

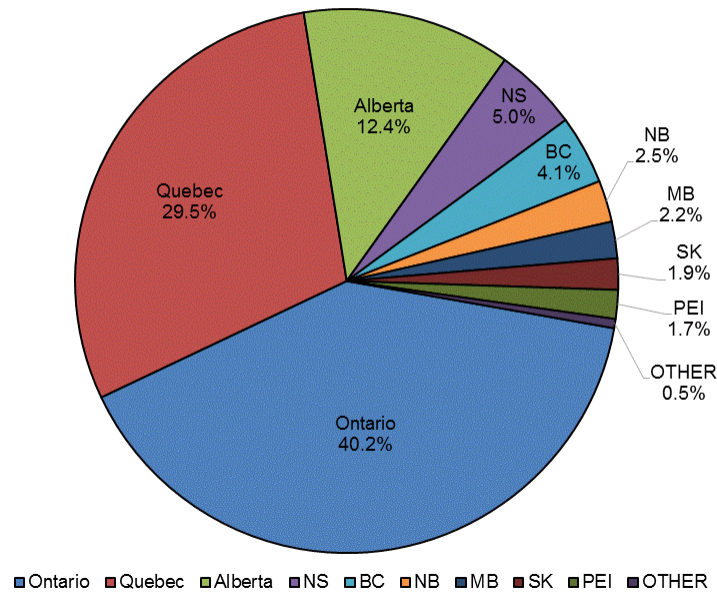


Ontario, with its aggressive policy to phase out coal, comprised 40% of total wind capacity in 2016, followed by Quebec and Alberta (see Figure 115, next page). Together these three provinces comprise 82% of Canadian wind power capacity. Figure 116 illustrates the location of the 217 wind generating stations in Canada by rated capacity.

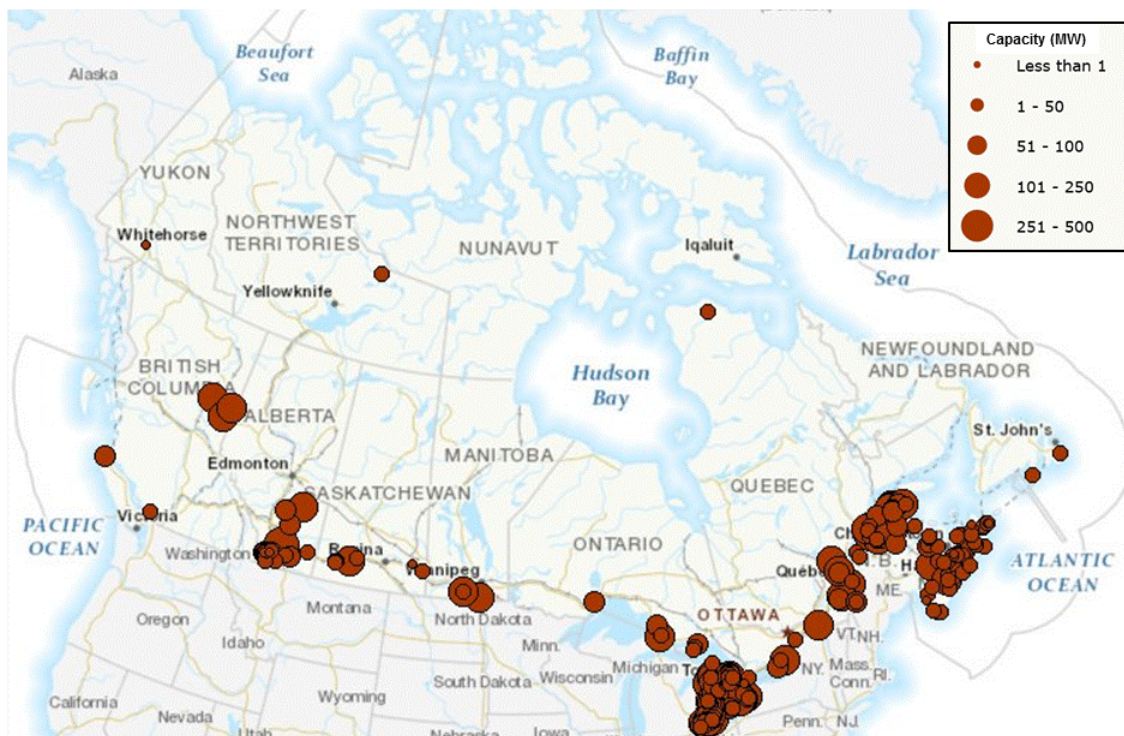
<sup>33</sup> Canadian Wind Energy Association, 2017, List of Wind Farms in Canada (as of December 31, 2016), [http://canwea.ca/wp-content/uploads/2013/12/Installedcap\\_PublicWebsite-Dec-31-2016\\_dk.pdf](http://canwea.ca/wp-content/uploads/2013/12/Installedcap_PublicWebsite-Dec-31-2016_dk.pdf)

<sup>34</sup> Natural Resources Canada, The Atlas of Canada - Clean Energy Resources and Projects (CERP), retrieved May 28 2017, <http://atlas.gc.ca/cerp-rpep/en/>

<sup>35</sup> Data from Canadian Wind Energy Association, 2017

**Figure 115: Wind generation capacity in Canada in 2016 by province.<sup>36</sup>****Figure 116: Wind generating stations in Canada as of early 2016, showing capacity (11,058 megawatts in total).<sup>37</sup>**

*There are 217 stations shown.*



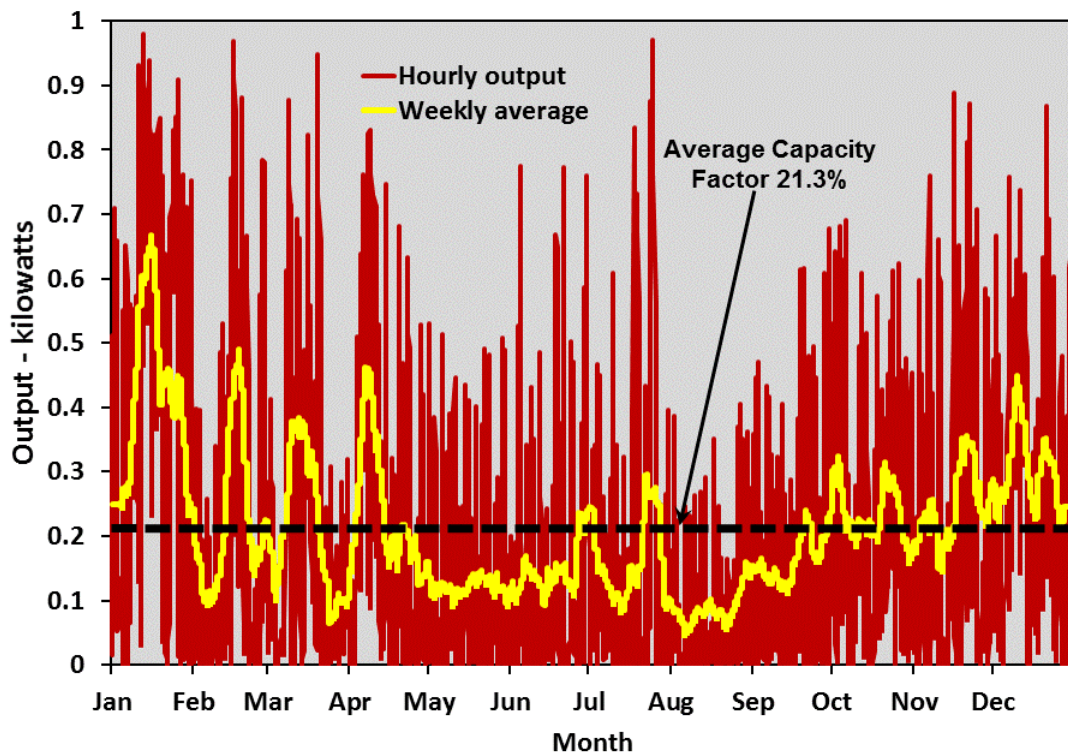
<sup>36</sup> Canadian Wind Energy Association, 2017, List of Wind Farms in Canada (as of December 31, 2016), [http://canwea.ca/wp-content/uploads/2013/12/Installedcap\\_PublicWebsite-Dec-31-2016\\_dk.pdf](http://canwea.ca/wp-content/uploads/2013/12/Installedcap_PublicWebsite-Dec-31-2016_dk.pdf)

<sup>37</sup> Natural Resources Canada Atlas of Canada, retrieved June 10, 2017, <http://atlas.gc.ca/cerp-rpep/en/>

A major issue with renewable sources such as wind and solar is that they are intermittent, and vary in output on an hourly (or even shorter) basis as well as seasonally. To maintain a stable grid, “dispatchable” sources of generation that can be rapidly ramped up and down must be available to provide backup power when the wind is not blowing and the sun is not shining. Figure 117 illustrates this issue for a theoretical windmill located at Calgary, Alberta, using 2014 climate data. At this location, the average capacity factor for the year is 21.3%, but is higher in winter than summer months. Hydropower is an ideal dispatchable renewable resource to back up this intermittency, where available, but simple cycle turbines burning gas are also commonly used. These can be rapidly ramped up and down to match wind generation’s intermittency, unlike more efficient combined-cycle gas generators, which are less suited to rapid changes in output.

