Generation Energy

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INTRODUCTION

Canada is rich in energy and other natural resources. As is the case today, in 2050, prosperity will come from a diversified energy landscape that leverages innovation and new technology to harness natural resource opportunities while meeting clean energy commitments. To this end, nuclear will feature strongly in four important ways:

1) nuclear will continue to be an essential part of Canada's baseload energy mix if the country is to achieve its GHG reduction targets under COP21 and clean energy goals under Mission Innovation;

2) baseload nuclear power will increasingly be considered as a complement to, and enabler of, renewable energy sources such as solar, wind and hydrogen;

3) small modular reactors (SMRs) will be key to the sustainable development of Canada's energy and other resources (such as the oil sands and the Ring of Fire) and will reduce the reliance on diesel generators for remote communities and the North; and

4) ongoing development of Canada's expertise in nuclear will continue to spur innovation, jobs, exports and growth in nuclear science and technology in health, energy, safety and security, environment and other areas, as well as maintain Canada's role in important international security and energy fora.

Canada is the second largest producer of uranium in the world, with the highest grade ore, primarily located in Saskatchewan. As a result, Canada has been playing a leading role in the full spectrum of nuclear technologies, including mining, fuel production, reactor design, nuclear power generation, decommissioning, environmental remediation, and radioactive waste management. Each of these activities is underpinned by a strong regulatory regime.

Furthermore, Canada has leveraged its expertise in nuclear science and technology to provide significant contributions in the fields of nuclear medicine, materials science, imaging, and nuclear safety and security. To 2050 and beyond, Atomic Energy of Canada Limited (AECL) and Canadian Nuclear Laboratories (CNL) will continue to enable Canadians to benefit from the development and deployment of peaceful and innovative applications of nuclear technology on the broadest scale.

BACKGROUND

Canada has a long and proud history of safe and successful use of nuclear energy. For more than 60 years, CNL has operated as Canada's premier nuclear science and technology organization, and has been instrumental in Canada becoming a "Tier One Nuclear Nation" – a select group of nations possessing the full spectrum of capabilities and resources in nuclear technology including uranium, reactors, waste management, research labs, education, regulation, and governance.

Carrying on this rich legacy, through CNL's expertise in physics, metallurgy, chemistry, biology, ecology and engineering, CNL is uniquely positioned to take a leadership role in building and sustaining a vibrant nuclear innovation strategy for Canada, by:

- connecting industry, government and academia to stimulate and enable collaborations;
- providing user access to specialised infrastructure;
- developing the highly qualified nuclear workforce of the future;
- facilitating innovation and commercialization of emerging technologies to power the Canadian economy; and
- providing leadership solutions to present and future challenges.

Today, Canada's internationally respected nuclear sector includes a $6B/year domestic nuclear industry, with 30,000 direct and 30,000 indirect jobs (including a large number of highly-specialized personnel). Nuclear energy makes up 16% of Canada's electricity mix, and over 50% in Ontario and 30% in New Brunswick. Furthermore, Canada has, over the years, contributed to the global supply of medical isotopes for cancer and heart disease diagnosis and treatment. From an innovation perspective, beyond the development of the CANDU technology and Cobalt-60 cancer treatment technology, nuclear research and development in Canada has led to two Nobel prizes in physics for work initiated at the Chalk River Laboratories by Dr. Bertram Brockhouse (1994) and Dr. Art McDonald (2015).

NUCLEAR AS PART OF A CLEAN ENERGY MIX

$26 billion are being invested in the refurbishment of Ontario's nuclear power plants. The Conference Board of Canada has estimated that the refurbishment underway at Darlington will create an average of 8,800 jobs while boosting Canada's GDP by $14.9 billion. This economic benefit is the result of a Canadian-based industry, based on Canadian technology, supported by a Canadian supply chain, and enabled by Canadian science infrastructure.

