Vision 2050

Canada's Nuclear Advantage

USING NUCLEAR ENERGY TO DELIVER A HEALTHY, LOW-CARBON CANADIAN AND GLOBAL FUTURE

A discussion document for Generation Energy
October 2017

canadian nuclear association cna anc association nucléaire canadienne

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EXECUTIVE SUMMARY

Imagine a Canada with a clean, affordable diversified energy system that leads the world in having achieved deep decarbonization. Imagine, too, an end to energy poverty in many small and remote Canadian communities that now struggle on diesel fuel. Imagine a Canada utilizing its natural endowment of energy sources – especially those that provide ample, reliable and affordable quantities of clean electricity to households and, increasingly, vehicles and transport.

Many Canadians want this sort of future. Joining them is the Government of Canada, as seen in the policy objectives and priorities of the federal government. Sharing such aspirations – and having the solutions to realize such aspirations – is Canada's nuclear industry.

Today there is a compelling alignment among Canadians, federal and provincial governments, and the nuclear industry about the energy outcomes and solutions we would all like to achieve. Our nuclear industry is working towards them in a practical way, along innovative, future-oriented pathways. This combination of vision, solutions, and technological pathways to get there is what we call Canada's Nuclear Advantage.

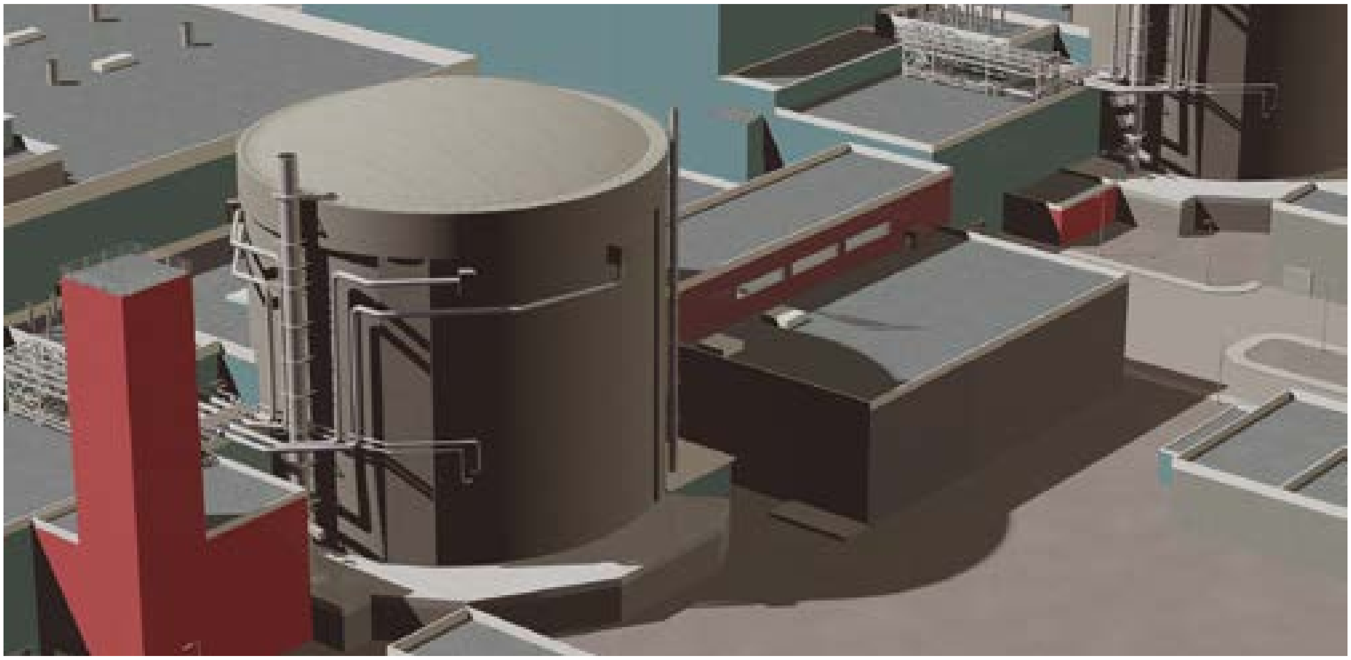
We invite Canadians and Canada's federal and provincial governments to examine this vision and its practical pathway and to note the strong alignment we share. At the same time, we issue a call to action: if we are truly serious about deep decarbonization, meeting GHG reduction targets, providing ample clean energy to all Canadians – then engagement is necessary. The recommendations we offer in this document focus on the most practical, time-urgent and effective steps that, taken now, can help Canada reach the energy future we all want.

Canada's nuclear industry forms a "super-cluster" of innovative companies and organizations that collectively place Canada on the map internationally in science and technology, engineering, high-quality construction and clean tech. The industry is therefore a strategic asset for Canada, not only at home but also internationally. Nuclear technology contributes to nine of the United Nation's seventeen Sustainable Development Goals (SDGs), bringing benefits to humanity to include and stretch far beyond clean energy to embrace health, nutrition, safe food, medical treatment and clean water.

Canadian policymakers and their international counterparts face severe environmental and energy policy challenges. Humanity will need the full toolkit of low-emitting energy sources and technology options. The industry today is poised on a new wave of innovative work in fuels, reactor designs, and applications.

Nuclear has great assets as a base-load power source, providing clean air with minimal land use. This is true worldwide – so the number of power reactors is going up, especially in China and India. Canadian power reactor technology has been exported to those two most populous countries and to several others. With these products – along with uranium and nuclear fuel supplies – Canada is effectively exporting clean air, lower land use and less need to dam rivers.

This performance in sustainable nuclear technology is already delivering on the spirit of Canada's Paris Accord commitments and actually making life better today in China, India, South Korea and elsewhere.



CANADA'S ENHANCED CANDU 6 (EC6) REACTOR DESIGN

THE PATHWAYS TO DECARBONIZATION

Nuclear technologies will allow Canada to better achieve its goals for clean, affordable, reliable energy in three major areas of pressing need:

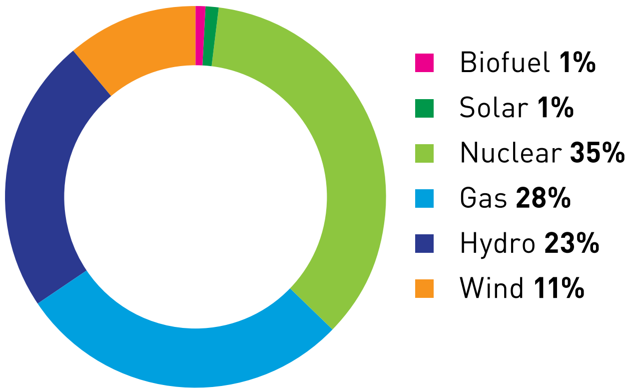
- Meeting global demand for grid power
- Decarbonizing industrial processes, and
- Supplying energy to remote locations

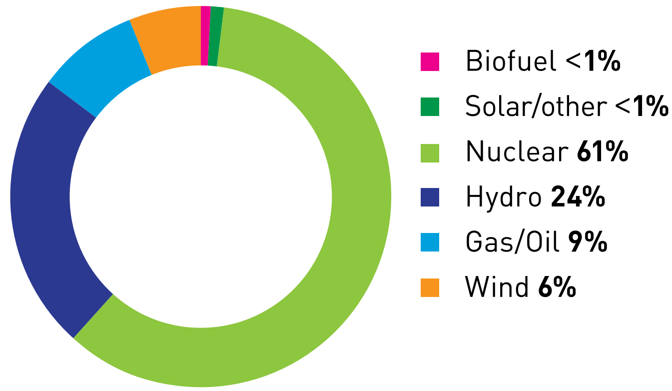
Dozens of designs currently under development could be market-ready within the decade. The bottlenecks lie in areas where government can assist – either directly, or potentially as a coordinator/facilitator between sectors. These include applications, regulatory models, public acceptance, financing, demonstrating the business case, logistics and procurement.

The nuclear industry in Canada is building up, not diminishing, its nuclear workforce and supply chain.

Sometime in the 2020s, Canada's top-tier capacity in nuclear technology will align with a huge global opportunity to provide sustainable, clean air energy. Canada will have the power to deliver on its own Paris Accord objectives and help the rest of the world do the same. Few or no other countries will have this same opportunity – and be able to do so entirely from Canadian-supplied nuclear technology, materials, research and development, and highly qualified personnel.

Grid-based new nuclear can take the form of large reactors, such as the Enhanced CANDU 6 reactor or large light water reactors, or in the form of small modular reactors. Canada's home-grown CANDU reactor technology remains a top performer in electricity affordability, reliability and safety. This family of outstanding reactor designs will continue to deliver these benefits to Canadians for decades to come, and will remain competitive in the market for medium and large reactors.





ONTARIO'S ELECTRICITY SUPPLY MIX IN 2017 BY INSTALLED CAPACITY (LEFT) AND BY POWER SUPPLIED (RIGHT)

For reactors of all sizes, Canada (with government leadership) will want to set key criteria for technology selection. Fleet synergies will be important to economic competitiveness in both reactor sales and in operation.

For small modular reactors (SMRs), Canada is already recognized internationally as a particularly favorable market and regulatory environment. Establishing a leadership position early will enable Canada to secure a significant share of a projected $400 billion to $600 billion global market for SMRs to supply not only electricity, but also hydrogen (a clean fuel for transport applications or as a form of energy storage), district heating, desalination of seawater, coupling to energy storage systems, and process heat for industrial uses (e.g. oil sands extraction and upgrading, steel manufacturing, chemical production).

