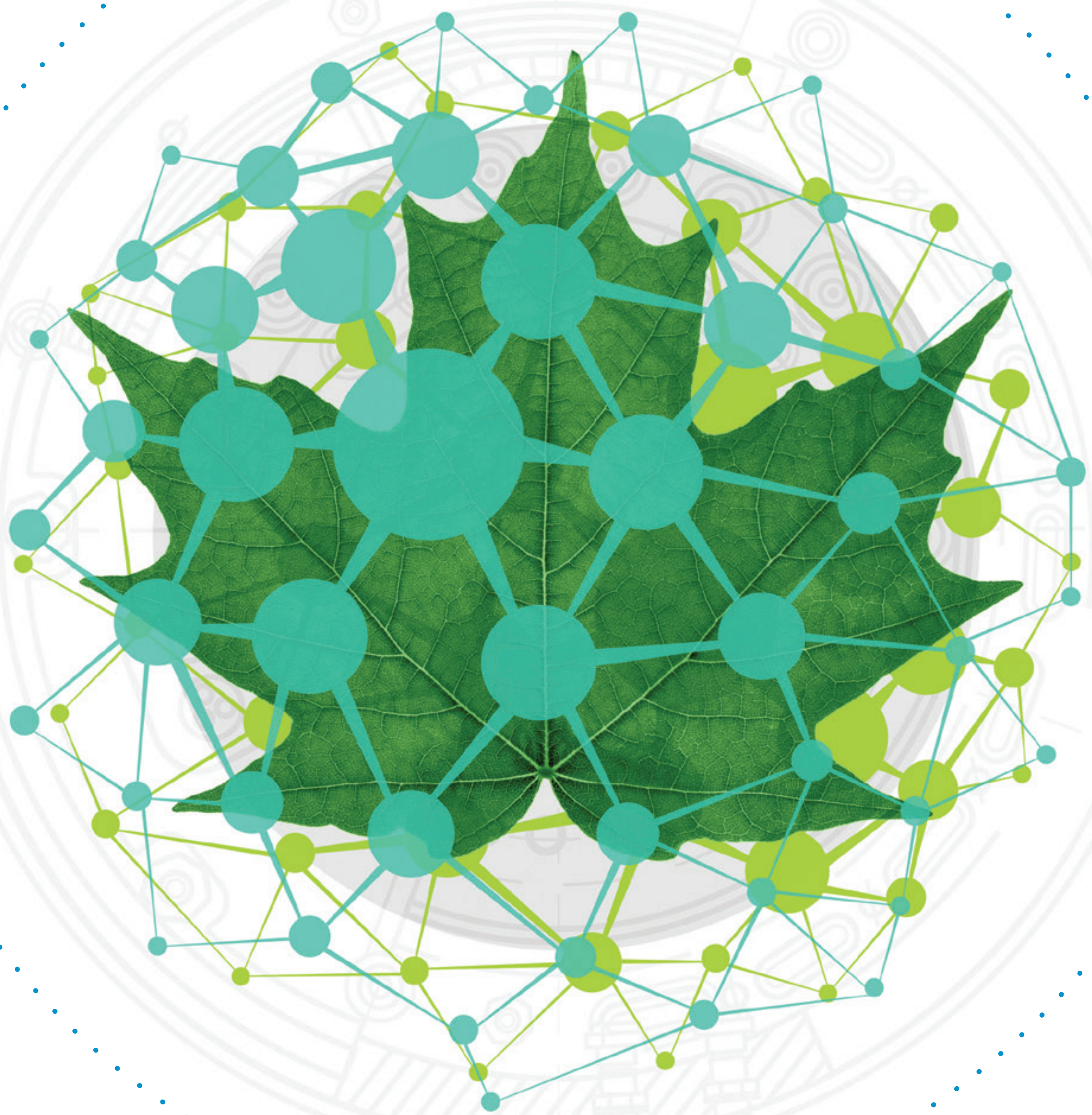

Summary Report

PERSPECTIVES ON CANADA'S SMR OPPORTUNITY

Summary Report: Request for Expressions of Interest—
CNL's Small Modular Reactor Strategy

Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

The place is Canada.
The time is now.
Your partner is CNL.

Mark Lesinski,
CNL President & CEO

SUMMARY REPORT:

PERSPECTIVES ON CANADA'S SMR OPPORTUNITY

Canadian Nuclear Laboratories has a long and rich history in nuclear innovation. For over 70 years, the company has pioneered ground-breaking, peaceful applications in nuclear science and technology that have impacted the lives of people all over the world, from nuclear medicine to fight cancer, to nuclear energy that powers our way of life.

We are now looking at a new opportunity for Canada: small modular reactors.

Small modular reactors, or SMRs, represent a key area of interest to CNL. As part of our Long-Term Strategy, announced earlier this year, CNL established the ambitious goal of siting a new SMR on a CNL site by 2026. With a domestic need for this technology, mature and robust regulatory programs, and fully-equipped laboratories to support such a project, CNL is uniquely positioned to support an SMR from concept to deployment. Ultimately, we intend to be a recognized global hub for SMRs, where multiple technologies are built and tested, drawing support from a strong team of world-class professionals.

As with any undertaking of this magnitude, establishing a new SMR industry comes with significant challenges. Specific issues confronting the successful deployment of SMRs are broad – from licensing and security to safeguards and waste management. Socio-economic challenges such as public acceptance are also critical. And so, CNL began this process by listening, through a Request for Expressions of Interest (RFEOI) with a view to fully understanding the environment in front of us.

On the following pages, you will find the feedback and careful consideration of 80 organizations and individuals from across Canada and the globe. The comments reflect a broad cross section of stakeholders, from technology developers and members of our supply chain, to end users in resource extraction and remote northern communities. Each one of these respondents sees opportunities in SMR technology, and has provided thoughts on how best to move this solution forward.

Today, CNL is undergoing an organizational renewal that will transform its Chalk River campus. This 10-year process, enabled by a $1.2 billion investment from the Government of Canada, will revitalize the Chalk River site, and build on CNL's historical strengths in nuclear physics and fuels, metallurgy, materials, chemistry, biology and engineering. Informed by global trends, CNL has combined federal and commercial priorities into focused, application-driven research and technology priorities delivered through programs in energy, health, safety and security, and the environment.

This step is simply the first in a journey towards the successful deployment of an SMR – but it is an important one. We hope that the organizations and individuals who contributed to this report will continue to work with us, so we can make the most of the opportunity in front of us, and come together to maximize the potential of this compelling technology.

The place is Canada. The time is now. Your partner is CNL.

Mark Lesinski,
CNL President & CEO

LIST OF ACRONYMS

SMR	Small modular reactors
CNL	Canadian Nuclear Laboratories
RFEOI	Request for Expressions of Interest
R&D	Research & Development
ST&I	Science, technology and innovation
S&T	Science & technology
PWR	Pressurized Water-cooled Reactors
HTGR	High-Temperature Gas-cooled Reactors
SFR	Sodium-cooled Fast Reactors
LFR	Lead-cooled Fast Reactors
GFR	Gas-cooled Fast Reactors
MSR	Molten Salt Reactors
MWe	Megawatt electrical
MWth	Megawatt thermal
COP21	21st Conference of the Parties*

LWR	Light Water Reactor
GHG	Greenhouse Gases
OEM	Original Equipment Manufacturer
CANDU	Canada Deuterium Uranium
CNSC	Canadian Nuclear Safety Commission
VDR	Vendor Design Review
vSMR	Very Small Modular Reactor
NRCan	Natural Resources Canada
GDP	Gross Domestic Product
PYE	Person Years of Employment
LCOE	Levelized Cost of Energy
FOAK	First of a Kind
WNA	World Nuclear Association
IAEA	International Atomic Energy Agency
TRISO	Tristructural Isotropic
NASA	National Aeronautics and Space Administration

* Referring to the countries that have signed up to the 1992 United Nations Framework Convention on Climate Change.

EXECUTIVE SUMMARY

On June 1, 2017, Canadian Nuclear Laboratories issued a Request for Expressions of Interest (RFEOI) to gather input on its small modular reactor (SMR) program. The objective of the RFEOI was to initiate a conversation about the potential interest in an SMR industry in Canada, and to better understand the role CNL can play in bringing SMR technology to market.

In response to this initiative, 80 submissions from organizations and individuals around the world were received – a strong indication of support from a broad range of stakeholders representing key areas of a potential SMR industry. This includes 19 expressions of interest to build a prototype or demonstration reactor at a CNL site spanning a wide range of SMR concepts. Overall, responses were submitted from SMR technology developers, potential end users, and other interested parties and stakeholders, including host communities, the nuclear supply chain and research and academic institutions.

The following report summarizes the results of this information-gathering campaign. While submissions came from a variety of stakeholders representing the feedback of a diverse group of interested parties, key themes did emerge in the submissions.

First, there is consensus that the establishment of an SMR industry in Canada would lead to economic benefit for Canada. Respondents believed that there is a strong but narrow opportunity to serve as an early adopter of the technology, and that capitalizing on it would establish Canada as a world leader in what will likely grow to become a global industry. RFEOI participants projected an increase in Canadian jobs, a growth in federal tax revenues, an increase in foreign investment in Canada, and greater export revenue, among other benefits.

Second, respondents believed that the development and deployment of SMRs aligns with Canada's commitment to combat climate change.

Third, SMR concepts were considered an attractive solution for remote off-grid communities and industries operating in remote locations, such as mining. Respondents argued that replacing diesel generators with SMRs, possibly along with other renewables, would establish energy independence and enable growth in remote communities.

Finally, respondents believe that SMRs have the potential to offer enhanced safety, noting that passive and inherent safety are key components of next-generation nuclear energy systems.

While there was agreement on the potential benefits that would come out of spearheading SMR development and deployment, there were also a number of important challenges that were raised across every stakeholder group. Funding for technology development and demonstration, social acceptability, the business case, and government and regulatory support were all discussed as potential hurdles that could limit or prevent the successful development and deployment of SMR technology in Canada.

The need for consistent, long-term political support was noted in many responses. Policy tools and financial support are needed to develop technologies; the industry will quickly be self-sustaining once established. Political leadership was also identified as important to support education and build public acceptance.

Overall, it is clear from the volume and quality of responses received that there is considerable interest in pursuing an SMR industry in Canada, and in testing this technology through a demonstration reactor at CNL. The RFEOI has provided CNL with better insight into the needs of the SMR community, the challenges in bringing SMRs to market, and the capabilities required to do so. CNL will include this information as it shape its programs.

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INTRODUCTION

Increasingly over the past decade, small modular reactors (SMRs) have been recognized as a potential alternative to large-scale nuclear reactors. SMRs are a strategic priority for CNL in support of its purpose to advance science and technology for a clean and secure world. Building on decades of experience in supporting and deploying numerous prototype, demonstration, research, and power reactors, CNL is well-positioned to support the development and deployment of SMRs, including hosting a demonstration facility.

