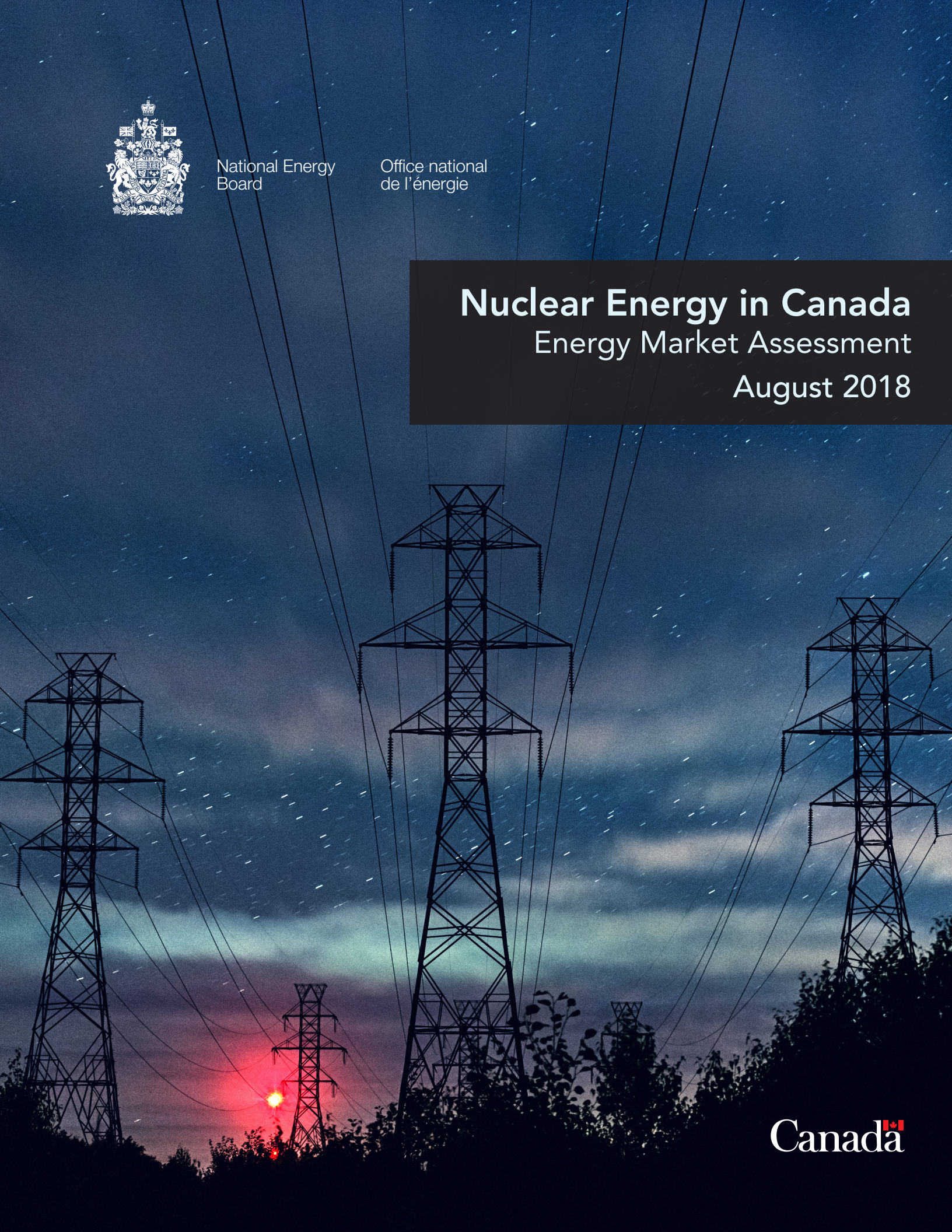

National Energy Board

Office national de l'énergie

Nuclear Energy in Canada

Energy Market Assessment

August 2018

Canada

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Nuclear Energy in Canada – Energy Market Assessment.

NE23-197/2018E-PDF
978-0-660-27506-2

This report is published separately in both official languages and is available upon request in multiple formats.

L'énergie nucléaire au Canada - Évaluation du marché de l'énergie.

NE23-197/2018F-PDF
978-0-660-27507-9

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About the NEB

The National Energy Board (NEB or Board) is an independent national energy regulator. The Board's main responsibilities include regulating:

- the construction, operation, and abandonment of pipelines that cross international borders or provincial/territorial boundaries;
- associated pipeline tolls and tariffs;
- the construction and operation of international power lines and designated interprovincial power lines;
- imports of natural gas and exports of crude oil, natural gas, natural gas liquids, refined petroleum products, and electricity; and
- oil and gas exploration and production activities in specified northern and offshore areas.

The NEB is also charged with providing timely, accurate and objective information and advice on energy matters.

About this Report

The NEB monitors energy markets and assesses Canadian energy requirements and trends to support its regulatory responsibilities. This report, *Nuclear Energy in Canada - Energy Market Assessment*, is one of a series of publications on energy supply, demand, and infrastructure that the NEB publishes regularly as part of its ongoing market monitoring.

Contributors to this report include: Cassandra Wilde, Kinsey Nickerson, and Josephine Deleon

Questions or comments? Please e-mail: energy-energie@neb-one.gc.ca

Data Sources and Methodology

Generation data for 2005 to 2016 are historical values based on data from Statistics Canada. Data for oil, natural gas, coal, nuclear, wind, and hydro generation is derived from Statistics Canada's Tables 25-10-0020-01 and 25-10-0019-01. These values are also used in Canada's Energy Future 2017: Energy Supply and Demand Projections to 2040 (EF2017). Generation data for non-hydro renewables includes biomass, solar, and wind. Data for 2017 are from EF2017. Capacity in 2017 is a modeled estimate based on the NEB's energy supply and demand model from EF2017.