The path to deployment requires leadership as well as broad engagement and coordination across the many stakeholders. They include potential host communities and the broader public, the federal government, reactor developers, reactor operators, the supply chain, regulators, as well as the provinces, territories and Indigenous peoples.

Community engagement and social acceptance at local, provincial/territorial and national levels will be a starting point. The agenda is much less about technology, and more about serving the needs of a human, social and environmental agenda.

BUILDING MOMENTUM

Now is the time to build momentum so the government's agenda, and Canadians, can benefit from clean nuclear solutions. We present **Vision 2050 – Canada's Nuclear Advantage: Using Nuclear Energy to Deliver a Healthy, Low-Carbon Canadian and Global Future**.

Canada can take a leadership role in creatively and effectively utilizing this huge strategic asset we have in our nuclear industry sector and the potential to achieve real solutions to climate and energy poverty challenges. We in Canada have the expertise, the resources, the proven technologies, the regulatory framework, the experience of working with local and Indigenous communities, the creativity, the desire and the vision. It's a question of will.

Our recommendations suggest where to begin, proceeding in partnership along the key pathways to a decarbonized and clean energy Canada: policy and programming support; investments in nuclear innovation; working with Indigenous people; continuing support to regulators; and fostering greater coordination and dialogue among all stakeholders who share not only bold and compelling aspirations for Canada's energy future – but also want to see practical, effective and innovative technology solutions to get us there.

1. INTRODUCTION

Imagine a Canada where energy poverty – the absence of affordable, reliable and clean electricity and heat – is a thing of the past. Not only in big cities, but throughout the country, including the most remote communities. Imagine the impact on development and growth, on education and empowerment, when there's enough light to read by, enough warmth to study, enough energy to inspire and create confidence in the future: community future, personal future.

IMAGINE THERE IS A SOURCE OF COMMUNITY-MANAGED ENERGY WHERE ENERGY CHOICE AND DEMAND IS MATCHED WITH THE KIND OF POWER, ELECTRICITY AND HEAT THAT LOCAL PEOPLE NEED AND WANT.

Imagine there is a source of community-managed energy, where the needs and traditions of Indigenous and local citizens come first and where the technology used for energy generation meets with the aspirations of the host community. Where energy choice and demand is matched with the kind of power, electricity and heat that local people need and want – and that their voice is heard.

Imagine a Canadian energy technology that produces massive quantities of clean, low-carbon electricity and heat on a 24/7 basis with no intermittency, no dependence on weather patterns, wind currents or amounts of sunshine. Where the fuel for such energy and the energy-generating platforms that produce it come from Canadian developed, Canadian based, proven technology, with the fuel mining, the plant and component manufacturing taking place in Canada.

IT'S REAL

There is a technology and an industry that can contribute significantly to all the above. It is Canada's nuclear industry. This industry shares the priorities voiced by Canadians. We want a country where no one lacks for the energy they need. We want solutions to the challenges of energy poverty, climate change, and how we are going to embark on large-scale and irreversible reduction of carbon emissions, while preserving jobs and growing the economy.

We see a strong and growing alignment between the aspirations of Canadians, the policy objectives and priorities of the Government of Canada, and what the industry itself is imagining – and doing – to bring the outcomes we all desire.

Our message to Generation Energy is about this compelling alignment – and the pathways to realizing the vision that industry, government and citizens share. It is about having a new and fresh look at the solutions that innovative and advanced nuclear technology can bring to the challenges ahead.

IT'S A STRATEGIC ASSET FOR CANADA

Canada's nuclear industry is a strategic asset. It is a $6 billion domestic industry that provides 30,000 direct and another 30,000 indirect jobs, many of which are highly skilled and involve cutting-edge technology. The nuclear industry is a powerful cluster of innovative companies and organizations that place Canada on the map internationally in science and technology, engineering, high-quality construction and clean tech.

More than that: the long history of innovation and expertise in nuclear technology – as manifested in Canada's nuclear science and technology eco-systems, with the Chalk River national laboratories jewel in the crown – gives Canada a large and credible voice on international security issues such as non-proliferation and nuclear safety. Over the years, the uranium fuel produced by Cameco and other mining companies in Canada have helped to avoid hundreds of millions of tons of greenhouse gas (GHG) emissions by fuelling nuclear reactors overseas. And the home-grown CANDU reactors operating not just at home but also overseas have similarly contributed considerably to national and international carbon/GHG emission reductions.

Canada's nuclear industry contributes to nine of the United Nations' seventeen Sustainable Development Goals (SDGs). And what other energy technology can one think of that is used for sterilizing medical devices, cancer diagnoses (nuclear medicine) and cancer treatment (Cobalt 60). Without Canada's CANDU nuclear reactors, there cannot be Cobalt 60 – and thus the treatment this medical isotope provides to millions around the world.

CANADA'S NUCLEAR INDUSTRY CONTRIBUTES TO NINE OF THE UNITED NATIONS' SEVENTEEN SUSTAINABLE DEVELOPMENT GOALS (SDGS).

A solutions-provider at home, a strategic asset internationally, an invaluable source of medical treatment – this is what Canada's nuclear industry offers. The industry today is poised on a new wave of innovative work. Our companies and labs are developing fuel to use recycled material from spent fuel, and to achieve greater consumption of the energy in such fuels. Our industry is experimenting with other fuels (thorium, mixed oxides) for use in Canadian-designed CANDU reactors and novel fuels such as molten salt. And it is progressing novel, practical concepts for bringing the promise of clean energy from nuclear fusion to the market in the coming decades.

Our industry is developing smaller advanced nuclear reactors that are distinguished by their passive safety systems, extremely small environmental footprint, portability for deployment away from electricity grids, and simplicity in construction.

It is working towards amplifying Canada's ability to meet clean energy targets by envisioning a modularity in design and construction of small and very small nuclear reactors and batteries, such that more communities – both on-grid and off-grid – can benefit from the quantities of heat and electricity they can produce.

And our industry is readying deployment of reactor solutions across all energy pathways with load-following capabilities to enable off-grid applications and integration with intermittent renewable energy sources in on-grid applications.

WE'RE GETTING STRONGER AT THIS

Added to this is the federal government's investment in the Chalk River laboratories to sustain its world-class capabilities and reputation in advanced nuclear and non-nuclear technologies and their manifold applications. And Ontario has embarked upon the largest clean-energy investment in the western hemisphere and most of the world by refurbishing 10 of Ontario's CANDU reactors. This will give the province another 40 years of clean, affordable energy – and an important foundation in its journey to a decarbonized energy system with greater electrification.

Today, international eyes are turning to Canada and its nuclear sector. At this pivotal point in the battle against climate change, it is important for the industry to describe its vision for Canada's future. It is also timely to tell Canadians that our vision is already being translated into reality by many innovative companies, large and small, pushing ahead with advanced nuclear designs and ideas ranging from on-grid large power reactors to off-grid industrial applications (mining and Ring of Fire, oilsands bitumen extraction) and further to off-grid remote deployments (remote and northern communities).

A WAY FORWARD FOR CANADIANS

This document sets out industry's vision and the alignment of this vision with the priorities, needs and solutions sought by Canadians and their governments. It moves from vision to practical activity by describing work underway as the industry presses forward with advanced and innovative technologies in the clean tech/clean infrastructure/clean energy spheres.

NOT ALL INDUSTRY'S AMBITIONS CAN BE ACHIEVED WITHOUT VITAL STAKEHOLDERS SUCH AS THE FEDERAL AND PROVINCIAL GOVERNMENTS LENDING THEIR SUPPORT.

This industry activity takes place largely along 3 important pathways. The document thus functions as a preliminary guide – similar to an Inukshuk – pointing the way ahead. The time-scale envisaged is to 2035 and then to 2050. The detailed roadmap of how the industry will traverse these pathways is still to be written. That is because, for each pathway, there are junctures where the industry cannot, by itself, move ahead to the next milestone, the next objective.

That is where a role for government is identified and encouraged. Not all industry's ambitions can be achieved without vital stakeholders such as the federal and provincial governments lending their support. The document identifies the points along the pathways where this support – political, policy, fiscal, investment – is most necessary. The Recommendations section notes these points and proposes ways and means by which governments could engage at decisive moments or in decisive areas to successfully move forward along the pathway.

Given the extraordinary alignment of industry, governments and citizens in achieving solutions in climate change and decarbonisation, in job creation and economic growth, in sustainable development and empowerment in Indigenous communities, in strengthening international security, in bringing Canadian leadership in this vital and innovative technology sector – we see joint endeavour and engagement as the immediate next step. The Recommendations are ways and means to help get us to our common goals.

2. THE NEED

Canadian policymakers and their international counterparts face severe environmental and energy policy challenges. Naïve responses to these challenges sometimes see electricity generation and use as part of the problem, and thus as activities to be constrained.

But electricity access is closely correlated to human lifespan, health, life quality, and our ability to survive and respond to environmental events (hurricanes, floods, fires, droughts). The world's population has many legitimate, essential needs for electricity. Electricity use is not going to decline without human welfare declining.

Moreover, decarbonization will require a shift toward greater use of electricity in areas where fossil fuels are currently in widespread use (especially transport and building heat).

True, there are many ways we can generate, transmit, and use electricity better and more efficiently. But even with conservation, we need to plan for more electric power use. No one clean energy source can supply this need. Humanity will need the full toolkit of low-emitting energy sources and technology options.

