SMR Development and Deployment Activities in New Brunswick

Presented at the 4th International Conference on Generation IV and Small Reactors G4SR-4

Toronto, Canada
2022 October 3-6

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Abstract

NB Power is working with two companies, ARC Clean Energy Canada and Moltex Energy Canada who are developing two advanced Generation IV Small Modular Reactors for potential deployment in New Brunswick, elsewhere in Canada, and around the world. This paper provides an update on the activities related to both designs and how NB Power is actively working with Ontario Power Generation, Bruce Power, SaskPower and Canadian Nuclear Laboratories on the Pan-Canadian approach for the development and deployment of SMRs. It follows on from a paper produced for the 2019 Annual CNS Conference (Reference 1)

1. Background

Nuclear energy has been a fundamental part of New Brunswick's energy mix for four decades, and New Brunswick has a history of being a Canadian leader in nuclear energy beginning with the construction of the Point Lepreau Nuclear Generating Station (PLNGS). The construction of PLNGS was completed in 1981, licensed to operate and began electricity production in 1982 and declared in-service in early 1983. The station underwent a refurbishment and life extension starting in the spring of 2008 and it returned to service in the fall of 2012.

PLNGS is a 705 MW(e) nuclear facility and was the first CANDU-6 reactor to be placed into operation. It provides non-emitting baseload energy to the electrical grid powering more than 333,000 homes per year. Currently, nuclear energy supplies approximately 36 per cent of the energy consumed in the province and results in a reduction of about 4 Mt of Greenhouse Gases (GHG) annually. The operation of the facility is also a valuable contributor to the economy, providing more than 2,700 direct and indirect jobs, $287 million in provincial GDP, and $29 million in provincial revenue. Eighty- five per cent of

the spending occurs within New Brunswick. The Point Lepreau site was originally intended to house multiple nuclear units. It has been the subject of multiple environmental assessments over the years, and as such is a relatively well-characterized site capable of supporting a number of SMR units and infrastructure.

Beginning in 2017, as part of the overall energy supply planning and to address the emerging requirements for GHG emission reductions, NB Power reviewed various nuclear supply options. Recognizing the potential benefits of the emerging SMR market, NB Power assessed over 90 SMR technologies for on-gird application. Based on a number of criteria such as nuclear safety, safeguards, reliability, environmental and waste, fuel supply, cost competitiveness, technological readiness, public acceptance and potential for economic benefits, NB Power focused in on advanced fast neutron spectrum reactors.

Advanced fast spectrum SMRs fall within the category of Generation IV reactors. They use a coolant other than water, such as molten salt or liquid metal and have inherent safety characteristics leading to less equipment, lower cost, ability to recycle their own used fuel, and will have superior ability to follow the intermittent output from renewable power sources. Nuclear reactors do not produce much high-level radioactive waste (HLRW) because they are a high-density power source. Advanced fast reactors can reuse their own used fuel many times over to produce significantly less (HLRW) than their Generation III predecessors and with a relatively shorter life cycle for disposal. Furthermore, these SMRs have the ability to reuse CANDU used fuel reducing the volume and associated long term storage requirements.

2. Establishment of the NB Advanced SMR Innovation Cluster

In 2018, in consultation with the Provincial Government, two advanced Generation IV SMRs technologies were selected. These were the ARC Clean Energy Canada's ARC-100 and the Moltex Energy Canada's SSR-W and its associated WATSS fuel conversion facility. The provincial government contributed $5 million to each vendor. This funding was in turn matched by each vendor[1].

Since 2018, both vendors have established offices in Saint John New Brunswick, hired staff, progressed their designs, progressing through the CNSC Vendor Design Review (VDR) process, advanced their project planning, and worked with the University of New Brunswick (UNB) to establish chair positions, curriculum, and plans for R&D to be performed at the Centre for Nuclear Energy Research at UNB. Both vendors have performed supply chain studies and have held discussions related to establishing a supply chain in New Brunswick. They have also been active in discussions with Indigenous representatives and the general public within the province to increase understanding of advanced SMR technologies.

[1] $10 million committed for nuclear research cluster (gnb.ca), Partner announced in nuclear research cluster (gnb.ca)

NB Power has been working cooperatively with the vendors and provincial government representatives. They have progressed pre-project planning and are conducting various activities associated with additional characterization of the Point Lepreau site. They have an extensive program related to Indigenous inclusion and public engagement. There is also active engagement with the New Brunswick public education system to increase teacher and student learnings on nuclear energy as part of the New Brunswick Centre for Excellence in Energy.