**Figure 117: Generation from one kilowatt of wind capacity from a tower 60 metres high located at Calgary, Alberta, in 2014.<sup>38</sup>**

*Hourly and weekly generation is indicated. The overall average generation is 21.3% of rated nameplate capacity, but this is highly variable.<sup>39</sup>*



Capacity factor varies with the wind resource. In a high-quality onshore location, capacity factors can be 30% or higher. Using Statistics Canada data, the average capacity factor of wind in Canada from 2011 to 2015 was 22.7%.<sup>40</sup> The UN’s International Renewable Energy Agency (IRENA) also provides data on wind generation and capacity for Canada, which yield a capacity factor of 26.5% in 2014.<sup>41</sup> In Alberta, where a high-quality wind resource exists in the southwestern part of the province, Statistics Canada data yield an average capacity factor of 34.4% over the period from 2011 to 2015.

<sup>38</sup> Data from NASA MERRA-2 database with bias-correction from Staffell and Pfenninger, 2016 – Vestas V80-2000

<sup>39</sup> Stefan Pfenninger and Iain Staffell, retrieved March 5, 2017, climate data sources NASA MERRA reanalysis and CM-SAF’s SARAH dataset, <https://www.renewables.ninja/#>

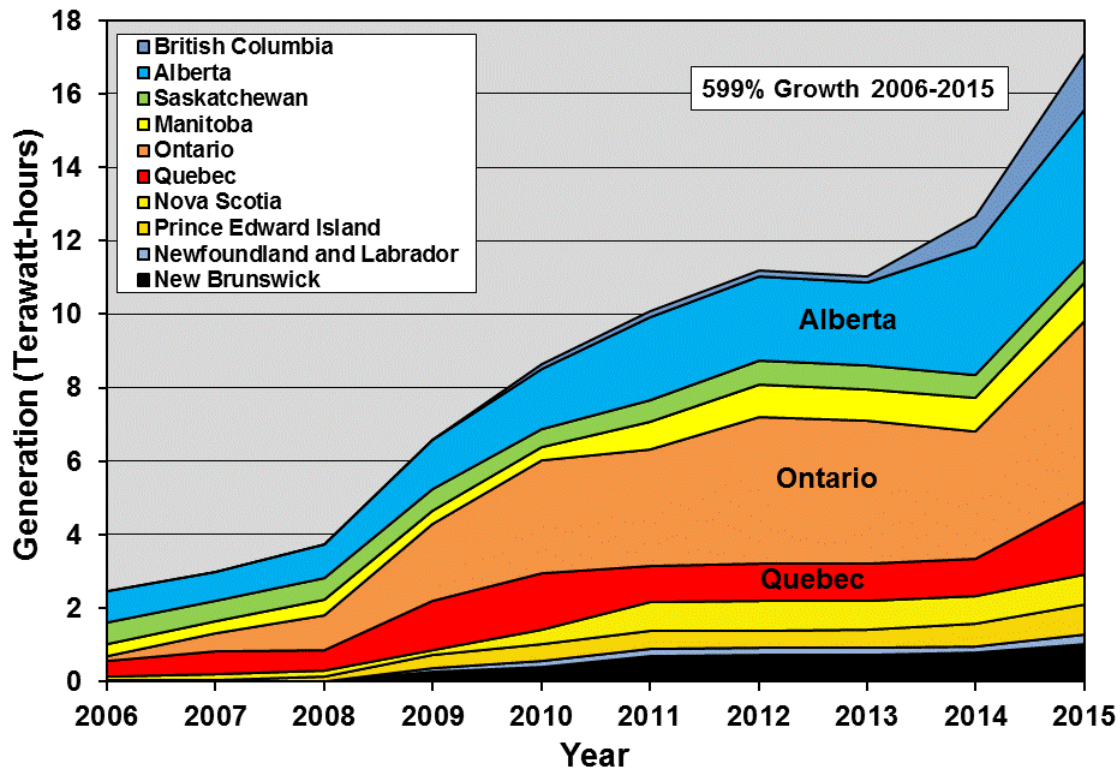
<sup>40</sup> Statistics Canada, CANSIM Tables 127-0007 and 127-0009 retrieved February 5, 2017.

<sup>41</sup> IRENA, Featured dashboard Capacity and Generation, retrieved April 15, 2017, <http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=54>



Figure 118 illustrates wind generation by province over the period from 2006 to 2015 using Statistics Canada data, which amounted to 2.7% of total Canadian generation in 2015. Total generation is likely somewhat higher than this given Statistics Canada's underestimation of total wind capacity (IRENA, for example, reports 22.5 TWh in 2014 versus 12.7 TWh from Statistics Canada; in 2015 the NEB reports 28 TWh versus 17.1 TWh from Statistics Canada).

**Figure 118: Wind generation by province from 2006 to 2015.**<sup>42</sup>

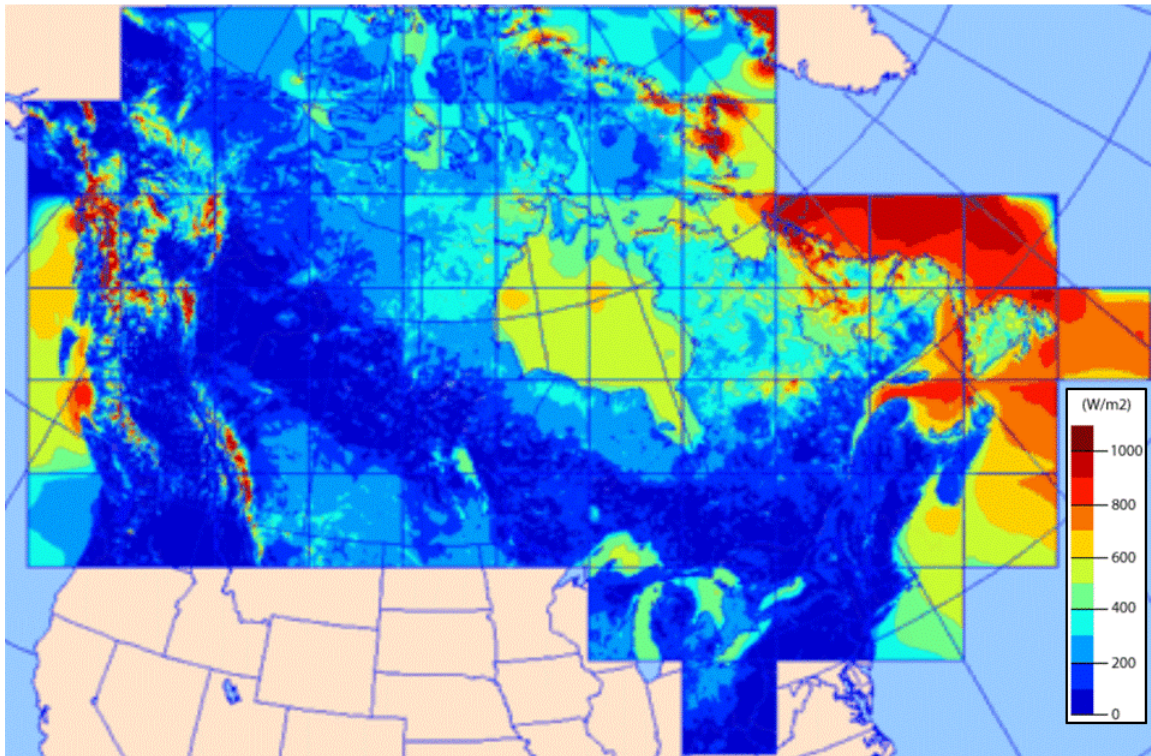


<sup>42</sup> Statistics Canada, CANSIM Table 127-0007 retrieved February 5, 2017.



The distribution of the potential wind resource in Canada is illustrated in Figure 119. The highest-quality resources are generally offshore, although these are costly to access and usually remote from demand centres, thus requiring costly new transmissions lines. Relatively high-quality resources are located in the prairies of southern Alberta, Saskatchewan and Manitoba, and along the Rocky Mountains of southern and central Alberta, as well as in localized high-potential resources in BC.