BENEFITS

Each source and each technology has some ancillary benefits (jobs, technology spinoffs, unexpected applications). In the case of nuclear energy, those ancillary benefits have included the nurturing of top scientific and engineering talent, and Canadian advantages in robotics, medical imaging, medical diagnosis and treatment, sterilization technology for medical supplies/devices and food products, materials science advances and advanced manufacturing. Nuclear's supply chain is mostly inside Canada, and embodies a higher proportion of science and engineering than other energy sources. Developing nuclear made a large contribution to Canada's emergence as an advanced, diversified high-technology economy in the twentieth century.

ELECTRICITY ACCESS IS CLOSELY CORRELATED TO HUMAN LIFESPAN, HEALTH, LIFE QUALITY, AND OUR ABILITY TO SURVIVE AND RESPOND TO ENVIRONMENTAL EVENTS (HURRICANES, FLOODS, FIRES, DROUGHTS). THE WORLD'S POPULATION HAS MANY LEGITIMATE, ESSENTIAL NEEDS FOR ELECTRICITY.

Nuclear has great assets as a base-load power source, providing clean air with minimal land use. This is true worldwide – so the number of power reactors is going up, especially in China and India. CANDU power reactor technology has been exported to those two most populous countries and to several others. With these products – including uranium and nuclear fuel supplies – Canada is effectively exporting clean air and lower land use and less need to dam rivers.

This performance in sustainable nuclear technology is already delivering on the spirit of Canada's Paris Accord commitments, and actually making life better today in China, India, South Korea and elsewhere.

PATHWAYS

There is broad consensus that meeting the government's GHG emission targets by 2050 will require deep decarbonization of Canada's energy system. Appendix A provides results of work by the Canadian Academy of Engineering on the scope of this challenge and the options for getting there. The bottom line is that massive electrification with low-carbon technologies will be needed.

New nuclear will be needed, along with other low carbon technologies, to achieve this at the lowest cost to Canadians (References 3 and 4).

In our assessment, which builds on this definitive work, nuclear technologies will allow Canada to better achieve its goals for clean, affordable, reliable energy in three major areas of pressing need both for Canada at home, and for Canada in the world:

- Global demand for **grid power**. We're there today in Canada, China, India, South Korea, Argentina and Romania, and others are getting more interested in nuclear as a way to deliver the power they need without air pollution, without GHGs, and without massive land use. This is an opportunity to respond to our government's commitment to drive down global GHG use and improve health outcomes while boosting Canada's clean-tech export strength.
- Decarbonizing **industrial processes**. Affordable, reliable, clean energy is often the limiting factor today in the viability of the development of Canada's natural resources in the north and in remote locations. Canada's oilsands operations, for example, emit large volumes of GHGs by burning a relatively clean hydrocarbon (natural gas) to produce a less clean one (synthetic crude oil). Substituting nuclear-generated heat into this process, which appears feasible from detailed engineering studies, would reduce Canada's GHG emissions and conserve our natural gas wealth for higher-value uses. This will reduce the environmental concerns around Canada's national brand and spur a global opportunity to help decarbonize other countries' industries.
- Delivering quality energy to **remote locations** worldwide (off-grid communities in Canada, small island populations, mountainous regions, military bases). As with combatting climate change, we need a full toolkit of energy options to meet human needs. Renewables help in remote locations, but they only partially decarbonize. The communities end up with triple capital investment (renewables, batteries, and diesel) without really being decarbonized. There may be a better solution that's cleaner, more portable, and less site-specific and energy-limited. Again, the opportunity is not limited to Canada, but Canada is already leading in this area.

THE PATHWAYS IN THIS DOCUMENT PURSUE SOLUTIONS TO THESE NEEDS BOTH FOR CANADA AT HOME, AND FOR CANADA IN THE WORLD: GLOBAL DEMAND FOR GRID POWER, DECARBONIZING INDUSTRIAL PROCESSES, AND DELIVERING QUALITY ENERGY TO REMOTE LOCATIONS.

CANADA IS ONE OF VERY FEW COUNTRIES – INDEED, VIRTUALLY THE ONLY ONE AMONG THE TRADITIONAL TOP-TIER NUCLEAR COUNTRIES – WHERE THE NUCLEAR ENERGY INDUSTRY IS ON AN UPSWING, AND IS THUS BUILDING UP, NOT DIMINISHING, ITS NUCLEAR WORKFORCE AND SUPPLY CHAIN.

URGENCY

We see two reasons for bringing urgency to building Canada's nuclear advantage. The first is that the government's agenda for meeting climate goals is so demanding. The second is that Canada's current advantage as an early deployment market for small reactors – our current nimbleness compared with other top-tier nuclear countries – will not last unless it is seized now.

In our view, technology (mainly meaning reactor designs) is not likely to be the limiting factor. Dozens of designs currently under development could be market-ready within the decade.

Rather, the bottlenecks lie in areas where government can assist – either directly, or potentially as a coordinator/facilitator between sectors: applications, regulatory models, public acceptance, financing, demonstrating the economics and the logistics, and procurement.

Today's urgency is less in technology development than in cross-sectoral teamwork. Each pathway has different requirements and challenges, and this document explores those differences.

3. THE NUCLEAR INDUSTRY TODAY

Canada is one of only a few top-tier nuclear countries – meaning countries that have capabilities across the whole spectrum of civil nuclear technology. In addition to the accumulated results of seven decades of investment in these technologies, we have some of the world's best uranium resources – and the two are linked by leadership in uranium processing, research into fuel flexibility and recycling, and fuel manufacturing and exports.

This not only raises our self-sufficiency and security in nuclear, and raises the domestic economic multiplier of investments in nuclear; it also makes us a stronger prospective partner in international relations and commerce.

This is reflected in the confidence shown by players in China – the country with by far the most rapid current nuclear new build program – in partnering with us on fuel flexibility and the Advanced Fuel CANDU Reactor (AFCR), which they are making an integral part of their reactor fleet for the century ahead.

Even more importantly, Canada is one of very few countries – indeed, virtually the only one among the traditional top-tier nuclear countries – in which the nuclear energy industry is on an upswing at home. The nuclear workforce and supply chain in Canada is building up, not diminishing, its nuclear workforce and supply chain.

- The program to refurbish (replace major components in) 10 of Ontario's 18 operating nuclear units over the coming 15 years is one of the largest clean energy investments in the world today – worth about C$25 billion. This is attracting interest from around the globe.
- Canada has restructured its Crown assets in nuclear over the past decade, and a dramatic renewal of the main nuclear laboratory – Canadian Nuclear Laboratories (CNL) – is underway. CNL recently invited expressions of interest in demonstrating Small Modular Reactor (SMR) technologies, and received eighty responses from a broad cross-section of stakeholders, including SMR technology developers, potential end-users, host communities, the nuclear supply chain, and research and academic institutions.
- Canada's nuclear regulator has a top record for nuclear safety, and at the same time is viewed globally as having the most robust yet progressive regulatory context for potentially deploying SMRs, which is attracting further investment to Canada.
- Canada's federal government recognizes nuclear as a clean energy technology for purposes of Mission Innovation – the multi-country commitment (following on the Paris Accord) to double research and development spending on clean energy technologies over five years.
- Canada has been progressing toward long-term solutions for nuclear waste management, including the Deep Geologic Repository(DGR) project.
- Our core reactor fleet is uniquely flexible in the fuels it can use – which many see as the way of the future for managing our waste. This is proving to be another special strength of our CANDU technology, along with online refueling and resistance to weapons proliferation.
- Our industry is partnering with its Chinese counterparts on advancing the capacity for re-using waste products through the Advanced Fuel CANDU Reactor (AFCR) project, which is likely to lead to further projects for Canada's nuclear industry in Asia.

This upswing has consequences for our positioning to take advantage of the growing global opportunity in nuclear, as the world becomes more carbon constrained.

A few key new nuclear technologies deserve to have their implications for the medium-term future highlighted here.

> **CANADA'S TOP-TIER CAPACITY IN NUCLEAR TECHNOLOGY IS ALIGNING WITH A HUGE GLOBAL OPPORTUNITY TO PROVIDE SUSTAINABLE, CLEAN AIR ENERGY. CANADA WILL HAVE THE POWER TO DELIVER ON ITS OWN PARIS ACCORD OBJECTIVES AND HELP THE REST OF THE WORLD DO THE SAME. FEW OR NO OTHER COUNTRIES WILL HAVE THIS SAME OPPORTUNITY.**

- **Generation III and III+ reactors:** We are improving the safety and reliability of our proven power generating technology. These reactors continue to deliver reliable, affordable, carbon-free power – and so they continue providing Canada's industry with opportunities for deployments and partnerships that decarbonize the world and clean the air people breathe.
- **Reactor life extension and renewal:** By having one of the largest fleet refurbishment and components replacement programs in the world, Canadians continue to deepen our technology and expertise in these essential areas. This is a core skill set in the global infrastructure game, where bringing longer life to capital-intensive assets is one of the keys to good economic performance.
- **Small reactor regulation:** International nuclear firms have been visiting and investing in Canada because the Canadian licensing process is seen as offering a high-quality environment for relatively near-term deployment of small modular reactors (SMRs) and other advanced reactor designs.