3. The ARC-100

The ARC-100 is a liquid sodium cooled fast spectrum non-pressurized pool reactor with an output of 100MW(e). It uses a sodium bonded metallic fuel that has an average enrichment of about 13%. This is referred to as High Assay Low Enriched Uranium (HALEU) fuel. The plant has a nominal design life of 60 years and has a 20-year refuelling cycle. It is a high temperature reactor (superheated steam at 14 MPa and 455^{o}C and 850^{o}C using topping heat) and as such can be configured for co-generation of electricity and steam for industrial applications, thus having a significant impact on the decarbonization of industry in Canada and abroad. Another ideal application is the production of hydrogen from a high temperature electrolizer or production of hydrogen-based products such as ammonia or synthetic fuels. The ARC-100 is also well suited for the side production of medical isotopes. The ARC-100 is based on a proven technology as demonstrated by the Experimental Breeder Reactor II (EBR-II) at Argonne National Laboratories. This prototype ran safely and effectively for more than 30 years. EBR-II also demonstrated the ability to recycle its used fuel and the use of other types of fuel. In addition, the Sodium Fast Reactor (SFR) System Safety Assessment from the Generation IV International Forum (GIF) noted that "*With more than 20 reactors built and in operation around the world and combining nearly 400 reactor years of operation, SFRs benefit from extensive design and operating experience feedback*".

In addition to the $5 million investment by the New Brunswick Provincial Government announced in 2018 that was matched by ARC Clean Energy, the Government of New Brunswick announced in 2021 an additional $20 million in funding to ARC Clean Energy, with the company providing $30 million in matching funds to progress through Phase 2 of the CNSC Vendor Design Review (VDR) process[2]. In 2022, ARC Clean Energy was selected for a Canadian Nuclear Research Initiative (CNRI) award where CNL will support ARC Clean Energy with extensive expertise in nuclear fuel fabrication and access to state-of-the-art research facilities at Chalk River to develop a prototype fuel pin fabrication line for ARC technology. The prototype work will also deliver a qualified

[2] Premier highlights growing confidence in New Brunswick during pandemic with increases in private investment, property sales and population growth (gnb.ca)

set of procedures for the development of a "made in Canada" production line to support a Canadian fleet approach.[3]

ARC is currently progressing Preliminary Design activities and is progressing VDR-2. In concert with NB Power, they are also working on fuel procurement activities and discussions with the Nuclear Waste Management Organization (NWMO) on long-term waste disposal strategies. They are supporting NB Power in the enhanced site characterization and preparation activities, as well as First Nations engagement, economic opportunities and public engagement. CNSC VDR Phase 2 is expected to be completed in early 2024. Both NB Power and ARC are working with various investors in the formation of owners consortium, which is expected to be announced in the spring of 2023, and NB Power expects to be in a position to submit an initial application for the licence to prepare the Point Lepreau site in June 2023. The potential for ARC to provide the electricity and source heat for the production of hydrogen and other synthetic (clean) fuels is also being actively explored as a means of further reducing the carbon footprint in the industrial and transportation sectors.

4. The Moltex SSR-W 300 and WATSS

The Moltex SSR-W 300 is a stable salt fast spectrum non-pressured pool reactor with an electrical output of 300 MW. Its liquid salt fuel is derived from used Uranium Dioxide fuel, such as used CANDU fuel using the WAste To Stable Salt (WATSS) process. The fuel salt is in individual fuel tubes and as such, is separate from the liquid coolant salt. This improves corrosion control, simplifies safeguard accounting and verification, simplifies reactor physics modelling and avoids fission products circulating though out the coolant system. It uses on-power refuelling and will recycle its used fuel, allowing existing inventories of used CANDU fuel to be used to generate power and be recycled again and again converting it largely to shorter lived fission products. The plant design incorporates a Grid Reserve System for storing heat, which allows the plant to provide peaking power for shorter periods of time up to three times the nominal power. This supports the use of intermediate renewable energy sources as well as smoothing out daily power peaks. The use of salt tanks for storing heat is a much lower cost way of storing energy relative to battery storage commonly associated with the use of renewable energy. The SSR-W is a high temperature reactor, and as such can be configured for co-generation of electricity and steam for industrial applications, which could include the production of hydrogen from a high temperature electrolizer or hydrogen-based products such as ammonia or synthetic fuels.