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Executive Summary

Electricity is generated from a variety of sources, including nuclear, hydro, natural gas, coal, wind, biomass, and solar. The main source of power generation in Canada is hydro, which accounted for 59% of Canada's total generation in 2016. Nuclear generation is the second highest source, at 15% of total generation in 2016. Canada is one of 30 countries that use nuclear power generation. Canada is the sixth largest nuclear generating country, generating 4% of the total nuclear power used in the world.

Ontario and New Brunswick are the only two provinces with operating nuclear power plants. Nuclear generation accounted for 58% of Ontario's total generated electricity in 2016, and 30% of the total in New Brunswick. In both provinces, it was the largest source of electricity generation. From 2005 to 2016, total nuclear generation in Canada increased by 10%. No new nuclear facilities were built during this time. Refurbishments and improvements at existing nuclear facilities in Ontario and New Brunswick were responsible for the increase.

Decisions to build any new large-scale facilities have been put on hold or cancelled amidst rising costs and lower than expected electricity demand growth. Instead, refurbishments will be used to extend the life of Canada's existing nuclear generation facilities. Those planned in Ontario and New Brunswick will extend the life of Canada's nuclear facilities beyond 2060. Looking forward, nuclear generation is projected to continue playing an important, but diminishing role in electricity generation in Canada. With no new large-scale nuclear capacity currently planned, and one pending plant retirement, nuclear power generation is projected to decrease by 9% from 2016 to 2040. By the end of the period, nuclear is projected to continue producing 12% of Canada's electricity. However, it moves from second largest source of power generation to third, behind hydro and natural gas.

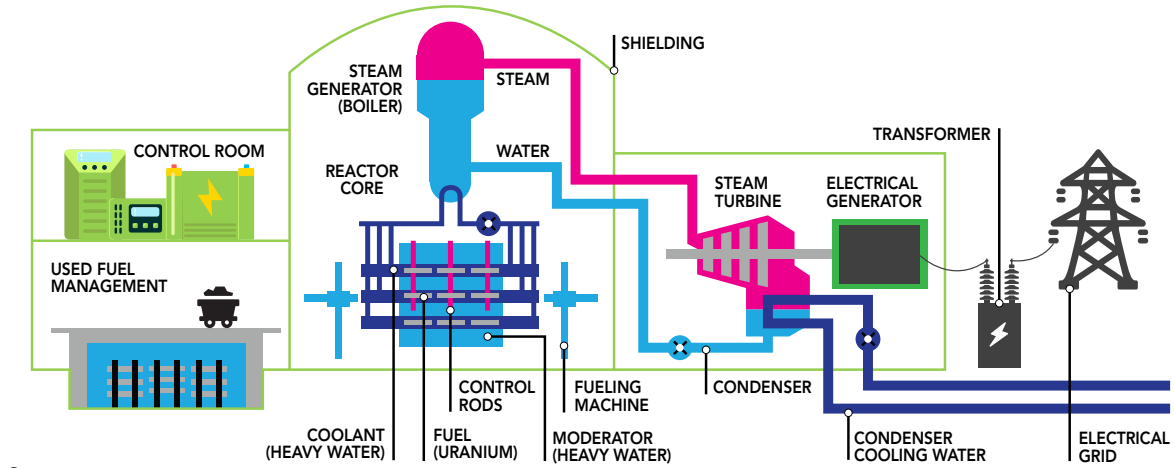
This report focuses on large-scale nuclear power facilities only. The outlook is based on current plans at existing facilities. It does not include the potential development of small modular reactors due to uncertainty about the scale and timing of their use in Canada.

Nuclear Electricity Generation

Electricity can be generated from numerous sources, including nuclear, hydro, natural gas, coal, and non-hydro renewables such as wind, biomass, and solar. Nuclear power generation, like generation from fossil fuels, uses thermal energy to generate electricity. However, nuclear generation does not emit any greenhouse gases (GHGs). Heat boils water, producing steam, which turns a turbine and generates electricity. While fossil fuels are burned to create heat, nuclear power generation uses a process called fission to heat the water. In nuclear fission, energy is released when atoms are split apart to form smaller atoms. All Canadian nuclear generation facilities use Canadian Deuterium Uranium (CANDU) reactors, which use uranium from Saskatchewan as fuel.

FIGURE 1

CANDU Reactor



Source:
CANDU

Potential Small Modular Reactor Development in Canada

Small modular reactors (SMRs) are small nuclear reactors with the capacity to produce 300 MW or less. Compared with conventional nuclear power plants, SMRs are less expensive and faster to build, can be scaled in size, and have more flexible site requirements. Three SMRs are currently in operation in the world; one each in China, India, and Serbia. Many more are in the planning and construction stages across the globe.

Currently, SMRs have no market penetration in Canada but could play a larger role in Canada's energy mix in the future. Due to the uncertainty around the development of SMRs in Canada, they are not included in the projections shown in this report.

Natural Resources Canada is developing an SMR Roadmap which involves funding to drive SMR development and deployment in Canada. For more information on SMRs, please see Natural Resources Canada and the World Nuclear Association.

Capacity vs Generation

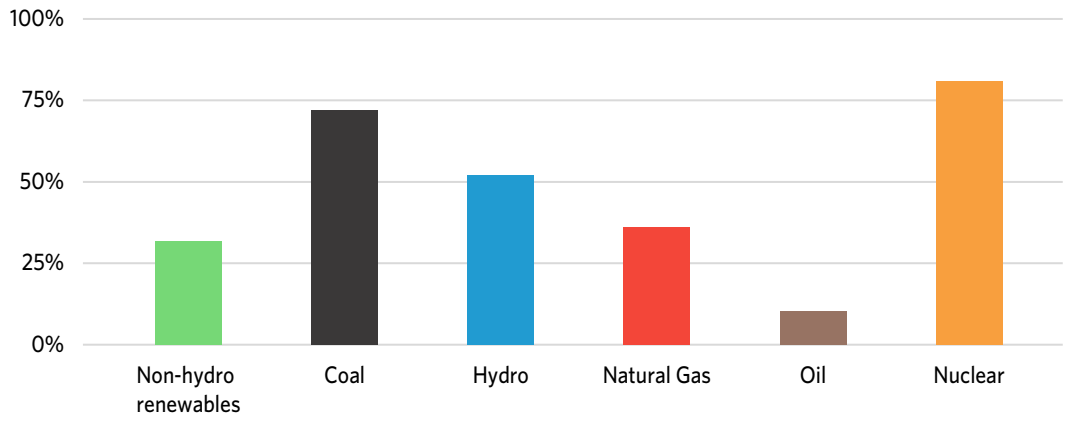
Capacity is the maximum electric output a facility can produce. Generation is the amount of energy actually produced. Generation facilities cannot always operate at full capacity due to maintenance and unplanned outages. Operating costs, market conditions, and the availability of necessary resources, such as wind and sunshine, also determine how much a generator runs.