**Figure 119: Mean wind energy potential in Canada at 50 metres above the land surface on an annual basis.**<sup>43</sup>



CANWEA commissioned a 2016 study to look at different scenarios of ramping up wind energy in Canada in terms of feasibility, new transmission lines required, emissions saved, US exports, etc. The study looked at four scenarios of up to 35% wind generation for Canada, all of which it found feasible. The 35% scenario would involve increasing wind capacity by five-fold to 65.2 gigawatts from current levels of 11.9 gigawatts, and would require wind to generate 50% of the electricity in Alberta, Saskatchewan and the Maritimes, which have the best wind resources. This would also require a significant number of new transmission lines and increased power exports to the US, which is highly integrated with the Canadian grid. The study assumed capacity factors of more than 35%, which are considerably higher than those observed from current installed wind capacity.<sup>44</sup> The study also assumed existing levels of electricity consumption will persist in the future, not the much higher levels projected by government plans to meet international emissions-reduction commitments in ECCC's mid-century strategy.

<sup>43</sup> Environment and Climate Change Canada, Canadian Wind Energy Atlas, retrieved June 10, 2017, <http://www.windatlas.ca/>

<sup>44</sup> CANWEA, 2016, Pan-Canadian Wind Integration Study (PCWIS), see Figure 1-3, <http://canwea.ca/wind-integration-study/full-report/>

ECCC's mid-century strategy scenarios for wind are given in Table 24. Up to an 18-fold increase in wind generation is called for at a cost of up to US\$366 billion. In the highest wind scenario (called "Current Tech Trottier"), 24% of Canada's electricity would be generated by wind. By comparison, CANWEA's 35% wind scenario of 212.7 TWh would only provide 9.4% of the expanded electricity requirement in ECCC's Current Tech Trottier scenario. Although the CANWEA study did not identify technical limits to its 35% scenario, the feasibility of the higher levels required by some of ECCC's scenarios remains to be proven.

**Table 24: Wind generation by scenario in Environment and Climate Change Canada's mid-century strategy.<sup>45</sup>**

*Also shown are the percentage of electricity generation by wind, the new capacity required (assuming an overall capacity factor of 30%) and the cost (assuming US2016\$1,877/kilowatt), excluding the cost of new transmission lines. The number of additional two-megawatt windmills needed is also shown.*

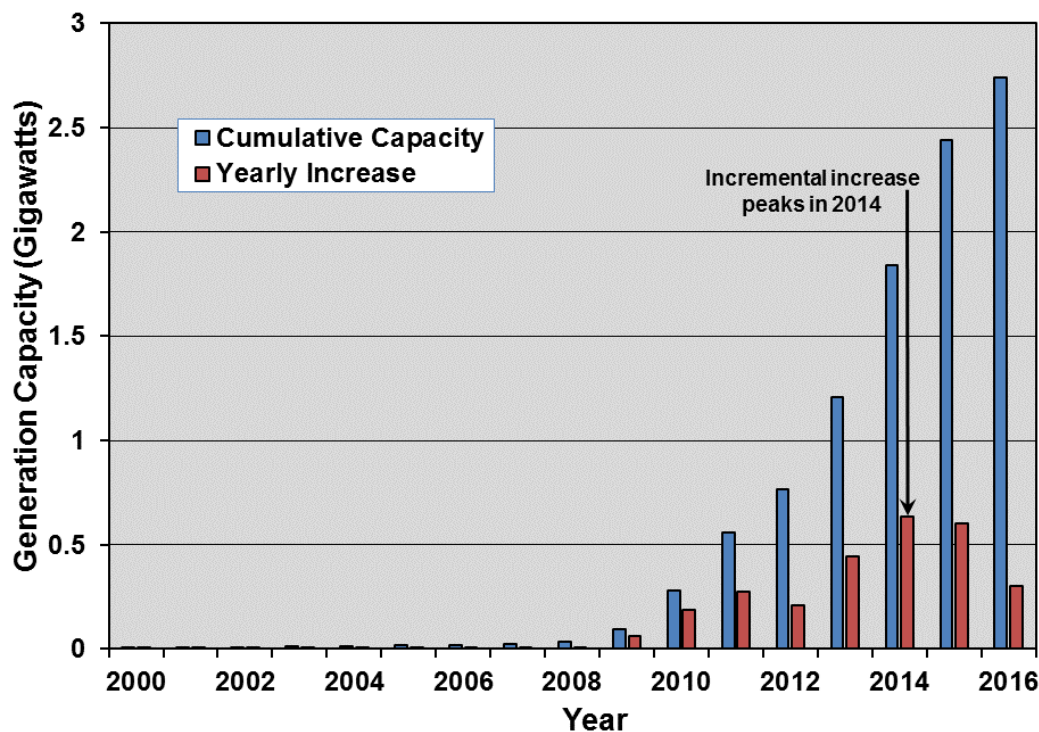
Scenario	TWh	% growth from 2015 levels	% of total generation	# of new 2MW wind mills needed	Cost of new wind mills (US2016\$B)
NEB 2015 Generation	28	0%	4.4%		
DDPP 2050	251	787%	17.0%	42,385	159.1
Current Tech Trottier 2050	540	1808%	23.9%	97,409	365.7
New Tech Trottier 2050	129	356%	8.0%	19,195	72.1
High Nuclear 2050	154	444%	9.3%	23,913	89.8
High Hydro 2050	228	705%	13.8%	37,992	142.6
High Demand Response 2050	32	13%	2.6%	701	2.6
NEB Reference in 2040	69	145%	9.5%	7,813	29.3

<sup>45</sup> Environment and Climate Change Canada, 2016, Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, see Figures 2 and 7, [http://unfccc.int/files/focus/long-term\\_strategies/application/pdf/canadas\\_mid-century\\_long-term\\_strategy.pdf](http://unfccc.int/files/focus/long-term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf)

### 3.4 Solar

Solar electricity generation capacity has grown from less than one-tenth of a gigawatt in 2009 to 2.7 gigawatts in 2016 (see Figure 120). This represents about 2% of 2016 Canadian capacity, although Statistics Canada reported that solar was just .14% of Canadian capacity in 2015 (see Table 16). Data in Figure 119 are from Natural Resources Canada and IRENA, which are believed to be more complete and accurate than data from Statistics Canada. Natural Resources Canada reports 134 grid-scale solar generating stations with a total capacity of 1.58 gigawatts, including two with 100 megawatts each.<sup>46</sup> These stations do not include distributed solar at the household-scale, which contributes an additional 1.1 gigawatts of capacity. Yearly additions of solar capacity have declined since peaking in 2014.

**Figure 120: Solar generation capacity in Canada from 2000 to 2016.**<sup>47</sup>



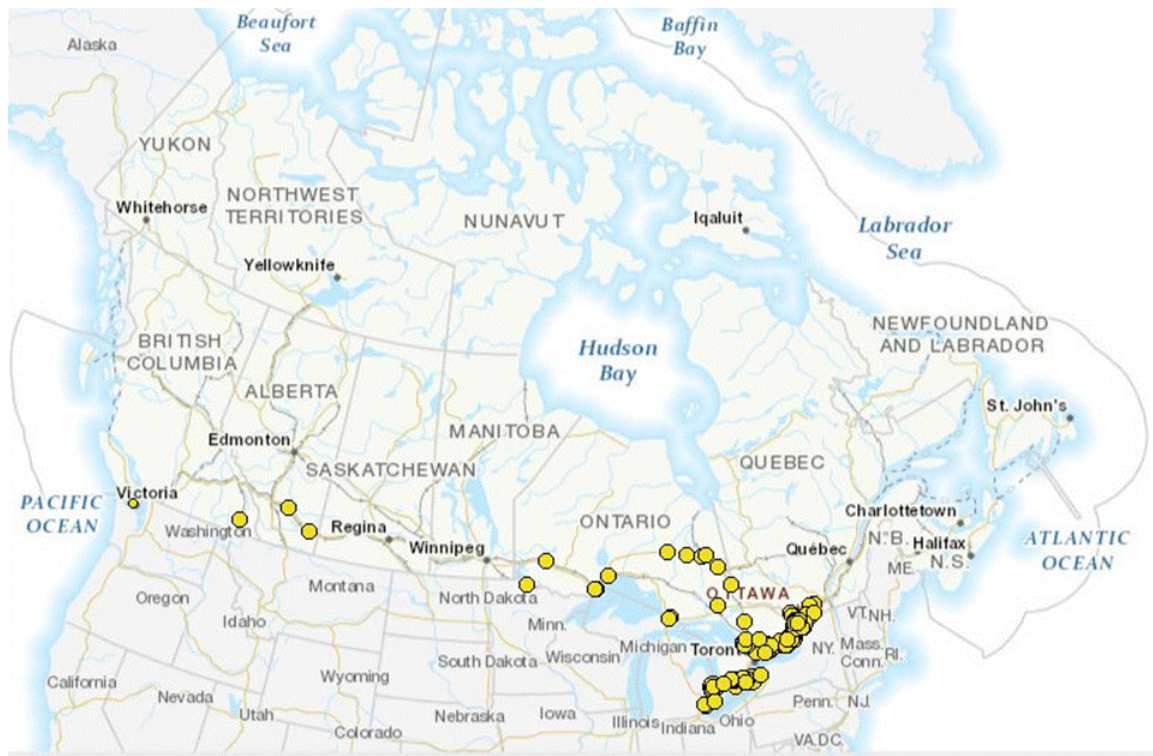
<sup>46</sup> Natural Resources Canada, The Atlas of Canada - Clean Energy Resources and Projects (CERP), retrieved May 28 2017, <http://atlas.gc.ca/cerp-rpep/en/>