[3] https://www.arcenergy.co/news/67/39/ARC-CANADA-PARTNERS-WITH-CANADIAN-NUCLEAR-LABS-TO-ADVANCE-FUEL-DEVELOPMENT-PROGRAM

The WATSS OXide fuel line, WATSS(Ox), converts used CANDU fuel into fuel salt for use in the SSR-300. This is a multi-stage process which removes the sheath, powderizes the fuel and converts it to U_3O_8, uses a molten salt-based process to remove the uranium, extract the fission products, and produces the final fuel salt. The main waste products are sintered depleted uranium dioxide and fission product laden salt. Once the fuel is irradiated in the SSR-W 300, the used fuel is then run through the WATSS Salt line, WATSS(Salt), to allow the used SSR-W fuel to be recycled once the fission products have been removed, by blending it back with in-coming fuel salt from WATSS(Ox) line as shown in Figure 1.

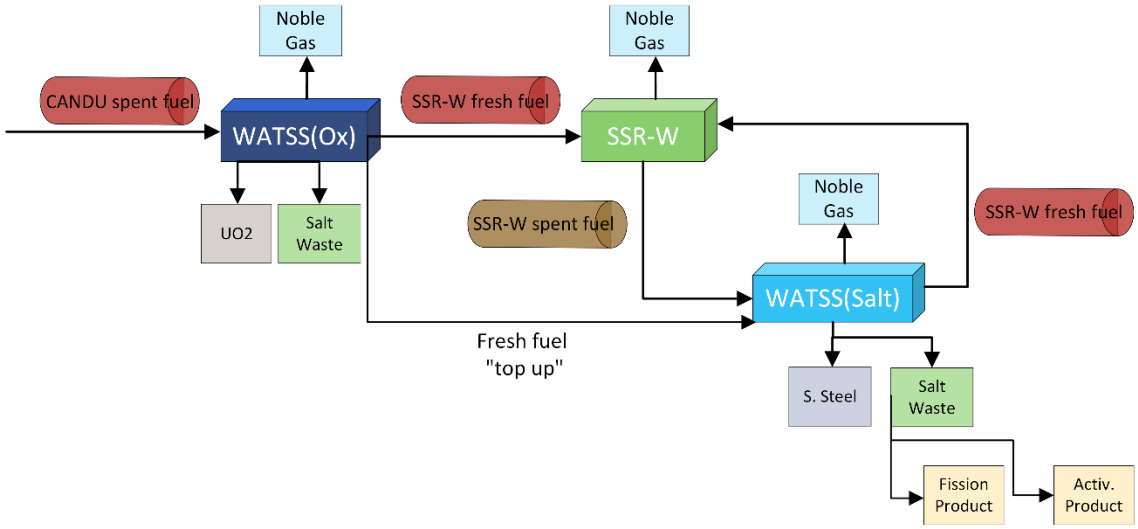

Figure 1 – Integration of WATSS and SSR-W

In addition to the funding provided by the New Brunswick Provincial Government in 2018 of $5 million that was matched by Moltex Energy Canada, on March 18, 2021, the Government of Canada announced $50.5 million in funding for Moltex Energy, with matching funds that will also be used to progress through Phase 2 of the Vendor Design Review. Federal funding was provided through the Strategic Innovation Fund (SIF) and the Atlantic Canada Opportunities Agency (ACOA)[4]. On March 30, 2021, OPG's Centre for Canadian Nuclear Sustainability (CCNS) announced it will provide $1 million in funding to assist Moltex in advancing the development of its used fuel recycling work[5]. In April of 2022, a strategic partnership between Moltex and SNC Lavalin was announced[6].

[4] Government of Canada invests in research and technology to create jobs and produce non-emitting energy - Canada.ca
[5] Media release > OPG collaborating with Moltex to study clean energy solutions - OPG
[6] https://www.moltexenergy.com/moltex-and-snc-lavalin-announce-strategic-partnership-to-advance-clean-nuclear-energy/

Moltex has completed VDR Phase 1 and is currently undergoing preparation activities for VDR Phase 2. They are completing the conceptual design stage and getting ready to begin preliminary design for the SSR-W. Research and development work is progressing for WATSS in parallel with the conceptual design. In concert with NB Power, discussions are underway with NWMO on long-term waste disposal strategies, as well as discussions with the International Atomic Energy Agency (IAEA) on non-proliferation safeguard strategies. Moltex is supporting NB Power with site evaluation and preparation activities, as well as First Nations engagement, economic opportunities and public engagement.

5. Vision of the New Brunswick SMR Innovation Cluster

The Vision is to commercially demonstrate both the ARC-100 and the Moltex SSR-W 300, fed by a WATSS plant, at the Point Lepreau site, with much of the manufacturing of the modules being done within New Brunswick. The first ARC unit will begin commissioning in 2029 and be producing power in 2030, this could be followed by 3 more ARC units at that site, and possibly up to 8 more ARC-100 co-generation units at other locations in New Brunswick, possibly repurposing other NB Power thermal generating station sites. These additional units would provide power to the Maritime region as well as to produce hydrogen and hydrogen-based products outside of peak times.