Electricity demand is highly variable, based on time of day and time of year. There must be enough capacity available to generate electricity when demand is highest, called peak demand. A well-functioning system must have minimum constant generation, referred to as baseload generation, as well as facilities that can provide peak generation.

The capacity factor, the level at which a facility is utilized, depends on a variety of factors. Some types of generation, like nuclear have higher capacity factors. Nuclear is well suited to providing constant baseload generation, due to its high efficiency, low operating costs, and the high cost to start and stop generation. Other types of intermittent generation, like wind and solar, have lower capacity factors because they depend on weather patterns. Generation that can be stopped and started more economically, like natural gas, is used as both baseload and peak generation.

FIGURE 2

Capacity Factors



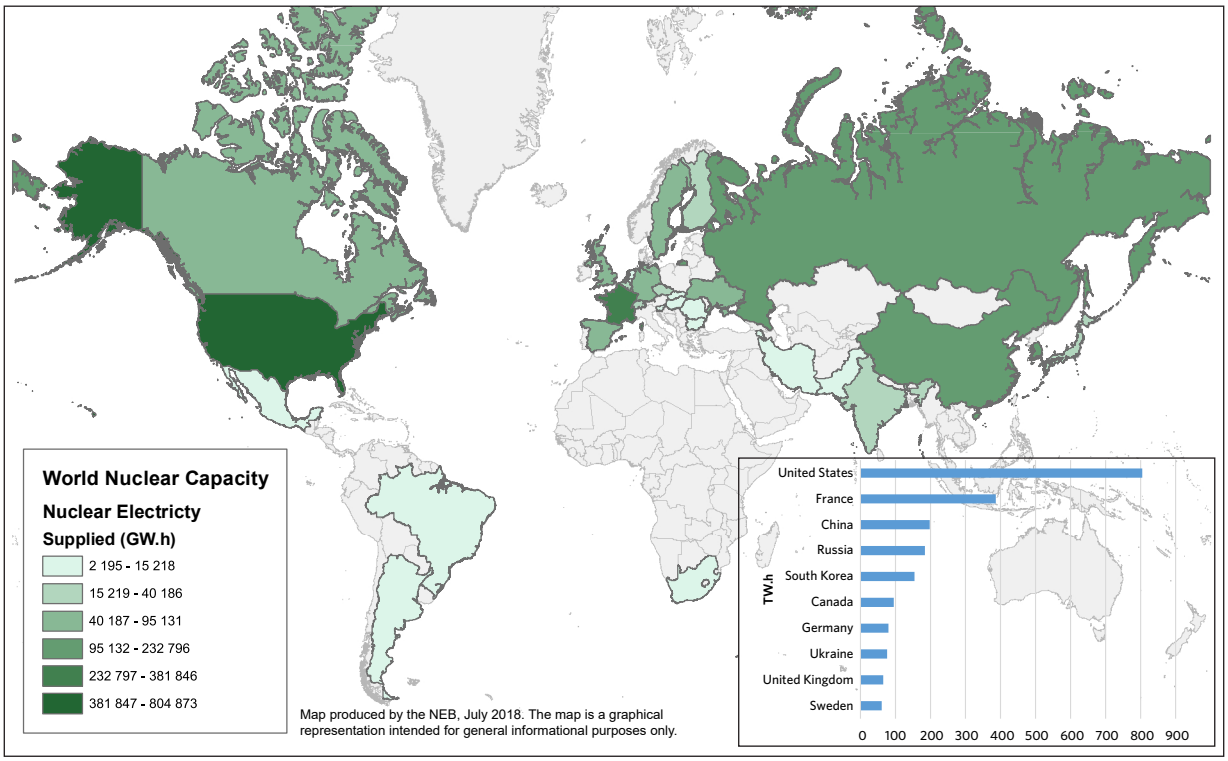
Source:
EF2017

International Comparison

In 2017, nuclear energy was used in 30 countries around the world. Approximately 400 nuclear reactors are currently operating, producing nearly 11% of the world's electricity. The reliance on nuclear as part of the generation mix varies from country to country, making up anywhere between 2% and 72% of total generation. France, the Ukraine, and Slovakia are most reliant on nuclear to generate their electricity, with nuclear making up 72%, 55% and 54% of their respective generation mixes. In Canada, nuclear generated 15% of total electricity in 2016. It also generated 4% of total nuclear electricity worldwide. This ranks Canada as the sixth largest generator, behind the United States (U.S.), France, China, Russia, and South Korea, which together generated 70% of the world's nuclear electricity in 2016. (Figure 3)

FIGURE 3

World map and select statistics of nuclear generating countries



Source:
International Atomic Energy Agency (NEB Map)

Construction of nuclear reactors has decreased from historical highs in the 1980s, when over 30 reactors started up in both 1984 and 1985. In 2015 and 2016, 10 reactors started up worldwide each year. This was the highest number of connections since 1990 and reflects China's growing nuclear program, which accounted for 65% of new reactors in 2015 and 2016.

The overall decrease in new construction is due, in part, to cost. Nuclear reactors are expensive to build, and today most are built with a large capacity in order to take advantage of economies of scale. Of the 53 nuclear power reactors under construction worldwide as of January 2018, 41 have a capacity greater than 1 000 MW.