<sup>47</sup> Data for 2015 and 2016 from IRENA Featured dashboard Capacity and Generation, retrieved April 15, 2017, <http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=54>; 2000-2014 data from NRCan National Survey Report of PV Power Applications in Canada 2014, [http://www.cansia.ca/uploads/7/2/5/1/72513707/national\\_survey\\_report\\_of\\_pv\\_power\\_applications\\_in\\_canada\\_2014.pdf](http://www.cansia.ca/uploads/7/2/5/1/72513707/national_survey_report_of_pv_power_applications_in_canada_2014.pdf). Note there is an order of magnitude difference between IRENA and NRCan capacity and Statscan which is an order of magnitude smaller, both in capacity and generation.

Figure 121 illustrates the distribution of grid-scale solar generating stations in Canada. With the exception of two stations each in Alberta and BC, all of the capacity is located in Ontario. This is due to the favourable fiscal environment in Ontario given its aggressive policies to promote renewable energy and phase out coal.

**Figure 121: Location of grid-scale solar generating stations in Canada.<sup>48</sup>**

*There are 134 stations with capacities of greater than .75 megawatts for a total of 1.58 gigawatts. Not shown is the distribution of household-scale solar capacity, which adds another 1.1 gigawatts of capacity.*

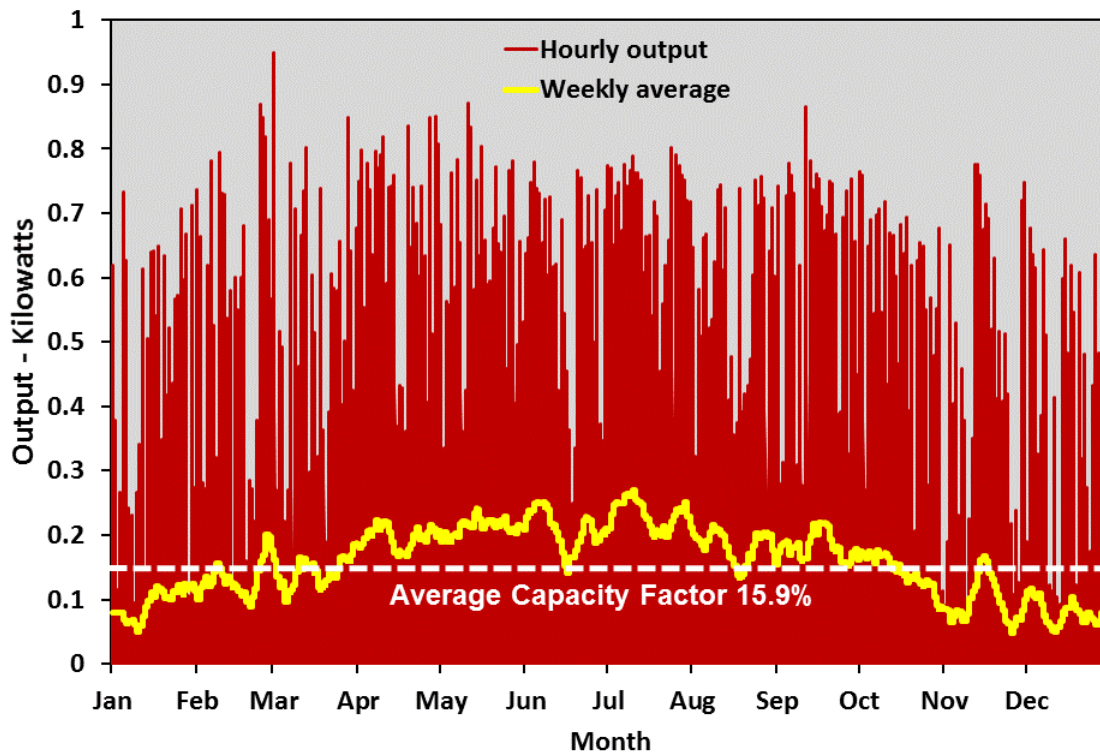


<sup>48</sup> Natural Resources Canada, Atlas of Canada, retrieved May 31, 2017, <http://atlas.gc.ca/cep-rpep/en/>



As discussed above with respect to wind, a major issue with renewable sources such as solar is that it is intermittent, and varies in output on an hourly (or even shorter) basis given cloud cover and day/night cycles. It also varies seasonally, with the highest output in summer months. To maintain a stable grid, “dispatchable” sources of generation that can be rapidly ramped up and down must be available to provide backup power when the sun is not shining. Figure 122 illustrates this issue for a theoretical one-kilowatt photovoltaic array located at Calgary, Alberta, using 2014 climate data. At this location, the average capacity factor for the year is 15.9%, but is above 20% in the summer and below 10% in the winter. Capacity factor also varies with the solar resource. In a high-quality location, capacity factors may approach 20% on average, although according to IRENA data, the capacity factor from all Canadian solar generation averaged just 12.5% from 2013 to 2014. As discussed earlier, hydropower is an ideal dispatchable renewable resource to back up this intermittency where available, but simple cycle turbines burning gas are also commonly used. Various methods of storage, including pumped hydro, thermal, compressed air and mass-scale batteries are also being deployed, but so far these have not been able to displace the need for dispatchable power sources like natural gas in most locations.

**Figure 122: Output from a theoretical one-kilowatt photovoltaic array located at Calgary, Alberta, illustrating intermittency and average output on a weekly basis in 2014.<sup>49</sup>**



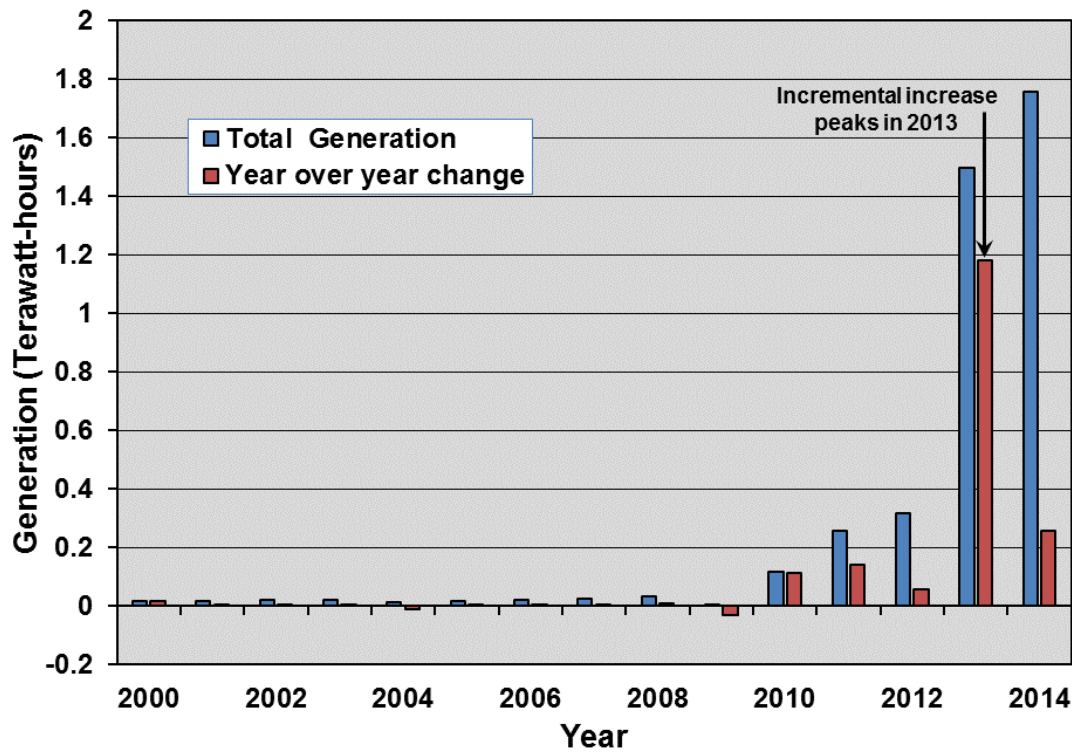
<sup>49</sup> Stefan Pfenninger and Iain Staffell, retrieved March 5, 2017, climate data sources NASA MERRA reanalysis and CM-SAF's SARA dataset, <https://www.renewables.ninja/#>



Figure 123 illustrates solar generation over the period from 2006 to 2014 using IRENA data, which are believed to be more complete than Statistics Canada data. Using NEB data, which are higher still, solar generated three terawatt hours in 2015, or about 0.5% of total Canadian generation in that year<sup>50</sup> (versus 0.05%, an order of magnitude less, reported by Statistics Canada in Table 16).