The Request for Expressions of Interest (RFEOI) was conducted between June and August 2017 to better understand: market interest in SMRs, including the siting of a demonstration or prototype; interest in R&D and other services at CNL to support SMR development; challenges and opportunities in bringing SMRs to market; and other interest and considerations in SMRs from a wide range of stakeholders.

The RFEOI was comprised of two sections – one for general submissions, and one for technology developers. The general submission section broad themes such as: the role of the respondent in an SMR industry, needs and obstacles to deploying SMRs, the role of R&D, and non-electrical applications of SMRs. The section for technology developers solicited more information on specific technologies, including: the envisioned benefits to Canada, the design, business considerations, and the requirements for a demonstration reactor that could potentially be built at a CNL-managed site.

Through the responses received, CNL is building an understanding of the capabilities of technology developers and other stakeholders – both what they would bring to a partnership with CNL, and what is needed for successful commercial deployment. Overall, input was received from SMR technology developers, potential end users of these technologies, and other interested parties and stakeholders, including but not limited to potential host communities, the Canadian nuclear supply chain, and research and academic institutions.

This report summarizes what we heard through the RFEOI. All the content is derived from the responses. This report compiles the information but does not attempt to draw conclusions or make recommendations based on the responses.

WHO RESPONDED

CNL received 80 responses to the Request for Expressions of Interest (RFEOI). Some responses represented multiple organizations, and some organizations were represented through multiple responses. Several individuals from potential host communities also responded. In total, 381 organizations and individuals were represented in the 80 submissions.

There is global interest in SMR development in Canada and at CNL. Responses were received from all around the world: 51 from Canada, followed by 11 from the UK and 9 from the US, with the remainder from other countries in Europe, Asia and South America (Figure 1). As the province with the highest amount of nuclear generation today, Ontario had correspondingly the greatest number of responses – 35. That said, 30% of Canadian responses were from outside of Ontario, demonstrating that interest in an SMR industry stretches across Canada (Figure 2).

Responses came from a wide range of stakeholders: reactor developers (22), product or service providers in the nuclear supply chain (27), utilities or other end users (5), academic/research institutions or other agencies (12), and communities and individual contributors (14) (Figure 3).

Input spanned every aspect of a future SMR industry, a strong indication that the breadth of expertise, capabilities and capacity exist to make this objective a reality in Canada. All parts of the life cycle of a reactor were represented, from design through licensing, operation, and decommissioning.

AREAS OF CAPABILITIES AND EXPERTISE THAT WERE SELF-IDENTIFIED BY RESPONDENTS

- engineering
- procurement
- construction
- manufacture of equipment and components
- licensing experts
- human performance/factors
- safety assessments
- technical readiness reviews
- commissioning
- operation
- decommissioning
- qualification of components
- inspection and tooling
- waste services
- economics analysis
- feasibility studies
- training and qualification
- design
- project management
- environmental protection
- risk assessment
- impact assessments
- quality assurance
- radiological protection
- nuclear criticality safety
- nuclear material management
- automation
- control systems and simulators
- fuel manufacture

Figure 1

RESPONSES RECEIVED FROM AROUND THE WORLD

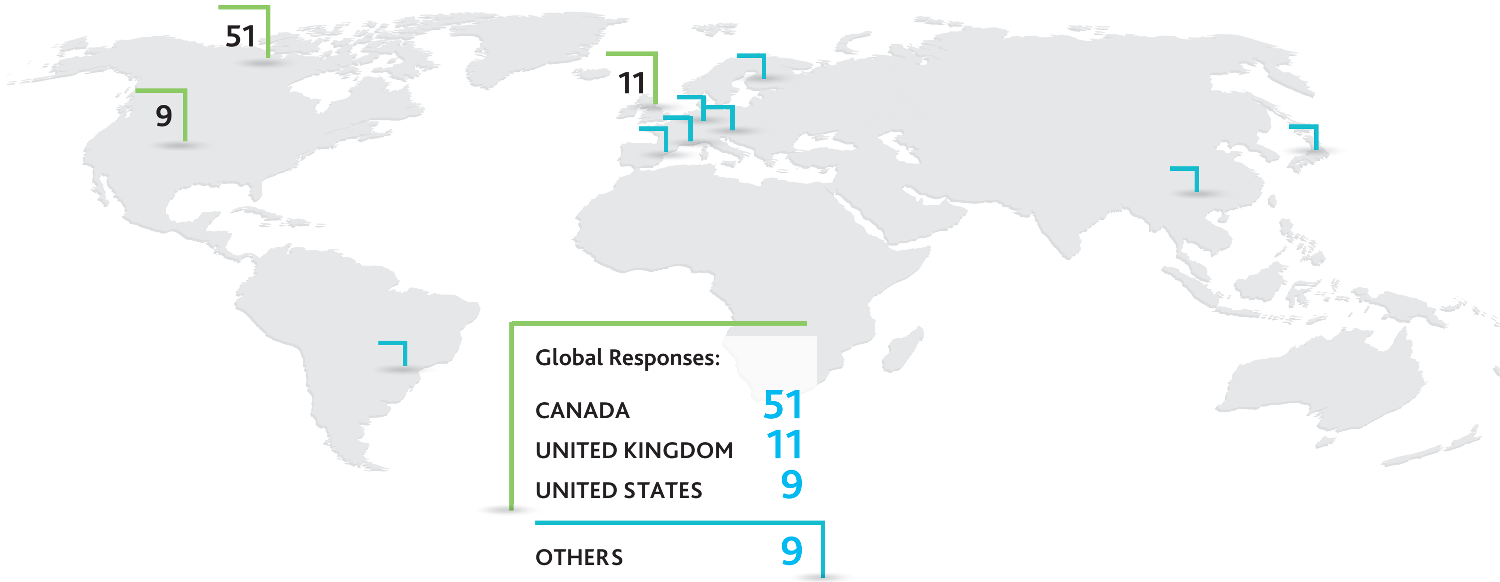


Figure 2

RESPONSES RECEIVED ACROSS CANADA

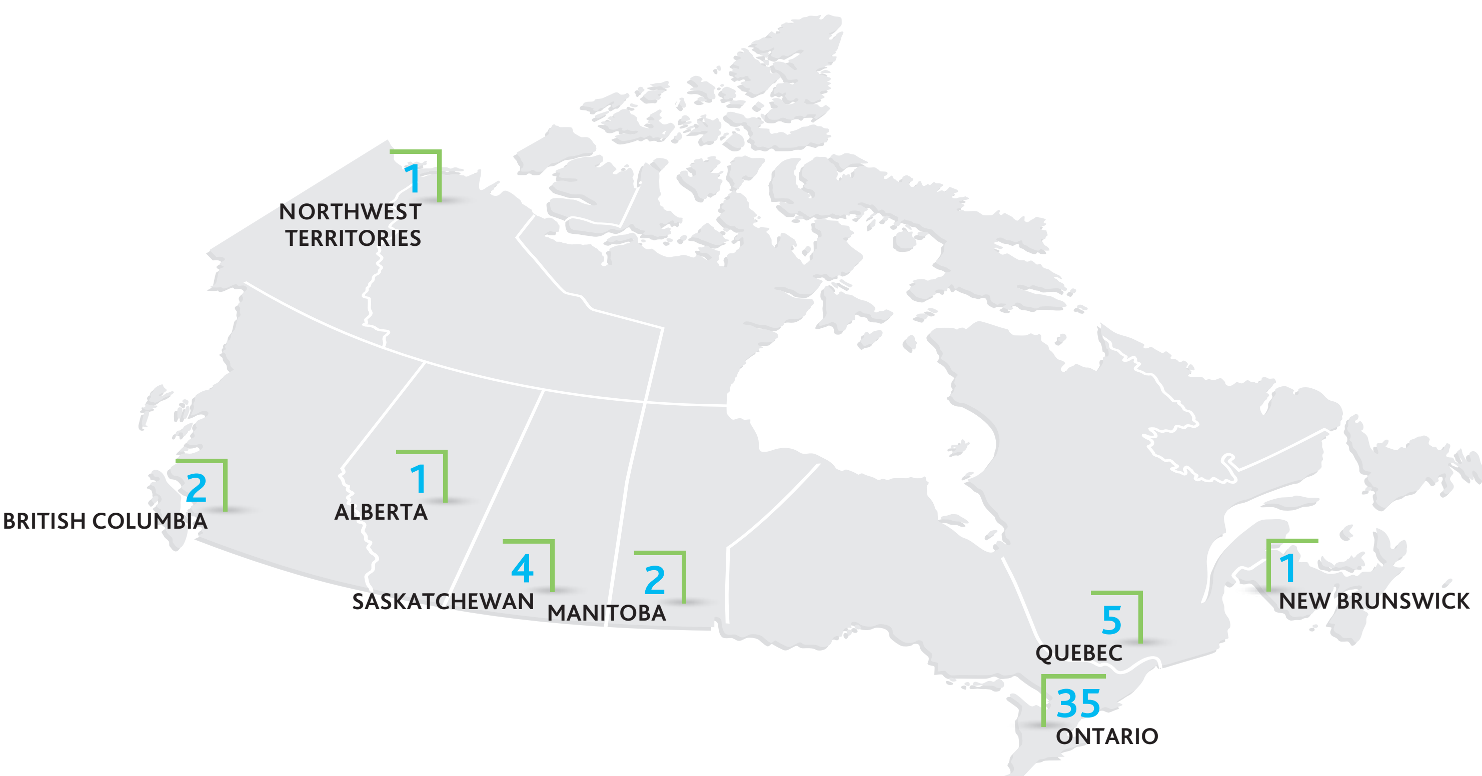
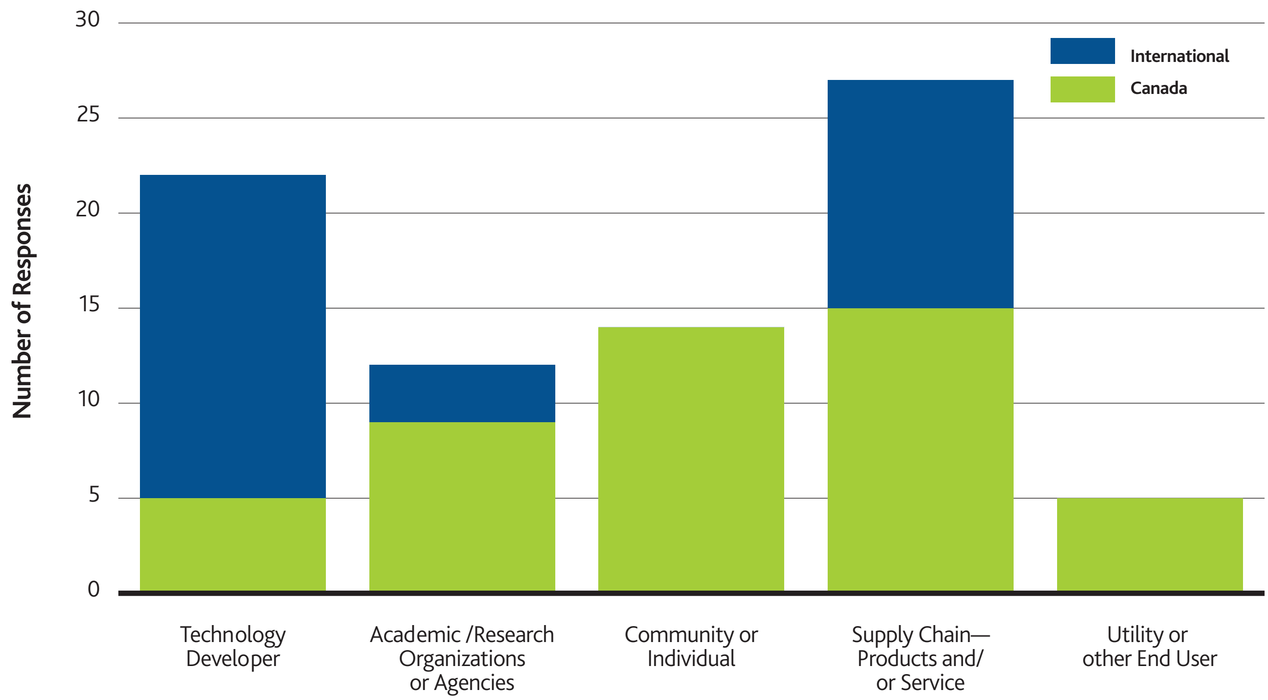