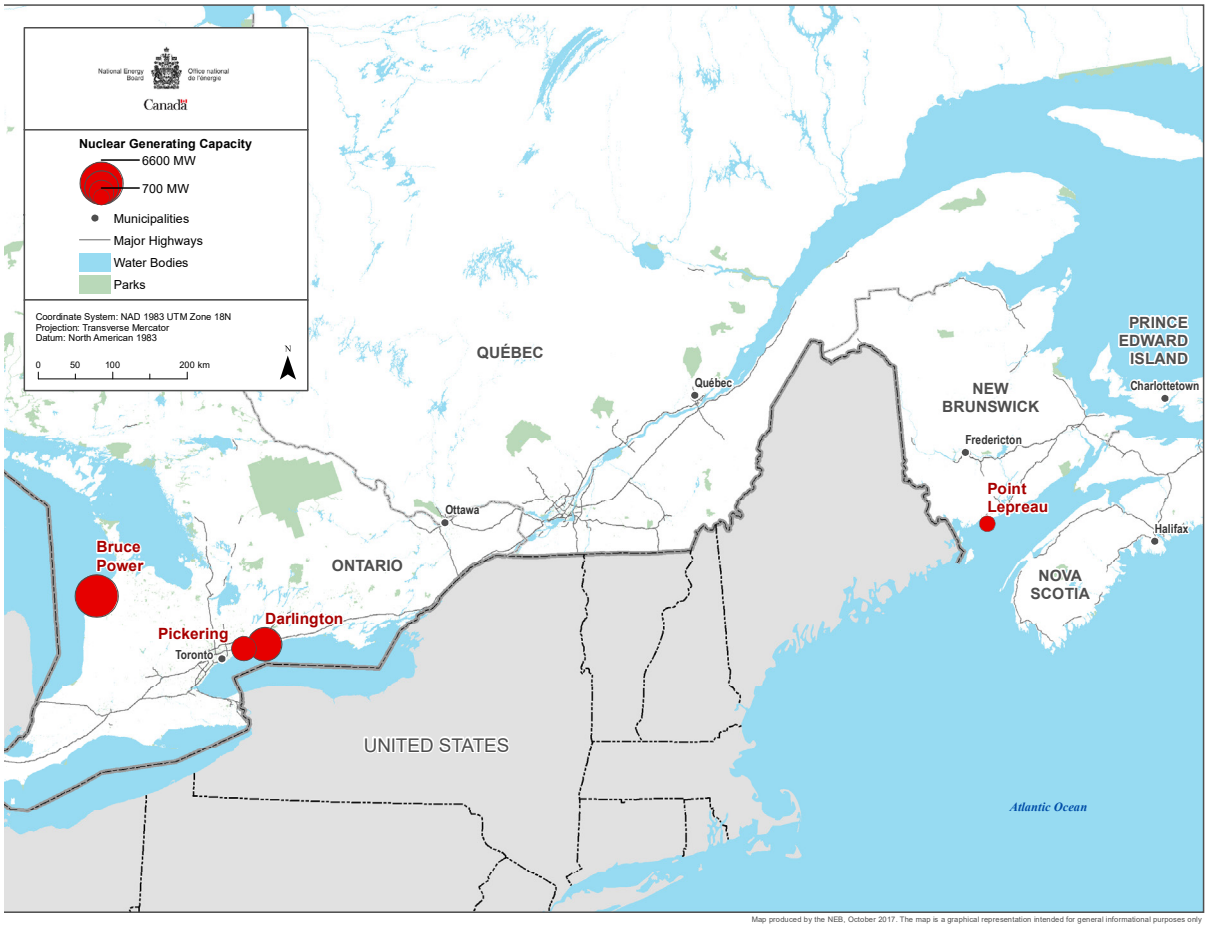
As construction declines, the average age of the world's nuclear reactors is increasing. In 2017, the average age of operating reactors was nearly 30 years. Canada's currently-operating nuclear reactors started producing electricity between 1977 and 1993. Like most countries, Canada has invested in refurbishing existing plants, rather than building new ones.

Nuclear Generation in Canada

Nuclear power plants have been producing commercial electricity in Canada since the early 1960s. Four active nuclear power plants are in operation in Canada, with 19 operating nuclear reactors (Figure 4). Three plants are located in Ontario and one in New Brunswick. Quebec is the only other province to have used nuclear generation. In December 2012, Quebec's Gentilly-2 nuclear generating facility was permanently shutdown.

FIGURE 4

Canada's nuclear facilities



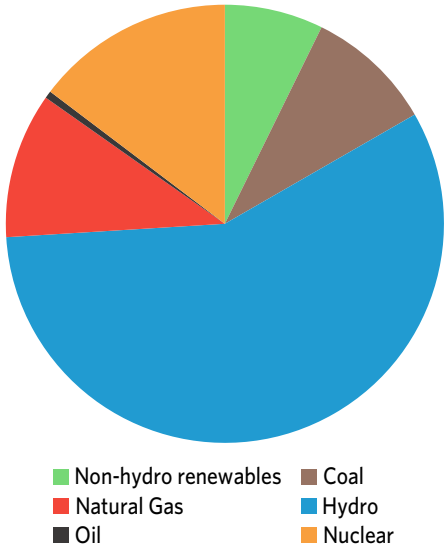
Source:
NEB

The mix of electricity generation sources in Canada varies significantly from province to province. The provincial mix is determined by a number of factors, including access to natural resources, historical infrastructure decisions, and policy initiatives implemented by provincial governments. Overall, Canada's electricity is generated primarily by hydroelectricity (Figure 5).

In 2017, an estimated 57% of all electricity in Canada was generated using hydro. Nuclear was the second largest generation type in Canada, accounting for 15% of generation. All other forms of electricity generation, including natural gas, coal, oil, and renewables each accounted for 10% or less of generation.