**Figure 123: Electricity generation from solar power in Canada from 2000 to 2014, based on data from the International Renewable Energy Agency.<sup>51</sup>**

*The National Energy Board reports generation of three TWh in 2015, which represents a large increase over 2014.*

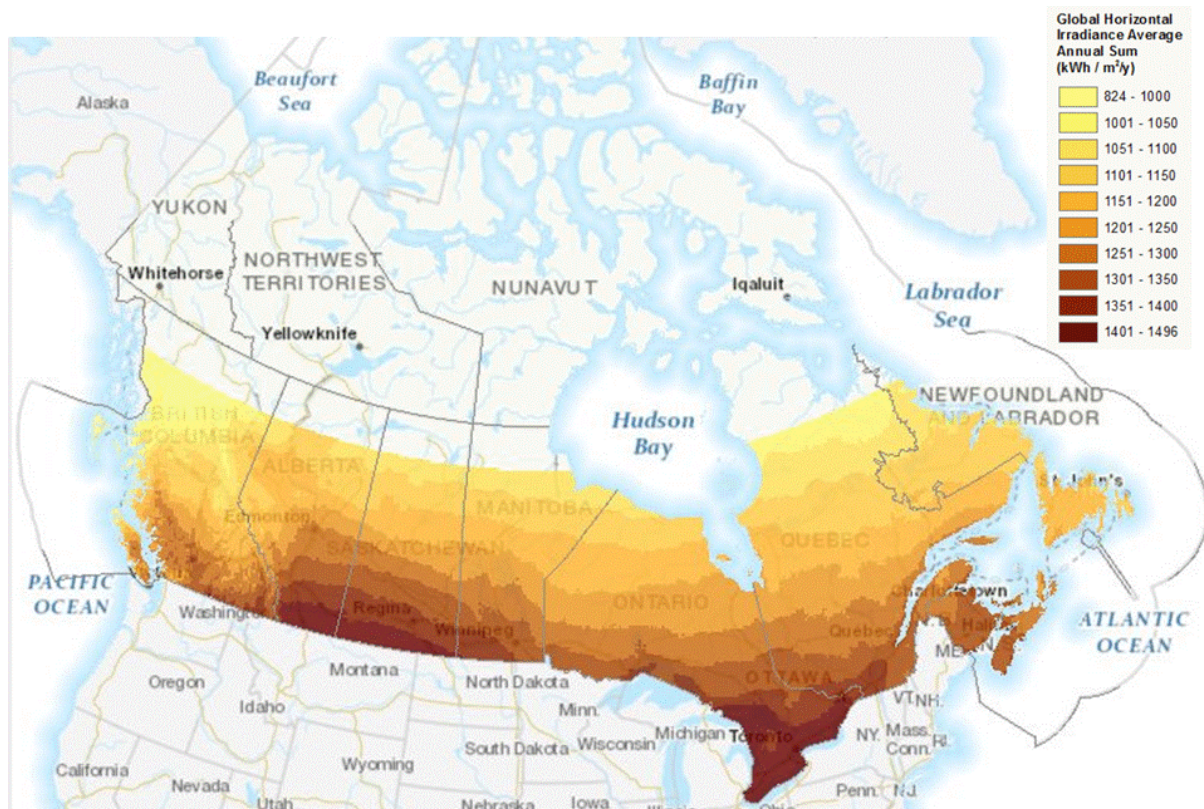


<sup>50</sup> National Energy Board, October 2016, Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040, Appendices, <https://www.neb-one.gc.ca/nrg/ntgrtd/fttr/2016updt/index-eng.html>

<sup>51</sup> IRENA Featured dashboard Capacity and Generation, retrieved April 15, 2017, <http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=54>

The distribution of the potential solar resource in Canada is illustrated in Figure 124. The highest-quality resources are located in southern Alberta and Saskatchewan and the Niagara Peninsula of Ontario, although other areas have potential. Climactic factors, such as persistent cloudy conditions in winter months on the Pacific Coast, can severely degrade output when it might be needed most. Unlike wind, however, solar is more conducive to implementation on a distributed basis at the household level, offering opportunities to reduce overall load on the grid even where commercial-scale projects may not make economic sense.

**Figure 124: Solar potential in Canada.**<sup>52</sup>



<sup>52</sup> Natural Resources Canada, Atlas of Canada, retrieved May 31, 2017, <http://atlas.gc.ca/ceep-rpep/en/>

ECCC's mid-century strategy scenarios for solar are given in Table 25. Up to a 32-fold increase in solar generation is called for at a cost of up to US\$185 billion. In the highest-solar scenario (called "High Hydro"), 6% of Canada's electricity would be generated by solar. In the lowest scenario ("High Demand Response"), even though solar generation would remain at current levels, its percentage of total generation would drop to 0.2% given the increase in electricity demand.

**Table 25: Solar generation by scenario in Environment and Climate Change Canada's mid-century strategy.<sup>53</sup>**

*Also shown are the percentage of electricity generation from solar, the new capacity required (assuming an overall capacity factor of 15%) and the cost (assuming US2016\$2,534/kilowatt), excluding the cost of other infrastructure such as new transmission lines.*

Scenario	TWh	% growth from 2015 levels	% of total generation	New capacity needed (GW)	Solar cost (US2016\$B)
NEB 2015 Generation	3.0	0%	0.5%		
DDPP 2050	74.0	2367%	5.0%	54.0	137.0
Current Tech Trottier 2050	24.5	715%	1.1%	16.3	41.4
New Tech Trottier 2050	3.0	0%	0.2%	0.0	0.0
High Nuclear 2050	18.0	500%	1.1%	11.4	28.9
High Hydro 2050	99.0	3199%	6.0%	73.1	185.1
High Demand Response 2050	3.0	0%	0.2%	0.0	0.0
NEB Reference in 2040	13.0	333%	1.8%	7.6	19.2

### 3.5 Biomass

There are 136 biomass-generating stations in Canada with a combined capacity of 2,843 megawatts.<sup>54</sup> Although many of these stations are small (70 have capacities of less than 10 megawatts), four are greater than 100 megawatts, with the largest being Atikokan-G1 at 205 megawatts, operated by Ontario Power Generation. These plants burn wood and agricultural waste, municipal waste and biogas, and provided 1.9% of Canada's electricity in 2015.<sup>55</sup> Biomass has an advantage over intermittent sources such as wind and solar as it is "dispatchable" and can operate at much higher capacity factors.

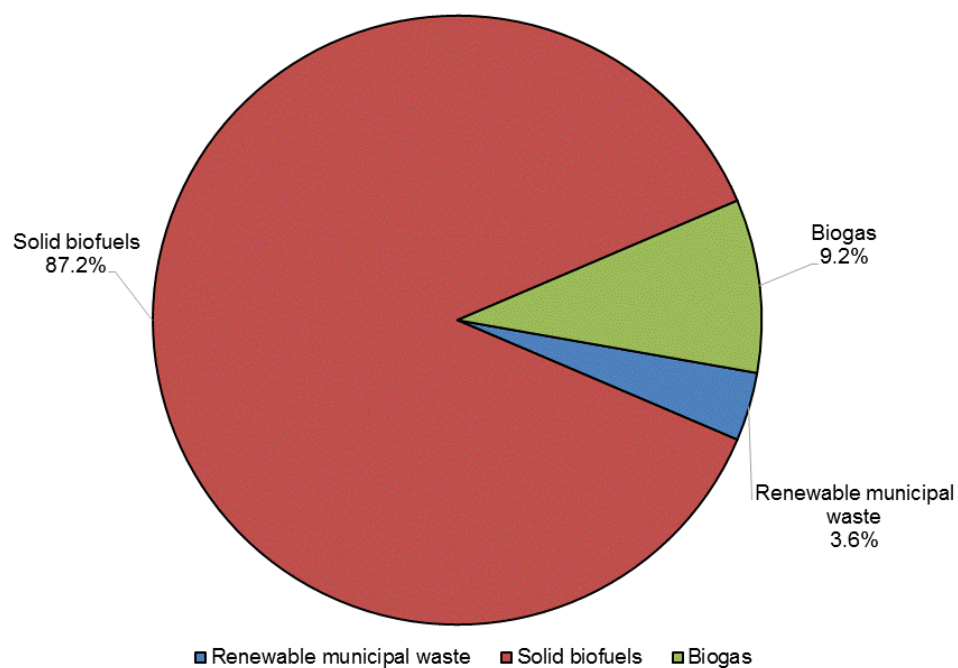
Figure 125 (next page) illustrates the distribution of these generating stations and Figure 126 illustrates the proportion of capacity by fuel type. As of mid-2017 there were six new stations either planned or under construction, which will add an additional 695 megawatts of capacity. These include the Fort St. James Green Energy Project in BC, which will become the largest biomass plant in Canada at 235 megawatts.