GETTING TO THE TOP

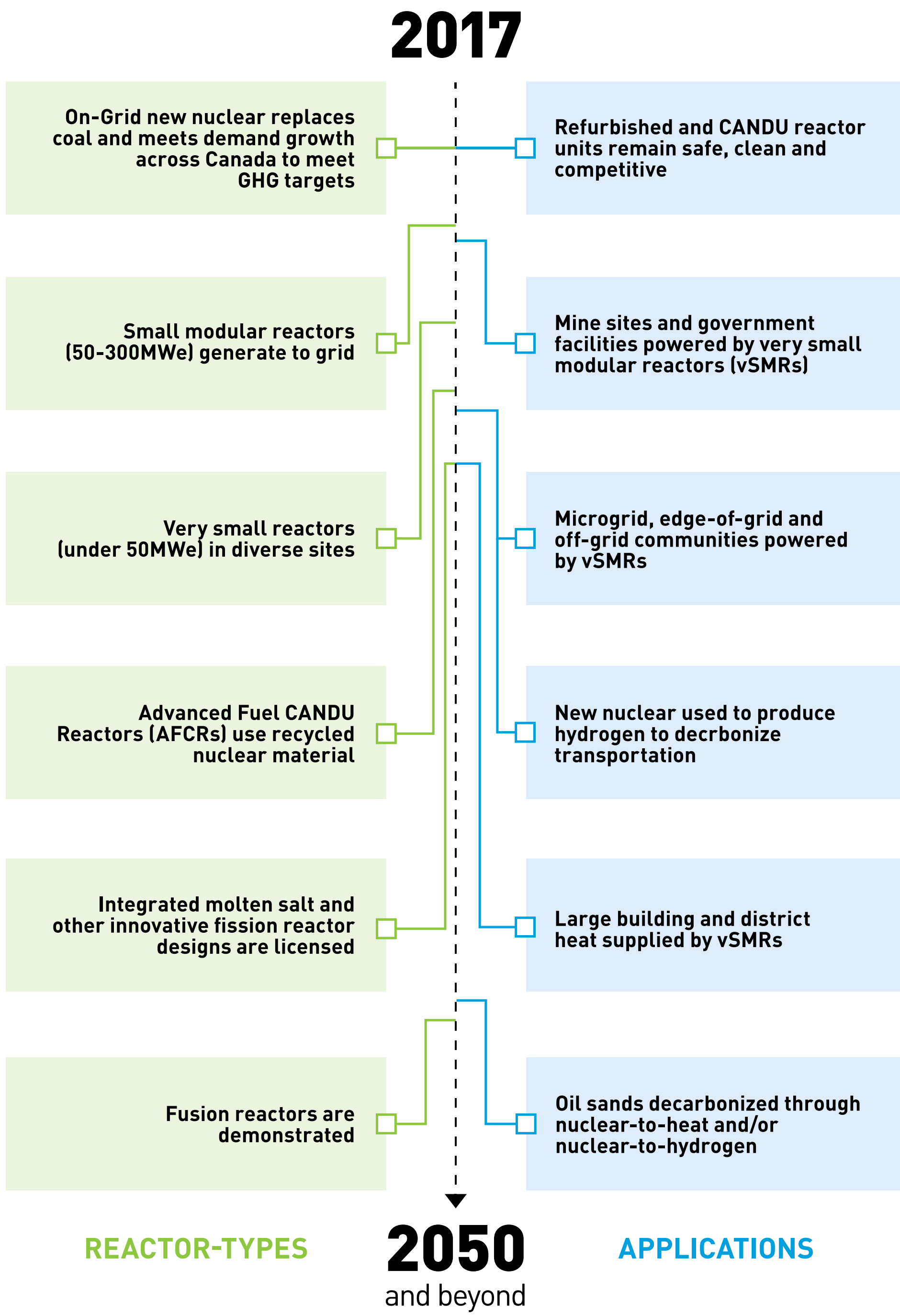
These activities are on track to put several of the building blocks of our industry – our manufacturing supply chain, our skilled trades and highly qualified personnel, and our safety and regulatory experts – at the top of their game within the coming decade. That time frame coincides with both the domestic and global opportunities for new reactor fleet procurement. That procurement could happen on any or all of the three pathways in our vision.

> **WAITING UNTIL THE OPPORTUNITY ARRIVES SOMETIME IN THE 2020s WILL BE TOO LATE. WE NEED TO GET ALIGNED AND PREPARED BEGINNING TODAY.**

Canada's top-tier capacity in nuclear technology is aligning with a huge global opportunity to provide sustainable, clean air energy. Canada will have the power to deliver on its own Paris Accord objectives and help the rest of the world do the same. Waiting until then to position ourselves will be too late. We need to get aligned and prepared beginning today.

4. A VISION FOR NEW NUCLEAR IN 2050

In August 2017, the Canadian Nuclear Association made a formal submission to the Government of Canada's Generation Energy consultation. That submission, which is publicly available on the Generation Energy portal, included the following representation of our vision for Canadian nuclear energy in 2050.



This section presents how our vision might be realized on three major technology pathways - with an overview shown in the figure below. Complementary material to this section is presented in Appendix D on hybrid energy systems and other applications of nuclear.

FUNDING AND FINANCING

It is well known in technology industries that funding and financing are among the most important barriers to delivering a product to users. The more dramatic a technology innovation is, the greater the challenges can be in creating a financing model that crosses the notorious "valley of death" between invention and commercialization.

TABLE 1 SUMMARY OF MAJOR TECHNOLOGY PATHWAYS

Pathway	2035	2050
Grid power	Canadians continue to benefit from clean, reliable, affordable power delivered to the grid by Canadian nuclear technology Our supply chain and workforce are in top competitive position as an accumulated result of $25B invested in nuclear refurbishments in Ontario New reactors are coming online in several provinces, and fleet benefits across the provinces start to take off A public-private partnership has been formed toward realizing a new, purpose-built research reactor	A fleet of nuclear reactors across the country have replaced fossil-fueled generating plants, and have contributed to the expansion of Canada's electricity supply needed for decarbonization Nuclear has actively supported the integration of renewables and storage technology into the energy portfolio while maintaining system resilience and reliability Investments in science and technology, including a research reactor, are leading to design improvements and deployment of the next generation of reactors
Remote communities	Dozens of Canada's 300-plus remote communities are having their social, energy and economic needs met by a fleet of small reactors with Canadian content The necessary ancillary capabilities and capacity for fleet deployment, including factory-based reactor manufacturing, fuel enrichment and reprocessing, and logistics have been proven, constructed and are in operation	Canada has an industry designing, operating and servicing very small reactors for domestic and global customers, and has economic benefits from participating in an international small reactor supply chain The majority of Canada's remote communities have experienced a marked improvement in quality of life, enabled through the provision of abundant, clean, affordable energy from fleets of small reactors

Pathway	2035	2050
Low-carbon resource industries	Canada has advanced toward our Paris Accord commitments while retaining our economic strengths, by starting to decarbonize key resource processes (like bitumen extraction from oilsands and remote northern mining projects) with clean nuclear energy	Resource development projects, and associated human development, have expanded significantly in Canada's north, enabled by the availability of affordable clean energy from advanced small nuclear reactors Canada's emissions are lower, and Canada's global brand in resource industries is stronger and greener Canada offers leading technology for clean industrial energy to other countries' industries
Waste	Because policy and regulatory decisions were made in a timely manner before 2020, Canada has a well-developed national strategy for managing all of its radioactive waste. Plans are well underway for permanent storage sites	Canada has permanent solutions for storing radioactive waste that are supported by the local community and by the public, and that operate well and safely

A NOTE ON FUSION ENERGY

Current nuclear energy systems use nuclear fission (splitting atoms). Nuclear fusion systems (fusing atoms), when they deliver sustained net positive energy, are expected to have advantages over fission, including less and safer waste.

As they have in nuclear fission technology for decades, Canadian researchers and industry are making important progress towards the conceptualization, design and commercialization of practical fusion power systems. Our vision anticipates that by 2050, practical fusion reactors will have been demonstrated and will be serious contenders for the next generation of nuclear energy deployments around the world.

Canada has a potentially significant role to play in demonstrating the way ahead in fusion reactor technology over the coming decades, such as in the area of small, modular fusion reactors. These bold, longer-term concepts dovetail well with our near to medium term vision for new nuclear in Canada.

PATHWAY ONE: ON-GRID ELECTRIC POWER

In order to achieve Canada's GHG emission reduction goals, several provinces will need to make decisions about replacing their coal fleets and meeting increasing electricity demand requirements driven by electrification of the broader industry. Saskatchewan, Alberta, Ontario and New Brunswick may need to contemplate how nuclear can support the achievement of their GHG goals in the near to medium term. Grid-based new nuclear can take the form of large reactors, such as the Enhanced CANDU 6 reactor or large light water reactors, or in the form of small modular reactors.

CANDU reactors are the world's only nuclear power solution that uses natural uranium, providing customers with access to global markets and a far larger range of possible fuel suppliers to choose from. Enhanced CANDU 6 (EC6) reactors are delivered with zero radioactive liquid emission technology and produce very little carbon dioxide and no nitrogen oxide, sulphur dioxide, toxic heavy metals, aerosols, ozone or other emissions. When displacing traditional coal, CANDU technology saves 13 million tonnes of carbon dioxide annually, or 6 million tonnes when displacing natural gas. Moreover, the EC6 is designed to exceed post-Fukushima safety standards.

There are 47 CANDU or CANDU-type reactors currently in operation worldwide. The EC6 reactor successfully completed the final stage (Phase 3) of the Canadian Nuclear Safety Commission pre-project design review, and is ready for deployment to operators requiring high safety margins, on-schedule and on-budget construction, high performance, economic competitiveness and operational reliability.

