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Understanding Small Modular Reactors

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Understanding Small Modular Reactors

Small modular reactors (SMRs) are smaller-scale versions of conventional nuclear reactors. SMRs are typically designed to produce less than 300MW of power, however, they can be phased together to form a larger plant capable of producing greater power output. (Orenstein 2020; CNSC 2016; Mignacca and Locatelli 2020; OECD 2016). SMRs use nuclear fission to produce energy: energy for electricity, hybrid energy systems, district heating, water desalination, and high-quality steam for heavy industry applications (CNA 2018). They are modular, i.e., the modules are engineered off-site and moved to places where they are needed. This type of manufacturing provides a higher quality of construction, reduced production time, and ease of installation on-site.

SMRs have a passive cooling system[1] that does not require operator actions or electronic feedback, making them much safer (CNSC 2016). SMRs are designed to have a maximum amount of fuel consumption with comparatively less nuclear waste per unit of energy produced (CNSC 2016; WNA 2020a). Some SMR designs can utilize both uranium-235 (U^{235}), an isotope of uranium, and spent fuel from other reactors. SMRs can also be used as breeder reactors to convert naturally available uranium-238 (U^{238}), the most common isotope of uranium, into a usable fuel source (WNA 2020a). Some reactors use thorium feedstock as an alternative to uranium, which offers comparatively reduced long-term waste radiotoxicity (Croff and Krahn 2016). SMRs have advanced safety features that are aiming to reach the standards of conventional nuclear reactors. These reactors, once deployed, can reduce carbon emissions compared to fossil fuel-based electricity generation.

Pan-Canadian Approach for SMR Development

In December 2019, the provinces of Ontario, New Brunswick, and Saskatchewan, signed a memorandum of understanding (MOU) to collaborate on the development and deployment of SMR. Their main objective is to provide clean, low-cost energy to off-grid and on-grid communities and industries to decarbonize the energy sector as much as possible (MOU 2019). On August 7, 2020, as part of Alberta's Recovery Plan, the Government of Alberta announced its intention to enter the MOU with its provincial partners.

Canada is estimated to have the world's largest deposit of high-grade uranium, and the highest cumulative uranium production globally, 538,546 tons from 1945-2019 (Statista 2020). Canada is the second-largest producer with 7,648 tons of uranium production in 2019, with Kazakhstan being the highest with 25,141 tons produced (WNA 2020c). With the quality and quantity of Canadian uranium production, it is estimated that investments in Canadian SMR projects could be valued at $5.3B between 2025-2040 (CNA 2018). Canada is an ideal country for the deployment of SMRs due to its mature supply chain, domestic uranium

[1] Most conventional nuclear accidents/reactor meltdowns have happened due to failures of the active cooling mechanisms and SMRs are safer due to passive cooling nature.

mining, along with extensive nuclear power operating experience, and nuclear research laboratories (CNA 2018).

According to the Canadian Small Modular Reactor Roadmap, convened by Natural Resources Canada (NRCan) to engage provinces and stakeholders for successful deployment of SMRs, the expected outcomes of SMR deployment include (Sheehan, Mclnerney, and Ridge 2020; CNA 2018):

- Facilitating the province in phasing out coal by 2030 by providing 90% of on-grid electricity generation by reducing the emissions.
- Reliable non-emitting heat and electricity generation for oil sand facilities, remote communities, heavy industry plants, and off-grid mines.
- Providing off-grid indigenous and remote communities with an option to replace their current reliance on diesel fuel for heating, desalination, and electricity generation.

Other renewable energy sources can be used for commercial and residential electricity supply, but they will not be able to provide heat. SMRs offer a viable option for reliable and low-cost energy.

Provincial Objectives for SMRs

Although the provinces share the common goal to provide a non-emitting, reliable, and low-cost energy alternative for off-grid and on-grid communities, each province also identified specific economic objectives.