Figure 3

NUMBER OF RESPONSES RECEIVED FROM VARIOUS STAKEHOLDER CATEGORIES



Canada needs cost effective electricity and space heating. The geography makes centralised grid systems prohibitive especially in remote locations. SMRs offer a potential solution which is also zero carbon.

Atomic Acquisitions Limited

SMRS:
THE WHAT AND THE WHY

Increasingly over the past decade, small modular reactors (SMRs) have been recognized as a potential alternative to large-scale nuclear reactors. SMRs may offer several advantages over traditional technologies, notably: a reduced size more suitable for some applications; the ability to purchase and construct in a modular way, decreases in up-front capital costs; simpler, less complex plants; and a reduced staff complement.In addition to electricity generation, SMRs can be part of an overall energy scheme that could include applications such as district heating, co-generation, energy storage, desalination, or hydrogen production.

SMRs retain the positive attributes of traditional nuclear reactors, including the safe and reliable production of energy with limited emission of greenhouse gasses. There are many different SMR concepts, ranging from technologically mature advancements of today's water-cooled reactors, to more advanced reactors based on Generation IV[1] nuclear technologies.

REACTORS UNDER DEVELOPMENT BY RESPONDENTS

Seven broad categories of reactor type[2] were reflected in the responses to the RFEOI by technology developers, see Figure 4. These categories are distinguished primarily by their fuel and/or coolant properties:

- Pressurized Water-cooled Reactors (PWR)
- High-Temperature Gas-cooled Reactors (HTGR)
- Sodium-cooled Fast Reactors (SFR)
- Lead-cooled Fast Reactors (LFR)
- Gas-cooled Fast Reactors (GFR)
- Molten Salt Reactors (MSR)
- Fusion Reactors

The dispersion of responses received is largely balanced across most reactor types, with the exception of GFRs and fusion reactors which were proposed by only one respondent each.The majority of respondents were developers of non-water-cooled reactor technologies, a distinct contrast to the predominant form of nuclear power installed in Canada and around the world today.

One of the distinguishing features of SMR technologies, inherent in the name, is their smaller designed size. Figure 5 illustrates the proposed electrical power output of the commercially deployed reactor facilities as self-identified by the respondents.

1 Generation IV International Forum (https://www.gen-4.org/gif/jcms/c_9260/public)

2 These categorizations are consistent with different types of nuclear power reactors identified by the World Nuclear Association (WNA), International Atomic Energy Agency (IAEA) and Generation IV International Forum (GIF)

Figure 4

REACTOR TYPES BEING DEVELOPED BY RESPONDENTS

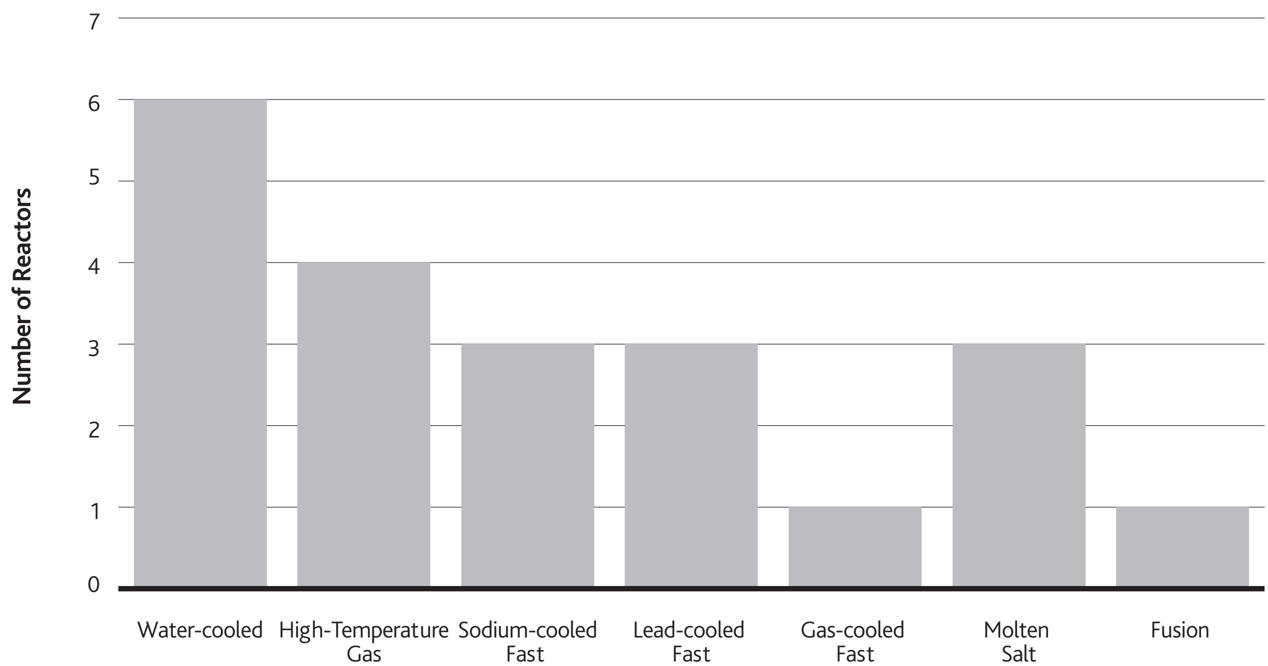
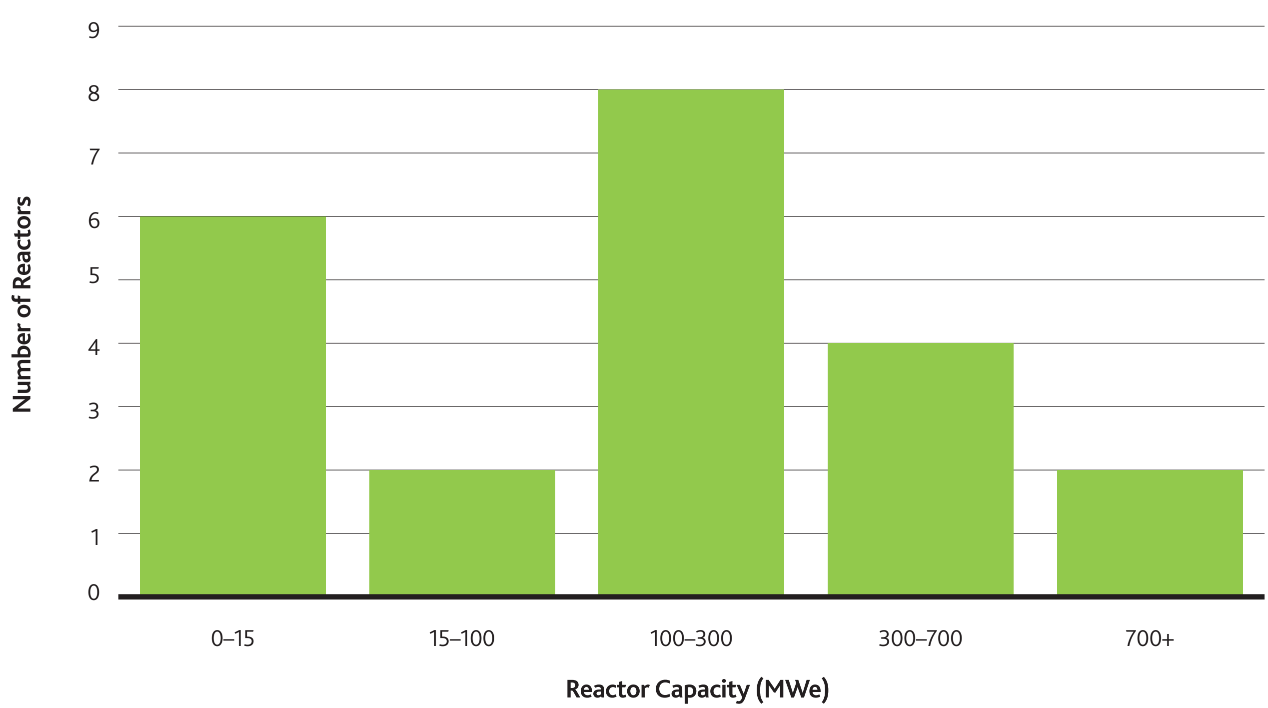


Figure 5

ELECTRICAL CAPACITY OF COMMERCIAL PLANTS BEING DEVELOPED BY RESPONDENTS



75% of the respondents are developing designs with less than 300 MWe of capacity, with 30% reflecting very small electrical power applications of under 15 MWe.

While nuclear power is typically thought of in terms of its electrical output, RFEOI respondents indicated that the thermal output (MWth) is also relevant due to the many applications for which the heat can be applied. The thermal output capacity of the different reactor types ranges from a factor of 2.4 to 3.1 times the electrical capacity for most units.