For on-grid purposes, the small modular reactors that are likely to be deployed are those in the 100 to 300 MWe range. The key benefits of grid SMRs are:

- Optionality to increase capacity in increments as demand increases, rather than building a large plant to meet future demand growth
- Compatibility in size for the grid infrastructure in smaller population areas

Several designs of SMRs are closer to commercialization than others, with those based on light water technology being the most likely to be commercialized in the nearer term. Given it is expected that new nuclear will be required by the mid-2030's, Canada will want to set key criteria for technology selection.

Such criteria might be geared to minimize first of a kind risk, help the SMR supply chain establish itself in Canada, and assist entry into offshore markets for SMRs. For the purpose of risk minimization, for example, criteria might include:

- Use of evolutions of existing commercially viable technologies that are based on currently proven technology
- Designs that can advance through regulatory processes on an appropriate timeframe
- Designs that are well advanced in commercial deployment

Economic competitiveness is an important consideration for grid size new nuclear. It is expected that new nuclear will need to be competitive with other comparable forms of generation once carbon costs are accounted for. For Grid SMR deployment in Canada, a key aspect of economic competitiveness will be fleet synergies in operating models, training and supply chain.

PATHWAYS TWO AND THREE: REMOTE APPLICATIONS – FOR CLEAN RESOURCE DEVELOPMENT, AND FOR COMMUNITIES

Many locations in Canada (and the world) lack access to clean, low-GHG energy from a reliable source, or indeed any source. Small modular reactors (SMRs) are an opportunity to deliver such energy. SMRs have a smaller electrical capacity than most current power reactors, anywhere between 1 MW and 300 MW, and are modular in both construction and deployment.

Canada has very extensive natural resources (for example, the Athabaska Basin oilsands contain oil reserves equal to some 165 years of current production). A carbon-constrained world will require Canadians – and others – to find ways to extract, process and use these resources with zero or very low net carbon emissions, if we are to use them at all. Even if one believes that humans will eventually cease using such resources, there will still have to be a large, global market for innovation in this area – if only in the interim while our use of resources declines.

MEETING COMMUNITY, GOVERNMENT, AND WORLD NEEDS

Many SMR concepts that are under development would provide energy on a scale commensurate with not just the current needs of Canada's remote locations, but with their economic possibilities – removing constraints to their growth. And SMRs could serve the needs not just of remote communities, but also of remote resource extraction industries, like mining and the oilsands.

Government objectives to reduce the use of diesel in the North (on grounds of both local air quality and GHG emissions), to improve energy quality and security, and to empower economic development could all be more decisively advanced in the long run by SMRs than by the foreseeable alternatives.

Canada is already recognized in the United States, the UK, and elsewhere as a particularly favorable market and regulatory environment for early SMR deployment. Establishing a leadership position early will enable Canada to secure a significant share of a projected $400 billion to $600 billion global market (Reference 9) in large/arctic countries, small island communities, and other places where people live off-grid or are not reliably served by the grid.

BEYOND ELECTRICITY

Non-electrical applications targeted by SMR designers include production of hydrogen (a clean fuel for transport applications or as a form of energy storage), district heating, desalination of seawater, coupling to energy storage systems, and process heat for industrial uses such as oil sands extraction and upgrading, steel manufacturing, and chemical production.

The outlet temperature, thermal and electrical power output required, and target market for such applications would influence the reactor design that would be most suitable to deliver the greatest human, social and environmental benefits in each case.

COMMUNITY ENGAGEMENT AND TECHNOLOGY READINESS

SMR technologies range from being immediately deployable, to mid-to-longer term deployable (i.e. in the timeframe of 2030 to 2050, and beyond) (Reference 10). Most developers that have expressed an interest in serving Canadian needs would require further development to address economic, regulatory and technical risks.

For any application, continued advancements will be necessary in areas such as: cyber security; safety systems; licensing of new, unfamiliar designs; reduction in operating costs; highly-trained personnel; non-proliferation and safeguards; and waste and fuel handling.

Community engagement and social acceptance at local, provincial/territorial and national levels will be a starting point. Canada's remote communities often have had negative past experience with transitory industry presence, and we need to start from a discussion of their needs and expectations, which could be very different from those in larger centres.

TWO DEPLOYMENT PATHWAYS WITH COMMON ELEMENTS

Two different applications are envisioned for remote SMRs; deployment in remote communities, and a clean source of energy to extract Canada's natural resources. The technologies used in both of these applications may be the same, and correspondingly the development pathways overlap. One key variance between the two pathways is the timeline to social acceptance and correspondingly to full deployment, which is expected to be longer in the case of communities.

The deployment pathway has 4 phases:

1. SMR demonstration
2. Early deployment at a remote government site, such as a military base
3. Deployment for remote resource extraction, e.g. mines
4. Remote communities

It is anticipated that the remote resource extraction industry will adopt these technologies ahead of other remote communities, mainly because resource extraction applications are more likely to involve a lone, or single major, customer and thus a simpler path to acceptance and procurement. SMRs that meet the business needs, including cost and deployment schedules, of the mining industry could see relatively early adoption, possibly in the 2020s, following successful demonstration of the technology.

The world nuclear industry has learned good lessons from past projects on how to de-risk new design work, making it more likely that next-of-a-kind plants are built on time and on budget. The lessons are in many areas including design optimization, project management, supply chain resiliency, and relationships with regulators (Reference 13).

The path to 2026, common to both deployment pathways, is aggressive from a timeline perspective, and would require work to begin now. An example timeline is as follows:

- Selection of one or more SMR designs for demonstration (2020) (recognizing the need for a government role in developing criteria for technology down-selection)
- Submission of licensing documents for the SMR demonstration: License to Prepare Site, Environmental Impact Assessment, License to Construct, License to Operate (2020-2025)
- SMR demonstration construction commences (2024)
- SMR demonstration commences operation (2026-7)
- Selection of the first site for early deployment (early 2020s)
- Subsequent license submissions, construction, and operation (2032) of the first deployment, including related ancillary infrastructure such as factory-based reactor manufacturing, fuel enrichment and reprocessing (depending on the selected fuel cycle(s) and transportation logistics

Such a timescale requires leadership as well as broad engagement and coordination across the many stakeholders: potential host communities and the broader public, the federal government, reactor developers, reactor operators, the supply chain, the CNSC, as well as the provinces, territories and indigenous peoples. The demonstration reactor will have a significant role in this education and engagement activity, providing a working facility that communities and other stakeholders can visit and experience.

REMOTE RESOURCE EXTRACTION

To best assist Canadians working in the resource sector at remote sites, small modular reactors (SMRs) and very small modular reactors (vSMRs) will need to be modular, and transportable with minimal on-site construction.

To fit with the timescale of development of a typical resource (such as a new mine), the timeline of deploying a small reactor – from conception, through licensing and construction, to operation – needs to be shortened from what has governed recent large-reactor projects.

As well, the lifetime of the reactor should match the lifetime of the mine (or else the reactor needs to be transportable to a new resource location so it can be used through its full lifetime).

TABLE 2 PATHWAY TO CLEAN ENERGY FOR REMOTE RESOURCE DEVELOPMENT

2026	▪ The commercial viability of the SMR has been demonstrated ▪ The first demonstration SMR has been constructed and commissioning is underway
2030	▪ The first demonstration SMR has been operating successfully for several years ▪ Successful early deployment of vSMRs to Canadian locations ▪ With the GoC as an early customer of these technologies, vSMRs have enabled at least 2 remote government facilities to be nearly carbon-free ▪ Building from the GoC site successes, vSMRs have been commercially deployed to multiple other Canadian locations, and ancillary infrastructure is in place ▪ More advanced concepts have been developed further and are ready for demonstration
2050	▪ Wide deployment of vSMRs at remote off-grid resource extraction sites ▪ vSMRs are part of the energy source of choice for any new resource development project ▪ Export market: The Canadian SMR industry is fuelling a vibrant global SMR market; Canadian-developed and manufactured SMR components are exported and installed in hundreds of SMRs world wide ▪ More advanced concepts have been demonstrated and are ready for deployment

REMOTE COMMUNITIES

There are some 319 remote communities in Canada (Reference 11). Most of the power plants, 96%, that serve off-grid communities in Canada consume fossil fuel, with the remaining 4% using hydro-power (usually with a diesel plant for backup). Many of these communities have small populations, and correspondingly low energy requirements.

However, these communities have large variation in their electricity needs: the baseload to peak demand can be great. Reliability is a crucial requirement; loss of power can have disastrous consequences in a remote community during the winter months. The installed capacity thus typically greatly exceeds the community's average demand.

Most of these communities have a current capacity of between 0.1 and 2 megawatts of electricity (MWe), which may increase, if and as these communities grow. Also, if a more reliable and lower cost source of electricity was available, it is anticipated that various social and economic activities will become more viable and so electricity usage will increase – usually a manifestation of greater human possibilities being realized.

Obviously, this will only happen where Canadians choose to accept their needs and wants being met though nuclear technologies. The demonstration effect of seeing nuclear working for Canadians elsewhere – starting with the provinces where it already delivers clean, reliable, affordable electric power – is presumably going to be influential. Ultimately, Canadians have to make their own decisions after being presented with fair, objective and complete information about their energy options, including nuclear.