1. **Alberta:**
   - Alberta aims to decarbonize its oil sands facilities, which are remote and off-grid; SMRs are versatile and scalable to meet those facility needs while also providing non-emitting sources of affordable energy (WNN 2020).
   - Alberta wants to diversify its economy and explore plausible opportunities to create jobs to support its COVID recovery, along with providing an affordable energy source through SMRs (WNN 2020; WNA 2020a).
2. **New Brunswick:**
   - The province anticipates connecting its off-grid and on-grid communities by generating low cost, non-emitting energy.
   - As SMRs are deployed, it could benefit energy-intensive industries, including the province's mining and manufacturing sectors, along with driving its economic growth and export opportunities. It is also focussing on intensive research regarding fourth-generation reactors (Government of New Brunswick 2019).
3. **Ontario:**
   - Ontario is focussing on bringing low-cost energy to its northern off-grid communities and their energy-intensive industries like the mining sector that are currently relying on expensive diesel power for heat and electricity.
   - Since SMRs can integrate with their currently established renewable energy system, they hope to provide incremental electricity supply as the demand wavers.
4. **Saskatchewan:**
   - According to the climate action plan, the countries which are a part of the Organisation for Economic Co-operation and Development (OECD) and European Union are expected to phase out coal by 2030 and the rest of the world by 2050 (Government of Canada 2017), and Saskatchewan electricity generation is mainly produced from coal and natural gas. Their main aim is to phase out coal through SMRs and provide off-grid and on-grid communities with non-emitting and economical energy services (Government of Saskatchewan 2019).
   - The province is expected to have at least 40% of its generation through non-emitting sources by 2030 (CNO 2019).

To convert a road map into an action plan, the provinces have decided on the following strategies for deploying SMRs throughout Canada. (Sheehan, Mclnerney, and Ridge 2020).

- **Demonstration & deployment:** The expenses and risks should be shared between the provinces and investors to encourage the deployment of SMRs.
- **Engagement with Indigenous communities:** Since one of the significant provincial goals is to provide a reliable, non-emitting, and inexpensive power source for off-grid communities, there is a need to engage with Indigenous and other remote communities to familiarize them with SMR technology and reduce their concerns regarding a new energy source.
- **Legislation, policies, and regulations:** Proposals on federal government impact assessment, nuclear liability, and waste management with regulatory efficiencies.
- **Partnership with international markets:** Working with the Canadian nuclear industry to build access to global markets and relationships.

Comparative Analysis of SMRs with Other Sources

Table 1 indicates comparisons of capital costs, operation/management costs (fuel costs are excluded), and emissions from each energy source.

- Capital costs are much higher for SMRs than conventional sources. However, in the long run, if fuel costs are included, SMR costs are comparable to traditional natural gas and coal-fired power plants.
- Since SMRs are capable of high fuel burn-up rates and the source, i.e., uranium, is a highly concentrated source of energy compared to gas/oil or coal, one kilogram of natural uranium will yield about 20,000 times as much energy as the same amount of coal (WNA 2020b).
- As Canada aims for a higher proportion of non-emitting sources within its energy systems by phasing out coal by 2030 (Sheehan, Mclnerney, and Ridge 2020), SMRs will play a role along with carbon capture, energy efficiency, and renewable energy options.
- SMRs have a higher capacity than other non-emitting sources (capacity is the maximum electric output a facility can produce), which is advantageous for consumers compared to intermittent sources.