WHY SMRS—THE GLOBAL CONTEXT FOR SMR DEVELOPMENT

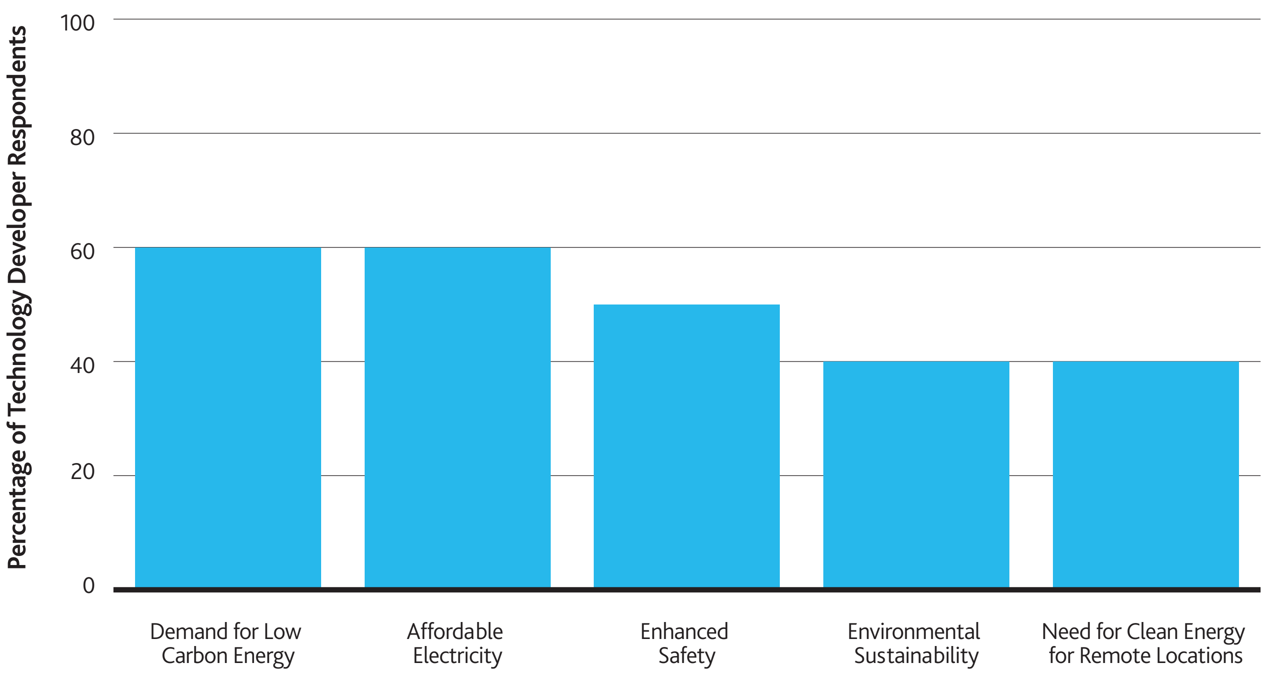
In addition to the need for electrical power, RFEOI responses indicate that SMR development is being driven by a number of emerging global issues:

- Demand for low GHG-emitting energy
- The need for low cost flexible and reliable electricity options
- Improved safety features over traditional nuclear power reactors
- Environmental sustainability
- A perceived market for clean energy for remote, off-grid locations

The extent to which the respondents identified the drivers behind the interest in SMR development is illustrated in Figure 6.

Figure 6

BENEFITS OF SMRS ACCORDING TO TECHNOLOGY DEVELOPER RESPONDENTS



KEY POINTS MENTIONED BY RESPONDENTS

SMRS ARE A SOURCE OF CLEAN, LOW-CARBON ENERGY.

- To meet COP21 objectives, significant numbers of new nuclear plants are required globally for climate control, energy security
- Growth in demand for low-carbon electricity in North American
- Clean energy sources are needed to power the approaching electrification of transport
- Provision of adequate clean energy is vital to our future on this planet

SMRS CAN MEET THE ELECTRICITY NEEDS OF A DIVERSE MARKET.

- Dispatchable, reliable and flexible to support grid stability
- Available when required
- Economically competitive with other supplies
- Respond to rapidly evolving energy markets and dynamics
- Developing nations must provide basic needs to their citizens
- LWR reactors active safety systems and very large-sized plants, have become too complicated with uncertain construction schedules that discourages end users

SMRS OFFER IMPROVED SAFETY FEATURES OVER TRADITIONAL NUCLEAR POWER REACTORS.

- Enhanced safety features support greater adoption of nuclear
- Inherently safe passive reliable safety features
- Reducing regulatory burden on countries unable to support infrastructure and want gradual access to nuclear power
- Reduced nuclear proliferation risk

SMRS MAY HOLD AN ADVANTAGE IN ENVIRONMENTAL SUSTAINABILITY.

- Smaller land-use footprint
- Reduction in the volumes of nuclear waste generated per energy output
- Potential to consume stockpiles of existing waste
- Address evolving geopolitics of environmental regulation
- Positive difference to our environment and to the lives and well-being of communities
- Raising global living standards without negative health and environment impacts

SMRS CAN SATISFY A MARKET NEED FOR CLEAN ENERGY IN REMOTE, OFF-GRID LOCATIONS

- Remote communities currently reliant on high greenhouse gas (GHG) emitting, and expensive, diesel
- Small energy demand, bringing power where it is most needed
- Mining applications
- Suitable for deployment to off grid and edge of grid locations
- High cost of transmission lines

APPLICATIONS BEYOND ELECTRICITY

Developers of SMR technologies are considering applications beyond the on-grid, baseload, electrical production of today's large-scale reactors. Targetted non-electrical applications vary depending on design. The outlet temperature, thermal and electrical power output, and target market all factor into the potential non-electrical uses for any particular reactor concept. Respondents to this RFEOI identified that SMRs could be applied to:

- District heating
- Industrial process heat
- Hydrogen production
- Synfuel production
- Heavy oil recovery
- Petrochemical refining
- Desalination
- Oxygen production
- Energy storage
- Marine propulsion
- Isotope production
- Recycling of spent fuel to reduce current spent fuel volume and liability
- Community infrastructure and services, such as greenhouses, wide-band internet for medical and educational use, and aquaculture

WHY CANADA

While not explicitly asked as a question within the RFEOI, several reasons for respondent interests in Canada were given in the commentary.It is clear from the responses that universally one reason for the strong interest of respondents in the Canadian opportunity is the release of the RFEOI itself. The interest in Canadian opportunities appears to be motivated by the following:

- The capabilities of CNL and the availability of its licensed sites to host demonstration reactors
- The extensive nuclear science and technology capabilities within Canada
- Well-established and capable supply chain with specialized and experienced nuclear suppliers
- Well-respected regulatory regime capable and willing to license a first-of-a-kind demonstration unit
- A potential domestic market for initial deployment
- Alignment with government priorities and policies, including combatting climate change, promoting economic growth, and driving innovation

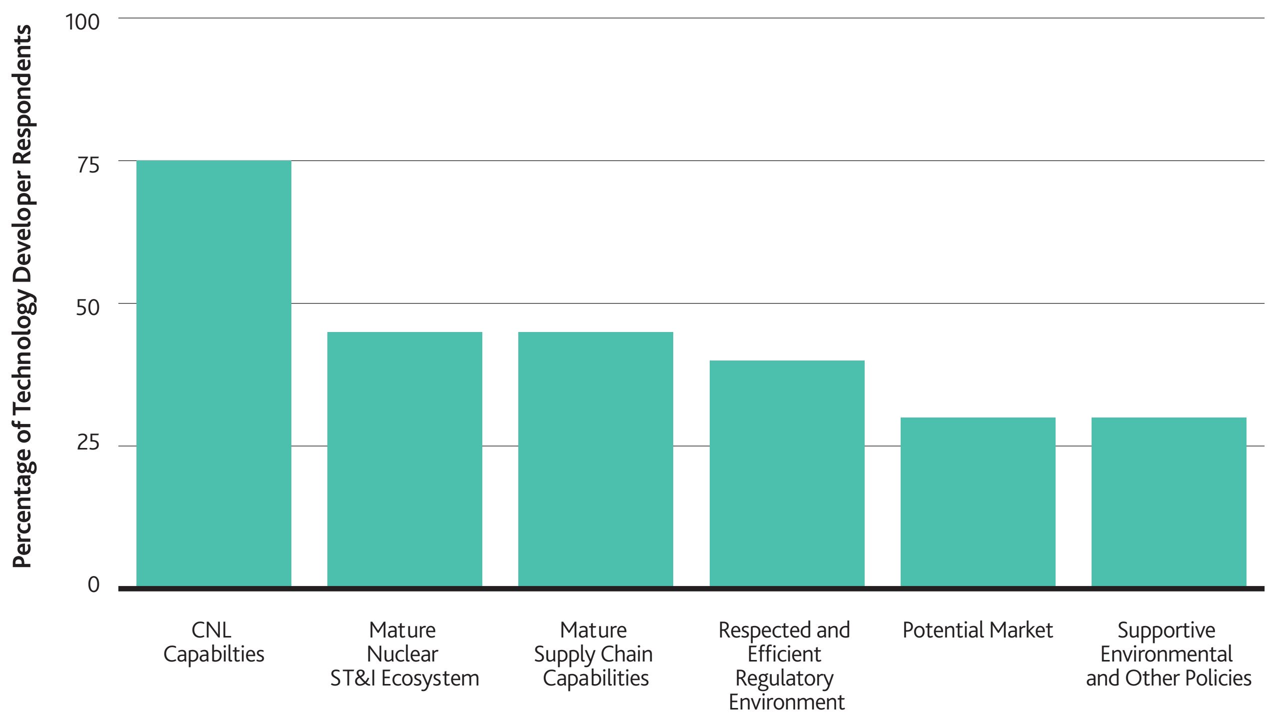
TOP 5

NON-ELECTRICAL APPLICATIONS:

1. Hydrogen production
2. District heating
3. Desalination
4. Coupling with energy storage
5. Process heat for industrial uses

Figure 7

REASONS FOR WHICH CANADA IS SEEN AS ATTRACTIVE TO SMR DEVELOPERS



There are three factors of note in these findings:

1. Canada's nuclear capability

This is the most important factor encouraging proponents to seek support in Canada. This capability includes, first and foremost, CNL's licensed sites and its capabilities, but also the mature nuclear supply chain and the associated mature science and technology capabilities of Canada's universities and research organizations.

2. The regulatory regime in Canada

The strength and integrity of Canada's regulator and attendant regulatory regime was a reoccurring theme in the RFEOI responses. That many respondents identified that they have approached the CNSC in advance of this RFEOI is testimony to that interest.

The Canadian Nuclear Safety Commission (CNSC) and the method in which they have implemented a robust but flexible regulatory regime that is accepting of new technologies was cited as a major enabler for the potential deployment of SMRs and advanced reactors in Canada. Many respondents commented on how the regulatory regime enables innovation in the nuclear sector in Canada, and that the CNSC licensing process should be a model for other regulators. The CNSC has been actively engaging input on how the Canadian regulatory framework can efficiently accommodate SMRs[3].