Since Ontario Power Generation has the bulk of the used fuel in Canada, Moltex could be well suited to support the Ontario energy/electricity market. There are also many countries with large used fuel stocks, such as the US, the UK and Europe that would benefit from Moltex units.

The ARC-100 units are also well suited for industrial application all across the country. An example is in Western Canada in the mining and the oilsands industry due to its ability to generate high-quality, ultra high temperature industrial scale heat, as well as for generating hydrogen. There is also a significant export market opportunity for both electrical and industrial applications, including desalination.

The value proposition for both technologies arise from a fleet approach benefiting in common design and common Operations, Training and Maintenance. Being simple designs, the staff at the operating stations is limited to a relatively small number of cross trained staff, supported by a central support fleet services organization.

6. Expected Economic Impact

Information from market studies, supply chain assessments, construction, site operation and fleet services operation were used to produce an economic impact assessment of the potential of these two advanced Generation IV technologies. Based on the results of the NB SMR Economic Impact Analysis[7], the activities required to develop the technologies, finalize the designs, construct/commission, and complete the owner/operator pre-operational activities for the two NB advanced on-grid SMR demonstration units at Point Lepreau will have the following one-time economic impact benefits for Canada during the 2020-2035 timeframe:

- Average of 1,458 direct and indirect jobs per year,
- $2.15 billion positive impact on GDP (i.e., direct and indirect), and
- $198 million in increased government revenue.

With the opportunity to expand this through a fleet of Canadian and globally exported units to 2060 of:

- Average of 17,900 direct and indirect jobs per year,
- $59 billion positive impact on GDP (i.e., direct and indirect), and
- $5.2 billion in increased government revenue.

These results indicate the value proposition for Canada is analogous to that for New Brunswick; that being economic development, clean energy to meet demand to fight climate change, and to fuel the growth of science and innovation

7. Government and Industry collaboration

NB Power and representatives from the New Brunswick Government participated with Natural Resources Canada (NRCan), other interested provinces, territories, and utilities in the production of the Canadian SMR Roadmap[8]. The report along with the supporting working group reports were released in 2018. NB Power and representatives from the New Brunswick Government also participated in the establishment of the SMR Action Plan[9].

The Pan Canadian SMR Roadmap recognized there is a tremendous opportunity for Canada as a tier-1 Nuclear Nation to benefit from SMR development, deployment and export due to:

- Canada's Policies regarding Greenhouse Gas reduction targets and penalties
- Our world class well respected nuclear regulator, the CNSC whose regulatory approach is technologically neutral

[7] https://smrnb.ca/category/publications/page/2/ (small reactors, big opportunities – Investing in Small Modular Reactor (SMR) technology is a made in New Brunswick contribution to the low carbon economy)
[8] https://smrroadmap.ca/
[9] https://smractionplan.ca/

- The extensive capability or our National Nuclear Laboratory – CNL
- The extensive nuclear expertise in design, analysis and operation
- An active extensive supply chain industry, and
- The excellent safety record of conventional reactors deployed across Canada
- The public support of nuclear energy in their host provinces

NB Power also collaborates with Ontario Power Generation, Bruce Power, SaskPower, Canadian Nuclear Laboratories and the Canadian Nuclear Association (CNA) in the CEO working group. This group along with the Candu Owners Group (COG) SMR Technology Forum, oversees much of the common industry activities in SMRs. NB Power participates in the various working groups that include the Inter-Provincial MOU team, SMR security task team, the SMR Nuclear Liability task team, the SMR Regulatory Reform working group, the SMR fuel task team, the Fuel Recycling and Reprocessing task team, the SMR Waste task team, and the New Nuclear Resourcing task team.

NB Power and representatives from the New Brunswick government are also working with NRCan, the CNA and other interested parties on the Hydrogen Nuclear Working Group and its sub teams, looking to advance the opportunities for Nuclear to generate clean hydrogen.