<sup>53</sup> Environment and Climate Change Canada, 2016, Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, see Figures 2 and 7, [http://unfccc.int/files/focus/long-term\\_strategies/application/pdf/canadas\\_mid-century\\_long-term\\_strategy.pdf](http://unfccc.int/files/focus/long-term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf)

<sup>54</sup> Natural Resources Canada, The Atlas of Canada - Clean Energy Resources and Projects (CERP), retrieved May 28 2017, <http://atlas.gc.ca/cerp-rpep/en/>

<sup>55</sup> National Energy Board, October 2016, Canada's Energy Future 2016: Update - Energy Supply and Demand Projections to 2040, Appendices, <https://www.neb-one.gc.ca/nrg/ntgrtd/fttr/2016updt/index-eng.html>



**Figure 125: Biomass generating stations in Canada, showing generating capacity.<sup>56</sup>****Figure 126: Biomass generation capacity in Canada in 2016 by fuel type.<sup>57</sup>**

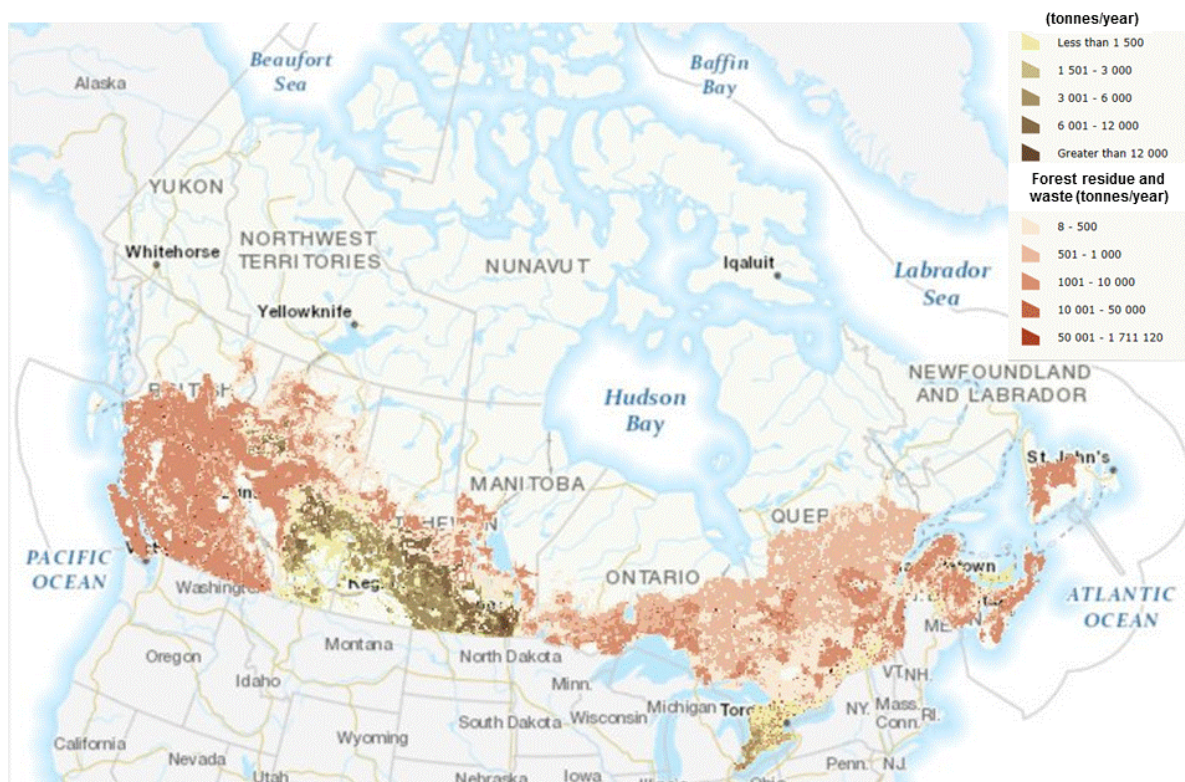
<sup>56</sup> Natural Resources Canada, The Atlas of Canada - Clean Energy Resources and Projects (CERP), retrieved May 28 2017, <http://atlas.gc.ca/cerp-rpep/en/>

<sup>57</sup> IRENA Featured dashboard Capacity and Generation, retrieved April 15, 2017, <http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=54;>

Biomass is considered part of the solution to greenhouse gas emissions as in theory all of the carbon dioxide released when it is burned is removed from the atmosphere as the biomass grows back. Increasing amounts of biomass are therefore included in many climate models that minimize future emissions, often in conjunction with carbon capture and storage. However, a closer look reveals that emissions from burning biomass are comparable to those from burning coal, with some biomass fuels, such as agricultural waste, being worse than coal.<sup>58</sup> Therefore, over the short term, biomass may exacerbate greenhouse gas emissions until the fuel regrows, which, depending on the fuel, could take 30 years or more.

Figure 127 illustrates the distribution of biomass potential in Canada from forest residue and waste and from cereal straw. Other potential sources include municipal solid waste and biogas from agricultural sources and landfills.

**Figure 127: Distribution of biomass potential in Canada from forest residue and waste and from cereal straw<sup>59</sup>**



<sup>58</sup> Intergovernmental Panel on Climate Change, Emission Factors for Greenhouse Gas Inventories, April 4, 2014, [https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors\\_2014.pdf](https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf)

<sup>59</sup> Natural Resources Canada, Atlas of Canada, retrieved May 31, 2017, <http://atlas.gc.ca/cerp-rpep/en/>



ECCC's mid-century strategy scenarios for biomass are given in Table 26. Up to a 9-fold increase in biomass generation is called for at a cost of up to US\$105 billion, although two scenarios do not consider future expansion of biomass. In the highest-biomass scenario ("High Nuclear"), 7.2% of Canada's electricity would be generated by biomass in 2050. In the lowest scenario ("New Tech Trottier"), even though biomass generation would remain at current levels, its percentage of total generation would drop to 0.7% from the current 1.9%, given the increase in electricity demand.

**Table 26: Biomass generation by scenario in Environment and Climate Change Canada's mid-century strategy.<sup>60</sup>**

*Also shown is the percentage of electricity generation from biomass, the new capacity required (assuming an overall capacity factor of 58%) and cost (assuming US2016\$4,985/kilowatt), excluding the cost of other infrastructure, such as new transmission lines.*