3. Business objectives

35% of respondents identified the desire to develop a strong Canadian original equipment manufacturer (OEM) and supply chain that would initially leverage the demand perceived in the Canadian market place, while 30% were proposing international partnerships with a firm eye on the global demand and competitive arena that is expected to unfold.

3 Canadian Nuclear Safety Commission, "Small Modular Reactors: Regulatory Strategy, Approaches and Challenges", Discussion Paper DIS-16-04, May 2016, and the "What We Heard Report- DIS-16-04", http://nuclearsafety.gc.ca/eng/acts-and-regulations/consultation/completed/dis-16-04.cfm

KEY POINTS MENTIONED BY RESPONDENTS

CNL OFFERS CAPABILITIES OF IMPORTANCE TO SMR DEVELOPMENT AND DEPLOYMENT.

- Capabilities suitable to advanced reactors development and deployment
- Facilities and infrastructure crucial for building and certifying an initial reactor in Canada
- Existing licensed sites suitable for a demonstration reactor
- Canada could host one of the few integrated nuclear sites for refueling operations

CANADA HAS A MATURE NUCLEAR SCIENCE, TECHNOLOGY AND INNOVATION ECOSYSTEM.

- Mature industry that has already experienced process of developing OEM technology with the CANDU reactor and has the capability to repeat this success
- University and trade school-educated workforce including technicians, scientists, and engineers
- Requisite nuclear infrastructure with advanced research centres, universities and Canadian industry facilities

CANADA'S POLICIES ARE WELL-ALIGNED WITH SMR DEVELOPMENT AND DEPLOYMENT.

- Existing federal government policies make Canada a nuclear friendly jurisdiction
- Canada is currently taking a strong leadership position in climate change mitigation
- Government has been signaling that nuclear and SMRs are important parts of Canada's clean technology innovation agenda
- SMR development is well aligned with NRCan's objectives

CANADA HAS A MATURE NUCLEAR SUPPLY CHAIN.

- Mature supply chain and experienced nuclear operators
- Requisite civil nuclear infrastructure
- Existing manufacturing capabilities developed for CANDU reactor
- All components of the reactor can be produced in existing Canadian facilities; viability of creating a Canadian original equipment manufacturer (OEM) and supply chain
- Canadian companies in particular are looking to develop in Canada with other Canadian partners
- Create a Canadian company to provide a fleet across Canada and for export
- Continue the partnerships with Canada that have been developing in the nuclear industry
- Combining international competencies and experiences for the development of an SMR would have a decisive advantage
- Develop collaborations on a global and national scale

CANADA HAS A RESPECTED AND EFFICIENT REGULATORY ENVIRONMENT.

- Predictable and reputable regulator
- Canadian Nuclear Safety Commission's Vendor Design Review (VDR) pre-licensing process
- Regulatory process that allows for quicker engagement

THE CANADIAN MARKET IS WELL SUITED TO SMR TECHNOLOGY.

- Canada is a potential SMR market
- Possibility to locate a small series of vSMRs

BENEFITS TO CANADA

In the RFEOI, developers of SMR technologies were asked about the benefits of their SMR technology to Canada. The benefits have been grouped into several categories: remote off-grid deployment, economic growth, grow R&D and innovation, employment and supply chain, a source of clean, low GHG-emitting, environmentally sustainable energy, and low-cost electricity.

It should be noted that 30% of the respondents to the General Submission section also provided perspectives on the potential benefits of SMRs to Canada, even though this was not an explicit question. The percentage of respondents that identified each these benefits is illustrated in Figure 8.

Developer respondents gave significant weight to the economic factors, innovation and the environment. Responses from outside of the technology developer response group had a greater focus on SMRs as an energy solution to Canada's remote off-grid locations, and as a source of clean energy.

Some highlights include:

Overall Economic Benefit

While most respondents agree that the potential economic benefits to Canada in terms of jobs, economic growth and Gross Domestic Product (GDP) are expected to be material, only six of the respondents provided quantified indications of the potential economic benefits, such as jobs and GDP.

Many of the quantified benefits identified by respondents rely on market size and penetration assumptions that were not fully disclosed.This is not surprising as respondents were clear that much work needs to be done to develop reasonable estimates of market potential. Many respondents cited existing market studies and statistics[4] , from which it may be inferred that employment and GDP expectations may be similar to existing nuclear installations.

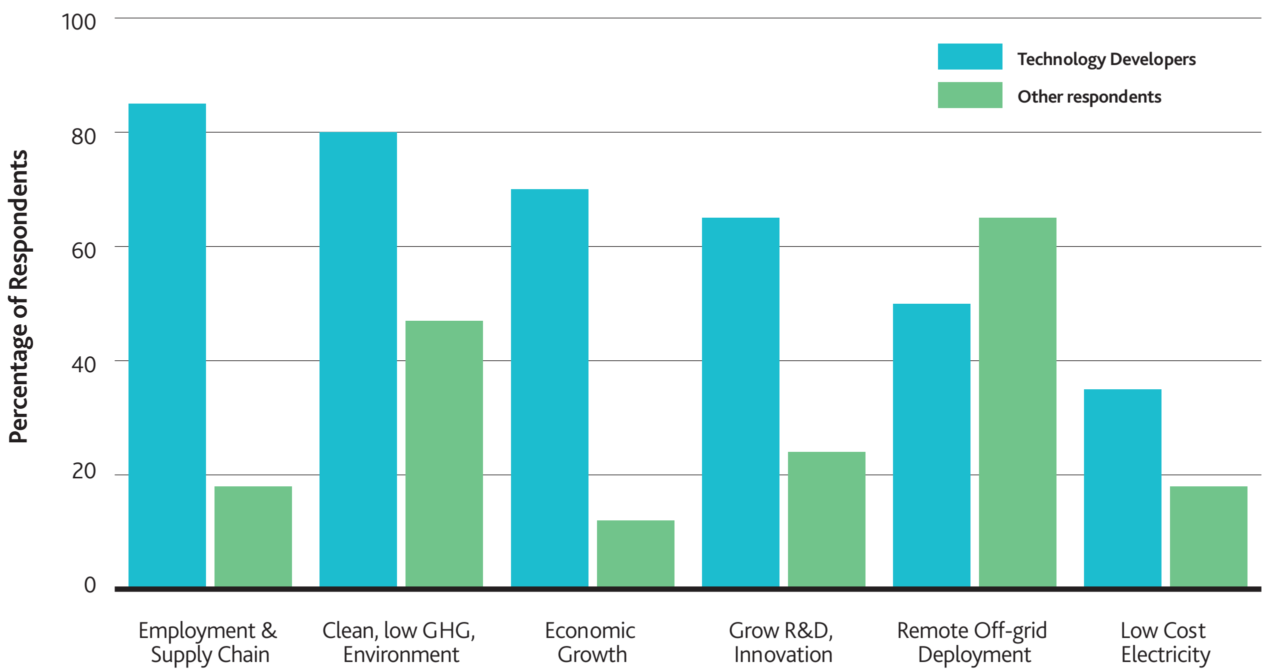
Employment and Supply Chain

17 out of 20 responses from technology developers made some statement about using or strengthening Canada's nuclear supply chain as part of the global opportunity, developing local suppliers, and sourcing components and materials from Canada where feasible. From the RFEOI responses, the jobs created will be not only in manufacturing, but also in a range of services that will engage Canadian companies in engineering, construction, legal, financial, and regulatory aspects of the project.

4 National Nuclear Laboratory, "Small Modular Reactors (SMR) Feasibility Study", 2014; Canadian Nuclear Association, Nuclear Factbook, 2016; Nuclear Energy Institute, "Nuclear Energy's Economic Benefits — Current and Future", 2014; PricewaterhouseCoopers, "The socio-economic impact of the nuclear power industry in France; International Energy Association, "World Energy Outlook 2017"

Figure 8

BENEFITS OF SMRS TO CANADA IDENTIFIED BY RESPONDENTS[5]



Some respondents provided indications on an employment-per-plant basis. Normalizing these estimates to a common frame of reference suggests that annual person years of employment (PYE) for operations could range from 0.5 to 0.6 PYEs per installed MWe capacity (for plants in the 300 MWe to 600 MWe range). Construction job estimates range from 1.4 to 2 PYEs per MWe of capacity. This is somewhat less than for today's operational reactors, as would be expected given the features of advanced reactors include significant automation for operations and modularization for construction. Respondents indicated that the type of employment would be generally higher skilled, and hence higher wage, positions.

Remote communities

Many SMR concepts are envisioned for remote off-grid communities or industries operating in remote locations, such as mining. Diesel is the main source of energy currently, which is both expensive and a source of greenhouse gases. Respondents expanded in their submissions, articulating about how replacing diesel generators with SMRs and possibly other renewables, would establish energy independence and enable growth in remote communities. Territorial subsidies to power utilities could be reduced, along with the overall cost of living. Respondents indicated that prospects for small businesses would improve, and the standard of living in these remote off-grid communities, including heath, education and life expectancy would increase.

Respondents noted that the use of cost-effective SMRs to power mining operations along with the co-generation of heat will improve the revenue margins of these operations. Ores that are otherwise not profitable to extract could be exploited, increasing local jobs.