Table 1: Different SMR Plants and Technologies Profiles

S.no	Plant	Net Plant Capacity (MW)	Net Plant Heat Rate (Btu/kWh)	Total CAPEX ($)	CAPEX ($/KW)	OPEX		Emissions (lb/MMBtu)			
						Fixed ($/kW-year)	Variable ($/MWh)	NOx	SO2	CO2	CO
1	SMR	600 (12*50MW)	10046	$ 3,714,547,800	$ 6,191	$ 95.00	$ 3.00	-	-	-	-
	SMR Individual	50	837	$ 309,545,650	$ 516	$ 7.92	$ 0.25	-	-	-	-
2	Ultra Super Critical Coal w/o Carbon Capture	650	8638	$ 2,389,716,000	$ 3,676	$ 40.58	$ 4.50	0.06	0.09	206	-
3	Ultra Super Critical Coal 30% CO2 Capture	650	9751	$ 2,962,823,200	$ 4,558	$ 54.30	$ 7.08	0.06	0.09	144	-
4	Ultra Super Critical Coal 90% CO2 Capture	650	12507	$ 3,819,201,000	$ 5,876	$ 59.54	$ 10.98	0.06	0.09	20.6	-
5	Internal Combustion Turbines	21.4	8295	$ 38,727,000	$ 1,810	$ 35.16	$ 5.69	0.02	-	117	0.03
6	Combustion Turbines Aeroderivative	105	9124	$ 123,453,000	$ 1,175	$ 16.30	$ 4.70	0.09	-	117	-
7	Combustion Turbine F Class	233	9905	$ 165,790,000	$ 713	$ 7.00	$ 0.60	0.03	-	117	-
8	Combustion Turbine H Class	1083	6370	$ 1,037,939,000	$ 958	$ 12.20	$ 1.87	0.0075	0.001	117	-
9	Combustion Turbine H Class, Combined-Cycle Single Shaft	418	6431	$ 453,237,000	$ 1,084	$ 14.10	$ 2.55	0.0075	-	117	-
10	Combustion Turbine H Class, Combined-Cycle Single Shaft with 90% CO2 Capture	377	7124	$ 935,262,600	$ 2,481	$ 27.60	$ 5.84	0.0075	-	12	-

Source: (EIA 2020)

Regulatory Review of SMR Designs

Canadian Nuclear Safety Commission (CNSC) is the federal regulator of nuclear power and materials. CNSC regulates the construction, operations, and decommissioning of power plants in Canada. Licensing the construction and operation of a nuclear power plant—SMRs included—is rigorous and potentially a lengthy process. CNSC also faceplates an optional process called Pre-Licensing Vendor Design Review (VDR). A VDR is conducted on request of a nuclear power technology vendor and completion of a VDR does not certify a reactor design or involve the issuance of a licence. According CNSC (CNSC 2020), a VDR provides an opportunity for a reactor vendor to verify prior to a licensing application that the proposed nuclear power plant design is addressing Canadian regulatory requirements in its design and safety analysis activities and developing the necessary evidence to support the adequacy of the proposed design.

Currently, VDRs are being conducted for about twelve SMR designs by CNSC. Four of those SMR designs are in phase two of the three phases VDR (CNSC 2020).

Conclusion

The deployment of SMRs may offer substantial economic and environmental benefits for the participating provinces, including the provision of reliable, non-emitting electricity to off-grid and on-grid communities, a partial solution to the phase-out of coal-generated electricity, decarbonization of the oil sands, and the provision of a diesel alternative to off-grid communities. Reducing emissions throughout Canada and the development of fourth-generation nuclear reactors offers the country an opportunity to expand its energy sector.

However, there are also challenges that the provinces might face as SMRs are deployed.

- SMRs are a relatively new technology that is evolving. Furthermore, there is currently no SMR industry that includes plant manufacturing, a specialized labour force, and fuel production and delivery. Therefore, initially the average cost of electricity produced by SMR will potentially be higher. This is counter to introducing lower-cost thermal and electrical energy. However, commercial deployment of SMRs will lead to technology maturation and learnings that will potentially lower the cost.
- Licensing of SMRs can be problematic since the current licensing structures and the safety requirements were designed for larger nuclear reactors. Since SMRs are new technologies, changes to the regulatory framework may be required.
- Canada still has the open question of how to store radioactive waste long term. The introduction of SMRs compounds that challenge.

It is expected that the SMR MOU partners will consider these issues as they work through the development and deployment of SMRs such that the benefits exceed the costs.

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