FIGURE 5

Canada's Generation by Source



Source:
EF2017

The Cost of Generating Electricity

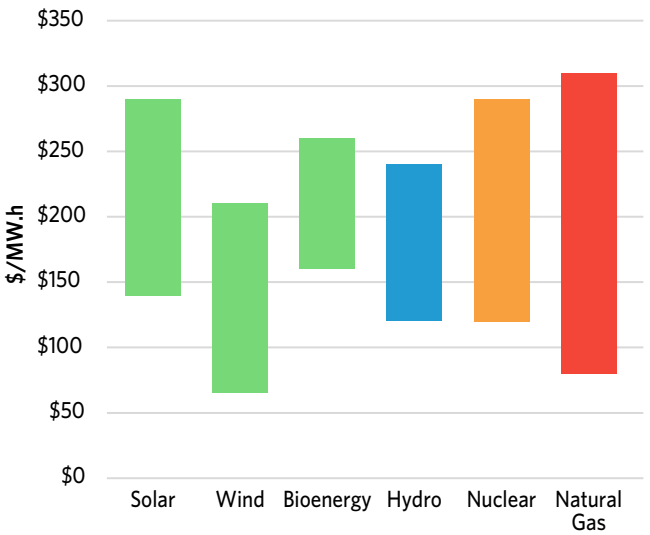
Generation facilities can have vastly different sizes, power outputs, efficiency levels, and other operational variables. Financially, the cost of initial investment, ongoing operations, maintenance, and fuel vary greatly.

One measure used to directly compare costs between technologies with such different characteristics is the levelized cost of electricity (LCOE). The LCOE is the price that a generator must receive over the life of a facility to breakeven. It takes into account all investments, operational costs and fuel costs over the life of the facility. It does not take into account the costs of decommissioning facilities. The values below have wide ranges, reflecting the costs of different facilities built over time.

Although LCOE allows for the direct comparison of technologies, it does have limitations. Values are highly dependent on projections, and do not consider non-financial factors, such as reliability and environmental costs.

FIGURE 6

Range of levelized costs of electricity in Ontario

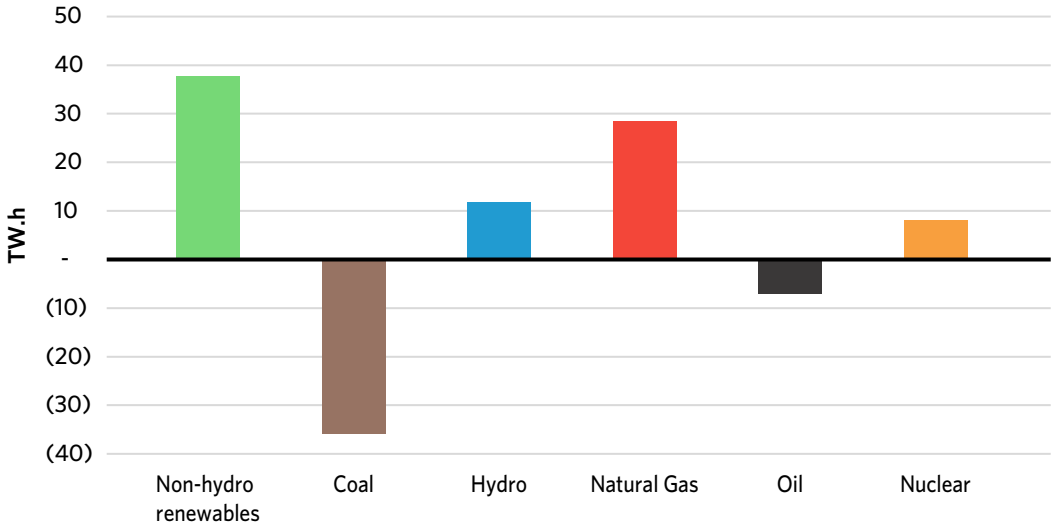


Source:
Independent Electricity System Operator (IESO), 2016 IESO Ontario Planning Outlook

The generation mix in Canada (Figures 7 and 8) has shifted over the past decade as technology changed and investments were made in renewable energy. In total, electricity generation in Canada increased by 50 terawatt hours (TW.h) from 2005 to 2017. Coal and oil generation decreased, while hydro, natural gas, non-hydro renewables and nuclear generation increased. Nuclear generation increased by 8 TW.h, or 9%, due to refurbishments at existing nuclear generating facilities.

FIGURE 7

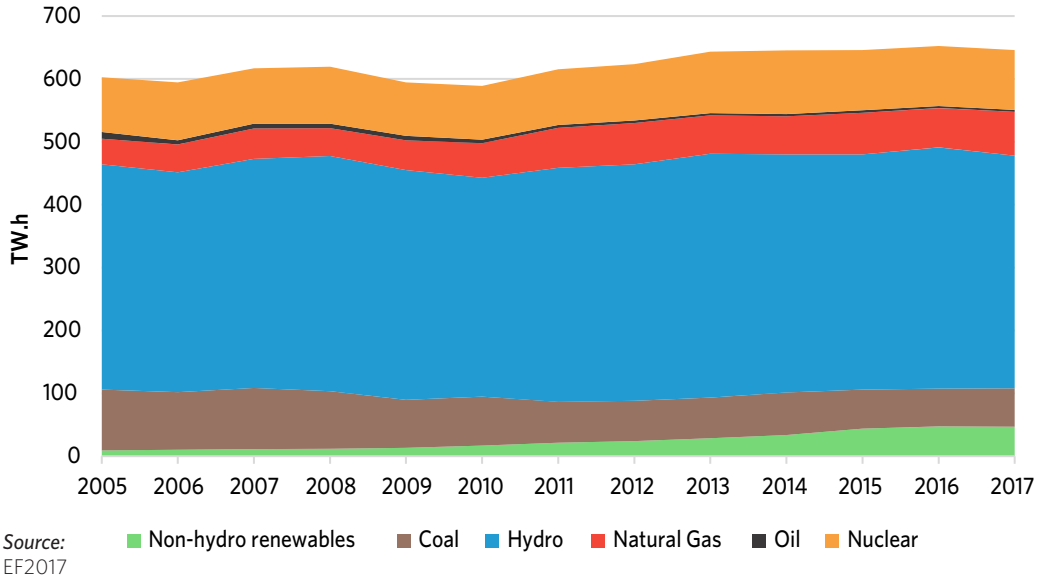
Canada's generation changes (2005 - 2017)



Source: EF2017

FIGURE 8

Generation in Canada (2005 - 2017)



Source: EF2017

Canada's regulatory framework for nuclear energy

Canada's nuclear industry is highly monitored and regulated. The Canadian Nuclear Safety Commission (CNSC) is Canada's independent nuclear regulator. CNSC's mandate is to:

- regulate the use of nuclear energy and materials to protect health, safety, and the environment;
- implement Canada's international commitments on the peaceful use of nuclear energy; and
- disseminate objective scientific, technical and regulatory information to the public.