TABLE 3 PATHWAY TO CLEAN ENERGY FOR REMOTE COMMUNITIES

2026	▪ The commercial viability of the SMR has been demonstrated ▪ The first demonstration SMR has been constructed and commissioning is underway *The demonstration phase is the same as for the resource extraction application above.*
2030	▪ The first demonstration SMR has been operating successfully for several years ▪ Successful early deployment of vSMRs to Canadian locations ▪ With the GoC as an early customer of these technologies, vSMRs have enabled at least 2 remote government facilities to be nearly carbon-free *This early deployment phase is the same as for the resource extraction application above.* ▪ Potential host communities for the first deployment have been identified and are watching the development of these opportunities
2050	▪ SMRs have been deployed to many or most remote off-grid communities ▪ vSMRs are part of the energy source of choice for any new energy project ▪ Export market: The Canadian SMR industry is fuelling a vibrant global SMR market; Canadian-developed and manufactured SMR components are exported and installed in hundreds of SMRs world wide ▪ Low technology readiness level (TRL) concepts have been demonstrated and are ready for deployment

MANAGING RADIOACTIVE WASTE

Canada's radioactive waste is managed well today. Not only is our waste stream extremely small, but the nuclear industry is the only energy industry that internalizes the cost of its impacts and incorporates this cost into the price of its energy product. Therefore, nuclear is the only energy industry that does not have a waste problem, or at least, nuclear has a better-managed waste stream than any other industry – though we are nevertheless constantly asked to explain how we plan to mitigate our waste problem.

Canada has effective organizations and forums working actively towards even better and more permanent waste solutions. These include the Nuclear Waste Management Organization, the former Nuclear Leadership Forum (2012-16), and the Radioactive Waste Leadership Forum. To develop very-long-term technical solutions for waste repositories, we look at how natural analogs (such as naturally occurring deposits of copper and bentonite clay) behave over hundreds of thousands of years.

Our vision is that, well before 2035, Canada will have a coordinated national strategy for managing all of its radioactive waste; and that before 2050, Canada will have permanent solutions for storing radioactive waste that are supported by the local community and the public and are operating well and safely.

WHAT THERE IS, AND WHAT'S NEEDED

There is an international consensus at the OECD Nuclear Energy Agency and the International Atomic Energy Agency about standards of good radioactive waste management. There are effective, successful storage facilities operating in several countries (France, Sweden, Finland).

Canada's nuclear industry has knowledge, technology and financial resources to deal effectively with our waste. But firm decisions are required imminently from government, so that we can have facilities operating in the needed time frame. Without political will to make these decisions, our industry's waste management capability is under-used and thus is itself being wasted.

5. BUILDING MOMENTUM

Canada's nuclear industry is ready to help with successful deployment and operation of nuclear fleets, whether the units are big or small, wherever they are applied.

We are also prepared to continue to invest in science and technical development, in obtaining regulatory approvals, in seeking capital in global financial markets, in positioning the workforce and supply chains for delivery of new build programs, and more.

To further improve the likelihood of delivering the benefits Canadians need from nuclear, this section highlights some areas where stakeholders should make greater progress together.

TIME IS SHORT

If Canada is to meet its international decarbonisation targets, the window for new nuclear program launch is now. The window is open today - but not for long. With further delay, emission targets become ever less attainable, our own runway shortens, competitors move forward into the space we currently own. Now is the time to build momentum so the government's agenda, and Canadians, can benefit from clean nuclear solutions.

THE VISION TODAY IS MUCH LESS ABOUT TECHNOLOGY, AND MORE ABOUT SERVING THE NEEDS OF A HUMAN, SOCIAL AND ENVIRONMENTAL AGENDA.

Building momentum means facilitating engagement and dialogue among stakeholders, analyzing our options and alternatives, and clarifying expectations. On many fronts, the federal government can use its convening power to create the conditions for effective and timely engagement and dialogue. In other cases, policymakers can reach out to subject-matter experts in academia, think-tanks, consultancies, industry and elsewhere to analyze and recommend how best to proceed.

Building momentum towards mobilizing nuclear's potential to help Canadians, along each of this report's three pathways, can be informed by the past experiences of nuclear new build programs. At the same time, it is imperative that we recognize that much is different – and many new strengths and possibilities exist – in today's context. The vision is much less about technology, and more about serving the needs of a human, social and environmental agenda. We are in a different world of information, industrial organization, government, and public engagement than in past decades. Creativity is explicitly part of our mindset and culture going forward.

ENGAGEMENT

New energy projects in Canada are struggling to advance. The present government is deeply engaged in the regulatory dimension of this issue, and the nuclear industry has participated both with government and with academic experts (Reference 8). Approaches to impact assessment and consultation that give affected stakeholders a meaningful voice, in advance of the regulatory process, are needed.

These approaches also need to recognize and engage a broader concept of stakeholder communities. While industry has an important role to play – and is reaching out to communities today – governments also have an important role in helping set the conditions for meaningful engagement.

Domestic deployment of new nuclear is a valuable precursor to successful Canadian nuclear industry sales internationally: foreign customers like to see the product being purchased in its home market. Canada's local supply chain is competitive, and will prosper if our domestic market draws internationally-sourced nuclear technologies into use in Canada.

INTERNATIONAL COOPERATION FRAMEWORKS

Government-to-government cooperation is essential. Cooperation happens through trade promotion, foreign investment policies and practices, cost-shared Science, Technology and Innovation (STI) programs and – in particular for matters nuclear – international safety, security and safeguards commitments and agreements. These are an essential underpinning to Canada realizing the full potential for new nuclear along each of the three energy pathways.

A good international cooperation framework includes a web of mutually supporting factors including treaties, agreements and memoranda of understanding; intergovernmental and inter-industry relations and informal linkages, multi-stakeholder committees, and other regular forums for dialog. With such a framework, Canada's domestic nuclear industry is better able to access international market opportunities, secure investment capital, participate in global value chains, localize leading edge nuclear technologies and access critical workforce skills.

Canada's existing international cooperation frameworks are a strength that can be leveraged to even greater effect. Targeted nuclear energy cooperation within North America and with Europe and the Asia-Pacific will be important to Canada's successful launch of new nuclear programs across the three pathways. Early and on-going government-industry dialogue is imperative to tailoring Canada's international frameworks to maximum benefit.

OPERATING MODELS

Most current nuclear energy has been built on a single operating model. This model defines the role of reactor owner, operator, nuclear license holder and customer.

While this well-understood model will continue to be relevant to the on-grid electricity pathway, it is less apparent that this works for the other two pathways. For example, the resource industry and territorial utilities are highly unlikely to have the capability and capacity to take on ownership and/or license-holder responsibilities for nuclear reactor fleets. Northern and indigenous communities have also had numerous negative experiences in the past with industries that have promised local benefits that have not been delivered. It is reasonable to expect that these communities will have concerns that the private sector can hold to decades-long commitments to safely operate and decommission reactors in their community.

New, creative and innovative operating models are likely required, models that are appropriately tailored to the realities of the specific energy pathway.

FUEL CYCLE AND WASTE MANAGEMENT

Among the more significant challenges and opportunities presented to new nuclear programs are the expectations and boundaries placed on the issue of reactor fuel cycles, fuel enrichment, fuel recycling and used fuel management. But, going forward, for each of Canada's three nuclear energy pathways, this is likely to be an area of dramatic innovation. Open-mindedness and creativity will be needed to align today's reality with tomorrow's possibilities.

Stakeholder dialogue and engagement, facilitated by the federal government, is needed to determine if there should be national expectations set with regard to fuel cycle and waste management options, and if so, what they are. This is seen to be an area where third-party expert advice, such as could be provided by AECL/CNL, SNC-Lavalin, the Council of Canadian Academies, or various other organizations could be helpful.

EARLY DIALOGUE IS NEEDED ON TARGET COSTS FOR ENERGY IN A DECARBONIZED ENERGY SYSTEM. TARGET COSTS WILL HELP INFORM AND DRIVE INDUSTRY'S INVESTMENT IN TECHNOLOGY DEVELOPMENT AND INNOVATION, AND WILL ALSO BE IMPORTANT IN INDUSTRY'S ABILITY TO SECURE INVESTMENT CAPITAL.

AFFORDABILITY

Energy cost is seen by many to be a key challenge in the federal government's quest to decarbonize its energy system. In the end, if Canadians do not deem their energy costs to be acceptably affordable, governments may be unable to develop the political support to drive decarbonisation programs forward.

New nuclear offers the potential to provide lower cost energy – and key drivers of affordability are discussed in Appendix C. However, it is industry's view that early dialogue is needed with governments, industry and consumers on what should be target costs for energy in a decarbonized energy system. Target costs for energy will help inform and drive industry's investment in technology development and innovation. Target costs will also be important in industry's ability to project its return on investment and to secure investment capital.

REGULATION

The Canadian Nuclear Safety Commission (CNSC) is respected globally for its world-class competence in setting and demanding very high safety and security standards for the licensing of nuclear power facilities. It is also recognized for providing clarity to industry on the regulator's requirements and related processes for obtaining regulatory approval.

Our regulator's standards are high, and with the clarity it has provided to industry on expectations, Canada is seeing many international nuclear vendors engaging the CNSC so as to be able to access its regulatory processes. A good, strong, reputable, independent regulator is a clear strength for industry.

Going forward, it will be important that the government ensures the CNSC has the capacity to exercise its regulatory responsibilities as demands for its services grow. It will be equally important that stakeholder communities are informed of, and have the opportunity to critique the standards of safety to which the CNSC subscribes.

PROCUREMENT

At some point – and likely at multiple points – in Canada's new nuclear programs, procurement for the construction of new reactors will occur. It is beneficial to provide clarity to industry regarding processes and expectations for procurement at the earliest opportunity.

