Should Canada Go Nuclear? An Analysis of Canada's Small Modular Reactor Strategy to Meet 2050 Net Zero Goals

by

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Project Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Public Policy

in the
School of Public Policy
Faculty of Arts and Social Sciences

SIMON FRASER UNIVERSITY
Spring 2022

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Abstract

Like most developed countries, Canada wants to reduce the risks and impacts of climate change. Doing so involves major decarbonization of Canada's energy sector. A major question is how to switch our current energy sector from fossil fuels to clean energy production while meeting energy demand and current employment rates. International organizations such as the Intergovernmental Panel on Climate Change (IPCC) have recommended a large increase in the world's nuclear energy production. A major barrier to constructing conventional nuclear power plants has been the complex regulations and large cost overruns of traditional reactors. Instead, the nuclear industry, and Canada aim to begin constructing Small Modular Reactors (SMR). These will potentially allow the nuclear industry to standardize production, realize scale economies in construction, and lower the regulatory burden. By building the reactor within a factory, companies hope to save time and costs relative to on-site construction. The question this paper addresses is how do we do that in Canada, and how much nuclear energy should we generate to meet our Net-Zero goals by 2050? The recommendation is based on analysis of the current literature and 10 expert interviews.

Keywords: small modular reactor; nuclear energy; net zero; clean energy; energy policy; climate change Canada

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List of Acronyms

AECL	Atomic Energy Canada Limited
CANDU	Canadian Deuterium Uranium
CER	Canadian Energy Regulator
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
COP	Conference of the Parties
COSIA	Canada’s Oil Sands Innovation Alliance
DOE	Department of Energy
ECCC	Environment, and Climate Change Canada
GDP	Gross Domestic Product
GHG	Green House Gas
HTGR	High Temperature Gas-Cooled Reactor
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCOE	Levelized Cost of Energy
LMSR	Liquid Molten Salt Reactor
LWR	Light Water Reactor
MOU	Memorandum of Understanding
MWh	Megawatt Hour
NPT	Non-Proliferation Treaty
NRCan	Natural Resources Canada
NWMO	Nuclear Waste Management Organization
OPG	Ontario Power Generation
PWR	Pressurized Water Reactor
SMART-LWR	System-Integrated Modular Advanced Reactor
SMR	Small Modular Reactor
TRL	Technology Readiness Level
TWh	Terawatt Hour

UNECE	United Nations Economic Commission for Europe
UNSCEAR	United Nations Scientific Committee on the Effects of Radiation
WNA	World Nuclear Association

Chapter 1.

Introduction

The impending existential threat of climate change has caused nations around the world to meet, collaborate, and select policies that reduce the emission of greenhouse gasses (GHG). In 2015, at the 21st Conference of the Parties (COP), Canada and 194 other countries reached the Paris Agreement, an ambitious agreement to limit climate change (Government of Canada, 2016). Article 2.1.a of the Paris Agreement states "Holding the increase in the global average temperature to well below 2 C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" (UNFCCC, 2015). There is wide agreement among scholars that countries, including Canada, have failed to meet emission targets. Canada has taken the position of hitting net-zero carbon emissions by the year 2050–a lofty goal considering the nation's current carbon emission output. The total production of GHG emissions in Canada for 2019 was 730 million megatons of CO2 equivalent (Government of Canada, 2021). Of this total, 26% of Canadian GHG emissions came from the production, mining, and drilling for oil and gas, while another 8.4% came from electricity generation (2021). This makes energy production one of the largest contributors to climate change. A major question for all countries is how to switch its current energy sector to clean energy production while meeting energy demand and current employment rates.

In 2018, the Intergovernmental Panel on Climate Change (IPCC) released a report to policymakers detailing four possible scenarios that could reduce GHG emissions enough to prevent environmental disasters (Allen et al., 2018). All scenarios included a major increase in the amount of nuclear energy in the current energy mix. In 2018, Natural Resources Canada released the Roadmap to the usage of Small Modular Reactors (SMR) in Canada (NRCan, 2018). This "roadmap" envisioned investment in small nuclear reactors (under 300 MW capacity) that have the potential to lower the levelized cost of energy relative to most large reactors. This roadmap detailed a path to implementing SMRs while engaging with all of Canada's relevant stakeholders (private manufacturers, provincial governments, Indigenous groups, etc.) In 2021, NRCan released an SMR Call to Action report that details step-by-step how Canada can begin to implement SMRs across the country (NRCan, 2021).

Nuclear development as a possible energy source in Canada is worth study. Since the mid-20th century, Canada has researched nuclear power plant designs and has an excellent safety record. Canada is also a major supplier of the world's uranium from its rich uranium deposits. Despite these facts, nuclear power remains a controversial technology. Among environmentalists, there is a split between strong advocates and staunch opponents (Harris, 2013). Nuclear advocates point out the greater efficiency of nuclear technology in energy production relative to alternative technologies, and the Canadian comparative advantage relative to other countries. Opponents argue that it is too expensive, that there are unresolved issues in the management of nuclear waste, and that the technology has caused catastrophes in other countries.

How does nuclear technology stand up against other available methods of energy production? The consensus among most – but not all – engineers and other environmentalists is that realizing zero GHGs requires a portfolio of different non-fossil energy technologies. This paper makes recommendations on the appropriate share of nuclear energy in meeting our Net-Zero goal. To begin, we briefly look at how Canada's nuclear energy sector has evolved over time and where it is today.

Chapter 2.

Background

2.1. Nuclear in Canada (History)

Among developed countries, Canada stands out as a nation with significant experience, and a strong foothold in the nuclear energy sector. Canada's nuclear legacy began against the backdrop of World War II. As the Americans took responsibility for nuclear weapons development, a joint agreement between Canada, the US, and the UK was reached for Canada to supply a laboratory for nuclear energy research, originally called Chalk River Laboratories. In 1942 A site was chosen on the Ottawa River near the village of Chalk River, Ontario. It still exists, under the name of Canadian Nuclear Laboratories (CNL) and is responsible for conducting Canada's nuclear research. In 1946, Ottawa set up the Atomic Energy Control Board and presented the Atomic Energy Control Act to the House of Commons. This became Canada's first major legislation governing nuclear energy and oversaw the "provision for the control and supervision of the development, application, and use of atomic energy, and to enable Canada to participate effectively in measures of international control of atomic energy" (Hurst & Critoph, 2014). One of the main functions of the Act was to govern research done at Chalk Laboratories. The research at this lab led to major leaps forward in nuclear technology. One such innovation was the development of heavy water reactors, which became the default for Canada's signature reactor, the Canadian Deuterium Uranium (CANDU) reactors.

In 1952, the Atomic Energy of Canada Limited (AECL) was formed as a Crown corporation to assume responsibility for the Chalk River project and others like it. The AECL partnered with the Hydro-Electric Power Commission of Ontario to build Canada's first nuclear power reactor at Rolphton, Ontario, in 1952. The reactor went fully live in 1962 and began providing power to Ontario's electricity grid. Having a running reactor allowed for scientists to develop additional innovations that increased the safety and longevity of the reactor.

In 1999 the Atomic Energy Control Act was modernized and updated to the current Nuclear Safety Control Act, governed by the new Canadian Nuclear Safety

Commission (CNSC). The new act included greater enforcement power over individuals or corporations, allowed the CNSC the ability to revoke their licenses, and also gave them power to delegate administrative functions to the provinces where appropriate. The CNSC currently holds responsibility for providing licenses to owners and operators of nuclear plants, uranium enrichment facilities, uranium mining facilities, and nuclear waste management facilities.

Today, Canada has 19 operating nuclear reactors, 18 located in Ontario and 1 in New Brunswick. Nuclear accounts for 60% of electric generation in Ontario, 39% of electricity generation in New Brunswick, and 15% for all Canada (CER, 2021). Saskatchewan is home to the second-largest uranium mines in the world and produces 1/5th of the global supply of uranium (NRCan, 2018, WNA, 2021). Quebec possesses sites that manage nuclear waste products and is home to SNC Lavalin, which owns the rights to the CANDU reactor design. During 70 years of nuclear power generation, Canada has a clean safety track record. This is largely attributed to the regulatory environment established early on. It quickly encouraged utilization of “passive safety measures", measures that will help automatically shut down the reactor in the event of an emergency. For this reason, the CANDU reactor has been exported to countries around the world such as South Korea, China, India, Argentina, Pakistan, and Romania (NRCan, 2018).

With the shortening timeline on climate change goals, countries are considering all available methods of reducing emissions within their energy sectors. When asked at the 26th COP in Glasgow whether we should consider nuclear energy as an option, Prime Minister Trudeau responded, “I think we’re going to need every different alternative … pursued and explored fully as we try to get off fossil fuels, … and that means investing more in wind, investing more in solar, and yes, exploring nuclear” (Chamandy, 2021). The options in the production of clean energy include solar, hydro, wind, geothermal and nuclear. Due to geographical factors, hydro and geothermal are limited on where they can be employed. Conversations on clean energy sources often centre around solar, wind, and nuclear. Nuclear possesses an advantage over wind and solar as it can act as a baseline source to power an electricity grid and can provide reliable, dispatchable energy under all weather conditions. A brief exploration of the development of nuclear reactor generations provides a better understanding of nuclear’s key advantages. It will also lead us to the most relevant advancements for the purposes of this paper – small modular reactors.

2.2. Evolution of Reactors

Nuclear fission is the essential mechanism that powers nuclear reactors. Fission is the process by which an unstable element is struck with a stray neutron. This leads to an atom splitting and releasing more neutrons causing a cascading effect by which atoms are struck and then release neutrons that in turn, strike other atoms. The splitting of the atom releases a great deal of energy in the form of heat.

The foundation of all reactor designs is to use the heat energy generated by fission to boil water, which in turn creates steam, which then spins a turbine and generates electricity. Many forms of energy production such as coal, gas, diesel, wind, geothermal, and hydro are designed to turn a turbine powering a generator. Nuclear stands above other methods due to the efficiency of energy production released from fission. But, this fission process needs to be controlled or it can runaway, creating a "meltdown". Reactor designs need to include a neutron absorber in the fission process to collect stray neutrons as well as a constant cooling mechanism to keep temperatures under control. Typically, reactor designs are named by the method in which they are cooled: boiling water reactor, gas-cooled reactor, heat pipe reactor.

The fuel for reactors is a mix of uranium 235, which is uranium's unstable form, and reacts to fission, and uranium 238 which acts as a neutron moderator. As the fission process continues, atoms split and reform creating new elements like tritium, thorium, xenon, and plutonium. These elements and the fission process produce radiation to be dealt with in the form of nuclear waste. It is important to note, this type of nuclear waste only accounts for 3% of all nuclear waste produced, the rest of which are clothing, tools, and other items in the plant itself that absorb radiation (WNA, 2022).

Nuclear reactors are classified under four generations of designs. The Gen I reactors were the initial power plants to demonstrate the potential of nuclear energy to investors (Goldberg & Rosner, 2011). Gen II refers to a class of commercial reactors designed to be reliable in energy production and economically viable. The majority of these reactors had "active safety" features, that needed to be initiated by the operators of the nuclear reactors in case of an emergency. These reactors were typically used between the 1960s-1990s and include the original CANDU reactor designs. Generation III designs are innovations from the Gen II light and heavy water reactor technology. Though there are many changes from Gen II to Gen III, they typically have extended design lifetimes, protection in the event of extreme events such as those associated with core damage, easier operation, but most importantly they use passive safety features that require no individual to do something in the event of an emerging meltdown or emergency (2011). Gen III+ reactors refer to advancements in Gen III reactors that reduce costs, increase lifespan, and simplify designs. Lastly, Gen IV reactors could best be summarized as the future of the technology. They build on all the advancements made in Gen III+ reactors and use completely new methods of fuel and moderator combinations. Examples include reactors fueled with liquid molten salt, graphite pebble-beds, or gas and liquid metal cooled reactors.

2.3. A Switch to Smaller Reactor Designs

A major shift in reactor designs has been to create smaller, more compact reactors. These are known as small modular reactors (SMRs) and are the focus of this paper. The major benefit of small reactors over conventional nuclear power plants is the potential cost efficiencies, relative to earlier designs (Hussein, 2020). Rather than taking advantage of economies of scale in operation, by building large plants, the SMR offers an "economy of multiples" whereby construction costs can be reduced through assembly-line mass production of a single design (Locatelli, Bingham, &. Mancini, 2014). This allows the nuclear industry to standardize production. By building the reactor in factories, companies can save time and money associated with regulatory barriers and delays associated with onsite construction (Hussein, 2020). Many SMR designs keep the size of the reactors sufficiently small that they can be transported on truck beds, shipping crates, and rail cars (2020). The International Atomic Energy Agency's (IAEA) definition of modularity includes both the reactor itself being modular but also components that need updating to be modular (IAEA, 2018). Given this, buyers receive a fully assembled product that needs only to fit into the designated nuclear site or one that comes in several pieces to be assembled on-site with ease (Hussein, 2020). The SMR is designed to be up to 300 MWe (IAEA, 2018). Comparably, modern reactors are typically 1100-1600 MWe (IAEA, 2018). To meet the electricity output of conventional plants, SMRs are designed so that multiple units can be used in tandem to meet energy needs (Locatelli, Bingham, &. Mancini, 2014). This allows for a reactor design in which small towns could use one unit, while big metropolitan areas could use 4 or 5 of the same kind. The ability to add more SMRs at a later date enables a power plant to incrementally build up its capacity without committing and risking large capital upfront (Hussein, 2020).

SMRs can include early Gen III designs as well as newer Gen IV designs. Most importantly, all SMRs rely on passive safety, ‘‘safety-by-physics rather than safety-by-engineering” (IAEA, 2018). SMRs can have many applications, e.g., generating electricity to burn nuclear waste; connection to existing electricity grids or serving communities off-grid. They may even “reduce the carbon footprint of the petroleum industry by producing the steam needed for enhanced oil extraction and refining, avoiding the burning of even more fossil fuels to generate the required heat” (Hussein, 2020). Unfortunately, SMRs suffer from the same negative perceptions as conventional nuclear. This paper addresses these perceived risks in Chapter IV.

2.4. Global SMR Development

Worldwide interest in developing nuclear energy to combat climate change has been growing since the early 2000s. For this reason, the potentially cost effective and scalable designs on SMRs are high on the nuclear development agenda of many countries. The first SMRs to be constructed were in Russia. These were two very small reactors mounted on board a ship that could supply electricity to the coastal town of Pevek in Russia (WNN, 2021). These two reactors, combined, provided 64 MWe to the difficult-to-reach town. Russia currently has produced six major SMR designs (NEI, 2019). As of late 2021, Russia has found its licensee to build Russia's first SMR power plant on land (WNN, 2021). This would be a larger 200 MWe SMR and is scheduled to generate power in 2028.