Together with the recent refurbishment in New Brunswick, these solidify nuclear's place in Canada's energy mix for decades to come – from now to 2050. They are fundamental to Ontario and New Brunswick meeting growing electricity demands with low GHG emissions. No other low-carbon option can meet the need for large-scale, baseload electricity generation that complements renewables.

The benefits of Canadian nuclear technology are known beyond our borders. China, for example, is interested in pairing CANDU reactors with their fleet of light-water reactors to generate more GHG-free energy from their used fuel that would otherwise be considered radioactive waste. China in particular is looking to use the CANDU technology to leverage used fuel as an energy source and reduce the total volume of waste per kilowatt of electricity produced. Candu Energy recently announced an agreement with China to move forward on leveraging this opportunity. The CANDU technology remains an important Canadian technology for domestic and export markets, and the Government continues to receive royalties from its decades of investments in this technology.

Beyond the near-term opportunities presented by small changes to current nuclear fuels, advanced nuclear fuel concepts are being developed worldwide to support long-term reliability of existing reactors and to enable the introduction of advanced reactors. These advanced fuels offer higher performance, increased safety, proliferation resistance and accident tolerance; they are also either recycled or recyclable. Many of these next-generation nuclear fuels cannot be manufactured via conventional processes applied to traditional uranium dioxide-based nuclear fuels. CNL is building on knowledge and expertise in fuel fabrication and materials characterization and performance to develop new additive manufacturing and other advanced manufacturing methods for nuclear applications.

NUCLEAR AS AN ENABLER OF RENEWABLE ENERGY TECHNOLOGY

Nuclear energy offers a mature, reliable, low-carbon partner for renewable technologies. In the decades to come, innovation will continue to improve the complementarity between nuclear and renewable technologies.

As set out by in the joint Nuclear Energy Agency and International Energy Agency Technology Roadmap for Nuclear Energy, "to achieve the goal of limiting global temperature increases to just 2 degrees Celsius by the end of the century, a halving of global energy emissions by 2050 will be needed. This will require an unprecedented transition in the way energy is consumed and produced." Canada's substantial decarbonization goals cannot be achieved solely by non-carbon electricity but will also require decarbonizing other currently carbon-reliant areas such as transportation[1].

[1] Robert Lyman, Climate Change for Canada: Examining the Implication, June 2015 (https://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwijjOurg5vVAhUI9YMKHWAPCncQFggmMAA&url=https%3A%2F%2Ffriendsofscience.org%2Fassets%2Fdocuments%2Fclimate_change_implications_Lyman.pdf&usg=AFQjCNGtzRen15CDHe0sgg3OvNrpMRjDdA, last accessed 2017 July 21).

Over the last ten years, the role of nuclear energy has been evaluated in high-renewable penetration scenarios where low-carbon baseload power is needed for grid stability. Similarly, reactors have been studied as a fundamental component of hybrid energy systems where excess power is used, not to generate electricity, but to provide heat and steam, and/or to produce hydrogen for a wide variety of industrial needs. Hydrogen fuel cells[2] for example, will enable the decarbonization of other sectors (e.g. transportation and manufacturing).

As hydrogen technologies have matured, costs have dropped to the point that hydrogen solutions are financially competitive with similar energy conversion technologies. Hydrogen technology offers low-carbon options for the energy and transportation sectors, which supports Canada's international commitments for carbon reduction.

Building on capabilities developed to support hydrogen safety, heavy water and tritium management in CANDU reactors, and leveraging recent capital investment in modern hydrogen laboratories, Canada, through AECL and CNL, has an opportunity to play a leading role in the demonstration of hydrogen-based bulk transport by 2020.

Energy storage technologies will also enable the efficient pairing of nuclear with renewable energy sources. While hydro, solar and wind energy sources are expected to become increasingly efficient and cost-effective, they will continue to be challenged by intermittency issues. This requires a stable baseload supply, which must be generated from fossil fuels or from low-carbon nuclear power. Pairing a clean source of baseload power with intermittent renewables and energy-storage technology, enables all three to operate at peak efficiency and to capture excess capacity for future use.