Low-cost electricity

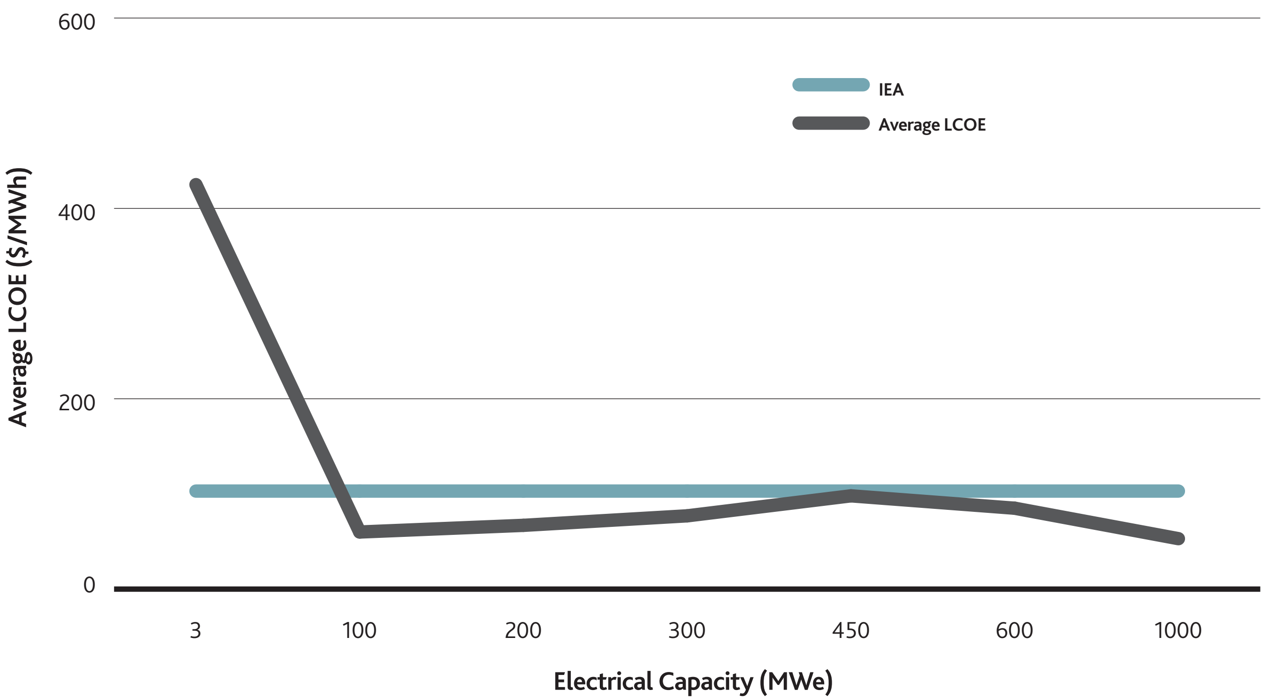
30% of developers emphasized the need for low cost electricity in their submissions as necessary basis for commercial success in penetrating markets. Figure 9 illustrates the projected levelized cost of energy (LCOE) of the various SMR designs according to theSMR developers. Most respondents indicated LCOEs under $100, with the lowest cost estimates at almost half that level. Some respondents quoted the Energy Information Administration[6]

5 This figure gives the percentage of respondents that included mention of the benefits of SMRs to Canada. 100% of developers mentioned benefits, only 29% of other respondents mentioned a benefit.

6 Energy Information Administration Annual Energy Outlook 2016

Figure 9

AVERAGE EXPECTED COMMERCIAL LCOE, $/MWH BY MWE PLANT SIZE



forecast LCOE for conventional nuclear as slightly over $100/MWh, indicated in Figure 9 for reference. The low costs are associated with 100–300 MWe capacity plants as well as the largest scale plants. The responses indicate that the expected costs rise dramatically with the very small plants, but also note that these reactors have different market drivers (e.g. offsetting high cost diesel).

SMRs in Canada will enable environmentally responsible development of natural resources.

Organization of Canadian Nuclear Industries

KEY POINTS MENTIONED BY RESPONDENTS

CANADA WILL BENEFIT THROUGH JOB CREATION AND SUPPLY CHAIN DEVELOPMENT.

- Employment throughout life-cycle including R&D, design, licensing, construction, manufacturing, plant operation, decommissioning
- All components can be produced in Canada without large new factories or assembly lines
- Willingness to source raw materials and components from Canadian suppliers, where feasible

CANADA WILL BENEFIT ON A NUMBER OF ENVIRONMENTAL FACTORS.

- Carbon free source of base load electricity
- Enable environmentally responsible development of natural resources
- Load following abilities allow integration with renewables
- Some reactors allow utilization of spent nuclear fuel resulting in a reduction of nuclear waste

CANADA WILL SEE ECONOMIC GROWTH.

- Commercialisation will yield sustained development and bring investment, intellectual property and employment
- First county to develop/deploy SMRs will attract further foreign investment

CANADA'S CAPACITY FOR SCIENCE, INNOVATION AND RESEARCH WILL GROW.

- Without new-build Canada will lose its status as a Tier 1 nuclear nation
- SMRs are an opportunity to reintroduce innovation
- Attraction of advanced technology companies to Canada
- CNL could establish foundations of top-notch R&D program that will attract international researchers and students
- SMR practices (i.e. modular design, manufacture and assembly) transferable to other sectors (e.g. aerospace and construction)

CANADA WILL BENEFIT FROM CLEAN, RELIABLE ENERGY IN REMOTE OFF-GRID LOCATIONS

- Grid independence where remote communities or industries are not connected to grid
- Economical alternative to remote areas use of diesel for electricity
- Additional applications of SMRs (such as district heating)

CANADA WILL BENEFIT THROUGH RELIABLE, LOW COST ELECTRICITY.

- Cost-competitive with other energy sources
- Provide low cost electricity as baseload or peaking

Nuclear should play a role in supporting Canada's carbon reduction commitments

Ontario Power Generation

REQUIREMENTS FOR SUCCESSFUL DEPLOYMENT OF SMRS

Most respondents offered what they perceived as requirements for successful deployment of SMRs in Canada. While there was a broad suite of topics mentioned in the responses, there was clear emphasis in the themes of: economic benefit, public acceptance, clean production of energy, safety, licensability, and reliability.

The percentage of responses that identified these requirements are shown in Figure 10.

There was variation among the respondents on how they approached the question of requirements for deployment: some identified required characteristics of a technology, such as safety, and others identified non-reactor needs, such as public acceptance.

It was clear from the responses that safety is paramount. While respondents, especially technology developers, discussed the safety characteristics of their reactor, it may not have been mentioned in the response as a requirement, so is not reflected in the data in the chart. Respondents see safety as a given characteristic of the technology. If exemplary safety was not present, the technology would not be considered. The focus of these responses was therefore on the other aspects required to achieve deployment.

The largest issue that arose from the responses to the RFEOI is economics; if the benefits to the economy of the reactor technology cannot be demonstrated, or if the capital or lifecycle costs are too high, then it will not be successful.

Respondents recognized the threat of climate change, and the opportunity for SMRs to provide a clean source of energy with near-zero greenhouse gas emissions.

Public acceptance of nuclear power at all levels, local, provincial, federal, and by all stakeholders, including Indigenous people, will be crucial to deploy SMRs.

SMRs must be licensable; the regulator must have a regulatory framework that can support these new reactor types, and be able to grant licences in an efficient to a predictable schedule and cost.

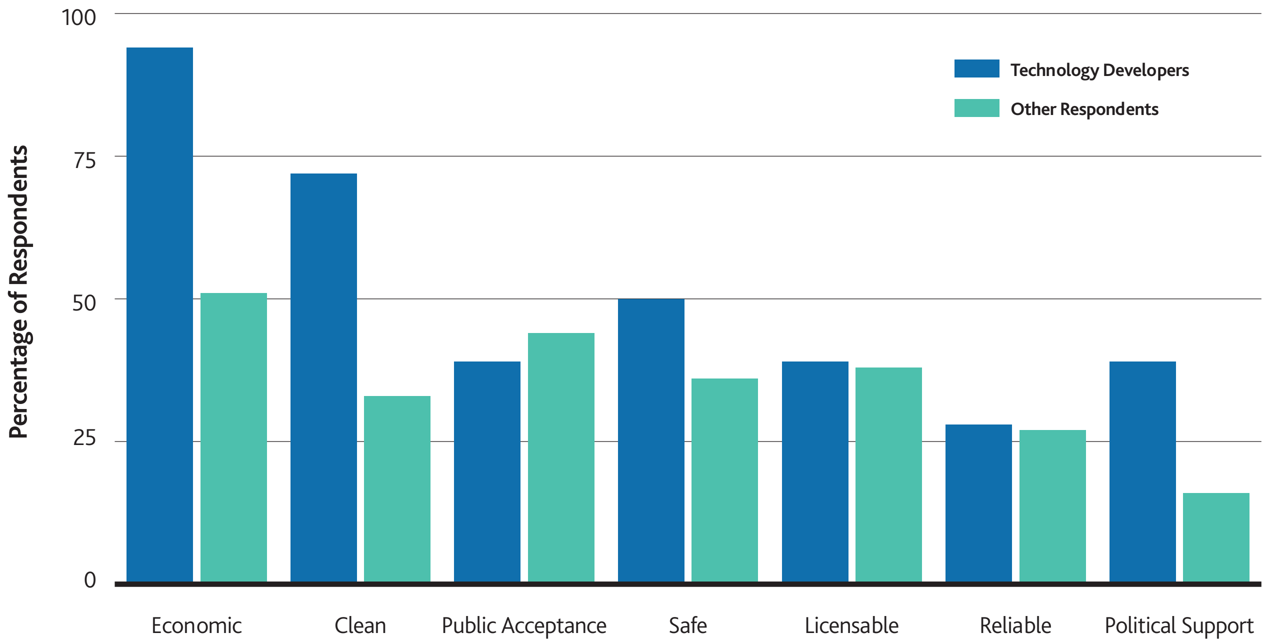
Especially for SMRs targeted for remote off-grid locations, reliability and minimal outages are important.

Consistent political support is needed to develop and deploy new technologies.

Further details from respondents on these points can be found in the exhibit.

Figure 10

PERCENTAGE OF RESPONDENTS THAT IDENTIFIED VARIOUS REQUIREMENTS FOR DEPLOYMENT OF SMRS[7]



Include First Nation communities and promote their participation as technical and business professionals or as vendors/suppliers

X-Energy

7 This figure gives the percentage of respondents that included mention of the requirements for successful deployment of SMRs in Canada. 82% of developers mentioned benefits, and 56% of other respondents mentioned a requirement.

KEY POINTS MENTIONED BY RESPONDENTS

SMRS MUST HAVE AN ECONOMIC BENEFIT.

- Positively impact the economy, both nationally and locally
- Create jobs, locally and elsewhere in the Canadian supply chain
- Affordable, clean source of energy
- Low capital cost
- Low lifetime costs
- Must be comparable to other energy sources
- Breakthrough economics are needed

SMRS MUST BE CLEAN.

- Near-zero lifetime greenhouse gas emissions
- Integrate with other renewable energy sources
- Component of a carbon-free economy
- Low waste production, actinide inventories and water requirements
- Must have a viable decommissioning and waste management strategy
- Return the site to green-field status

THERE MUST BE SOCIETAL AND LOCAL SUPPORT.

- Awareness, acceptance and support
- Acceptance at all levels, nationally, provincially and locally
- Communities must "buy-in"
- Positive local economic impacts are needed to gain community acceptance
- Indigenous community engagement and acceptance is crucial, especially with regards to the Canadian north
- SMRs must be accepted by society as a whole
- The broad challenges to social acceptance of nuclear energy are equally applicable to SMRs
- Community-informed decision process

SMRS MUST BE SAFE.

- Must contain substantial safety characteristics
- Improved safety over contemporary plants
- Must possessing inherent and/or passive safety features

SMRS MUST BE LICENSABLE.

- The regulator must be sufficiently assured that SMRs are safe to issue licences
- The licensing process should be efficient
- Need certainty on the cost of the licensing process
- Need certainty on the duration of the licensing process
- Applicable codes and standards for design, procurement, construction and operation

SMRS MUST BE RELIABLE.