China had major plans for nuclear builds as early as 2012, and were said to be leading the nuclear revival (Bratt, 2012). China’s long-term clean energy goals are to replace nearly all of its 2,990 coal-fired generators with a clean alternative by 2060 (Bloomberg, 2021). To reach this goal, China is planning at least 150 new reactors in the next 15 years (2021). These reactors would be both large and small and to date China is planning to invest a total of $440 billion USD into these reactor builds (2021). That would place China as the largest nuclear investor globally. With regards to SMRs specifically, China connected their own SMR to the electricity grid in Shidao Bay at the end of 2021 (Murtaugh & Chia, 2021). This reactor is a 200 MWe SMR. The chairman of the state-backed China General Nuclear Power Corp. stated that their long-term goal is to have 200 gigawatts of nuclear power generation by 2035, with room for many more SMRs.

The US Department of Energy (DOE) has also been encouraging SMR developments through various funding schemes since early 2012. In November 2012, the DOE announced its decision to support the B&W 180 MWe Power design (WNA, 2021). This would involve a five-year cost-sharing agreement by which the DOE would invest up to half of the total project cost (2021). The DOE also signed agreements with three companies interested in constructing demonstration small reactors at its Savannah River site in South Carolina (2021). These reactor designs ranged from 25 MWe to 160 MWe. More recently in 2020, the DOE launched the Advanced Reactor Demonstration Program (ARDP) offering $160 million, on a cost-share basis for the construction of two advanced reactors that could be operational within seven years (2021). The two reactor vendors chosen were TerraPower and X-energy, which each received $80 million grants. The DOE has further pursued investment in SMRs by offering an initial $30 million funding under the ARDP for five US-based teams developing reactors that could be deployed over 10-14 years (2021). The first US based design was approved in 2020 by the U.S. Nuclear Regulatory Commission. This design was the NuScale's 60Mw light water reactor scheduled to be online in 2029.

In 2014, the UK government published a report on SMR designs and potential for use in the country. Two years later, the UK Department of Energy & Climate Change (DECC) called for expressions of interest in a competition to identify the best value SMR for the UK (WNA, 2021). The department announced that it would invest at least £250 million over five years. By 2018 it was announced that eight SMR vendors were awarded contracts up to £300,000 to produce feasibility studies for the first phase of the UK's Advanced Modular Reactor Feasibility and Development project. In terms of cooperation with the US, the US based company NuScale has openly stated that it aims to deploy its SMR technology in the UK with UK partners for first operation in the late-2020s. Most recently, in 2021 the UK government announced that it would contribute £210 million in grant funding to an SRM build from Rolls-Royce that would match private investment in the project. The Rolls-Royce SMR team aims to build 16, 470 MWe pressurized water reactors.

Of course, with one of the largest nuclear fleets in any country, France has begun to examine SMR technology. For some background, the 1973 oil shocks highlighted to the French that dependence on imported Middle Eastern oil could be problematic and electricity generation from nuclear power could provide energy security (Bratt, 2012). Today, France has the world's highest percentage of electricity produced by nuclear power at 76 percent. It is also the world's largest electricity exporter (Bratt, 2012). This being said, the most recent large reactor built in France exceeded €8 billion in costs and was constructed 10 years later than initially intended (Louis, 2021). In 2019, the French Alternative Energies and Atomic Energy Commission announced a new SMR design for the country (WNN, 2019). The design was the "Nuward", a SMR with a capacity of 300-400 MWe and scheduled to be built by 2033 (2019). In 2021, French President Emmanuel Macron announced that the number one priority for his industrial strategy was for France to develop innovative small-scale nuclear reactors by 2030 (Seibt, 2021). Backing up this statement he unveiled a €30 billion, five-year strategy to build on the country's history as a leader in nuclear energy development (2021).

South Korea is another major country to rely on nuclear energy. It operates 24 reactors that provide about one-third of South Korea's electricity (WNA, 2021). In 2017 the president announced a nuclear energy phase out over the next 45 years, but South Korea has reversed this decision and intends to utilize SMR technology (Hosokawa, 2021). In late 2021 the government designated $281 million USD for construction costs of an over $500 million USD project (2021). Currently, the Korea Atomic Energy Research Institute has been developing the SMART (System-integrated Modular Advanced Reactor). This is a 100 MWe pressurized water reactor with an operating lifetime of 60 years (WNA, 2021). South Korea's SMR aspirations have even led them to develop in Canada. A South Korean team led by Hyundai Engineering will work on the construction of a small modular reactor in Alberta (Chang-won, 2021). This would be a 100 MWe, sodium fast cooled reactor with plans for a demo construction site to begin as early as 2022 (2021).

This is not an exhaustive list but includes some major players (**Table 1** shows a timeline comparison for all the above-mentioned countries). Interest in implementing SMRs to produce clean energy has been expressed by India, Australia, Japan, Saudi Arabia, Poland, and the Czech Republic. These countries have either look to purchase SMRs from the above countries or supply some part of the supply chain.

Table 1. Comparing National On-Shore SMR First-of-a-Kind Development Timelines

Country	Province	SMR Type	MWe	Completion Date
China		HTGS	200	2021
Canada	Ontario	MMR	15	2026
Russia		RITM-PWR	200	2028
Canada	Ontario	LWR	300	2028
US		LWR	60	2029
Canada	New Brunswick	SCFR	100	2030
Canada	New Brunswick	SSR-W	300	2030
France		PWR	300-400	2033
South Korea		SMART-LWR	100	~
UK		PWR	470	Early 2030s

The above list of countries moving to develop SMR technologies within their borders demonstrates its growing international economic interest. Each country is helping to revitalize and develop the nuclear supply chain by pursuing its own designs, mining, fuel reprocessing, manufacturing, and competitive regulatory environment. There is a competitive dynamic underway, as countries seek an advantage in SMR design. Countries are aiming to be first movers in this energy space. Doing so would enable the first moving countries to enjoy economic benefits in the form of increases in GDP, tax revenue generation, exports, and job creation.

2.5. How Canada can Lead in SMR Technology

The above literature demonstrates that: 1) nuclear energy should probably be a major non-fossil technology for generating electricity; 2) Canada is well positioned to take advantage of new generations of nuclear technology given its long, successful history in nuclear technology; 3) Many countries across the globe are pursuing this technology as a reliable form of clean energy; 4) Given the above points, Canada should seriously consider the potential of SMRs as a clean energy source for its 2050 energy portfolio. The question from here, is how do we do that, and how much nuclear capacity do we need?

The best way to begin to answer these questions is with the headway made by the Natural Resources department (NRCan) of the federal government has undertaken tentative initiatives to co-ordinate provincial power utilities and other stakeholders. The two most important public documents are “The Canadian SMR Roadmap” (2018) and “The “SMR Action Plan” (2021). The SMR Roadmap included partnerships with interested provinces, territories and power utilities, and indigenous groups. Through a series of expert working groups and workshops held across Canada, NRCan gathered feedback on the direction for the possible development and deployment of SMRs in Canada. The report identifies Canada as one of the world’s most promising domestic markets for SMRs. It estimated the potential value for SMRs in Canada at $5.3 billion between 2025 and 2040, $150 billion globally during the same period. The Roadmap outlines three major areas of application for SMRs in Canada: on-grid power generation, for provinces phasing out coal in the near future; heavy industry application, for example SMRs for oil sands producers and remote mines that need reliable bulk heat and power cleaner than their current energy sources; off-grid power, specifically for heating, and desalination in remote communities that currently rely on diesel generators. The Roadmap concludes with five key findings (NRCan, 2018):

1. For Canada to be successful in this space we need a fleet-based approach. This is in order to benefit from standardization and economies of series equating to reduced capital costs decrease as more units are produced.

2. SMR technology needs to be demonstrated in Canada to become a first mover of the technology.

3. Investment risks need to be shared among governments, power utilities, and industry in order to meet SMR demonstration and deployment goals in Canada.

4. Ongoing engagement with the public will be important to address safety, waste management, and cost concerns of SMRs

5. Some modernization of the regulatory framework will be necessary to respond to the SMR paradigm shift in the nuclear industry

Building on the Roadmap, in 2021 NRCan released the SMR Action Plan. This report responds to the recommendations made in the SMR Roadmap and brings together more parties – 55 organizations contributed to the Roadmap; over 100 organizations engaged in the "Team Canada" Action Plan. Team Canada includes the federal government, provinces and territories, Indigenous communities, power utilities, industry, academia, and the general public. Each member of Team Canada has contributed a chapter to the Action Plan, describing the actions they are taking to develop SMRs for Canada.

Some provinces (e.g., British Columbia and Quebec) have available clean energy without SMRs, and are not part of Team Canada. The Action plan solidifies the key provinces in this movement, namely, Ontario, New Brunswick, Saskatchewan, and perhaps the Yukon (NRCan 2021). It also names SMR vendors that could take hold of the industry and develop a potential supply chain.

Despite these high-profile reports, there are identifiable gaps in government reports and academic literature. SMR technology relies on (Gen III+ and Gen IV) innovations. These are technologies yet to be demonstrated. Though dates for demonstration of SMRs have been set at Canadian Nuclear Laboratories and by Ontario Power Generation in Canada, how much nuclear energy generation can be achieved by 2050? The SMR Action Plan also suggests that Alberta and Saskatchewan are moving much slower in this area than Ontario and New Brunswick. This is to be expected given where our nuclear history lies; however, Alberta and Saskatchewan remain Canada's largest carbon emitters due to reliance on coal-fired power plants and oil sands (Government of Canada, 2021).

Vendors can present misleading realities under the guise of SMRs. Modularity has been defined differently by different vendors creating confusion about what is actually being delivered (Hussein, 2021). Some vendors define modularity to indicate building a full power station from multiple smaller reactors. (If you need 1200MWe total, you begin with one 300MWe reactor and add three more later.) This is an old definition and isn't that helpful. The Fukushima Daiichi plant meets this definition. Alternatively, some mean modularity to indicate a parallel to shipbuilding. When building large ships, a technique to save construction cost and time is to manufacture modules (parts of the ship) and bring them on-site to build. This is the better definition of modularity. Vendor designs vary substantially, with some technologies being usable relatively soon and others being 15 years away.

This paper aims to take all of these questions to inform what is actually able to be achieved with the utilization of SMRs given technological and time constraints to meet Canada's own 2050 Net Zero goals.

Chapter 3.

Methodology

This study is qualitative in nature; however, quantitative data are used where available with regards to estimates of economic costs and emission reductions. A literature review has been conducted to gather available data. This informed measures around best practices, and supplemented by expert interviews.

The primary source of information is interviews with experts in various fields: experts at the Canadian Nuclear Laboratories, Canadian Nuclear Safety Commission, MIT Nuclear Reactor Laboratory, Innovation, Science, and Economic Development Canada, Natural Resources Canada, Ontario Power Generation, Alberta's Ministry of Energy, and Alberta Innovates. These experts cover a broad range of expertise including nuclear engineers, scientists, policy makers, economists, managers of utility companies, and industry experts. Though I reached out to anti-nuclear environmental groups for interviews, I was unsuccessful. For this reason, I included a section on risks of nuclear energy perceived from an anti-nuclear perspective and measure it against the academic research and expert opinion on the subject.

The information gathered in interviews is presented in common themes raised in each interview. Each interviewee was asked four general questions about nuclear energy in Canada to draw out consensus (or lack thereof) across experts. Then, a set of 5-8 questions was asked that honed in on their specific SMR expertise (with some overlap across experts). The information from these interviews will be presented as themes that inform the ultimate policy recommendations of this paper.

Chapter 4.

Perceived Risks of Nuclear

This section aims to take seriously the arguments against nuclear energy and measures them against the academic research in the area. The opinions reflected here come from organizations such as Greenpeace, the David Suzuki Foundation, Pembina Institute, Environmental Law Society, and the Union of Concerned Scientists. Though there is dissenting opinions within these groups, the main view can be summed up as pursuing nuclear energy as a source of clean energy would replace the problem of GHG emissions with other, equally unacceptable, impacts and risks (Suzuki & Hanington, 2021). The main perceived risks of nuclear energy often mentioned are: meltdowns of reactor core, disposal of nuclear waste, possibility of reactors enabling proliferation of nuclear weapons, and history of cost overruns.

Beyond these risks, are perceived risks without foundation in facts. The first spurious argument is that a nuclear reactor could cause a nuclear explosion, like an atom bomb. No nuclear reactor, from the 1940s till now, has been capable of generating a nuclear explosion (WNA, 2021). A nuclear bomb uses very compact fuel to generate the power needed for a nuclear explosion. Specifically, when uranium is mined from the ground, there are two isotopes found. The uranium capable of producing fission is uranium 235. This makes up only about 0.5 - 0.7% of all the uranium mined. The rest of the mined uranium is uranium 238, which is inert to the fission process. In countries other than Canada, an enrichment process takes place to increase the amount of uranium 235 from less than 1% to between 3-4%. There is a large gap between this share of fissile uranium found within a reactor and the share, around 90%, found in a nuclear bomb. This is not to mention the various passive safety, and cooling systems found within a reactor, not present in a bomb. Additionally, there are high amounts of enriched plutonium often involved in nuclear bombs and hardly present in reactors. Again, this makes a nuclear type explosion impossible from a nuclear reactor. The real concern here is the case of a reactor meltdown which will be explored in depth down below.

A second, unfounded argument is that it is not necessary to have a baseload or dispatchable sources of energy production. Dispatchable power refers to sources of electricity that can be dispatched *on demand* at the request of power grid operators, according to market needs. Electricity usage varies by time of day. Subject to capacity, dispatchable sources provide a minimum capacity available at all hours of the day, even if renewable sources are not available.

Baseload power is the minimum amount of electric power needed over a period of time, such as a day (Donev, Hanania, & Stenhouse, 2020). This is used with other more flexible modes of power production to meet electricity demands when they peak at 6pm and everyone comes home. Typically, baseload power sources are provided by gas, coal, hydro and nuclear. To include solar and wind as baseload sources requires adequate storage capacity of renewable power. Storage costs vary depending on context (IEA, 2020, chapter 6). Adding storage costs, minimizing the overall system levelized cost of generating electricity cannot be based on a comparison of the levelized cost of individual technologies independent of dispatchability. Since the move to clean energy sources, future baseload power must be met by hydro, nuclear, or renewables with storage. Anti-nuclear articles written at the David Suzuki Foundation, Pembina Institute and Renew Economy challenge the conclusion that we need conventional dispatchable and baseload power sources (Suzuki & Hanington, 2021, Diesendorf, 2011, Winfield et al, 2006). Their claim is that baseload power means too much power when you don't want it, and not enough when you do (Diesendorf, 2011). They instead argue that we need a flexible power source so that we can meet supply and demand instant by instant (2011). An example used is a German state that relies on a net 100% of renewables, or parts of Australia that meet up to 40% of annual electricity with renewables (2011). The German state mentioned, small in size, assure a baseload and dispatchable energy from other nearby states (2011). Though Australia may reach near 40% of electricity generation annually from renewables, this blurs the variability of renewable energy supplied at different hours of the day. We must ask, how much power is being produced by solar and wind, at night, or when the wind isn't blowing? This further illustrates the need for a baseload power source.