On December 1, 2019, the provinces of Ontario, New Brunswick and Saskatchewan signed a Memorandum of Understanding (MOU)[10] that establishes a framework for deployment of SMRs in each respective jurisdiction. This was amended in April 2021 to also include the province of Alberta. NB Power, Ontario Power Generation, SaskPower and Bruce Power work collaboratively with the government departments with the aim of:

a) To work co-operatively to advance the development and deployment of SMRs to address the needs of New Brunswick, Ontario, Saskatchewan and Alberta with regards to addressing climate change, regional energy demand, economic development, and research and innovation opportunities,
b) To work co-operatively to address key issues for SMR deployment including technological readiness, regulatory frameworks, economics and financing, nuclear waste management, and public and Indigenous engagement,
c) To work co-operatively to positively influence the Federal government to provide a clear unambiguous statement that nuclear energy is a clean technology and is required as part of the climate change solution,
d) To work co-operatively to positively influence the Federal government to provide support for SMRs identified in the Canadian SMR Roadmap and as requested by the

[10] https://news.ontario.ca/opo/en/2019/12/premier-ford-premier-higgs-and-premier-moe-sign-agreement-on-the-development-of-small-modular-reacto.html

CEOs of Ontario Power Generation (OPG), Bruce Power, New Brunswick Power Corporation (NB Power) and SaskPower,

e) To work co-operatively to positively influence the Federal government to make changes as necessary to facilitate the introduction of SMRs,
f) To work co-operatively to inform the public about the economic and environmental benefits of nuclear energy and SMRs, and
g) To work co-operatively to engage with other interested provinces and territories to explore the potential for SMR deployment in their jurisdictions.

In addition to the general co-operation, two specific outputs were produced. These were the Feasibility Study for the Development and Deployment of SMRs in Canada[11], released in March 2021, and the Strategic Plan for the Deployment of Small Modular Reactors[12], released in March 2022.

8. First Nations Inclusion

NB Power, the Provincial Government, ARC Clean Energy and Moltex Energy recognize the importance and are committed to including First Nations in the development and deployment and exploring economic opportunities of SMRs in New Brunswick. NB Power has an extensive and very active First Nations and Public engagement program. In addition to an extensive program of face-to-face and virtual meetings and open houses, supporting material is available on [13].

NB Power has been collaborating with the consultative bodies for all First Nations in New Brunswick: Wolasteqey, Mi'gmaq and the Peskotomuhkati through monthly meetings. NB Power also collaborates with the Tribal Councils and Economic Development Officers from all 16 First Nations Communities in New Brunswick on economic opportunities such as supply chain, equity, and business development. First Nation companies have been hired to lead Environmental and Traditional Knowledge Studies for the deployment of SMRs at the Lepreau site.

NB Power is also working with the First Nations to produce an Indigenous Inclusion Guide that contains a vision of five key pillars: Leadership, Relationships, People, Economic empowerment and Environmental Stewardship. The key principles of the vision are: listening with open minds, creating an environment of collaboration, delivering on commitments, and working towards a mutually beneficial future. The vision and its components were created from the recommendations outlined in the Truth and Reconciliation Commission Report, in particular action 92 related to business and reconciliation.

[11] https://www.opg.com/documents/feasibility-of-smr-development-and-deployment-in-canada-pdf/
[12] Provinces Release Strategic Plan To Advance Small Modular Reactors | News and Media | Government of Saskatchewan
[13] https://smrnb.ca/

- Consultative bodies
  - Wolastoqey Nation in New Brunswick (WNNB)
  - Mi'gmawe'l Tplu'taqnn Inc. (MTI)
  - Kopit Lodge
  - Peskotomuhkati Nation at Skutik

- Tribal councils
  - Wolasteqey Tribal Council Incorporate (WTCI)
  - North Shore Micmac District Council Inc.
  - Mawiw Council Inc

9. Conclusion

Additional significant nuclear capacity will be required to address the world-wide climate change challenge. NB Power believes that in addition to life extension of the current generation of nuclear reactors, the potential future growth of nuclear lies in advanced fast small modular reactors and in particular, the Moltex SSR-W and ARC-100 designs.

A demonstration of these technologies at the existing Point Lepreau site would represent a pivotal step towards the establishment of a vibrant local supply chain and technical support organization. The developing global need for zero-emissions, dispatchable energy sources, would bring significant economic growth to New Brunswick and to Canada. A fleet-based approach to SMR deployment within Canada and around the world reduces capital and operational costs, improving the cost-effectiveness associated with the deployment of SMRs.

10. Acknowledgements

The authors acknowledge the support provided to this paper by ARC Clean Energy Canada, Moltex Energy Canada, and the NB Department of Natural Resources and Energy Development.

11. Reference

1. "Overview of the New Brunswick SMR Initiative and Resulting Impacts for the province of New Brunswick", by D. Sollows, B. McPherson, and P.D. Thompson, paper Presented at the 39th Annual Conference of the Canadian Nuclear Society and 43rd Annual CNS/CNA Student Conference, held at the Westin Ottawa Hotel, Ottawa, ON, Canada, 2019 June 23-26.