CNSC takes a lifecycle approach to regulating nuclear power plants. It regulates all stages of each nuclear power plant in Canada, from the environmental assessment required before plant construction, to the decommissioning and long-term waste management of the facility once operations are ended.

Canada's provinces and territories also have a role in the regulation of nuclear energy generation. Provincial and territorial governments are responsible for electricity policy and legislation and, through public utility boards and commissions, for regulating electricity generation facilities; including some aspects of nuclear facilities.

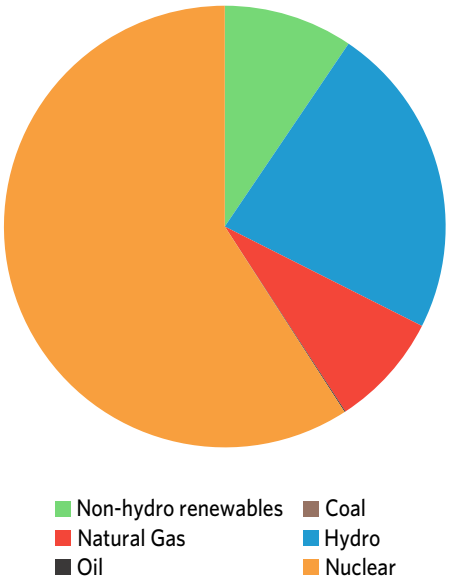
For more information on the regulation of nuclear energy in Canada and other key government departments that play a role in the nuclear energy, visit Natural Resources Canada.

Ontario

Ontario has approximately 13 500 MW[1] of installed nuclear capacity. Ontario relies on nuclear generation for baseload power generation. Nuclear is the largest source of power generation in the province, accounting for an estimated 58% of total electricity produced in Ontario in 2017 (Figure 9). From 2005 to 2017, nuclear generation increased from 78 TW.h to 90 TW.h due to refurbishments and improvements at existing nuclear facilities. (Figure 10) In 2014, the province successfully phased out the use of coal, which generated 19% of electricity in 2005. Coal, which contributed to baseload generation, has largely been replaced by nuclear and a combination of natural gas and non-hydro renewables.

FIGURE 9

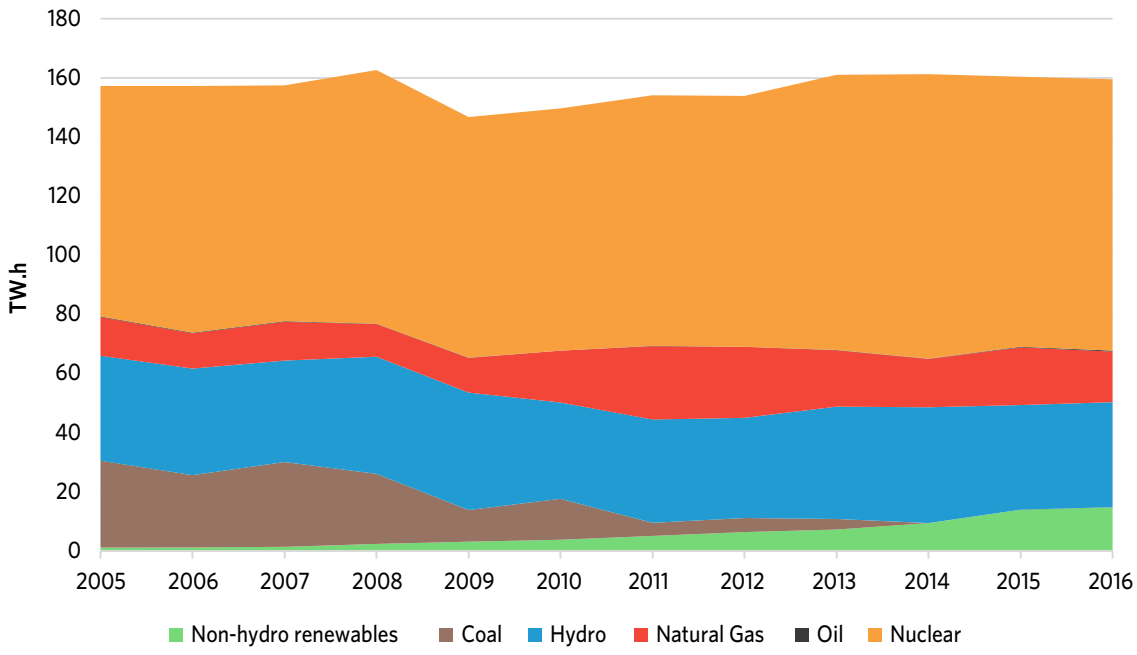
Ontario generation by source



Source:
EF2017

FIGURE 10

Generation in Ontario (2005 - 2017)



Source:
EF2017

1 13 500 MW gross capacity. All capacity numbers included in this report reference the gross capacity of the nuclear reactors.

Three nuclear power plants operate in Ontario. Bruce Power, located in Kincardine, operates Bruce A and B Nuclear Generating Stations. They have eight reactors with an installed capacity of approximately 6 600 MW. Four of the reactors at Bruce A were shut down in the late 1990s. Two of the units were returned to service in 2003 and 2004, and the remaining two in 2012. Bruce Power has plans to refurbish six reactors between 2020 and 2033, which is intended to extend the life of the station beyond 2060.