The problem of renewable variability illustrates the lack of understanding around an energy source's capacity factor. Capacity factor is the ratio of an energy source's average electricity production over its actual electricity capability (Mueller, 2020). An example is a 100 MWe wind farm capable of producing 100 MWh during peak winds. It may produce only 30 MWh on average annually because winds are variable and usually light. This wind farm would have a capacity factor of 30% (Bellemare, 2019). Wind farms often have a capacity factor of 35% and solar farms 25% (Mueller, 2020). Among non-fossil sources of electricity, nuclear plants have the highest capacity factor at 92% (2020).

One last argument is that the GHG emissions reductions from nuclear energy use is negligible or non-existent (Suzuki & Hanington, 2021, Réseau Sortir du nucléaire, 2015). These critics state that countries that produce large amounts of nuclear energy still have carbon emissions too high to combat climate change (2015). This can be said about any mode of energy production. Carbon emissions come from many sources in a country other than the energy sector. This includes, heating, transportation, mining, manufacturing, agriculture etc. Anti-nuclear groups commonly cite a study that examines 123 countries over 25 years and finds that countries that invested in renewable energy lowered their carbon emissions much more than those reliant on nuclear energy (Suzuki & Hanington, 2021, Hambleton, 2021, Hays, 2020). However, this study finds that in countries with a high GDP per capita, nuclear electricity production is associated with relatively lower carbon emissions. In countries with a low GDP per capita, nuclear electricity production is clearly associated with CO2 emissions that tend to be higher (Sovacool et al, 2020). This finding is not surprising and does not imply that emissions reductions from nuclear energy use are negligible.

The major illustration of over-reliance on renewables is Germany. One need only look at total emissions produced in Germany after they began to shut down their nuclear plants in response to Fukushima, Germany re-opened fossil fuel sources and became dependent on imported gas and oil (much of it from Russia). Studies estimate that the nuclear phase out in Germany has led to an average of 36.3 Mt of carbon emissions per year (Jarvis, Deschenes, & Jha, 2019).

There are legitimate concerns with nuclear energy. These concerns must be assessed in the context of academic literature and expert opinion. The concerns I will describe next are: meltdowns, waste, proliferation, and costs.

4.1. Nuclear Meltdowns

The most salient meltdown events to date occurred at Chernobyl, Fukushima, and Three-Mile Island. As mentioned above, these were not nuclear explosions (like an atom bomb). Still, these events have left lasting, negative impressions of nuclear energy for the public. Anti-nuclear groups typically use these events as reasons not to pursue nuclear energy. On closer inspection, these events stand out in their uniqueness. These events combine old reactor technology, lack of safety systems, and human error. Here I focus on Chernobyl and Fukushima, due to their massive coverage in media, public discourse, and overlap with issues at Three-Mile Island.

In 1986, a reactor failure occurred at Chernobyl, Ukraine. Historians who have documented the events agree that the causes were multiple, involving both basic design flaws and human error that could have easily been avoided (WNA, 2021, Infield, 1987). The Chernobyl reactor was an older design (Gen II) known as the RBMK-1000 reactor. This was a reactor design specific to the Soviet Union at the time and not used anywhere else in the world (WNA, 2021). Two major design failures in this specific reactor were the lack of a containment unit and a positive feedback loop that caused the reactor to produce more, and more heat despite losing all water in the reactor, which would typically shut the reactor down. Both design features were used in the RBMK reactor to save costs (Aden et al, 2007).

The containment building is a three-foot-thick layer of concrete capsule, with a steel liner as a final failsafe (WNA, 2022). Should anything in a reactor ever be damaged or radiation released, it would be contained by this structure. This was not the case during the Chernobyl incident, as countries surrounding the Ukraine desperately tried to figure out how to contain the radiation that had spread. The second design issue was straying from the design of other typical reactors of that time. In reactors like the CANDU reactor, water is used both to create steam to turn a turbine and as a moderator for fission reactions (Rouben, 1999). Being a moderator means that water can slow down the firing of neutrons making them more likely to hit other atoms, increasing the energy produced. This CANDU design allowed heat to increase uncontrollably (in the onset of a meltdown), the water will evaporate. With no water moderating neutrons so that they better produce fission, the reactor will slow and stop. Simply put, the RBMK reactor did not rely on the water as a moderator and instead used other methods of neutron moderation. When the water was completely evaporated, the nuclear reaction continued and became worse (WNA, 2021).

These design flaws were key in the event that took place that night. Reactor personnel wanted to do a safety test. To begin, they reduced the reactor to levels far lower than regulation allowed in an attempt to test how much energy the reactor would continue to produce under these conditions (2021). They then tried to bring the reactor back up to regular operating status. This too was highly advised against as when reactors drop to low levels, they should be brought back up to power slowly over the course of three days (Infield, 1987). Instead, reactor personnel removed all but 8 out of 211 control rods to bring the reactor up to speed (1987). The reactor started reaching normal levels again so they began to insert the control rods in. However, these control rods were tipped with graphite (another design flaw), which first increased the fission reactions even further before slowing it down (1987). This in turn caused the reactor to release enormous amounts of heat. All of this culminated in two large chemical explosions, releasing radiation into the countryside.

This is a simplified account that avoids some of the physics for non-expert readers such as the Xenon build up in the reactor. It is clearly evident that there were a host of mistakes and design flaws behind this historic event. In Canada, our reactors are beyond Gen 2 designs and include more passive safety systems. Canada does not use graphite tipped rods to moderate reactors; instead, we have passive safety systems in place, and we have containment buildings for additional safety. What is currently protecting people in the area near Chernobyl is a containment building built after the accident. Experts conclude that an event like Chernobyl couldn’t happen with Gen III reactors given the design differences (Rouben, 1999, WNA, 2021).

Fukushima was different from Chernobyl, but immensely important in misgiving about nuclear energy. There were four active reactors at the Fukushima Daiichi plant site. All were old designs dating back to the early 1960s (WNA, 2021). On March 11th, 2011 Fukushima was hit by one of the worst earthquakes to ever hit the coast of Japan.

The earthquake was magnitude 9, the 4th largest earthquake in recorded history (U.S Geological Survey, 2019). In response, the control rods were lowered into the reactor, and backup diesel generators turned on in the process of cooling the reactor. Unfortunately, less than an hour later, the reactors were again hit, but this time by a tsunami so massive it sent cruise ships onto metropolitan areas (Kyodo, 2013). This tsunami that broached the walls designed to protect from smaller tsunamis and disabled the backup diesel generators (WNA, 2021). Without these generators, cooling stopped, and the heat from the reactors experienced runaway fission. The increasing heat evaporated the water meant to cool the fuel, building up steam in the reactor core (2021). Steam circulated out of the reactors but a buildup of hydrogen gas caused an explosion in 3 out of the 4 reactor building tops (2021). These building tops were designed with blast panels to easily blow off in case of emergency, leaving the reactor and other parts of the building intact (2021). The fuel, which had become so hot at this point as to melt the fuel rods into a magma, melted through the bottom of the pressure vessel, and fell onto the bottom of the 2.6 meter thick concrete containment vessel (2021). This reduced the intensity of the heat and enabled the magma to solidify (2021). The hydrogen explosions released radiation into the air, but ill effects were avoided as the area had a 20km radius evacuation (2021). It is important to note that not a single worker involved in the ongoing shutdown of the reactors became exposed to radiation levels that would produce radiation sickness and no one was killed as a result of the power plant (2021). In fact, after Fukushima one prominent environmentalist wrote in the Guardian that as a result of the disaster at Fukushima, he now supports nuclear energy (Monbiot, 2011). The reason Monbiot gave was that an old reactor with poor safety could be hit by a major earthquake and tsunami, yet not result in any deaths.

The design of the reactor at Fukushima required it to be near the ocean. For this reason, safety considerations in the event of a tsunami were constructed. However, in the case of the Fukushima Daiichi reactor site, 18 years prior to the meltdown scientific knowledge had emerged about the likelihood of a tsunami of over 15 meters (2021). The reactor operators and the Japanese nuclear safety agency were negligent not to build higher walls in light of the evidence (Lochbaum, 2014). This, along with a few other missteps from the Japanese government, generated doubt about the reliability of the information being provided and the competence of government officials (2014).

These two events showcase the necessity of nuclear design with passive safety systems and a competent, independent nuclear regulator. It is also important to consider how countries responded to these events. In response to Fukushima, Germany began to shut down all existing nuclear power plants. This has seen a net increase in the use of non-clean energy sources, and thus their total carbon emission (Jarvis, Deschenes, & Jha, 2019). Other countries confident with their nuclear designs and regulators continued to operate and even expand nuclear operations. Notable examples are France, Finland, Russia, South Korea, Poland, China, Sweden, and Canada.

4.2. Waste

Nuclear waste is a second major concern, especially concerning for environmentalists who want energy production without any waste production. With an increase in nuclear reactors, we are engaging in a trade-off between significantly reducing carbon emissions in the energy sector with the production of another kind of waste, which needs to be contained for a very long time.

The total amount of nuclear waste used to meet an individual's energy needs in their lifetime would be the size of a pop can (CNA, 2020). The waste from nuclear power plants comes in three forms, low-level waste, intermediate-level waste, and high-level waste. Low-level and intermediate-level waste includes clothing, tools, equipment, and other items in the plant itself that absorb radiation (CNSC, 2020). They make up 97% of all waste produced by nuclear power plants and remain radioactive for a relatively short period of time (WNA, 2022). The long-life, high-level waste comes from the result of the fission of uranium creating a host of other unstable elements. This is the other 3% of nuclear waste, known as spent fuel. It needs much more careful consideration (2022). All the nuclear waste produced in Canada over the last 60 years could lay in a little over three football fields (NWMO, 2020).

In Canada and other countries, spent fuel is first removed from the reactor core, contained in its protective casing, and placed in a bed of water inside the reactor (WNA, 2022). In the water, plant operators are protected from the radiation of the fuel as the water absorbs the radiation and cools the incredibly hot fuel. This process usually takes seven to ten years. After 10 years of cooling at the reactor site, more than 99 percent of the radioactivity has decayed away (2022). The used fuel bundles are then further sealed in canisters designed to inhibit the release of any radiation (2022). Countries differ in their methods of dealing with these canisters from here as they will remain highly radioactive for a few hundred years and mildly radioactive for thousands of years (2022). The US has traditionally stored its waste in a mountain. Switzerland has used dry storage containers, made of reinforced high-density concrete 20 inches thick and lined inside and outside with a half-inch of steel. The concrete provides an effective barrier against radiation. France recycles and reprocesses its used fuel to get more use from the waste, though this can be expensive. Finland is looking to be the first to bury waste deep underground in a geological repository that can then be cemented in (NWMO, 2020). This is Canada's current strategy and is currently selecting a site.

Two important things to note with nuclear waste are, first, new technologies and even some existing ones offer the potential to continuously recycle nuclear waste as fuel. The World Nuclear Association states that approximately 97% of all waste could be used as fuel in certain types of reactors (WNA, 2022). Recycling used fuel would greatly reduce the radioactivity of the final waste product. We may want to reconsider sealing away our waste forever. Second, we often consider nuclear as the only energy source with waste. Natural gas and coal power plants create waste that can pollute nearby bodies of water and other environments. Even technologies like solar can produce toxic waste. Solar panels eventually die and need replacement. The International Renewable Energy Agency projects that total waste from solar panels could total 78 million tonnes by 2050 (Atasu et al, 2021). Panels are often recycled for aluminum, copper, and silver and then disposed of. Sam Vanderhoof, the CEO of Recycle PV Solar stated in an interview that 10% is recycled, the rest goes to landfills or overseas (Stone, 2020). What is left of these panels can contain toxic amounts of lead (Tao et al, 2020). Current studies suggest that it isn't profitable for businesses to engage in more solar recycling, so they likely won't (2020). This is not to say that we should abandon solar. Waste management is critical in all energy production.

4.3. Weapons Proliferation

Another argument is fear that either a terrorist group or country will use the fuel to make a nuclear bomb. These fears are especially prevalent in the generations closest to WWII or those who lived through the Cold War. It is a legitimate fear to worry about. This has never been more true as Russia has made threats of nuclear weapons use in its conquest of Ukraine in 2022. Arguably, the largest international bodies that have played a role in preventing the spread of nuclear weapons have been those involved in the safe use of nuclear energy, namely, the International Atomic Energy Association (IAEA) and the implementation of the Nuclear Non-Proliferation Treaty (NPT) in 1963. Before this treaty, President Kennedy estimated that up to 20 nations will have a nuclear weapons capacity in ten years due to new inventions (Carnegie, 2003). Though production of energy through nuclear reactors has grown eight-fold since the early 1970s, the world has seen a massive disarmament of nuclear weapons during the same time (WNA, 2022). This is easily possible because the fuel inside reactors and weapons grade fuels are uniquely different. Fuel in a reactor is largely uranium and with other by-products produced as the reactor runs such as plutonium can come about during the running of the reactor. Even of the 1.15% of plutonium created in the reactor during operation only about half (plutonium 239) of that would be suitable for weapons (WNA, 2021). Since it would take about 10 kilograms of nearly pure plutonium 239 to make a bomb, producing this through a reactor would require 30 years of reactor operation (2021). Additionally, you would need to remove the fuel every 3 months (making your reactor useless for energy production) to get the correct isotope of plutonium (2021). This is to say that trying to build a nuclear weapon through the use of the reactor alone would be expensive, time consuming, dangerous and nearly impossible.

Some potential issues can come about through the reprocessing of fuel. Reprocessing spent nuclear fuel can be beneficial by getting more use out of the fissile uranium left in the spent fuel. This can protect against a uranium shortage and reduce the total amount of nuclear waste. The fear of reprocessing is that it separates the other plutonium elements from the uranium. Again, this is a small amount of plutonium 239 and it is combined with other isotopes such as plutonium 240. Plutonium 240 is considered a serious contaminant for weapons use due to higher neutron emission and higher heat production (WNA, 2021). These other plutonium isotopes are almost impossible to separate out (Bratt, 2012). Here again, one would need to take the small amounts of plutonium out through a complicated extraction process, collect at least 10kg of plutonium, and then enrich that plutonium through use of either gaseous diffusion or centrifuge technology (2012). Both of these are incredibly expensive and technical to carry out. For this reason alone, it greatly diminishes the likeness of a individual or terrorist group creating a nuclear bomb. Given the vast amounts of money, technical expertise and human capital to create a bomb it would need to be pulled off by a country.