- Plants must have high availability
- Plants need to minimize operational outages
- Especially important for off-grid applications and potential industrial consumers of process heat

THERE MUST BE POLITICAL SUPPORT.

- Deployment of SMRs requires public policy support from all levels of government
- Suggested policy tools included tax incentives (including carbon taxes), power purchase agreements, public-private partnerships, loan guarantees, and partial public financing of plants
- Political support needs to be consistent, as nuclear reactors take a long time to deploy, and have a long lifetime
- Create suitable market conditions
- Create an early market, using SMRs as a solution to other government goals, such as reducing the carbon emissions of military operations and at remote locations, or providing power purchase agreements for "first of a kind" (FOAK) technology deployment

Indigenous peoples were mentioned in many submissions. SMR technology developers and other industry players recognize the importance and imperative to engage indigenous peoples. These comments included:

- The need for continuous, respectful and competent dialogue with indigenous organisations and municipalities in northern Canada.
- Including First Nation communities and promoting their participation as technical and business professionals or as vendors/suppliers.
- Providing ownership, management, and economic partnership opportunities with the local and indigenous communities.

Respondents discussed how Indigenous peoples, particularly those living in remote communities currently using diesel as a main source of energy, could potentially benefit greatly from SMRs. As the SMR industry develops, these communities will need to be consulted and engaged in this process to ensure the perspective of potential end users are understood.

Other requirements mentioned by respondents included:

- Operation beyond electricity generation
- Simple design and operation
- Quick deployment
- Well understood and quantified risks
- Reactor must be transportable
- Schedules must be accurate and predictable
- Off-grid reactors must have the capability for remote monitoring
- Designs must be standardized
- Designs must be scalable
- Must have minimal staffing requirements
- Early consideration and incorporation of safeguards issues, especially for novel designs
- Option to recycle current spent fuel inventories for use as a fuel source

A key weakness of the nuclear industry in Canada is that “scientists talk to the scientific public”, rather than to the Canadian public.

Systèmes Humains-Machines Inc.

CHALLENGES TO SMR DEPLOYMENT

Obstacles or challenges facing the deployment of SMRs were identified in many responses. The most frequently stated challenges were: financing of the first-of-a-kind unit, social acceptance, regulation of an unfamiliar technology, a strong business case, and government support.

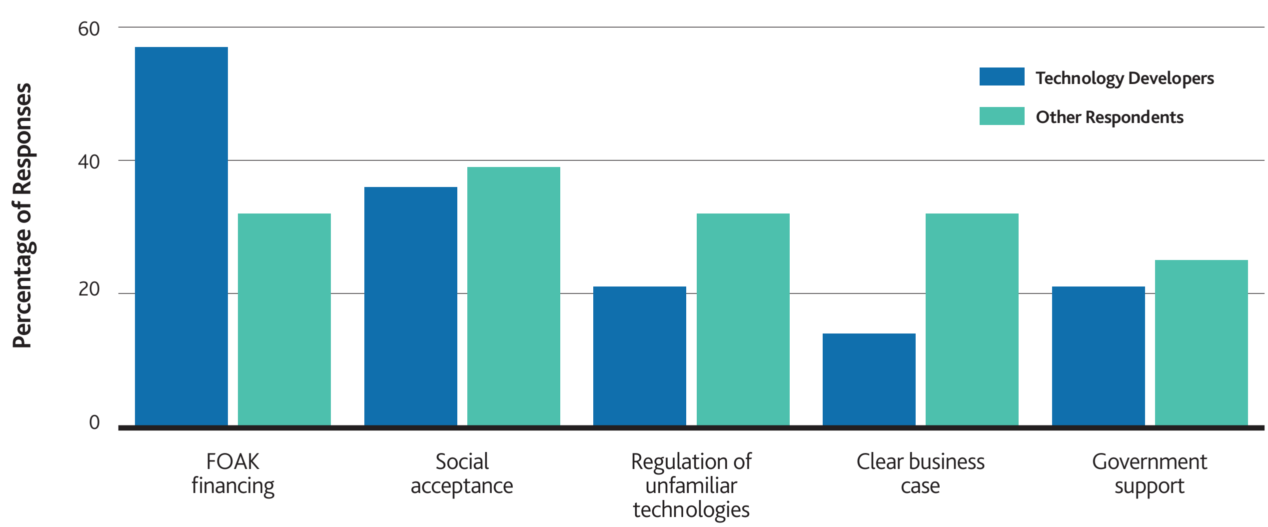
The percentage of responses that identified each of these requirements is shown in Figure 11.[8]

Challenges identified here and the requirements highlighted in the previous section, are often linked; the achievement of a requirement identified in the previous section was typically viewed as a challenge to be overcome by respondents. Similarly, some of the challenges identified here are associated with recommended areas of further research in the R&D section that follows.

The financing of the first-of-a-kind unit of a new technology, which has higher risks than established technologies was the leading challenge. This was closely followed by gaining public acceptance. Though many respondents view the Canadian regulatory regime as strong and enabling of new technologies, there is still some apprehension about the ability to regulate unfamiliar technologies. A clear business case, particularly for technologies intended for new markets was highlighted, in particular by non-developer respondents. Support of governments, also listed above as a major requirement, is also viewed as a challenge to deploying SMRs.

Figure 11

PERCENTAGE OF RESPONDENTS THAT IDENTIFIED VARIOUS CHALLENGES FOR DEPLOYMENT OF SMRS[8]



8 This figure gives the percentage of respondents that included mention of the challenges to deployment of SMRs in Canada. 64% of developers mentioned a challenge, only 35% of other respondents mentioned a challenge.

KEY POINTS MENTIONED BY RESPONDENTS

THERE ARE CHALLENGES IN FINANCING A FIRST-OF-A-KIND OR DEMONSTRATION PLANT.

- Costs of the FOAK would be several hundreds of millions to over a billion dollars
- No single entity is likely to shoulder all of the risk
- Government support of some kind will be required

SOCIAL ACCEPTANCE OF SMRS IS AN OBSTACLE.

- Nuclear energy faces many challenges with social acceptance
- Education is needed
- The lack of acceptance was attributed to lack of familiarity
- There is a history of poorly communicating the benefits of these technologies
- Broad public support for the deployment of SMRs is not clear
- There is no certainty for the continued willing support of a host community
- Government needs to support the education and public awareness process

DEVELOPMENT TO DEPLOYMENT NEEDS CONSISTENT GOVERNMENT SUPPORT.

- Political and public policy support is a requirement
- Political support needs to be maintained over the decades need to achieve successful deployment
- Facilitation is needed between the levels of government
- Clear and enduring federal and provincial policies are needed

SUCCESS REQUIRES A CLEAR BUSINESS CASE.

- Proposed business plans may not be realizable
- Customers, whose needs are demonstrably met by the proposed SMRs, have not necessarily been identified
- Doubt about the accuracy of cost predictions and the risks of cost overruns
- Economic competitiveness is not clear
- Costs are market-dependent; higher costs are expected for remote, off-grid markets

UNFAMILIAR TECHNOLOGIES MAY PRESENT LICENCING CHALLENGES.

- Wide recognition of Canada as the best place to license new technologies
- It was widely recognized that most of the regulator's experience lies with water-cooled reactors
- Many of the proposed reactor technologies employ novel coolants and/or fuels.
- Uncertainty that these other reactor types could be licensed under the current framework in an efficient manner, with predictable cost and duration of the licensing process[9].

Other obstacles mentioned by respondents include:

- Unclear that there is an energy demand
- Waste liabilities
- Lack of sufficient highly qualified personnel
- Unproven technologies, and the substantial amount of early R&D required
- Siting of a FOAK
- Readiness of the supply chain
- Lack of operational experience

9 The CNSC has been actively engaging input on how the Canadian regulatory framework can efficiently accommodate SMRs, as evidenced by the discussion paper, *Small Modular Reactors: Regulatory Strategy, Approaches and Challenges*, DIS-16-04, released 2016 May.

STAKEHOLDER PERSPECTIVES

Most stakeholder groups identified similar requirements and challenges as presented previously. Nevertheless, certain points were emphasized within identifiable stakeholder groups.

Potential **utilities, operators and end users** placed substantial emphasis on their requirement for energy sources that had minimal greenhouse gas emissions and otherwise limited environmental impacts. Favourable economics were also a priority. This stakeholder group raised the concern that there are currently too many proposed reactor types among SMRs. Responses included the proposal of a pan-Canadian approach, in which selection of a technology and the development a fleet of near-identical SMRs was encouraged. It was noted that this standardization will reduce costs and uncertainties. Some respondents raised concerns about the challenges in licensing unfamiliar (i.e. not water-cooled) SMRs technologies.

Responses from the **extractive sector** (including oil and gas and mining) expressed an interest in better understanding the potential role of SMRs in environmentally sustainable resources extraction, in support of lowering their GHG emissions. For SMR technologies to work for these applications it was stressed that they need to be reliable, safe, and cost competitive with respect to established technologies. A technology that can deliver both power and heat is additionally attractive. The mobility of the technology was also noted as they would only be needed for the duration of a project, and the ability to relocate the reactor following the conclusion of a project would be important. One respondent suggested that a model based on leasing, refurbishment and redeployment would be ideal. Minimizing longer-term environmental impacts and liabilities would also be an important factor.

Members of the **nuclear supply chain**, including product and service providers, underlined the need for an adequate supply chain and encouraged engagement between members of the supply chain and other stakeholders. Technological readiness of SMRs was a concern, and successful operation of a demonstration plant was considered a prerequisite for successful deployment. High priority was placed on issues of economics, safety, and licensing.

Reactor technology developers considered both the economics of SMRs, as well as securing the financing for a prototype or demonstration plant, to be high priority items. The issue of technological readiness was also emphasized.

Advocacy and industry organizations emphasized the need for SMRs to possess substantial, improved, or inherent safety.

Communities and individuals most frequently emphasized the need for favourable economics. Successful operation of a demonstration plant was considered a prerequisite for wider deployment, but there was uncertainty about where such a plant would be located. Host community acceptance of SMRs was obviously important for this stakeholder group.

Academic and research institutions placed significant emphasis on the social acceptability of nuclear energy and its crucial role in the successful deployment of SMRs. Challenges posed by nuclear waste and legacy liabilities were uniquely emphasized by this stakeholder group. Additional R&D requirements were also noted as potential obstacles in the way of successful deployment.

Of the risks and issues identified that are potential obstacles to the deployment of SMRs, most of them are economic, political and social in nature, rather than being technological.

Sylvia Fedoruk Canadian Centre for Nuclear Innovation Inc.