Ontario Power Generation (OPG) operates the Darlington Nuclear Generating Station, located in Clarington, and the Pickering Nuclear Generating Station, located in Pickering. Darlington houses four reactors with an installed capacity of approximately 3 700 MW. In October 2016, OPG started refurbishing all four reactors, which is scheduled for completion in 2026. Pickering houses six operating reactors, with an installed capacity of approximately 3 100 MW, and two reactors which have been permanently shut down. OPG plans to operate Pickering until 2024.

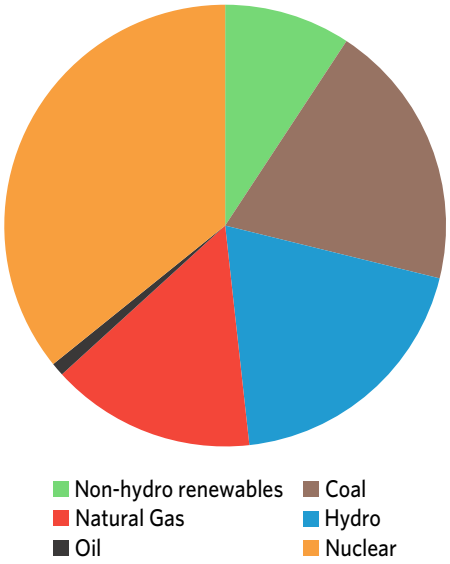
Ontario currently has no plans to add additional nuclear capacity to the energy mix. In 2013, the province deferred the construction of two new nuclear generating units planned for Darlington, due to low electricity demand growth in the province. Ontario released its 2017 Long Term Energy Plan in October 2017. In it, the Government of Ontario recommitted to moving forward with the refurbishment plans for Bruce and Darlington and the shutdown of Pickering.

New Brunswick

New Brunswick has 705 MW of installed nuclear capacity. Nuclear generation is the largest source of power generation in the province. In 2017, nuclear generation is estimated to have produced 39% of the electricity in New Brunswick (Figure 11). Like Ontario, New Brunswick relies on nuclear generation to provide baseload electricity.

FIGURE 11

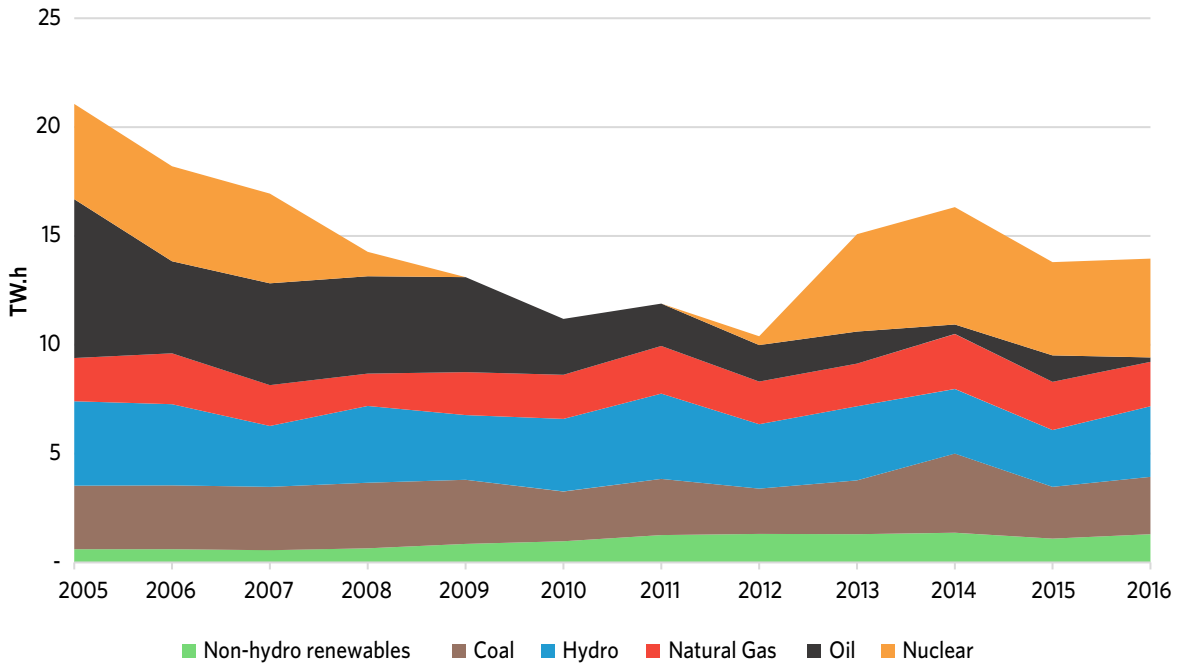
New Brunswick generation by source



Source:
EF2017

FIGURE 12

Generation in New Brunswick (2005 - 2017)



Source:
EF2017

The Point Lepreau Generating Station is the only nuclear power plant in the province. It is operated by New Brunswick Power and houses one nuclear reactor. Point Lepreau was shut down in 2008 for refurbishment and returned to service in November 2012. It is expected to be operational until about 2039. During Point Lepreau's refurbishment, New Brunswick relied on electricity imports to meet demand (Figure 12).

Other Canadian Provinces

Other provinces in Canada have considered nuclear generation over the years, but for a variety of reasons, have not added it to the mix. Nuclear is best used as baseload generation, and some provinces, such as British Columbia and Manitoba, have access to sufficient hydro generation to meet baseload demand. Other provinces, such Prince Edward Island, and the Territories, do not have the population size to support large scale nuclear generating facilities. In addition, construction costs and political choices to avoid nuclear, in some regions, have limited its use in Canada.