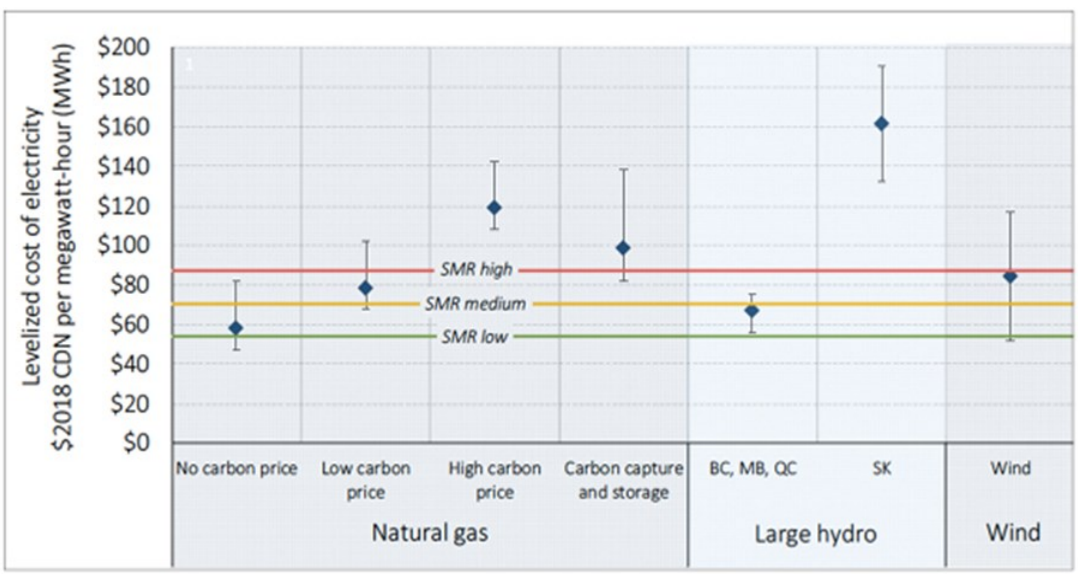
A country looking to make a nuclear bomb from a reactor would require a reprocessing plant to enrich plutonium to weapons grade levels. A reactor itself in not sufficient to create a bomb for the reasons described above. As of 2012, countries that have reprocessing technology include France, the UK, India, Japan, China, Pakistan and Russia (2012). What is needed to ensure these waste recycling plants don't devolve into weapons manufacturing is rigorous international regulation. The IAEA and the Nuclear Suppliers Group (NSG) have put in place successful systems, regulating the supply of nuclear materials and auditing facilities (2011). One of the three pillars of the Non-Proliferation Treaty is that all parties be able to develop nuclear energy for peaceful purposes and benefit from international cooperation in this area (2011). This has been an incentive for countries to sign the NPT. By doing so they can work cooperatively with other countries and share knowledge that would advance their own goals. In this way, nuclear energy has actually helped our goals towards the nuclear disarmament of countries.

4.4. Cost Overruns

In order for any green source of energy to be considered by the utility or business sector, it needs to be cost competitive with existing energy sources (OECD/NEA, 2000). It is no secret that the construction of large nuclear power plants has led to significant time and cost overruns. Take the example of the Watts-Bar nuclear power plant built in the US and said to have taken 40 years to build (Iurshina et al, 2019). Stories like this scare investors, but don't tell the full stories. In a comprehensive analysis of historical costs of nuclear plants, Lovering and Nordhaus examine the average costs of plants globally, not just in the US (2016). They find evidence of mild cost escalation in many countries and cost declines in some countries. Factors such as utility structure, regulatory regime, additional safety requirements, scarce parts, and re-designs all contribute to cost overruns. However, countries like South Korea were able to lower the cost of nuclear energy by addressing these issues before construction began (2016). The authors conclude their findings suggest that there is no inherent cost escalation trend associated with nuclear technology (2016).

In order to compare the cost competitiveness of SMRs, we can look at the levelized cost of energy (LCOE) against other clean energy sources. LCOE is a measure of total cost per unit of electricity produced in the operating lifetime of the technology measured. This includes all construction and operation costs. **Figure 1** shows LCOE estimates from on-grid SMRs along with gas, hydro, and wind. This analysis was done on behalf of the federal government (NRCan, 2018). The NRCan working group concluded that SMRs are competitive with alternatives including large nuclear power plants, diesel, natural gas, hydro, wind, and solar when measuring LCOE (2018). As a note, solar was not included in the figure as it was deemed more expensive than wind generation (2018). The analysis concludes that, even with unfavourable assumptions for on-grid SMRs (including a higher discount rate, costs for subsequent SMRs of the same design, and less innovative technology), SMRs are competitive with all aforementioned energy types, assuming a carbon price is in place (2018).

Figure 1. Comparison of levelized cost of electricity from on-grid SMRs with other options: Best case (6% discount rate, more innovative technology)



Source: NRCan- SMR Roadmap, 2018

Chapter 5.

Interview Themes

A total of ten interviewees participated in informing this study. The interviewees came from a range of disciplines including nuclear engineers, scientists, policy advisors, economists, political scientists, utility representatives, provincial government representatives, investor groups, energy project managers and regulators. Most interviewees wore more than one of these hats either currently or in the past. The information from these interviews is presented below as key themes that arose across many of the interviews. The themes outline the benefits and challenges of SMR adoption in Canada.

5.1. Considerations for Utilities

Provincial power utilities have many contending issues to be considered in their final energy mix output. Utilities can be public as in Ontario, New Brunswick, or Saskatchewan, or private companies as in the case of Alberta. Many interviewees mentioned that power utilities need to consider the emissions targets set at the federal level as a constraint on their final energy mix strategy. Interviewees unanimously spoke of the reduced carbon emissions from the use of nuclear energy. This was best illustrated in my interview with a representative from New Brunswick Power. They pointed out that the United Nations Economic Commission for Europe (UNECE) released a large report examining the lifecycle of carbon produced by all energy producing technologies. In a carbon life cycle analysis, the report finds that nuclear has the lowest carbon footprint, measured in grams of CO2 equivalent per kilowatt-hour (kWh) of electricity, among all energy producing technologies (UNECE, 2021).

However, GHG reduction is only one dimension of energy production that utilities contend with. Utilities need to consider future increase in demand, the need for dispatchable power generation in peak demand hours and sub-optimal weather conditions, and delivery of power at an affordable price to their consumers. Representatives from Ontario Power Generation (OPG), New Brunswick (NB) Power, Canadian Nuclear Laboratories (CNL), and the federal government all predict a massive increase in electricity demand by 2050 on the order of 2-3 times current generation. This is congruent with the modeling done by the International Energy Association (IEA, 2021). The reasons for this increased demand are threefold: population growth trends, the electrification of industries such as transportation and indoor heating to meet climate goals, and the energy needs of developing countries and rural/remote areas of developed countries.

Utility managers realize that their power capacity must meet energy needs in the worst environmental conditions. Utility representatives at OPG and NB Power both point to the dilemma of building up large wind and solar farms. In the right conditions they may produce the full 1200MWe of clean energy they were constructed for, but in dark, cold nights of winter months, they produce limited energy or none at all. For this reason, utilities need reliable dispatchable energy sources year round. The available options for utilities are coal, natural gas, hydro, and nuclear. There remain issues with each technology, which are discussed below.

The federal SMR Policy representative, the federal economist, OPG, and NB Power representatives all agreed that utilities need to take seriously the final price of power delivered to their ratepayers. The analysis done in the SMR Roadmap shows that the levelized unit cost of energy (LCOE) for SMRs is comparable to other alternative energy technologies. The federal SMR Policy Advisor pointed to a SMR feasibility study prepared by four Canadian utilities (OPG et al, 2021). It concludes that the levelized cost of electricity (LCOE) alone does not explain the whole picture: "The [additional] system costs to maintain the reliability of renewable generation as delivered by dispatchable resources like nuclear, hydro and fossil generation are substantial and increase the larger the penetration of renewables" (OPG et al, 2021, p.34). Similarly, a study done by MIT considering the impact of nuclear power on the cost of electricity when deep decarbonization is desired finds that the cost of electricity is lower with a larger nuclear share as opposed to trying to decarbonize with renewables alone (Buongiorno et al, 2019). Both representatives from OPG and NB Power state that, when they project their future clean energy portfolio, a high share of nuclear power produces the best price for ratepayers. Their expertise also includes formal analysis of other popular clean energy modes of production such as wind, solar and hydro. This leads to the next theme, comparing the benefits and challenges of SMRs with other methods of energy production.

5.2. Comparing Other Energy Technologies

Interviewees consistently insisted on the need to compare the pros and cons of each method of energy generation. Individuals often have negative opinions about nuclear energy due to waste, meltdowns, technological readiness, and costs. However, nuclear energy is one of the few modes of energy production that is heavily regulated from the point at which uranium is mined from the ground, transported, enriched, used as fuel, temporarily stored, and disposed of. This cannot be said of other modes of clean energy production. My interviewees note that nuclear energy production has disadvantages but wind, solar, hydro, and natural gas with CCUS also have disadvantages.

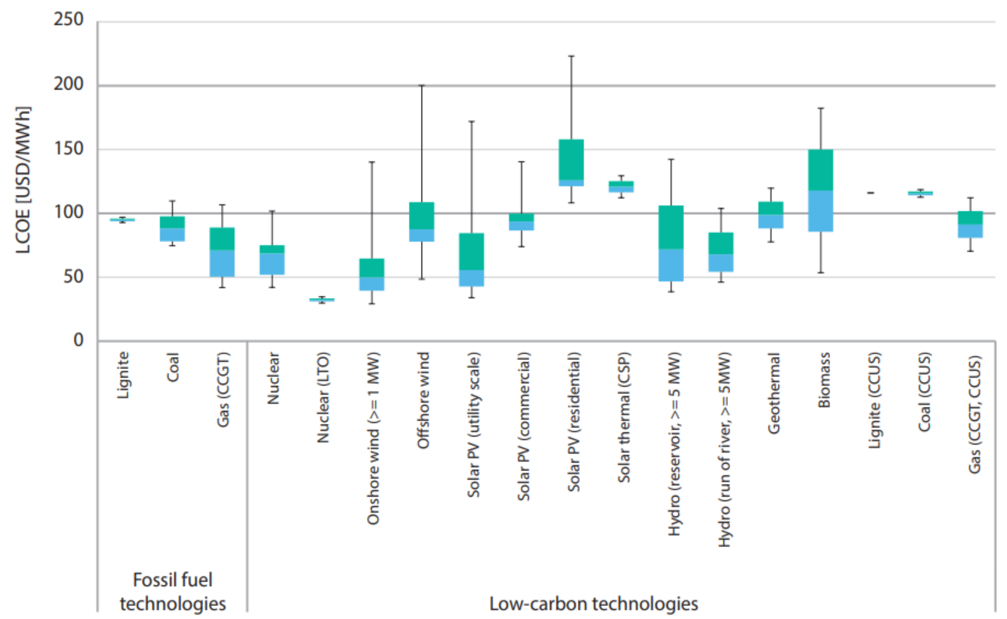
Interviews with representatives at OPG, MIT Nuclear Laboratories, NB Power, and CNL mentioned some of the challenges and limitations of solar and wind energy:

- *Determination of full cost of solar panels and wind:* Interviewees brought up the fact that, at least in North America, solar panels are often subsidized by government. Secondly, they note the recent journalism linking the cheap production of solar panels driven by forced labour of the Uyghur Muslims in China (BBC, 2021). Thirdly, the price of component minerals such as lithium and copper are increasing, which may in turn raise the price of solar and wind energy production.

- *Solar panel waste*: A few interviewees noted that the waste from solar panels contains toxic elements that are sometimes shipped to developing countries to manage. Unlike the radiation from used fuel that reduces over time in nuclear energy waste, these toxic elements never become less toxic to humans.

- *Dispatchable capacity*: When talking about wind and solar energy, the dispatchable capacity issue comes up. A 1200MWe wind or solar farm may only generate an average of 300MWe (25% capacity in this example). To be adopted widely, there needs to be far more storage capability for wind and solar. This technology will increase demand for batteries, which will further increase the costs of battery expenses. This point is further expressed in the IEA's *Projected Costs of Generating Electricity (*Lorenczik et al, 2020). This report states that the lack of reliability of renewables requires either dispatchable back-up or storage to ensure security of supply at all times. Chapter 6 of this report estimates that storage for renewables would add an additional $30/MWh. **Figure 2** shows the IEA's 2020 projected LCOE for each method of electricity generation (excluding renewables combine with storage). They state that Nuclear is the dispatchable low-carbon technology with the lowest expected costs in 2025. This is consistent with the messaging from my interviewees at OPG, NB Power and the federal government.

Figure 2. IEA's 2020 LCOE by Technology (USD)



Note: Values at 7% discount rate. Box plots indicate maximum, median and minimum values. The boxes indicate the central 50% of values, i.e. the second and the third quartile.

Source: Lorenczik et al. (2020). Projected costs of generating electricity-2020 edition

Note to Reader: LCOE for wind or solar in this figure does not include the additional $30 USD estimated minimum storage cost in chapter 6 of this report. Storage costs are also sensitive to context.

Hydro and natural gas with CCUS technology can match the capacity and baseload energy that nuclear provides. Again, there are challenges:

- *Geographic limitation of hydro*: Three provinces (BC, Manitoba and Quebec) are blessed with an abundance of hydro energy. However, this technology is limited by geography. My NB interviewee noted that New Brunswick has maxed out its hydro capabilities. Similarly, a representative from Alberta Innovates mentioned the limited potential to build hydro in Alberta.

- *Uncertainty of interprovincial grid*: Why not build transmission lines from hydro abundant provinces to hydro deficient provinces? My interviewee at NB Power stated that New Brunswick does exactly this with Quebec. The caveat is that in the Memorandum of Understanding (MOU) between the two provinces Quebec will supply hydro energy unless they need it themselves. This poses major risks for energy security when both provinces need to power homes when everyone gets home from work on cold, dark days. The federal SMR Policy Advisor emphasized the high cost of interprovincial transmission infrastructure. At the end of the day, such a grid does not guarantee energy supply for importing provinces.

- *Cost overruns of hydro projects*: Both Site C and Muskrat Falls have realized large cost overruns. Over the next decades, climate change may increase frequency of droughts in much of Canada, which reduce hydro capacity.
- *Uncertainty of natural gas with capture and storage technology*: Interviewees stated that CCUS has yet to be proven on a large scale, is costly, and may potentially generate more CO2 than it puts away. The IEA's *Projected costs of generating electricity* find that natural gas with CCUS becomes cost competitive only with a 100 USD carbon tax (2020). Researchers at the MIT Energy Initiative find that, as we try to capture 100% of emissions with CCUS, it will require additional energy which in turn, produces more emissions (Moseman, & Herzog, 2021).