Among the many questions to be answered are: Will there be competition? What criteria will be used for selection? What is the procurement schedule? Will there be additional requirements, such as localization? And more. Early dialogue, to inform the options for procurement processes and expectations, is essential.

WORKFORCE

The critical path to industry's capacity to service new nuclear programs is through the competencies and capacity of its workforce. Industry requires lead-time to develop and prepare the workforce. Universities and colleges require lead-time to turn out the graduates needed by industry.

Canada's nuclear industry finds itself in a highly favourable position today, having ramped up its workforce to meet the demands of Ontario's nuclear refurbishments. This is a workforce that will be ready to take on the demands of new nuclear programs over the coming 5 to 10 years as refurbishments move to completion. With appropriate dialogue and early planning, Canada can have a nuclear workforce ready to take on the challenges of ambitious new nuclear programs that can help the government, and Canadians, get the full potential human, social and environmental benefits of nuclear in the decades ahead.

DEMONSTRATION AND FIRST-OF-A-KIND

Customers are unlikely to commit to new nuclear programs unless the technology has been proven, built and economically de-risked. There is a need for a coordinated program to demonstrate and de-risk the technology prior to new build construction.

Canada's national nuclear laboratory, Canadian Nuclear Laboratories (CNL), is ideally suited for the demonstration of new nuclear designs and indeed has started the engagement with reactor vendors and governments on the possibilities for demonstration. Government/industry engagement to coordinate these activities is deemed to be helpful in ensuring that technology demonstration aligns with the needs for new nuclear programs.

6. RECOMMENDATIONS

Nuclear energy today is an important part of Canada's clean energy mix, and can make a large contribution to addressing the climate change imperative.

Advancing nuclear technology can also play an important role in addressing other policy priorities, including:

- providing clean and reliable heat and energy to remote communities;
- improving the health of Canadians through advanced medical applications;
- creating jobs and economic growth by growing domestic and export business;
- exporting decarbonization to growing markets worldwide; and
- maintaining Canada's global leadership, keeping Canadian experts authoritative and valued in international discussions on nuclear nonproliferation, safety, safeguards, and security.

That said, there is important work to be done by all stakeholders to put in place the policy, regulatory, social and technology foundations necessary to see the next generation of nuclear success for Canada.

And there is urgency to this work. New technologies need to be embraced or accepted by various Canadian communities of interest, and soon enough that they can help make the kind of difference on GHG emissions that the Paris Accord calls for. That means 2035 or sooner.

WHERE TO BEGIN – TOGETHER

The following recommendations highlight where to begin.

1. Given the dual urgency – the need to tackle climate change on a national and international basis, and the need to make the most of Canada's current lead and agility in accommodating new reactor technologies – **strong policy and programming support** is needed from federal and provincial governments to position nuclear as an essential part of Canada's clean energy strategy.

   This includes:

   - clear policy statements reinforcing nuclear as an important enabler, alongside renewables and other energy sources, of Canada's clean energy future;
   - the exercise of the considerable influence of the government and the Prime Minister internationally to assert nuclear technology as an important part of innovation, clean energy, sustainability, economic growth and prosperity;
   - work to have nuclear recognized within clean energy fora such as COP 21/23, Mission Innovation and the Clean Energy Ministerial;
   - support to Canadian nuclear businesses by facilitating access to: foreign governments and markets, financial supports through the Canada Account, Export Development Canada, and other government resources; and,
   - support for agreements, licences and security requirements for the export of nuclear technology, uranium and fuel.

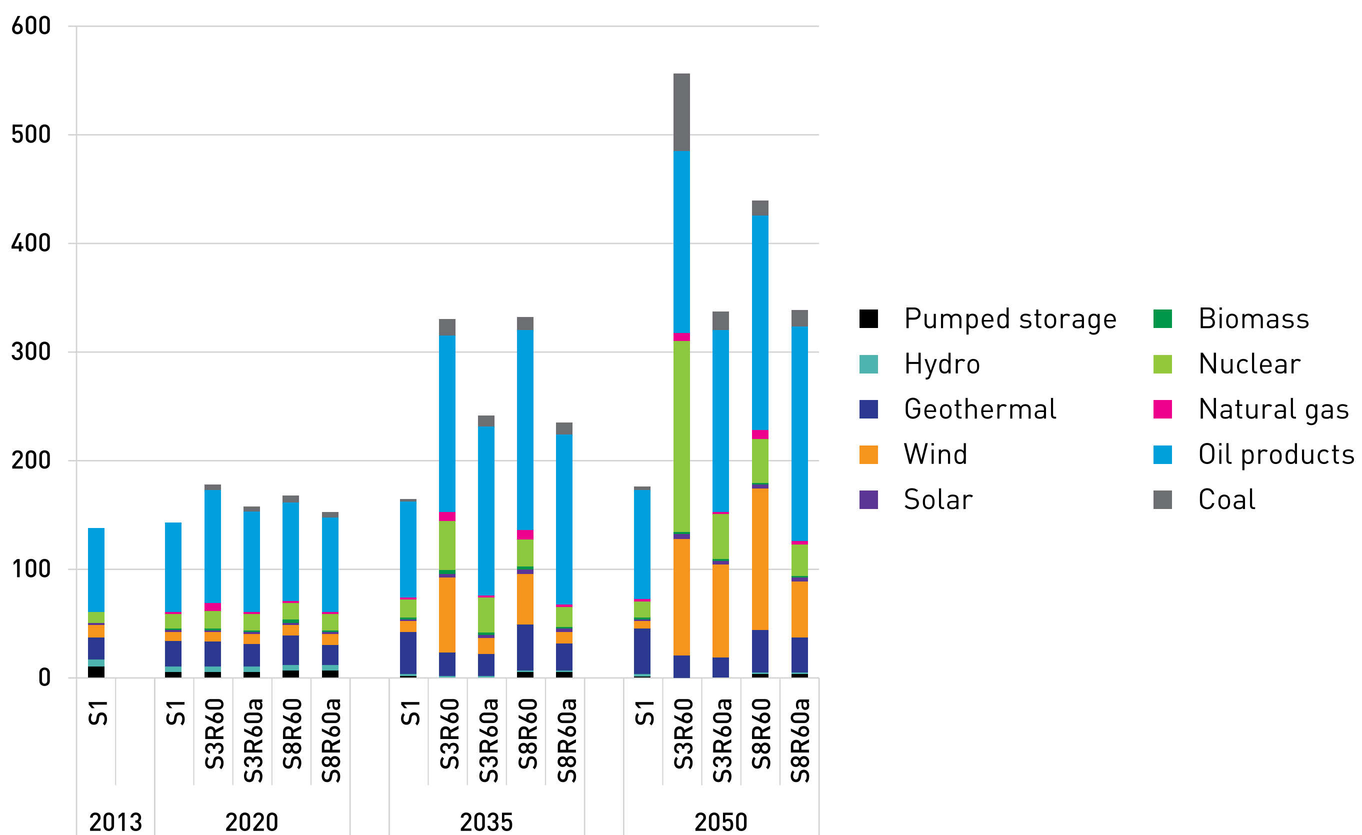
2. Given the importance of science and innovation as a means to long-term prosperity for Canada, and the potential for SMRs to play an important role in addressing priorities for clean energy in the north, energy security for indigenous peoples, sustainable resource development, and the future of clean baseload power, there is a need for **investment by industry and governments in nuclear innovation**, including:
   - government being an early customer, in particular for very small reactors for military bases or other facilities, to lower the risks to the first private investor;
   - investment by industry and federal and provincial governments in AECL and CNL for coordinated pan-Canadian research, development and demonstration of SMR technology;
   - the creation of financial vehicles for governments and industry to share risks inherent in advancing new technologies, such as public-private partnerships, and financial guarantees;
   - involvement of stakeholders and end-users in all stages of technology development and marketing to ensure that innovation is connected to needs and demand; and,
   - proper consideration of the full "cradle to grave concept" in technology development that takes account of full lifecycle costs, including full accountability for waste, and determining how spent fuel from new technologies will be integrated into Canada's comprehensive waste management strategy.
3. Given the importance of reconciliation with indigenous peoples, the potential for nuclear technology to bring energy security to remote, northern and indigenous communities, and the need to consider the end-user and other stakeholders at all stages of planning and development - government and industry should **work inclusively with indigenous people and all stakeholders**, including by:
   - beginning a dialogue now with indigenous and other stakeholders, leveraging the mechanisms and channels existing through INAC and other governmental and non-governmental agencies; and,
   - exploring opportunities for business partnerships with indigenous peoples, communities and businesses to develop and deploy nuclear technologies.
4. Given the world-class standing and effectiveness of the CNSC and its regulatory framework, the government should **provide ongoing support to the CNSC and possibly also to applicants**, including:
   - the financial support and ongoing autonomy necessary for the CNSC to continue to ensure the safety and security of the nuclear industry, and oversee the full scope of the nuclear lifecycle, including all aspects of environmental protection; and
   - helping to offset some of the cost of licensing a new design.
5. Given that Canada's nuclear industry is a strategic asset with respect to many policy priorities, and its long-term success relies equally on business, and federal and provincial governments, there is a need for **ongoing coordination and dialogue between all stakeholders**, including:
   - the creation of a Nuclear Innovation Council (NIC), comprised of members from federal government departments and agencies, interested provincial governments, indigenous and host communities, as well as industry representatives. The council would provide advice and coordination on all matters relating to the nuclear sector and would be important in guiding the implementation of all other recommendations outlined in this report; and,
   - the commissioning, perhaps by the NIC, of third-party experts to produce studies, analyses and recommendations to inform and support engagement and dialogue in critical matters, including operating models, affordability, fuel-cycle and waste management, procurement and demonstration; and
   - a shared approach to fleet-wide efficiencies for the operation and maintenance of new reactor units to ensure there are adequate economic and social benefits across Canada.