Quebec is the only other province to have used nuclear as part of its generating mix. Gentilly-2, owned by Hydro Québec, housed one reactor with a capacity of 675 MW. Gentilly-2, which was reaching the end of its service life, had initially been scheduled for refurbishment. However, in 2012, the Quebec government announced that the plant would be permanently shut down. Power in Quebec is produced predominantly through hydro generation and nuclear generation played a small role in the province. From 2005 to 2012, the last year in which Gentilly-2 was operational, nuclear generation accounted for 2% of total generation.

Hydro generated 90% of the electricity in British Columbia in 2016. In 2002, the Government of British Columbia launched a vision for the province's energy plan, which included a commitment to not use nuclear power. This commitment is included in the province's Clean Energy Act, which includes achieving "British Columbia's energy objectives without the use of nuclear power". In 2016, 97% of Manitoba's and 95% of Newfoundland and Labrador's electricity was generated using hydro. Both provinces have more than enough hydro capacity to meet demand in the province and are net exporters of electricity.

In Alberta, Saskatchewan, and Nova Scotia, power is primarily generated through coal and natural gas. Nuclear generation has been considered in all three provinces, but has not been developed and none of the provinces have plans to build any nuclear facilities.

In Alberta, where power generation is privatized, the government last commented publically on nuclear generation in 2009. At the time, the government commissioned a study of nuclear power generation in Alberta. After its publication, the Alberta government stated that it would consider nuclear power plants on a case-by-case basis and that no government resources would be spent on developing nuclear energy.

Saskatchewan has been considering the feasibility of nuclear for over 40 years. Today's nuclear plants are too large for the province power grid, however SMRs may have potential to work in the province in the future. Research into SMRs is underway. However, the technology is emerging and not currently available as an option for use in Canada.

In Nova Scotia, a study was conducted in 2012 as part of the application for construction of the Maritime Link that examined various options for power generation in the province. The study concluded that given technology at the time, nuclear power generation was not economically feasible in Nova Scotia. In addition, The Nova Scotia Power Privatization Act prohibits the construction of nuclear power plants.

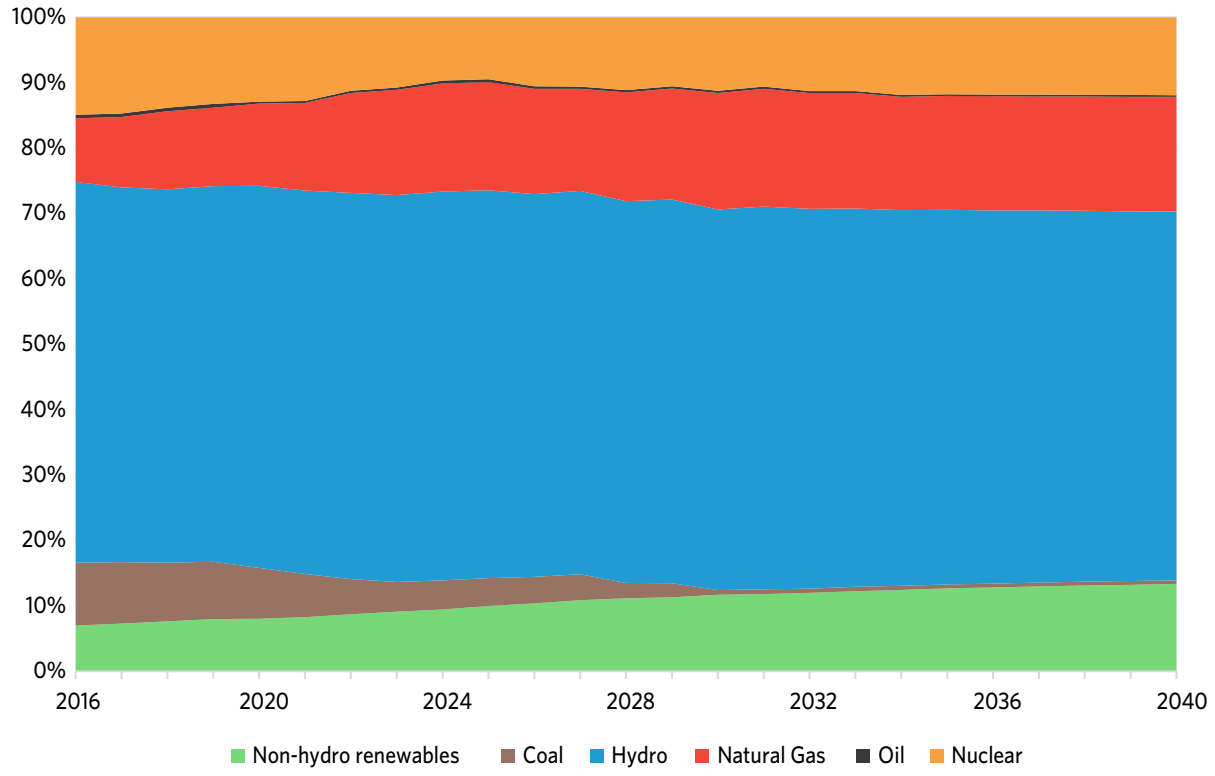
Prince Edward Island and the Territories have the smallest populations in Canada and do not have the demand to support a nuclear power plant. They had a combined capacity of 702 MW in 2016, just over half the capacity of the average nuclear reactor under construction globally in 2017.

The Future of Nuclear Generation in Canada

Looking forward, nuclear energy generation will continue to play an important but diminishing role in Canada. The cost of building new nuclear facilities continues to increase, while efficiency and technology improvements continue to reduce the cost of building new renewable electricity generation facilities. Investments are planned over the next two decades to extend the life of Canada's nuclear generating facilities, but with no new capacity expected and one plant closure, nuclear generation is projected to decrease.

FIGURE 13

Canada electricity generation projection (2016 - 2040)



Source:
EF2017

In EF2017, the NEB projects that from 2016 to 2040, nuclear generation in Canada will decrease by 9%, from 95 TW.h in 2016 to 87 TW.h in 2040 (Figure 13). By 2040, nuclear is projected to supply 12% of Canada's electricity, falling from the second to the third largest generation type, displaced by increased generation from non-hydro renewables and natural gas.