From this look at both the benefits and challenges of each technology, my interviewees all made explicitly similar statements:

- We need nuclear energy to help meet Canada's 2050 Net-Zero targets, and
- Each province will have a different clean energy portfolio that considers its own geographical advantages. We need all methods of clean energy production to fight climate change.
- As mentioned above, there are closer and later timelines for technological advances in each mode of energy production. SMRs are no different, and interviewees discussed which technologies are readily available and which need time to develop.

5.3. Technology Development

Is SMR technology ready for deployment and use? To fully understand this question, we should revisit Canada's SMR Roadmap. This report identifies three potential uses of SMR technology. Stream 1 is on-grid power generation, for provinces phasing out coal in the near future. Stream 2 is intended for heavy industry application, which includes SMRs for oil sands producers and remote mines. Stream 3 is intended for off-grid power, used for heating and desalination in remote communities, which currently rely on diesel generators.

The two scientists at CNL predicted that each stream will have its own technology and design. SMRs for on-grid applications are typically larger, reaching

300MWe. Stream 2 SMRs typically have lower MWe output but operate at much more intense levels of heat. Because of this, they will often rely on newer Gen 4 technologies like Liquid Molten Salt Reactors or High-Temperature Gas-Cooled Reactors. Stream 3 micro-reactors are the smallest. They typically range from 2 to 15 MWe. A study by Froese et al. (2020) finds that the demand in such communities is too low to enable affordable LCOE via SMRs.

Stream 2 technologies raise issues with timing of technical innovations. To begin, the experts at CNL advised that all SMR designs can ultimately be built. The science and engineering behind them are sound. However, both the CNL and MIT Nuclear Lab experts informed me, much research and development investment need to go into a design before it is ready for construction. The US-based company Terrapower was brought up as a good example. It receives public investment, backing from Bill Gates and employs a few hundred people to model, test, and ultimately build a demonstration unit. Additional funding is required to find or train workers with the proper technical skills and pay for one-of-a-kind manufactured parts. CNL experts stated that, through this kind of public investment, many innovations in the nuclear energy sector have come from Canada. Historical examples include heavy water reactor designs, natural uranium as a fuel source, Zero Power research reactors, and the NRU reactor (the most powerful research reactor in the world at the time). Canada led the way in medical isotope creation, and the testing of fuel types and reactor materials. Many companies designing Liquid Molten Salt Reactors will use historical examples to prove the effectiveness of their technology. The most commonly cited example is the Molten Salt Reactor Experiment conducted at the Oak Ridge National Laboratory between 1964 and 1969. The expert at MIT Nuclear Laboratories qualified this comparison: this reactor didn't run continuously for 5 years. It ran for only 482 days which means likely only 1-2 years. While it was operational, it only operated at 8MW thermal (650c). This proved the physics, but the materials still need to be proven under intense heat and radiation over time.

The positive news was that each scientist said that these newer, safer stream 2 technologies could begin construction given the high investment from both the public and private sector. However, the Alberta Innovates expert expressed concern about the timeline for these stream 2 technologies. Alberta intends to decarbonize its oil and gas sectors, but it will likely be interested in what technologies are available. Stream 2 SMR technologies are predicted to be available around 2034-2040. Should CCUS or clean hydrogen or some renewable technology be available sooner, the Pan Canadian SMR approach may lose the Alberta oil and gas sector market. In turn, this reduces the potential nuclear demand for this technology in Canada, which would reduce scale economies. Still, the experts from Alberta Innovates and the Albert Ministry of Energy mentioned that Alberta may need SMRs, as there are very few alternatives for eliminating GHGs associated with oil extraction in the oil sands.

The most readily available stream seems to be stream 1, especially if we consider Canada's closest design, the GE Hitachi BWRX 300, the design selected by OPG to be constructed by 2028 at the Darlington site. This is the tenth evolution of GE Hitachi's reactor design. It relies on a well-known boiling water reactor design. This timeline would put Canada as one of the first to build SMR market reactors. Experts from CNL and MIT Nuclear Lab agree that this technology is ready for demonstration and deployment. The SMR feasibility study states that SaskPower is potentially looking to build four of these BWRX 300 reactors by 2040 (OPG et al, 2021). My interviewee at OPG estimates that there is a reasonable possibility of 10 BWRX reactors built by 2030, and another 10 – 20 more by the 2040s. This is not surprising as GE Hitachi Nuclear Energy, BWXT Canada Ltd. and Synthos Green Energy announced they would build 10 BWRX-300 reactors in Poland (Patel, 2022).

From this information we gain many valuable insights. Canada will likely need three different SMR designs. However, investments in stream 1 will be the key driver of SMR development in Canada. This means the more provinces that join this strategy, the more likely to see SMR development in Canada. Though there are many SMR designs to choose from, a useful heuristic that came from the scientists interviewed was to make sure the SMR vendor had high R&D investments and lots of employees with experience in constructing and managing nuclear power plants. We can use this rule of thumb to eliminate quite a few SMR vendors as potential leaders in this race.

5.4. Barriers to Entry

All modes of energy production come with a set of disadvantages. Each of my interviewees was asked to explain the current SMR challenges. The most common responses were market factors, regulatory issues, and – largest obstacle of all – public opinion.

If nuclear technology is to be economically viable, we need to build reactors as smaller, complete units in a factory, and then transport them on site. Doing so will lead to efficiencies by taking advantage of a streamlined process that becomes cheaper per unit the more are built. Many interviewees agree that the first-of-a-kind, demonstration unit will be the most expensive, and the scale economies will come later when we mass produce one reactor type. We are still in the realm of economic speculation without any concrete pilot SMRs from which to learn. A federal economist reminded me that Canada had been a first mover in reactor technology. Whether CANDU was a successful project depends on the measure. The CANDU design reactor provided Ontario with a large amount of clean on-grid energy, established Canadian IP, and created long-term high paying jobs. However, exporting these reactors was not as lucrative as hoped. Canada is one of the very few countries that use our heavy water technology. If we develop new SMR technologies, we may again be the only country to end up using them, reducing the market potential of the SMR strategy.

France is the classic example of a country that used a fleet approach to building reactors. It was successful, but France had the benefit of choosing a reactor design well established in other countries. My interviewee at OPG stated that no one has perfect information on SMRs. We won’t get granular pricing on reactor builds for the public until the first BWRX 300 reactor at Darlington starts its construction. The federal Policy Advisor for SMRs I spoke with said we also need to look at where the jobs are coming from. We need to think of the necessary industrial ecosystem. SMR investments are able to provide many jobs within Canada in the forms of mining, manufacturing, reactor operations, construction, and maintenance. If we place a high priority on wind and solar investments, we will have to import a high proportion of the necessary components. We thereby lose many potential jobs. The takeaway here is that the “fleet approach” (scale economies in construction) may not be the desired cheap nuclear option. However, we won’t know until we try.

A second challenge has been regulatory issues. One limitation mentioned in my interview with a MIT Nuclear Labs Scientist was that US-based NuScale is a similar light water reactor design and is just as ready as Canada's BWRX 300 SMR. It took almost two decades to receive the Nuclear Regulatory Commission's (the US nuclear regulator) approval. An economist working on SMR files in the federal government stated that Canada has the advantage of new investment to refurbish existing nuclear power plants in Canada, and so far these projects are on-time and on-budget. CNL scientists added that it is these non-technology regulatory aspects can make a project run out of money or be delayed.

The interviewees all say that the policy around nuclear power could use improvement. An expert nuclear political scientist I spoke with mentioned that we should reassess the security requirements for these smaller reactors. Small reactors often require one man and a dog to be protected – not the small army you see at conventional reactors. NB Power's representative stated that the environmental and design assessments done by CNSC should be expedited for subsequent builds of the same reactor design. The Alberta Ministry of Energy representative stated that provinces need to create the proper regulatory channels for SMR adoption and build connections with the CNSC, which Alberta is beginning to do now. Additionally, if all the above-mentioned provinces do apply for licences to build and operate SMRs, the CNSC will have to greatly increase its assessment capacity. All of the experts recognize that the regulatory process must keep public confidence. The CNSC remains a respected regulator for its independence and due diligence. The wrong policy change here could damage public trust. This is likely the largest barrier SMRs face.

Dating back to the 1960s, nuclear energy was viewed as the technology that would lead the way to the future. Experiments like the nuclear reactor using liquid molten salt as fuel were common. Designs for nuclear powered spaceships, submarines, and even airplanes were drafted. During this time, the public was excited at nuclear energy's potential. However, the back-to-back accidents in 1979 at Three-Mile Island and in 1986 at Chernobyl created widespread fear of nuclear technology. Further fear was stoked from the word "nuclear" during the Cold War and Cuban missile crisis. Each interviewee mentioned public opinion as a challenge. The political scientist, who had researched public attitudes in Canada, suggested avoiding the word "nuclear" and instead talking about small modular reactors, thorium power, or liquid molten salt reactors as an effective branding exercise. Apparently, public attitudes have not shifted much since Chernobyl. Fukushima barley moved the needle of public opinion as seen in **Table 2**.

Table 2. Comparing the Nuclear Support across Provinces, Pre and Post Fukushima

	Ontario	New Brunswick	Saskatchewan	Alberta
Public support: polls pre-Fukushima	60–65%	45–55%	50–55%	50–55%
Public support: polls post-Fukushima	50–55%	45–50%	45–50%	45–50%

Source: Bratt, D. (2012). Canada, the Provinces, and the Global Nuclear Revival: Advocacy Coalitions in Action. pg. 278

The best evidence on Canadian attitudes is Duane Bratt (2012) *Canada, the Provinces, and the Global Nuclear Revival: Advocacy Coalitions in Action*. The book shows that public support across Ontario, New Brunswick, Saskatchewan, and Alberta remained between 45-65% across the provinces, before and after Fukushima (Bratt, 2012). However, public support is highest where nuclear already exists. In Canada, this is in Ontario and New Brunswick. However, as some interviewees pointed out, opponents of nuclear energy oppose it viscerally. Past public consultation in Saskatchewan saw vehement anti-nuclear groups follow the process from city to city (2012). This meant that the same small group of anti-nuclear individuals had their opinions represented across every stop in the province, making them seem much larger than they were. One interviewee drew a parallel with the minority of Canadians who opposed democratically approved provincial COVID constraints and shut down Ottawa in opposition to such decisions. The take-away on this aspect is the consensus among interviewees that the public needs to be more informed on the pros and cons of all energy production methods. We could begin by informing Canadians about the long successful history and competitive advantage we have with nuclear energy.

5.5. Canadian Advantage

Many interviewees brought up Canada's distinct advantages over other countries in terms of our strong nuclear history, supply chain, and economic benefits. As previously mentioned, Canada boasts a nuclear safety record of 70 plus years. Interviewees attributed this record to the quality of regulation. The CNSC has maintained the balance of providing regulatory policies that utilities can navigate while maintaining public trust. This regulatory record is sometimes cited by SMR vendors tempted to migrate from US to Canada. Many American SMR vendors (like NuScale, X-Energy, GE Hitachi, Ultra Safe Nuclear Corporation, and Westinghouse) have established a foothold in the Canadian market. This augurs well for attracting the skilled nuclear workforce required to operate power plants and many of the allied manufacturing capabilities. Representatives at NB Power estimate that up to 80% of reactor parts could be developed in Canada. The mining company Cameco can help to deliver fuel from the large uranium deposits in Saskatchewan while BWXT Canada currently manufactures reactor parts. NB Power and OPG sees these as giving Canada a first mover advantage.

Interviewees at Alberta Innovates and the Ministry of Alberta stated that oil and gas companies are interested in SMRs for their mining and extraction operations. Big oil and gas companies (such as Canadian Natural Resources, Cenovus Energy, Imperial, MEG Energy, and Suncor Energy) have created a framework with the federal government called the *Oil Sands Pathways to Net Zero initiative* to reach Net-Zero by 2050 (Pathways Alliance, 2021). Their long-term goal is to invest and utilize SMR technology as part of its overall GHG reduction strategy.

The economic benefits from American SMR vendors and oil sands companies vouching for SMRs in Canada could be substantial. Many interviewees spoke about the benefits Canada could receive in terms of job creation, GDP increase, and tax revenue generated. Examining the SMR feasibility study gives concrete numbers. The construction of 5 BWRX 300 reactors could create 1,528 jobs during project development, 12,455 jobs during manufacturing and construction, and 1,469 jobs during operation. The study estimates an increase of $17 billion contributed to Canada's GDP and an increase of government tax revenue of $5.4 billion (OPG et al, 2021).

Chapter 6.

Policy Options

The policy recommendations presented here are grounded in the main takeaways of international, federal government, and corporate reports on achieving net Zero goals by 2050. First, I briefly describe the relevant policy reports in this area. Then, I extract the key takeaways and use them in combination with the energy generation numbers given by the Canadian Energy Regulator to develop a set of policy options.

IPCC. 2018. Report to Policy Makers:

This summary to policy makers illustrates potential pathways to limit temperature increase to 1.5°C. Four different pathways are modeled to achieve the required net emissions reductions. All pathways proposed include an increase in nuclear energy as a method to decarbonize, but the increase varies across pathways. Relative to the 2010 world nuclear share of electricity generation, the four pathways require increases in nuclear share by 2050 ranging from 98% to 501%.

IEA. 2021. World Energy Outlook:

This report states that the new energy economy needs to be more electrified, efficient, interconnected and clean. We will see further electrification of transportation and heating. However, it notes that public spending on sustainable energy in economic recovery packages has been insufficient. They estimate that only one-third of the necessary investment required has been announced in the pledges of nations coming up to COP 26. They also find that nearly half of the emissions reductions achieved in the IEA's Net Zero Emissions by 2050 report come from technologies that today are at the demonstration or prototype stage. Across all IEA scenarios, the share of renewables in electricity generation expands to reach 40-70% by 2050. They conclude that these grids will need to be more flexible and robust and require dispatchable low-emissions sources of electricity, such as small modular nuclear reactors.

Canada's Net Zero Accountability Act. 2021:

This Act is the governing legislation of the Government of Canada's commitment to achieve net-zero by 2050. It requires that each proposed emissions reduction plan include a list of criteria. The important criteria for the policy proposals here are: a greenhouse gas emissions target for the year to which the plan relates; a description of the key emissions reduction measures the government of Canada intends to take to achieve the target; a description of any relevant sectoral strategies; a projected timetable for implementation; and a summary of key cooperative measures or agreements with provinces, territories, and other governments in Canada. To varying degrees, these will be incorporated into the SMR policy options presented below.