NUCLEAR AND CLEAN RESOURCE DEVELOPMENT

New reactor systems such as Small and very Small Modular Reactors (SMRs and vSMRs) are being developed to provide energy on a scale commensurate with the needs of Canada's resource industries – for example mining and fossil fuels extraction.

SMRs have been recognized as important offerings of the modern nuclear industry. These reactors may provide a viable local energy source and an alternative energy solution to larger, capital-intensive traditional nuclear reactors. With a reduced size and capital outlay for specific applications, and the ability to be purchased and constructed in a modular way, SMRs can drive down costs through economies of scale manufacturing, as well as reduce economic risks and waste liabilities.

That said, SMR deployment requires development to prove the economics and to address technical risks. Continued advancements will be necessary in areas such as: cyber security; safety systems; licensing of

[2] Through a chemical reaction, fuel cells combine hydrogen and oxygen to produce electricity, heat, and water, providing energy storage technology comparable to batteries.

"modular" designs; reduction in operating costs; highly-trained personnel; non-proliferation and safeguards; and, waste and fuel handling. It is likely that such advancements will need to be first shown in a demonstration plant before larger deployment can be realized. Whether a demonstration unit or one of a fleet of SMRs, community engagement and acceptance will be critical, particularly since SMRs and vSMRs are targeted for areas less familiar with nuclear technology. Canada is poised to take up these challenges. Canada is one of only a very small number of countries worldwide that has the full range of experience in designing a reactor system, and then leveraging it as the basis of a domestic industry, an export industry and a source of ongoing research, development and innovation. Together with Canada's strong regulatory environment, Canada is very well positioned to once again take a leadership role in the introduction of the next generation of nuclear energy, including small and very small modular reactors that are ideally suited to provide clean energy to northern communities and remote natural resource extraction installations. There is a growing national and international interest in small and very small modular reactors, and Canada has a significant opportunity to remain at the forefront of this emerging technology. In particular, CNL (which operates AECL's sites on its behalf) has expressed its interest in hosting a demonstration SMR or vSMR, and in providing the supporting R&D and technology development.

In addition to electricity generation, SMRs can be part of an overall energy scheme that includes district heating, co-generation, energy storage, desalination and hydrogen production. These traits are particularly attractive to remote off-grid applications in northern communities where consistent, reliable and low GHG emission electricity is needed.

If Canada is to assert itself as a leader in this area, or even as a leader in a niche aspect of this technology area, additional and targeted investment would be needed in the near term. CNL has issued a Request for Expression of Interest (RFEOI) to gather information from a wide cross section of stakeholders, including technology developers and potential host communities, as a means of better assessing opportunities for the laboratories and for Canada to be a leader in this area. AECL and CNL will assess the responses to the RFEOI and be positioned in the fall to articulate the risks and opportunities going forward.

NUCLEAR FOR INNOVATION, SCIENCE, JOBS, AND EXPORT

Nuclear research is integral to the fabric of Canada's science and technology landscape. The Chalk River Laboratories are Canada's largest scientific site, and the science and technology that is enabled there, and the scientists that are trained, often go on to have impact in ways unimaginable. Nuclear science and technology research is a breeding ground for a broad spectrum of scientific applications and discoveries which will be needed to fuel Canada's energy future. This is evidenced by the fact that Chalk River was home to the early research that led to two of Canada's Nobel Prize winners and the work of those individuals has had global impact across many sectors.

Examples of the diversity of nuclear research in Canada include: developing new technologies for the detection of illicit materials at Canada's borders, and understanding the effects of low-dose radiation on living things, in part, to understand the broader health effects of routine medical imaging on patients.