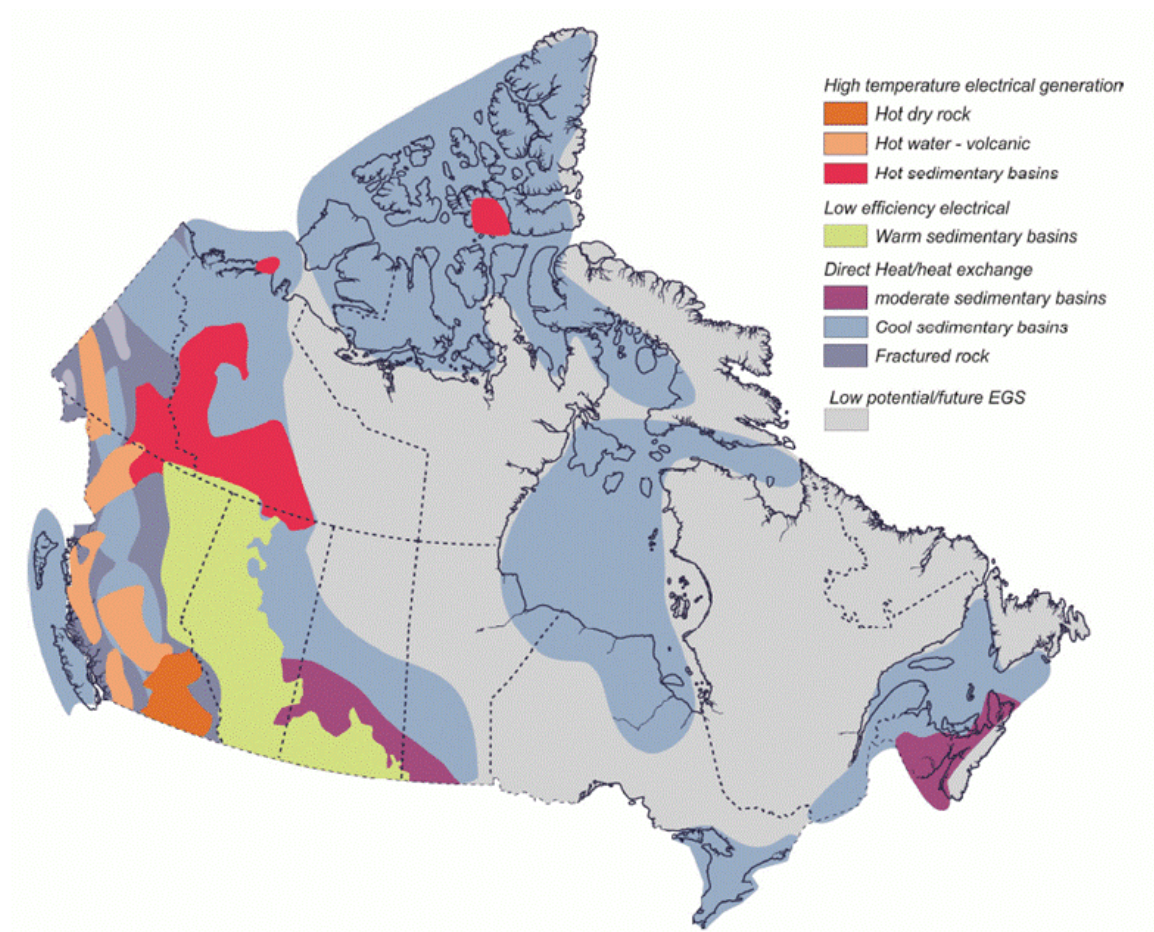
Scenario	TWh	% growth from 2015 levels	% of total generation	New capacity needed (GW)	Biomass cost (US2016\$B)
NEB 2015 Generation	12.5	0%	1.9%		
DDPP 2050	12.2	-3%	0.8%	-0.1	-0.3
Current Tech Trottier 2050	20.4	63%	0.9%	1.6	7.8
New Tech Trottier 2050	12.2	-3%	0.7%	-0.1	-0.3
High Nuclear 2050	118.3	845%	7.2%	21.0	104.5
High Hydro 2050	57.1	356%	3.5%	8.8	44.0
High Demand Response 2050	16.3	30%	1.3%	0.8	3.8
NEB Reference in 2040	15.3	23%	2.1%	0.6	2.8

<sup>60</sup> Environment and Climate Change Canada, 2016, Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, see Figures 2 and 7, [http://unfccc.int/files/focus/long-term\\_strategies/application/pdf/canadas\\_mid-century\\_long-term\\_strategy.pdf](http://unfccc.int/files/focus/long-term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf)

### 3.6 Geothermal energy

Grasby et al.<sup>61</sup> provide a comprehensive review of geothermal resources in Canada, including a map of potential, which is illustrated in Figure 128. Most of the potential for high-efficiency electricity generation is located in high-temperature gradient parts of BC and the southern Yukon and Northwest Territories, with potential for low-efficiency generation in the cooler sedimentary rocks of Alberta, northeast BC and southern Saskatchewan. Despite considerable exploration in BC, mainly in the 1970s and 1980s, there are no geothermal generation stations in Canada, although Natural Resources Canada lists two announced projects—South Meager Creek in southwest BC and Mount Layton in northwest BC.<sup>62</sup> Exploration for geothermal resources for electricity generation is both high-cost and high-risk, which has limited its development.<sup>63</sup> Given the history of geothermal exploration in Canada to date, it seems unlikely that it will provide major amounts of electricity in the near or medium term.

**Figure 128: Geothermal potential in Canada, categorized by end use.**<sup>64</sup>



<sup>61</sup> S. E. Grasby et al., 2012, Geothermal Resource Potential of Canada, Geological Survey of Canada Open File 6914, [http://publications.gc.ca/collections/collection\\_2013/rncan-nrcan/M183-2-6914-eng.pdf](http://publications.gc.ca/collections/collection_2013/rncan-nrcan/M183-2-6914-eng.pdf)

<sup>62</sup> Natural Resources Canada, Atlas of Canada, retrieved June 26, 2017, <http://atlas.gc.ca/ceep-rpep/en/>

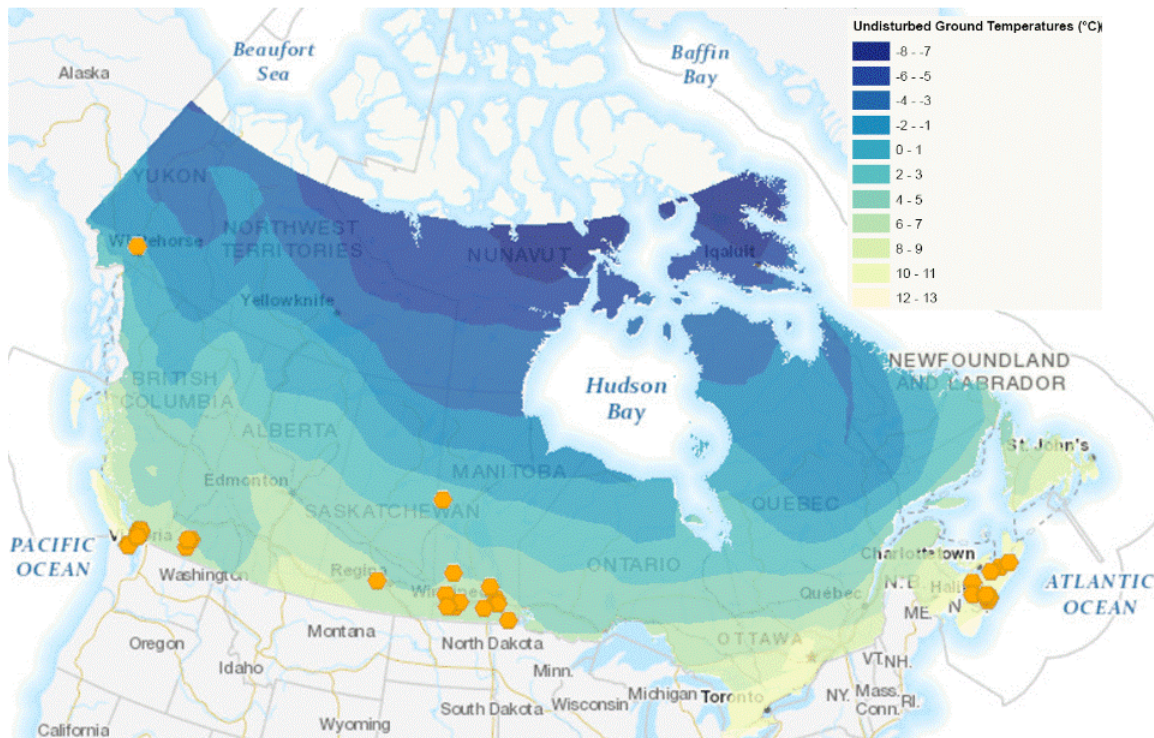
<sup>63</sup> Business in Vancouver, "Geothermal generating little heat in energy sector", July 28, 2014, <https://www.biv.com/article/2014/7/geothermal-generating-little-heat-in-energy-sector/>; see also Ross Beaty, "Geothermal, Solar, Wind, Run of River Energy with Ross Beaty", September 12, 2015, <https://www.youtube.com/watch?v=Hokns5udu6Y>

<sup>64</sup> S. E. Grasby et al., 2012, Geothermal Resource Potential of Canada, Geological Survey of Canada Open File 6914, [http://publications.gc.ca/collections/collection\\_2013/rncan-nrcan/M183-2-6914-eng.pdf](http://publications.gc.ca/collections/collection_2013/rncan-nrcan/M183-2-6914-eng.pdf)

Using geothermal energy for heating is likely to be a much larger contributor to displacing fossil fuel energy than using it for electricity generation. There are many geothermal heating projects in Canada, with more planned. Figure 129 illustrates the near-surface geothermal heating potential in Canada and the distribution of major projects. There is also a large potential for using ground source heat pumps on a smaller distributed scale to displace fossil fuels for heating residential buildings.