Environment and Climate Change Canada's (ECCC). 2020. Healthy Environment and Healthy Economy Report:

This is the federal government's climate plan. It is a report published by the federal environmental ministry and outlines the specific goals and clean tech investments to achieve net-zero by 2050. The plan estimates that, by 2050, Canada will need to produce up to two to three times as much clean energy as now. The aim is to create secure, long-term jobs and careers that will benefit the middle class. This will be achieved by numerous federal clean tech investment programs including: $2.5 billion as part of the Canada Infrastructure Bank clean growth plan for the next 3 years; and $3 billion over five years from the federal government's new Strategic Innovation Fund – Net Zero Accelerator. Though this report mainly focuses on investment to advance smart renewable energy and grid modernization projects, it briefly mentions supporting the goals of the SMR Roadmap and Action Plan

Natural Resources Canada. 2018. SMR Roadmap &
Natural Resources Canada. 2021. SMR Action Plan:

Produced by Natural Resources Canada (NRCan), these reports outline federal, provincial, and private decision making with regards to Canada's future use of SMRs. The initial Roadmap states that, for Canada to be successful in realizing net-zero, we need a SMR fleet-based approach to realize scale economies in construction. Additionally, investment risks need to be shared among governments, power utilities, and industry in order to meet SMR demonstration and deployment goals in Canada. In the Action Plan, organizations across Canada outline their roles and plans for SMRs. The government of Canada's chapter states an acceptance of the Roadmap recommendation (#1) cost-sharing SMR projects, and recommendation (#2) on risk-sharing for first-commercial projects. They also state an intent to give a clear signal to industry groups on steps to take towards SMR development. A key industry group is the Canada's Oil Sands Innovation Alliance (COSIA). COSIA explains their interest in pursuing SMRs to decarbonize the oil sands industry. A deeper look into the Oil Sands to Net Zero report gives an estimate of Oils Sands future usage of SMRs (Pathways Alliance, 2021).

Cenovus, Suncor, Imperial, Canadian Natural, MEG Energy, and Conoco Philips. 2021. Oil Sands Pathways to Net Zero:

This is the climate strategy of the oil sands industry. This report gives broad estimates of the emissions reductions that will accrue from each technology method available to them by 2050. These technologies include CCUS, direct air capture, electrification, which includes SMRs, process efficiencies, and "other levers". It is important to note that the industry expects CCUS to provide nearly half of emissions reductions. SMRs, while mentioned as one of the key technologies, doesn't appear as important in their projections.

These policy reports provide an up-to-date framework on which to build policy recommendations. These takeaways include:

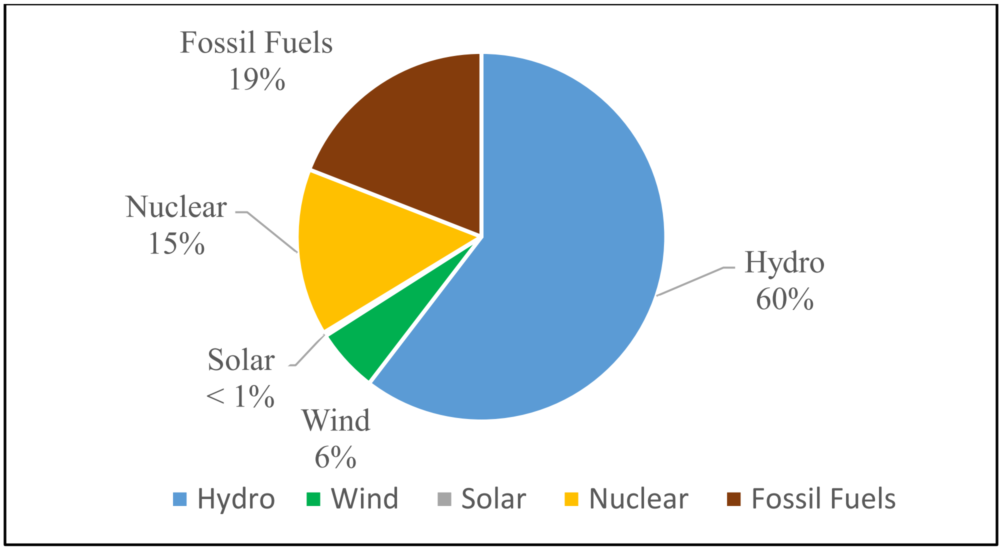
- A 2050 energy mix will need to include moderate to massive energy generation via nuclear energy both to meet a projected increase in energy demand and to provide additional dispatchable power given an increase in non-dispatchable renewables.
- Government clean energy investment announced prior to COP 26 has been severely lacking. Almost half of our projected emissions reductions will come from technologies not ready today.
- A federal Canadian emissions reduction policy needs to be substantiated by specific emissions reduction plans (grounding recommendations in the above reports, and including numbers projected by the Canadian Energy Regulator's estimates for 2050 electricity generation).

- Through ECCC's climate plan there are pathways to achieve a greater SMR investment from the federal government if recommended. The federal government also accepts the SMR Roadmap's cost-sharing and risk-sharing recommendations

- While the oil sands industry has expressed interest in SMR technology, there needs to be more government incentives to do so before the industry voluntarily invests heavily in SMRs. This is especially important as most of Canada's emissions will come from this industry

Canada's current energy generation portfolio, in terms of share by technology, is presented in **Figure 3.** The challenge is, by 2050, to dramatically increase electricity generation and simultaneously reduce to 5% the present 19% share from fossil fuel technologies. The total electricity generated in this figure was 643 TWh for 2018 (Statistics Canada, 2021). The Canada's Energy Future estimated generation and technology shares for 2050 with an "Evolving Policies Scenario" (see Figure 3). It predicts 876 TWh generated annually by 2050, an increase of 228 TWh in 2050 relative to 2018. (As a note, this number is significantly lower than estimates given by Ontario, New Brunswick, ECCC and the IEA). These numbers will be used for each policy option. Each policy option is a percent range in 2050 of total generation arising from nuclear, the TWh generated by nuclear, and estimate of number of 300 MWe SMRs needed to realize the relevant option. The provinces considered for each policy include Ontario, New Brunswick, Saskatchewan, and Alberta. This is because they make up 85% of Canada's current electricity generation by fossil fuels, have expressed interest in SMR development, signed an MOU for SMR production in Canada, and provinces such as BC, Manitoba, and Quebec have already achieved major decarbonization.

Figure 3. Canada's Current Electricity Generation Portfolio, 2018 (Total 648 TWh)



Source: Statistics Canada. Table 25-10-0020-01 Electric power, annual generation by class of producer: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2510002001

Note to reader: For ease of reading, biomass/geothermal has been removed for its insignificant electricity generation and oil, coal, and natural gas are combined under "fossil fuels" to simply interpretation further. This goes for all subsequent pie charts.

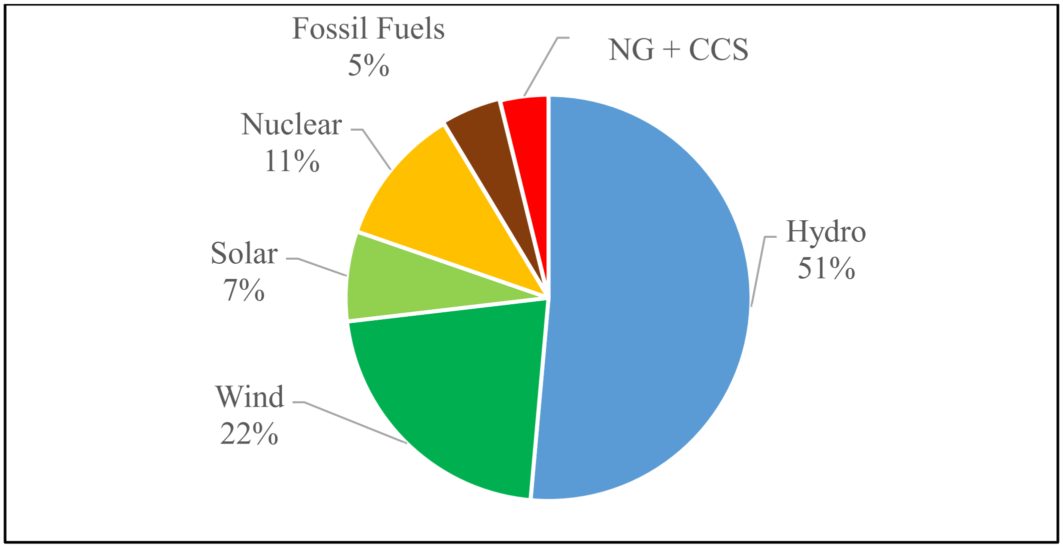
6.1. Policy Option 1: Status Quo Investment, 10-15% Nuclear Power Share of Power Generation by 2050

This option is a continuation of the Canadian nuclear status quo. The energy predictions here are taken from the Canadian Energy Regulator's (CER) Energy Fact Sheet predictions for 2050 with an evolving policies scenario. This scenario sees a policy landscape that largely relies on renewables. Electricity demand will increase by 228 TWh. The projected nuclear share of total electricity generation in 2050 declines to 11%, an increase of only 1 TWh. Given a range of error, this policy aims for 10-15% nuclear generation by 2050. **Figure 4** shows a complete breakdown of the CER predicted scenario in 2050.

Figure 5 gives a percent breakdown of the additional electricity generation needed on top of today's current production. Nuclear will make up 0% of the increase (it will actually be a decrease in nuclear energy production); 78% will be derived from wind and solar. Specifically, this policy recommendation would see nuclear energy production go from 97.2 TWh annually in 2018 to 96.4 TWh in 2050. This is a total decrease of 0.8

TWh annually equivalent to less than the output a single 300 MW SMR. This would imply Alberta and Saskatchewan adopt another non-fossil technology to clean their on- and off-grid emissions.

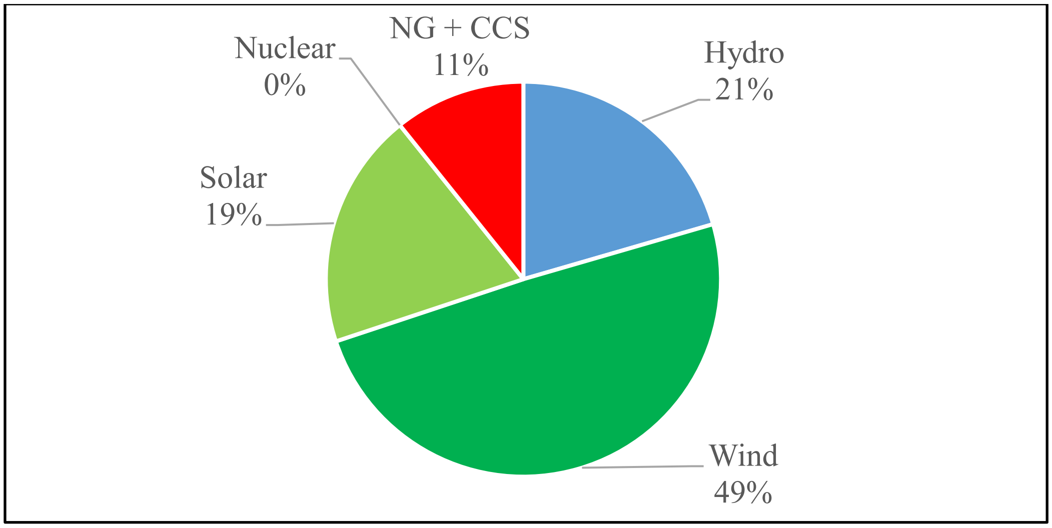
Figure 4. Option 1, Canada's CER Predicted Electricity Generation Portfolio, 2050 (Total 875 TWh Annually)



Source: Canada's Energy Futures 2021 Fact Sheet: Electricity - Total Generation by Energy Source - Evolving Policies Scenario: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021electricity/index.html

Note to reader: For ease of reading, biomass/geothermal has been removed for its insignificant electricity generation and oil, coal, and natural gas are combined under "fossil fuels" to simply interpretation further. This goes for all subsequent pie charts.

Figure 5. Option 1, Canada's CER Predicted Additional Electricity Generation Portfolio, 2050 (Total 228 TWh Annually)



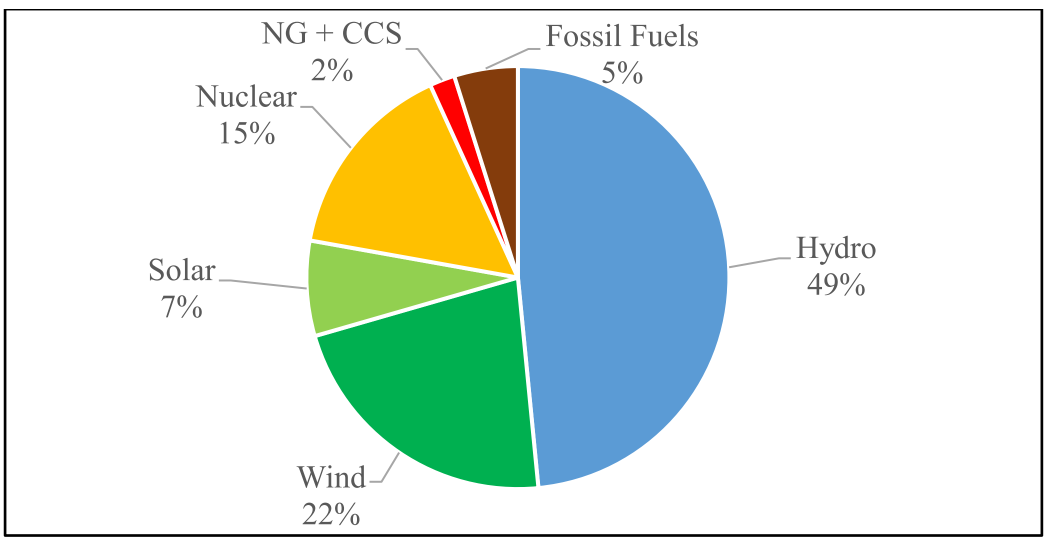
Source: Canada's Energy Futures 2021 Fact Sheet: Electricity - Total Generation by Energy Source - Evolving Policies Scenario: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021electricity/index.html

Note to reader: For ease of reading, biomass/geothermal has been removed for its insignificant electricity generation and oil, coal, and natural gas are combined under "fossil fuels" to simply interpretation further. This goes for all subsequent pie charts.