APPENDIX A: TROTTIER SCENARIOS

There is broad consensus that meeting the government's Paris Accord commitments will require the deep decarbonization of Canada's energy system. The comprehensive Trottier Energy Futures Project (Reference 3) of the Canadian Academy of Engineering lays out in stark terms the magnitude of the challenge.

The study conducted systematic analysis of multiple scenarios for Canada's future energy system with varying mixes of energy supply and distribution, coupled with energy conservation. Among other findings, the study concludes that meeting the government's GHG targets for 2050 will require a massive increase in electrification of energy supply through low carbon technology. It also concludes that to achieve this at the lowest possible cost to Canadians will require a diverse set of low carbon technologies, including nuclear.

The chart below, extracted from the Trottier report (Figure 151), provides an indication of the scope of transformation that the study projects will be required. It shows the degree of electrification required to realize a 60% reduction in Canada's GHG emissions compared to 1990 levels for four energy supply mixes (scenarios S3, S3a, S8 and S8a) that the study assesses to be lowest cost, compared to the study's "status quo" scenario (S1). This analysis suggests that by 2050, Canada will need to have increased electrification by a factor of 3 to 5 compared to today, with nuclear power contributing between some 15-30% of the future supply. These projections are intended to be indicative and to provide stimulus for further analysis, recommendations and decision-making by governments, industries and communities.



APPENDIX B: ECONOMIC DRIVERS FOR NUCLEAR ENERGY

Several factors drive the cost of new nuclear down, particularly when it comes to new nuclear for on-grid applications.

Shorter Construction Times: New nuclear reactors are using modular construction techniques, whereby major components are prefabricated and shipped from factories to the plant site by rail or truck. SMRs use modular construction techniques to a greater extent by having the vast majority of their components factory manufactured and then shipped to site for final assembly. This significantly reduces construction time by simplifying plant site activities required, which in turn reduces the cost for financing and construction.

Lower Up-Front Costs: SMRs have significantly lower up-front capital costs compared to large reactors. Their smaller cost allows them to be more financeable for utilities. They can also be built in multi-module sets. This allows one unit to generate electricity and revenues while subsequent units are being constructed.

Design Simplification: Several SMRs have significant design simplifications that can be achieved through the incorporation of size-specific inherent safety features. By some estimates, these simplifications can reduce up-front capital costs by 15%.[1]

Stable Fuel Costs: Unlike natural gas or diesel, uranium fuel costs are low and offer long-term price stability. They also account for a much smaller portion of plant operation than in fossil-fuel plants.

Competitiveness with Natural Gas: According to a recent study on the economics of SMRs, there are many conditions and scenarios that could result in SMRs being comparable with the costs of a natural gas combined cycle plant.[2] Indeed, according to the Trottier Study, comparisons of scenarios that included nuclear and those that did not found that the scenarios that did not have nuclear resulted in an overall higher cost.[3]

[1] "CURRENT STATUS, TECHNICAL FEASIBILITY AND ECONOMICS OF SMALL MODULAR REACTORS", OECD, JUNE 2011, P. 15.

[2] SMR START, "THE ECONOMICS OF SMALL MODULAR REACTORS," NEI, SEPTEMBER 2017, P.2.

[3] TROTTIER STUDY, P. 229

Economies of Scale through Fleet Deployment: By 2035, after the first few plants begin operation, SMRs would be cost-competitive with alternatives if they were built as a fleet. Canadian manufacturers would be able to produce components on a commodity basis, purchasing of fuel and ongoing maintenance would reduce procurement costs, and operator training efficiencies would be gained by having the best-in-class experience of several reactors. Cost savings through economies of scale would be further enhanced by having Canadian manufacturers supplying to a global fleet of SMRs.

Several studies have pointed to the fact that very small modular reactors (vSMRs) are expected to be competitive with diesel power generation (Reference 7). The drivers of these vSMR costs include:

- **Shorter Construction Times:** vSMRs are meant to be factory produced and shipped to site. Given their smaller size, construction times are likely to be even shorter than SMRs.
- **Lower and stable fuel costs compared to diesel:** Long-term diesel prices are expected to rise from $0.99/L (2015) to $2.39 by 2040.[4] Uranium, on the other hand, is a smaller portion of overall costs in a vSMR (expected to be on the order of four to eight percent, depending on design) than fuel is in a diesel generator. As well, uranium pricing is expected to remain relatively stable over the long-term.
- **Economies of scale from a fleet of vSMRs:** There is potential for vSMRs to be used at a large number of mining sites across Canada. In a fleet approach that uses similar technology, one can achieve significant cost savings by streamlining manufacturing and producing components on a commodity, rather than a special-built, basis. These economies of scale are enhanced by linking the Canadian supply chain to export opportunities for vSMRs.

[4] HATCH STUDY, P. 58.

APPENDIX C: PUBLIC-PRIVATE PARTNERSHIPS

Nuclear projects involve roles for both the private and public sectors. Private sector reactor vendors are already investing their resources in reactor design, development, licensing and supply chain preparedness in Canada.

To advance the technology to the next stage of development and build-out, various public-private partnership models need to be explored, including the following:

- Private sector vendors can advance their reactor design and development at Canadian Nuclear Laboratories with federal government investment in research and development, as well as science and technology for Small Modular Reactors.
- Public-private financing options may be considered to underwrite the risk for new builds. These options can include:
  - Government grants for technology development;
  - Private financing with a federal loan guarantee and/or a federal technology risk guarantee; and/or,
  - Full government financing for new builds.

APPENDIX D: HYBRID ENERGY AND OTHER APPLICATIONS

LOW-CARBON HYBRID ENERGY SYSTEMS

As discussed above, SMRs, and specifically vSMRs, have important applications in supplying low-carbon electricity for resource development. Nuclear technology also offers important opportunities alongside other energy technologies in support of substantial decarbonisation. This includes the use of nuclear as a partner to support intermittent renewable sources and in the hydrogen economy. Nuclear reactors can be part of an overall energy scheme that includes district heating, co-generation, energy storage, natural resources development, desalination and hydrogen production.

Canada's substantial decarbonization goal – to reduce greenhouse gas emissions by 30% below 2005 by 2030 – cannot be achieved solely by non-carbon electricity but will also require decarbonizing other currently carbon-reliant areas such as transportation, light industrial use (fork lifts, etc.), private and fleet cars, light rail, buses, passenger and freight trains, and transport trucks.[5]

Nuclear technology can be used to support these goals through direct hydrogen production, contributing to the science of fuel-cell technology, and generally, being a partner in the decarbonisation of the manufacturing and transportation sectors. 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 has an opportunity to play a leading role in the addressing the economic, production capacity and delivery challenges.

With respect to variable renewables, 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. The U.S. Department of Energy, for example, is investigating the technical and economic viability for a range of possible nuclear-renewable hybrid energy system configurations. The objective is to identify alternative future energy arrangements that are capable of supporting environmental, sustainability and economic goals while maintaining grid resilience.[6]

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[5] **R. 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).**

[6] **S.M. BRAGG-SITTON ET AL, "NUCLEAR-RENEWABLE HYBRID ENERGY SYSTEMS: 2016 TECHNOLOGY DEVELOPMENT PROGRAM PLAN", INL/EXT-16-38165, IDAHO NATIONAL LABORATORY AND OAK RIDGE NATIONAL LABORATORY, 2016.**

OTHER APPLICATIONS FOR NUCLEAR

While the need for clean and reliable baseload electricity is the driver for much of the nuclear innovation in Canada, nuclear research and development has had tremendous impact outside of nuclear energy. Most notably, nuclear R&D has led to breakthrough Canadian technologies in cancer therapy, and at its peak, Canada supplied more than 50% of the global demand for the key medical isotope – molybdenum-99. Indeed, nuclear R&D contributes to innovation in multiple areas beyond energy, including: health, safety, security, non-proliferation, and the environment.

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

Other examples of the diversity of the research 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 broader health effects of routine medical imaging on patients.

Advances of many of the enablers of new nuclear technologies are transferrable to many of Canada's other industrial sectors. For example, advanced manufacturing, modular design and assembly that will be key for the economic development and deployment of SMR fleets are transferable to other sectors such as aerospace and construction.

More broadly, nuclear research is integral to the fabric of Canada's S&T landscape. Of note, the Chalk River Laboratories is Canada's largest scientific site, and the scientists that are trained there, often go on to have impact in ways unimaginable. 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. The recent investment of $1.2B by the Government of Canada in the revitalization of the Chalk River Laboratories is a strong recognition of the need for nuclear R&D to support Canadian priorities in energy, health, safety and security, and more broadly, in innovation, science, jobs and the economy.

Going forward, investments in nuclear R&D to advance the energy opportunities discussed above, are expected to bring broad benefit, inside and outside of the nuclear sector. While the Chalk River Laboratories are foundational to Canada's nuclear innovation capacity, researchers across the country in federal laboratories, universities, other research organizations, and industry are all important to a strong and dynamic S&T capacity in Canada. Investments by federal and provincial governments in advanced nuclear energy technologies will have follow-on benefits in maintaining and strengthening the depth and breadth of Canada's scientific capacity, with all of the economic potential that such capacity can bring.

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