Also, the science and technology being done to advance nuclear reactor systems often has broader application to non-nuclear industries. For example, research aimed at developing advanced materials to withstand the high temperatures and pressures of the next generation of nuclear reactor, which would also have application in improving pipeline durability and safety, and may find use in refineries and other industries that operate at high temperatures and pressures.

Through AECL, the government is investing $1.2B over 10 years to revitalize the aging Chalk River Laboratories. Funding will serve to renew the site, including new and renewed science facilities. By investing in renewing the laboratories' infrastructure, the government is leveraging the laboratories' unique capabilities with a goal of fostering innovation across the value chain.

That said, looking out to 2050, targeted investments in SMRs and a new neutron source would be needed to continue to exploit the full benefit of nuclear across sectors.

NUCLEAR AND WASTE

In addition to being low-carbon, nuclear power generates an incredibly small volume of waste compared to the electrical power generated. That being said, Canadians rightly continue to challenge all energy sources, including nuclear, to meet the highest standards with respect to safety, security, environmental protection, waste management, and cost-effectiveness.

On this point, it is important to reinforce:

- the exemplary track record of the Canadian nuclear industry in safe operation;
- the important role of nuclear working in concert with other renewable technologies such as wind and solar in providing a clean and reliable energy mix;
- the nuclear industry is regulated by an independent regulator, which is respected worldwide; and
- the waste from nuclear energy is well understood and managed and being funded by producers under a legislative and regulatory framework.

In Canada, solutions for used fuel and lower levels of waste are being developed in ways that are environmentally responsible and aligned with international standards.

SUMMARY

For more than 70 years, nuclear science and technology has evolved to meet the needs of Canada and the world for clean, reliable energy, sustainable economic growth, and public health, safety and security. Looking out another 30 to 40 years, 2050 sees Canada continuing to thrive at home and abroad, with the

nation's nuclear innovation capacity driving a clean-growth economy, creating well-paying jobs and realizing Canada's climate change goals.

By 2050, Canada's nuclear energy sector domestically and internationally will be characterized by:

- Reliable, clean, economic baseload nuclear power that has helped Canada achieve and sustain its climate change goals
- Efficient partnerships with energy storage technologies to take advantage of generation peaks and enable de-carbonization of other sectors (e.g. transportation and manufacturing)
- Advanced SMRs and vSMRs that provide tailored on- and off-grid electricity and co-generation solutions to remote communities and resource development projects

This vision will contribute many benefits to Canada:

- Increased GDP, export earnings potential, and highly skilled, durable employment
- Lower electricity costs, helping to drive growth throughout the economy
- Lower environmental impact, including reduced GHG emissions
- Attraction and development of highly qualified scientists and engineers
- Increasing competitiveness and performance against global innovation metrics

THE PATH FORWARD

For nuclear power to fulfil its potential and be fully integrated in the 2050 energy landscape requires an ongoing commitment by the private sector, and all levels of Government.

In the near term, provincially-funded refurbishments must proceed on time and on budget. Canadian companies pursuing nuclear opportunities abroad need to be successful.

The Canadian Government has shown strong support for nuclear. Its essential place in Canada's energy and innovation landscapes has included nuclear energy as part of its clean-energy portfolio under Mission Innovation - putting a spotlight on the importance of nuclear in meeting Canada's clean-energy goals, and has reinforced nuclear's role in the Pan-Canadian Framework on Clean Growth and Climate Change.

Fulfilment of a 2050 vision for nuclear energy can be enabled by the Government's continued investment in a federally-funded S&T program; and support to enable the CANDU technology and its supply chain at home and abroad. Investment in public/private partnerships will encourage innovation in new technology, the development of SMRs/vSMRs and other nuclear innovations.

Opportunities arising from programs such as the recently-identified "Supercluster" Initiative, support for "big science" infrastructure, and investments supporting energy for northern communities would prove invaluable so that nuclear science can continue to drive innovation across a multitude of sectors, for the benefit of Canada and Canadians.