**Figure 129: Near-surface geothermal heating potential in Canada.<sup>65</sup>**

*Also shown are major geothermal heating projects.*



### 3.7 Tidal power

Tidal power is still in its early stages of development worldwide. It suffers intermittency on a twice-daily basis as well as seasonal fluctuations in tidal height, but unlike solar and wind, its intermittency and power generation levels are highly predictable. In Canada, there has been some development in the Bay of Fundy in Nova Scotia, which has one of the highest tidal ranges in the world. A 20-megawatt tidal generating station (Annapolis Tidal) has been in operation since 1984 and a smaller station (Cape Sharp Tidal Venture), at up to four megawatts, has recently been commissioned.<sup>66</sup> The FORCE tidal demonstration project is also under construction there. Although there is considerable potential for tidal power in coastal regions, so far production has been very limited and it is unlikely to become a significant source of electricity in the near or medium term.

<sup>65</sup> Natural Resources Canada, Atlas of Canada, retrieved May 31, 2017, <http://atlas.gc.ca/ceep-rpep/en/>

<sup>66</sup> Op cit., see also "Tidal Energy Project in the Bay of Fundy" <http://www.nrcan.gc.ca/energy/funding/current-funding-programs/cef/4955>

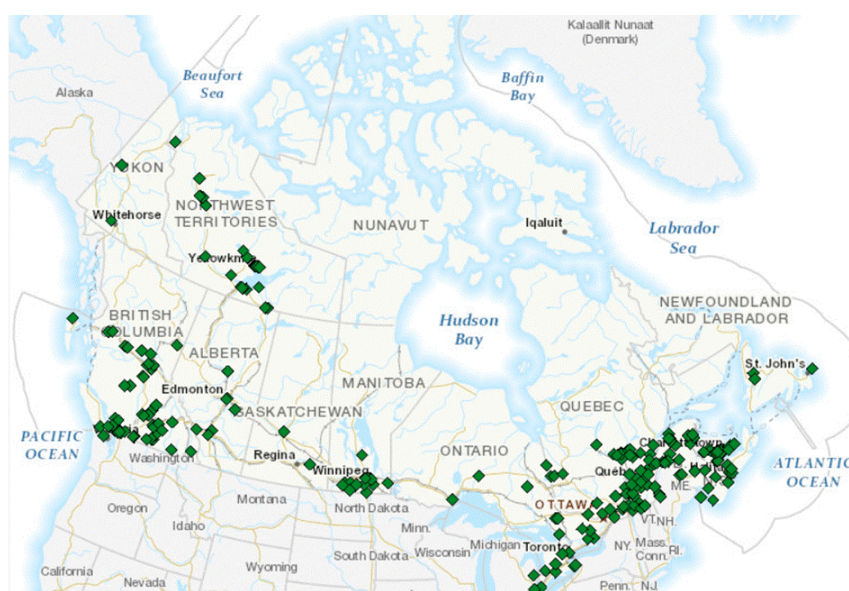


### 3.8 Biomass and biofuels

In addition to electricity generation, biomass is also used for heating in many large- and household-scale applications, as well as in the production of liquid fuels, which can be used directly (biodiesel) or blended with gasoline (ethanol).

There are 270 large-scale biomass heating facilities in Canada, as illustrated in Figure 130. The biomass feedstocks most commonly used are wood chips and sawdust (often generated by onsite milling operations), followed by wood pellets, crop residue, construction and demolition waste, and other sources (see Table 27). Canada is a major producer of wood pellets at 44 plants. In 2017, 79% of estimated production of 2.2 million tonnes of wood pellets will be exported, mainly to Europe (74% of exports go to the United Kingdom).<sup>67</sup> In addition, many rural households rely on wood for heat.

**Figure 130: Location of the 270 large-scale biomass heating facilities in Canada.**<sup>68</sup>



**Table 27: Fuel sources for large-scale biomass heating facilities in Canada.**

Biomass fuel	Number of facilities
Woodchips/sawdust	126
Wood pellets	95
Crop residue	11
Construction & demolition wood	11
Bark/hogfuel	6
Whole logs	1
Other	20
<b>Total</b>	<b>270</b>

Canada has a federal mandate for 5% bioethanol in gasoline (although some provinces are higher, for example Manitoba at 8.5%) and 2% biodiesel in diesel fuel and heating oil. Canada does not have sufficient

<sup>67</sup> U.S. Department of Agriculture, 2016, Gain Report, Global Agriculture Information Report, [https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual\\_Ottawa\\_Canada\\_8-9-2016.pdf](https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Ottawa_Canada_8-9-2016.pdf)

<sup>68</sup> Data from NRCan Atlas of Canada, retrieved June 29, 2017, <http://atlas.gc.ca/cerp-rpep/en>

production capacity from its 14 refineries to meet its bioethanol requirements, and therefore is a net importer of 36% of its consumption. Canada is self-sufficient in its biodiesel requirements, although there are significant imports and exports depending on the location of its 10 biodiesel production plants. Most ethanol is made from corn and wheat, whereas biodiesel is made from used cooking oil, canola oil, soybean oil and animal fats, in descending order of consumption. Given the inputs of fossil fuels to biofuel production in the form of transport fuel, fertilizers and power, and the resulting low energy return on investment (EROI is less than 1.6 for corn-based ethanol and 1.3 for biodiesel),<sup>69</sup> biofuels are a marginal replacement for fossil fuels at best.

Biomass and biofuels are touted as a major component of managing greenhouse gas emissions given that they regrow after use and sequester their emissions. However, when initially burned biomass has greenhouse gas emissions comparable to coal, and biofuels are comparable to their fossil fuel counterparts (see Table 28). In the case of forest products, it may take several decades for regrowth to sequester the emissions from combustion, so in the short term their use exacerbates the emissions problem. Agricultural byproducts can be recycled more quickly, but are also useful nutrient sources for future crops if they are composted instead, thus avoiding the need for fossil fuel-based fertilizers.

**Table 28: Emission factors (carbon dioxide, methane and nitrous oxide) for biomass fuels compared to fossil fuels.**<sup>70</sup>

(MMbtu = million british thermal units)

Fuel	CO <sub>2</sub> kg/MMbtu	CH <sub>4</sub> kg/MMbtu	N <sub>2</sub> O kg/MMbtu
Agricultural biomass byproducts	118.17	32	4.2
Solid biomass byproducts	105.51	32	4.2
Wood and wood residuals	93.80	7.2	3.6
Biodiesel (100%)	73.84	1.1	0.11
Ethanol (100%)	68.44	1.1	0.11
Biomass gas	52.07	3.2	0.63
Natural gas	53.06	1.0	0.10
Anthracite coal	103.69	11	1.6
Bituminous coal	93.28	11	1.6
Sub-bituminous coal	97.17	11	1.6
Lignite coal	97.72	11	1.6
Municipal solid waste	90.70	32	4.2

Biomass and biofuels are an important niche source of energy, but are unlikely to be scalable to displace a major portion of existing fossil fuel use. The issue of the minimal net energy yield from biofuels is also an important consideration that limits their contribution to greenhouse gas reduction, given the energy that must be used to produce them and the fact that their emissions are comparable to fossil fuel when burned.

Nonetheless, ECCC's mid-century strategy calls for a large scale-up of "renewable fuels" in its scenarios. Biodiesel and ethanol production provide 1.3% and 3.8%, respectively, of current diesel and gasoline consumption.<sup>71</sup> Canada is not self-sufficient in ethanol and must import some of its requirements.

<sup>69</sup> Hall et al., 2014, EROI of different fuels and the implications for society, Energy Policy, <http://www.sciencedirect.com/science/article/pii/S0301421513003856>

<sup>70</sup> Intergovernmental Panel on Climate Change, 2014, Emission Factors for Greenhouse Gas Inventories, [https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors\\_2014.pdf](https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf)

<sup>71</sup> U.S. Department of Agriculture, 2016, Gain Report, Global Agriculture Information Report, [https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual\\_Ottawa\\_Canada\\_8-9-2016.pdf](https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Ottawa_Canada_8-9-2016.pdf)

Depending on the scenario, a two-fold to 10-fold scale-up in the use of so-called renewable fuels is called for by 2050—mainly ethanol and biodiesel to replace liquid fossil fuels.<sup>72</sup>

## Further reading

To find other sections of this report, download the full report or access related resources, please visit [energyoutlook.ca](http://energyoutlook.ca).

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<sup>72</sup> Environment and Climate Change Canada, 2016, Canada's Mid-Century Long-Term Low-Greenhouse Gas Development Strategy, see Figure 8, [http://unfccc.int/files/focus/long-term\\_strategies/application/pdf/canadas\\_mid-century\\_long-term\\_strategy.pdf](http://unfccc.int/files/focus/long-term_strategies/application/pdf/canadas_mid-century_long-term_strategy.pdf)









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520 – 700 West Pender Street  
Vancouver, BC V6C 1G8  
604.801.5121 | [ccpabc@policyalternatives.ca](mailto:ccpabc@policyalternatives.ca)  
[www.policyalternatives.ca](http://www.policyalternatives.ca)



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