6.2. Policy Option 2: Moderate Investment, 15-20% Nuclear Power Share of Power Generation by 2050

This policy option proposes that the federal government increase current SMR investments via a moderate investment strategy. This would maintain the current percentage of electricity generation from nuclear power. It takes the same CER Energy Fact Sheet predictions for 2050 with an evolving policies scenario and alters them based on a few data points. This policy option recognizes that Ontario, New Brunswick, Saskatchewan, and Alberta combine to make up 41% of the total electricity generation in Canada (Statistics Canada, 2021). Furthermore, they currently produce 85% of Canada's total fossil fuel generation (2021). This policy option takes seriously the stated goals of OPG, NB Power, SaskPower, The Energy Ministry of Alberta, and The Oil Sands Industry's interest in SMRs. Here, it is assumed that the predictions for wind and solar stay the same as option 1, however hydro and natural gas with CCUS is assumed to be half of the additional predicted electrical generation from now to 2050. That extra generation capacity would be met instead by SMRs leading to a jump from 97.2 TWh annually today to 131.4 TWh in 2050. This policy strategy makes sense as nuclear can be a good alternate dispatchable/baseload power source from hydro and gas. This option sees a 2018-2050 increase of 34.2 TWh annually produced by nuclear power. It would require about 14 300MW SMRs. The exact final electricity generation powered by nuclear in 2050 would be 15%, as is the 2018 share. Given uncertainty, we will define this as 15-20% nuclear generation by 2050. **Figure 6** shows a complete breakdown of the adjusted CER predicted scenario in 2050. Given that the energy demand for Canada will increase by 228 TWh for the year 2050, **Figure 7** gives a percent breakdown for each energy method for the new electricity generation that will be needed on top of today's current methods of production. Examining the data this way shows that nuclear will supply 13% of the needed increase in electricity generation. This assumes the use of the most readily available SMR technology in Alberta and Saskatchewan.

Figure 6. Option 2, Canada's CER Predicted Electricity Generation Portfolio Adjusted for Moderate Investment, 2050 (Total 875 TWh Annually)

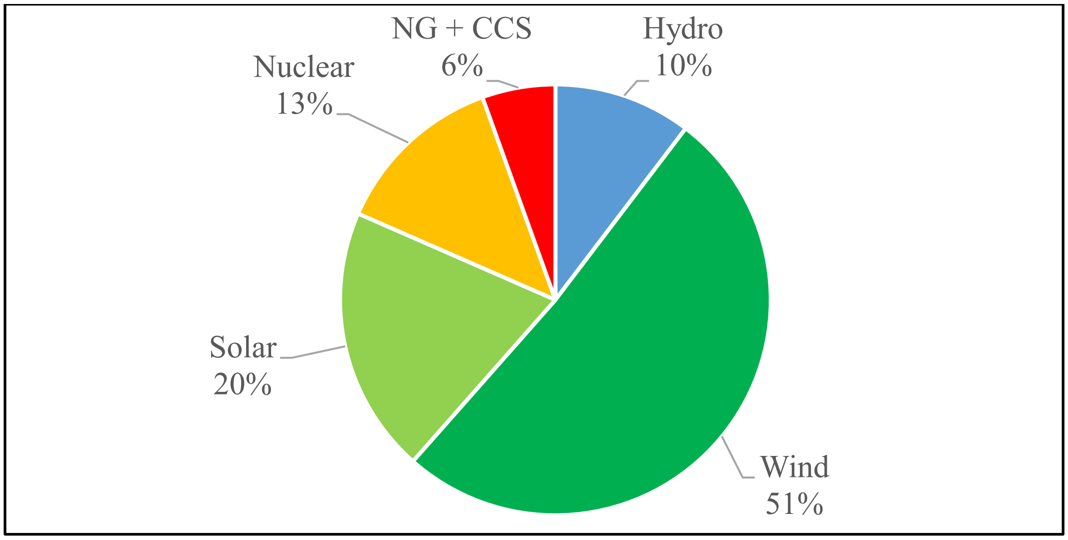


Source: Canada's Energy Futures 2021 Fact Sheet: Electricity - Total Generation by Energy Source - Evolving Policies Scenario: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021electricity/index.html

Note to reader: For ease of reading, biomass/geothermal has been removed for its insignificant electricity generation and oil, coal, and natural gas are combined under "fossil fuels" to simply interpretation further. This goes for all subsequent pie charts.

Numbers in option 1 have been adjusted by halving the percent of energy generation estimated by CER to be carried out by hydro and gas with CCS. This is based on the interviewees information that hydro will be limited in ON, NB, SK and AB. Additionally, CCS is still in early technology stages.

Figure 7. Option 2, Canada's CER Predicted Additional Electricity Generation Portfolio Adjusted for Moderate Investment, 2050 (Total 228 TWh Annually)



Source: Canada's Energy Futures 2021 Fact Sheet: Electricity - Total Generation by Energy Source - Evolving Policies Scenario: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021electricity/index.html

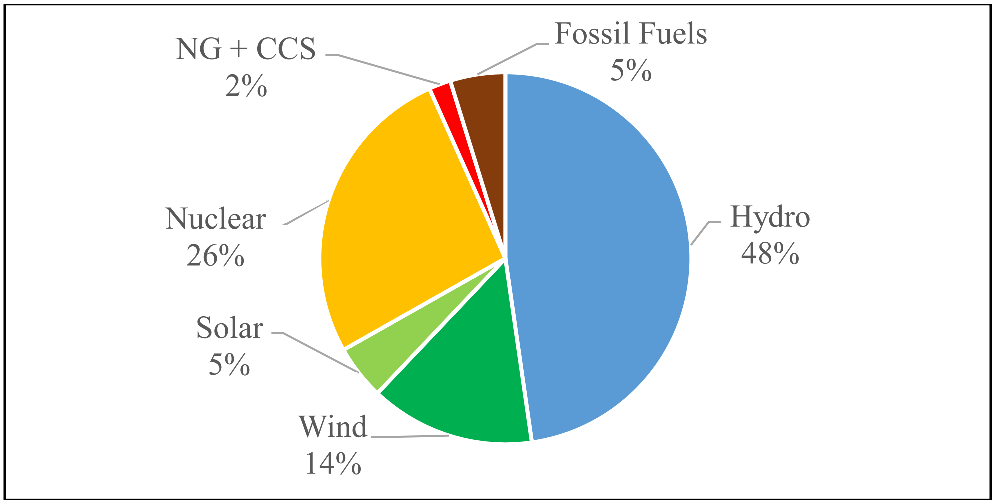
Note to reader: For ease of reading, biomass/geothermal has been removed for its insignificant electricity generation and oil, coal, and natural gas are combined under "fossil fuels" to simply interpretation further. This goes for all subsequent pie charts.

Numbers in option 1 have been adjusted by halving the percent of energy generation estimated by CER to be carried out by hydro and gas with CCS. This is based on the interviewees information that hydro will be limited in ON, NB, SK and AB. Additionally, CCS is still in early technology stages.

6.3. Policy Option 3: Aggressive Investment, 25-30% Nuclear Power Share of Power Generation by 2050

This policy option proposes that the federal government adopt an aggressive increase in SMR investments. It still utilizes the CER Energy Fact Sheet predictions for total 2050 power generation with an evolving policies scenario and alters them on additional data points from option 2. Again, this policy recognizes that Ontario, New Brunswick, Saskatchewan, and Alberta combine to make up 41% of the total electricity generation in Canada and produce 85% of Canada's total fossil fuel generation (Statistics Canada, 2021). This policy option takes seriously the stated goals of OPG, NB Power, SaskPower, and the Energy Ministry of Alberta interest in SMRs. However, it assumes that the Oil Sands Industry's interest in SMR use is unrealistic. Increases in hydro and natural gas with CCUS are assumed to be half of the additional predicted electrical generation from now to 2050. Additionally, the share of solar plus wind power are estimated to perform at two-thirds what the CER has predicted in option 1. The additional generation capacity would again be met instead by SMRs leading to an increase from 97.2 TWh annually today to 227.8 TWh in 2050. This policy strategy sees nuclear as both a good baseload power and dispatchable power source. To reach this policy strategy it would require massive uptake in SMRs in on-grid, off-grid (for mines), and oil and gas applications. This option sees an increase of 130.6 TWh annually produced by nuclear power by 2050. To realize this increase would require about 54 300MW SMRs. The exact final electricity generation powered by nuclear in 2050 would be 26%. Using a range of error, option 3 entails 25-30% nuclear generation by 2050. **Figure 8** shows a complete breakdown of the adjusted CER predicted scenario in 2050. Given that the energy demand for Canada will increase by 228 TWh for the year 2050, **Figure 9** gives a percent breakdown by each energy method for the additional annual electricity generation needed on top of today's current methods of production. Examining the data this way shows that nuclear will make up 44% of the additional electricity generation needed. This probably implies investment in many SMR technologies including liquid molten salt and high temperature gas reactors with large utilization in Alberta and Saskatchewan on- and off-grid.

Figure 8. Option 3, Canada's CER Predicted Electricity Generation Portfolio Adjusted for Aggressive Investment, 2050 (Total 875 TWh Annually)

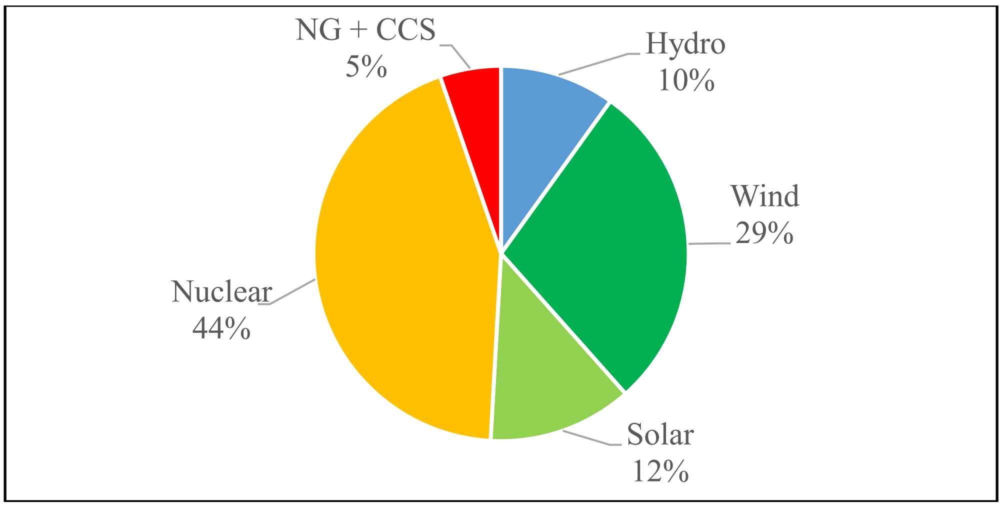


Source: Canada's Energy Futures 2021 Fact Sheet: Electricity - Total Generation by Energy Source - Evolving Policies Scenario: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021electricity/index.html

Note to reader: For ease of reading, biomass/geothermal has been removed for its insignificant electricity generation and oil, coal, and natural gas are combined under "fossil fuels" to simply interpretation further. This goes for all subsequent pie charts.

Numbers in option 1 have been adjusted by halving the percent of energy generation estimated by CER to be carried out by hydro and gas with CCS and reducing renewables by 1/3rd. This is based on the interviewees information that hydro will be limited in ON, NB, SK and AB. Additionally, CCS is still in early technology stages and renewables need to be complemented with a significant amount of high capacity, dispatchable power generation.

Figure 9. Option 3, Canada's CER Predicted Additional Electricity Generation Portfolio Adjusted for Aggressive Investment, 2050 (Total 228 TWh Annually)



Source: Canada's Energy Futures 2021 Fact Sheet: Electricity - Total Generation by Energy Source - Evolving Policies Scenario: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021electricity/index.html

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Numbers in option 1 have been adjusted by halving the percent of energy generation estimated by CER to be carried out by hydro and gas with CCS and reducing renewables by 1/3rd. This is based on the interviewees information that hydro will be limited in ON, NB, SK and AB. Additionally, CCS is still in early technology stages and renewables need to be complemented with a significant amount of high capacity, dispatchable power generation.

Table 3. Total Power Generation and SMR Calculations for Each Policy Option

CANADA'S TOTAL POWER GENERATION	***TWh***
Electricity generation, 2018	***648***
Electricity generation, 2050	***876***
Net Energy Increase, 2018 - 2050	***228***
OPTION 1	
Nuclear 2018 (15%)	***97.2***
Nuclear 2050 (11%)	***96.36***
Difference	***-0.84***
OPTION 2	
Nuclear 2018 (15%)	***97.2***
Nuclear 2050 (15%)	***131.4***
Difference	***34.2***
OPTION 3	
Nuclear 2018 (15%)	***97.2***
Nuclear 2050 (26%)	***227.76***
Difference	***130.56***

ANNUAL POWER GENERATION PER 300 MW SMR	
SMR Capacity Factor (low estimate)	***0.9***
hours per year	***8760***
SMR capacity (MW)	***300***
annual power generated / SMR (MWh)	***2,400,000***
annual power generated / SMR (TWh)	***2.4***

REQUIRED SMRS	
OPTION 1	***< 1***
OPTION 2	***14***
OPTION 3	***54***

Chapter 7.

Criteria and Measures

OBJECTIVE 1: GHG Reductions by 2050 (x2)

Criterion: Likelihood of realization of GHG Reductions by 2050, with competing technologies and limitations

Measure: Considers the projected end energy mix for each policy option and assesses the probability of success based on background literature and information and recommendations from expert interview.

Option 1: Status Quo, 10-15%, 1 SMR	Option 2: Moderate Investment, 15-20%, 14 SMRs	Option 3: Aggressive Investment, 25-30%, 54 SMRs
Low	Med	High

Policy option 1 ranks the lowest likelihood to deal with net-zero emissions by 2050. Though this is consistent with the Canada Energy Regulator's current proposed energy mix, it does not reflect the recommendations of OPG, NB Power, Alberta Innovates, or the IPCC's summary for policy makers. It relies too heavily on non-dispatchable power generation technology such as wind and solar. It also over-estimates the extent that additional hydro energy will be produced in Ontario, New Brunswick, Saskatchewan and Alberta. Option 2 ranks medium as it is more in line with the advice and current projects in each province of concern. It has a lower percent of hydro generation, reflecting the geographical limitations of new hydro in the four relevant provinces. Policy option 3 ranks highest as it extends nuclear share of required electricity. This is in line with the SMR Road map and Action plan, which sees multiple uses for all SMR streams and technologies. It also addresses the issues of hydro, gas with CCUS, and renewables raised for option 1 and 2.

OBJECTIVE 2: Cost (x2)

Criterion: Levelized cost of energy (LCOE) for nuclear power generation in each policy option

Measure: Uses the estimated levelized unit cost of nuclear energy for each option.

Option 1: Status Quo, 10-15%, 1 SMR	Option 2: Moderate Investment, 15-20%, 14 SMRs	Option 3: Aggressive Investment, 25-30%, 54 SMRs
High	Med	Med

Option 1 was rated the highest for the largest LCOE from all nuclear power generation. The figure used to assess this option was the LCOE for a CANDU 6 reactor analyzed by the Canadian Energy Research Institute (Ayres, McRae, & Stogran, 2004). It estimated an LCOE of $88.64/MWh in 2003 CAD (2004, p.14). Using the Bank of Canada inflation calculator in comes to $114/MWh in 2018 CAD.

Policy option 2 and 3 both use the LCOE with a 6% discount rate provided in the SMR Roadmap. It also takes the high-end measurement from this at $85/MWh in 2018 CAD giving them both a medium ranking for cost. If the efficiencies of SMR production are assumed to be correct, these both could be argued to rank as low costs. However, as these cost efficiencies cannot be definitive, the LCOE estimate for SMRs used here is more conservative.

OBJECTIVE 3: Safety

Criterion: Assess the safety concerns for the reactor design for each policy option

Measure: Considers the safety features used in the proposed reactor type for each policy option and the potential risk and consequences of a meltdown. Assessment informed by background research and interviews

Option 1: Status Quo, 10-15%, 1 SMR	Option 2: Moderate Investment, 15-20%, 14 SMRs	Option 3: Aggressive Investment, 25-30%, 54 SMRs
Med	High	High

The safety objective for policy option 1 was rated medium. Not that it is unsafe; rather, it relies on older CANDU reactor safety systems, which are less reliable than in SMRs. Specifically, the CANDU 6 reactors in use today have horizontal fuel rods. In the event of a meltdown these fuel rods would begin to bend toward the ground due to gravity. This bending of the fuel rods slows and may even stop the meltdown. Additionally with the water in the reactor acting as a moderator, when it completely steams off due to a meltdown the fissile reaction would be slowed (see section on meltdowns for more detail). Policy options 2 and 3 are rated high for the use of more modern reactor passive safety systems. Using the new GE Hitachi BWRX 300 reactor, the passive safety system includes the ability for steam generated in the reactor to be utilized through a cooling system that requires no intervention or electricity. Policy option 3 implies that some SMRs would have the benefit of the safety designs found in policy option 2, plus the passive safety systems of newer Gen 4 reactors. One such safety feature is the “freeze plug” found in liquid molten salt reactors. This plug melts at a specific temperature so that, if the reactor ever becomes too hot, all the liquid fuel is drained into storage tanks, completely stopping the reactor.

OBJECTIVE 4: Technological Readiness

Criterion: Potential timeline to be completed given the state of the technology

Measure: Uses the Technology Readiness Levels (TRL) scale and assess the TRL of each proposed reactor type in each province. This is used by the federal government and is a scale from 1 to 9. Assessment informed by interviews with engineers and scientists working with technology.

Option 1: Status Quo, 10-15%, 1 SMR	Option 2: Moderate Investment, 15-20%, 14 SMRs	Option 3: Aggressive Investment, 25-30%, 54 SMRs
High	Med	Low

The status quo option ranks highest on TRL levels. It relies on reactor technology already operating like the CANDU 6 (TRL 9: "Actual technology proven through successful deployment in an operational setting") and the closest SMR to begin completion, the GE Hitachi BWRX 300 (TRL 7: "Prototype ready for demonstration in an appropriate operational environment"). Option 2 ranks medium due to its reliance on the most readily available SMR tech, the GE Hitachi BWRX 300 (TRL 7: "Prototype ready for demonstration in an appropriate operational environment"). Policy option 3 ranks lowest because of its inclusion of lower scoring TRLs like high temperature gas, and liquid molten salt reactors (TRL 6: "System/subsystem model or prototype demonstration in a simulated environment" and TRL 5: "Component and/or validation in a simulated environment"). These TRL levels are informed from my discussions with CNL and MIT nuclear scientists.

OBJECTIVE 5: Extent of non-nuclear Dispatchable Power

Criterion: Considers the new dispatchable power generation needed in each province

Measure: Uses literature and expert interview recommendations to estimate the dispatchable power needed in the provinces considered.

Option 1: Status Quo, 10-15%, 1 SMR	Option 2: Moderate Investment, 15-20%, 14 SMRs	Option 3: Aggressive Investment, 25-30%, 54 SMRs
Low	Med	High

This objective measure requires some assumptions about renewables and hydro backed by literature and expert interviews. Assumption 1: Grids require a specific, typically large amount of dispatchable power to meet hours of high electricity demand. Assumption 2: Renewable energy production such as solar and wind experience a "duck curve". Over the course of a day there is a timing imbalance between peak demand and peak renewable energy production. For example, solar may provide much of the power required during daylight hours, but solar does not contribute at the evening peak. Hence, solar does not lower the need to invest in dispatchable non-fossil technologies, essentially nuclear and hydro. The remaining sites for low LCOE hydro dams are limited as suggested in my interviews. The conclusion is that a policy scenario with a high amount of nuclear would be best to meet our dispatchable power requirements and complement the use of renewables. For these reasons option 1 ranks lowest, option 2 medium and option 3 ranks highest.

OBJECTIVE 6: Public Acceptance

Criterion: Negative public opinion generated by each policy option

Measure: Considers polling data in each province for nuclear opposition, notable anti-nuclear advocacy groups and expert interview information on existing nuclear public opinion trends.

Option 1: Status Quo, 10-15%, 1 SMR	Option 2: Moderate Investment, 15-20%, 14 SMRs	Option 3: Aggressive Investment, 25-30%, 54 SMRs
High	Low	Low

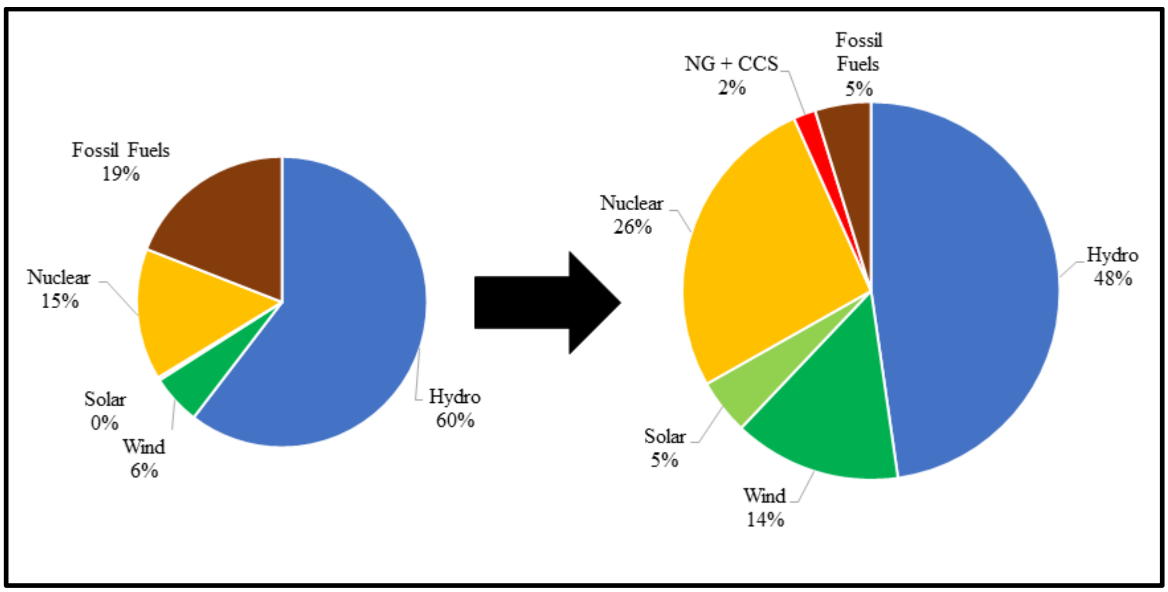
For this objective public acceptance ranks highest for option 1. It relies on technologies that have received significant public approval. Most existing projects are located in Ontario, where public approval of nuclear is highest. Both option 2 and 3 rank low because they imply new nuclear projects built in provinces such as Alberta and Saskatchewan. These are provinces with no current nuclear projects. Public acceptance of nuclear energy in these provinces is much lower than in Ontario. My interview with a Canadian political scientist who researches nuclear public opinion informed me of results in past nuclear public consultations for both Alberta and Saskatchewan.

Below is the final scoring for each policy option with all criteria included. For all criteria except cost, options are ranked low, medium, and high. Low is worth 1 point, medium 2, and high 3. Cost is reverse scored where low cost receives the highest points. Based on the importance of cost and GHG reductions for this problem they were double weighted.

Objective & Measure	Option 1: Status Quo, 10-15%, 1 SMR	Option 2: Moderate Investment, 15-20%, 21 SMRs	Option 3: Aggressive Investment, 25-30%, 55 SMRs
GHG Reductions by 2050 (x2): Likeliness of meeting GHG Reductions by 2050, with competing technologies	Low	Med	High
	2	4	6
Cost (x2): Levelized unit cost of energy for nuclear technology used in each option	High	Med	Med
	2	4	4
Safety: Assess the risk of meltdown given the safety features of the technology	Med	High	High
	2	3	3
Tech Readiness: TRL scale used by federal government and informed by interviews	High	Med	Low
	3	2	1
Dispatchable Power: Provincial dispatchable power met or exceeded according to interviews and literature	Low	Med	High
	1	2	3
Public Acceptance: Polling data in each province for nuclear opposition, notable anti nuclear advocacy groups	High	Low	Low
	3	1	1
Overall Score	=13	=16	=18

The above analysis shows that when all relevant criteria are scored, policy option 3 scores the highest. This would see an aggressive increase in the federal government's investment in SMRs. In this option, nuclear energy would represent 26% of Canada's total energy mix by 2050, which would require approximately 54 300 MWe SMRs. An important thing to point out is that this option also sees a near fourfold increase in Canada's use of renewables. Renewables would make up just under 20% of our total energy mix shown in **Figure 10.** The large increase in nuclear energy does not undermine the push for renewables. Both are necessary and complement each other. The amount of SMRs recommended may seem like a lot. However, this estimate may be far under what we actually need. The CER numbers used in this analysis assume an approximate 25% increase in our energy use by 2050, while OPG, NB Power, ECCC, and the IPCC predict a 100-200% increase. If these organizations are correct, we would require more than 54 SMRs to assure 26% of nuclear in our energy grid in 2050. We are in a time of transition. Any strategy to decarbonize will require a major departure from the present.

Figure 10 Energy Generation Porfolio in 2018 (648 TWh) Transition to Reccomended 2050 (876 TWh) Policy Option



Chapter 8.

Conclusion

By viewing our future energy mix through the lens of the Canadian Net-Zero GHG emissions by 2050 legislation, this paper assesses whether we will require nuclear energy to attain net zero, and furthermore, how much nuclear we should accommodate. The background literature found that each jurisdiction will need to consider its specific geographic conditions and advantages to determine its specific energy investments. It also found that Canada has a large advantage over other nations developing new small modular reactors as we have a successful history of nuclear use, large uranium mines, a capable supply chain, a trusted independent regulator, and the necessary academic research laboratories. Transitioning the production of electricity from fossil to non-fossil fuels is a major concern for the provincial and federal governments. 85% of the total electricity generation from fossil fuels in Canada is from Alberta, Saskatchewan, Ontario, and New Brunswick (Statistics Canada, 2021). Each of these provinces has stated an intent to use SMRs to reduce their GHG emissions. Evidence of this can be found in both my expert interviews, and in the MOU for SMR development in Canada (Ontario et al, 2020).

However, this paper finds a disconnect between the nuclear energy projections of the provinces, those of the oil sands industry, and the federal government. While the provinces aim for ample nuclear power generation, the Oil Sands to Net Zero report relies on few SMRs. Instead, it prefers large investment in CCUS. The federal message is unclear. Though the natural resources ministry seems to favour nuclear, evidence suggests, the environmental ministry does not (Chamandy, 2021). At the centre of the federal government is the Prime Ministers Office. It has yet to provide clear messaging about the future of nuclear in Canada, beyond a vague quote from Trudeau (Chamandy, 2021). Through the information provided by the literature and 10 expert interviews, this paper concludes that strategizing Canada to achieve 25-30% of total electricity generation by 2050 is the best Net-Zero strategy of the policies discussed. This would require the development of roughly 54 300 MWe reactors or equivalent using multiple reactor designs to meet on- and off-grid needs. Achieving this goal with our current landscape would be difficult; however, many interviewees provided specific policy recommendations that can probably achieve the energy mix recommended:

- **Increase CNSC Capacity:** to deal with the greater amount of reactor regulatory approvals required for a successful SMR strategy, the CNSC will need a larger workforce.

- **Reduce Regulatory Requirements for Subsequent SMR Builds:** All of the necessary regulatory processes should be completed for new reactors. However, subsequent builds with same design and with the same operator could benefit from reduced regulatory time utilizing already established information.

- **Re-evaluate Security requirements for SMRs**: Due to the inherent size difference and containment design of the SMR, experts argue that a 300 MWe SMR should not require the same security as a 1500 MWe conventional reactor.

- **Give SMRs Access to All Federal Clean Energy Funding:** Allow SMR vendors to access all federal funding programs designed for development and deployment of clean energy. Some clean energy programs are currently limited to renewables (e.g., Green Bond Framework)

- **Hasten Price Incentives for Oil Sands to Decarbonize:** To increase the speed of decarbonization in the oil sands industries, clear price incentives need to be set. This can be achieved by higher carbon pricing or cap and trade policies. As it stands, the oil sands industry is moving much slower than provincial utilities at decarbonizing.

- **A Clear Federal Message:** The federal government needs to take a unified stance on SMR technology, messaged from the top. This will give both investment signals to private industry and open up public dialog.

- **Public, Energy Information Initiatives:** Deliberate public information campaigns about the pros and cons of each energy generation method need to begin. This will allow Canadian citizens to make informed decisions about Canada's final energy mix. It will hopefully also reduce nuclear energy's biggest obstacle, public acceptance.

Additional to these policy recommendations, the current Canadian SMR demonstration projects will hopefully play a large role in attracting investment and informing public opinion. Four demonstration projects are on their way in Canada: GE Hitachi is looking to demonstrate a 300 MWe reactor at the Darlington site in Ontario for on-grid use in 2028; Global First Power is building a 15 MWe reactor at Canadian

Nuclear Laboratories for use in remote communities or mines, to be completed in 2026; ARC Energy Canada is developing a 100 MWe advanced reactor for on-grid or heavy industry use in New Brunswick, estimated to be completed in 2030; lastly, Moltex Energy backed by New Brunswick, is looking to demonstrate their SSR-W 300 MWe reactor, which could use CANDU waste as fuel, estimated to be completed in 2030.

If successful, these demonstration projects may increase public trust for new nuclear technology and enable a positive discussion about Canada's use of nuclear energy. Success of these demonstration projects may also attract private investment and enable Canadian SMR exports to countries that also require nuclear to decarbonize.

Canada has committed itself to the Paris Agreement, which is to hold the increase in the global average temperature well below 2 C above pre-industrial levels. There has been wide agreement by scholars that countries, including Canada, are failing to meet their emission targets. The current energy projections for 2050 given by Canada's Energy Regulator are misaligned with the ambitions of high fossil fuel use provinces and with sound energy policy that requires adequate dispatchable power. If Canada backs the current provincial SMR MOU, that would see a large increase in SMR investment; it would make more credible the commitment to meet our Net-Zero emissions strategy. Furthermore, we would be building a new global industry in Canada. This would see major increases in GDP, tax revenues, and job creation. SMRs could be the complementary technology to enable increased generation share from renewables.

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