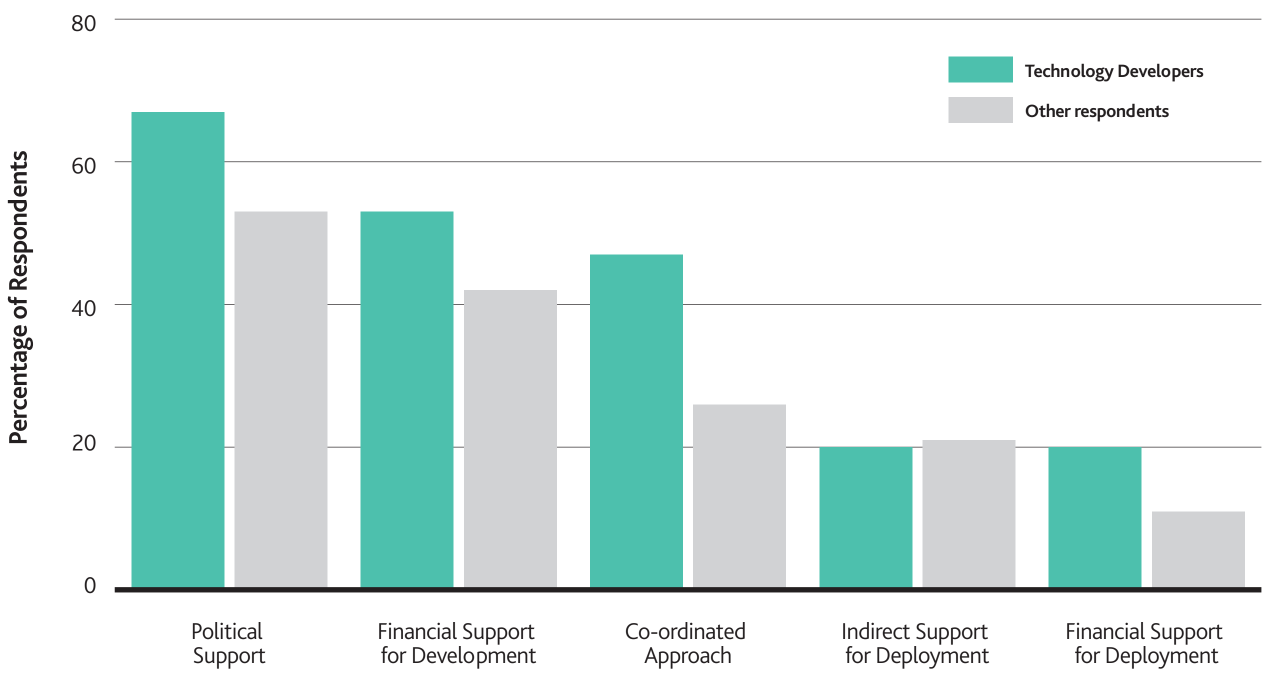
GOVERNMENT:
A CALL FOR SUPPORT

Respondents identified many roles that government could undertake to encourage an SMR industry in Canada. Respondents called for the Government to provide: clear and consistent political support for nuclear generation and SMRs in particular, financial support for development, co-ordinated approach across levels of government, indirect support for deployment, and financial support for deployment.

Figure 12 shows how developers and other respondents viewed the need for government roles.

Figure 12

ROLES FOR GOVERNMENT IN THE DEVELOPMENT AND DEPLOYMENT OF SMRS ACCORDING TO RESPONDENTS[10]



10 The figure shows the percentage of respondents that mentioned government roles. 75% of developers mentioned a role for government, 33% of others mentioned a role for government.

Developers and other RFEOI respondents shared a similar view as to the priorities for government roles. The need for political support was the most commonly requested role. Financial support to the development came second, correlating with the risk associated with a first-of-a-kind technology. A coordination effort is warranted to ensure Canada's needs are served most economically for Canadians. Financial support for deployment was discussed by a few, but more notably, the benefit of other forms of indirect government support for deployment, such as creating and governing market conditions, were raised by almost 30% of developers. Support by governments in competitor markets including China, Russia and the United States was also noted.

The long timelines and exceptionally high upfront costs add significant risk to first movers. One respondent stated that an undertaking of this size across any sector would be extremely difficult without some form of sovereign guarantee of backstop, even if the project could be delivered to schedule and budget. Some respondents maintained that the industry could be quickly self-sustaining once a demonstration was established and return-on-investment proven.

It was also noted that the nuclear industry in Canada is currently geographically concentrated; the deployment of SMR technologies would expand beyond the regions with nuclear experience and history. A coherent and co-ordinated approach both federally and provincially would be needed to ensure success.

To align the various levels of governments, regions, communities, and stakeholders, some respondents proposed a national or pan-Canadian strategy. Such a national approach was noted in the context of the government of Canada's current Innovation Supercluster Initiative, under which support and co-ordination of national assets, including R&D efforts across the country could be aligned and leveraged.

> Each vendor or provider will need to engage with the public…, but it is incumbent upon the government to support that education process on a broad level.
>
> **StarCore Nuclear**

KEY POINTS MENTIONED BY RESPONDENTS

POLITICAL SUPPORT IS NEEDED FOR SUCCESSFUL ADVANCEMENT OF SMRS.

- Clear political backing for nuclear generation and SMRs in particular
- Commitment from government that support will continue and be stable for the future
- Support public awareness and education processes to gain broad public support for SMR deployment
- Strong policy on combatting climate change supports development of nuclear power

FINANCIAL SUPPORT WILL BE KEY TO FUTURE DEVELOPMENT.

- Initial role in supplementing funding requirements and mitigating risks to attract investors in SMR development, consistent with large scale innovative FOAK research endeavours
- Reactor projects benefit from government support and direction allowing quicker progress
- Adequate financing infrastructure (private, government, or international investment) exists to support demonstration and commercialization
- Confidence that SMR deployment strategy has the funding required (a mix of government, utilities, and private investors) to outline long-term commercial deployment viability
- Government commitment to be an early market adopter of technology, e.g. use SMRs in federal facilities with national security missions as a means to meet zero carbon emission objectives
- Sovereign guarantee or backstop
- Loan guarantee program
- Support through initial investments

DEPLOYMENT REQUIRES A COORDINATED APPROACH.

- Alignment of national, regional and local politics
- Alignment between CNSC, the federal and provincial governments and SMR technology developers driven by need for use in Canada
- Facilitation between interests of all stakeholders

THERE ARE AMPLE OPPORTUNITIES FOR MEANINGFUL, INDIRECT SUPPORT.

- Create an enabling policy environment
- Creation of suitable market conditions including international trade opportunities, and how regulators work together on global lessons learned
- Provide a clear framework for development of SMRs in Canada
- Adjust support based on market conditions
- Governance of fair energy market appropriate to SMRs deployment economics

DEPLOYMENT PRESENTS NEW OPPORTUNITIES FOR GOVERNMENT SUPPORT.

- Public private partnerships for FOAK given high financial risks
- Feed-in-tariffs
- Power purchase agreements to guarantee a revenue stream and attract private capital
- Government funded deployment of SMRs
- Manufacturing incentives

R&D AND TECHNOLOGY DEVELOPMENT NEEDS

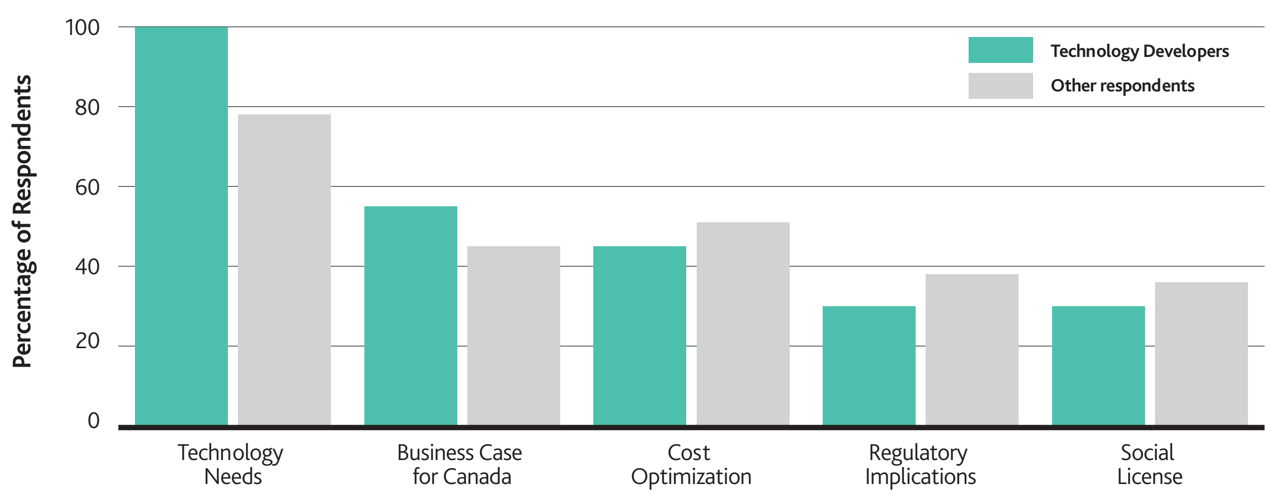
Respondents identified technical areas of R&D needs, but also broader areas where more information is required. While most of the technical R&D capabilities required to advance SMR development were identified by the developer respondents, much feedback was also received by the other respondents. The broader areas largely related to ensuring that there is a pathway to deployment of these technologies, first in Canada, but also as an export.

Research needs to ensure a pathway to deployment that were identified by respondents are summarized in Table 1 and Figure 13 and include such items as:

- Technology suitability to Canada,
- Business case for Canada
- Life cycle cost optimization
- Regulatory implications
- Public perception/social licence.

Figure 13

PERCENTAGE OF RESPONDENTS THAT IDENTIFIED VARIOUS AREAS OF RESEARCH AND ANALYSIS REQUIRED REGARDING A PATHWAY TO DEPLOYMENT[11]



11 The figure shows the percentage of respondents that mentioned areas of R&D and analysis. 100% of developers mentioned R&D, 93% of others mentioned R&D.

Table 1

AREAS OF RESEARCH AND ANALYSIS REQUIRED REGARDING A PATHWAY TO DEPLOYMENT

TECHNOLOGY NEEDS	• Includes the CNL S&T capabilities and other capabilities that respondents are developing or will need for deployment
BUSINESS CASE FOR CANADA	• Consideration of financing, commercialization potential, export potential, cost-effectiveness against alternative technologies. Includes market research, financial modelling, economic and feasibility analysis, optioneering, assessment of economic benefits such as job creation. • Prioritizing a technological solution(s) for deployment in Canada. Includes consideration of scale, cost, safety, load following capability, modular construction, alignment of the technology with the market, commercialization potential, export potential and minimizing duplication of technology development.
LIFE-CYCLE COST OPTIMIZATION	• All costs including manufacturing, construction, plant operation, maintenance, life-cycle emissions, mining, Balance of Plant, decommissioning and waste management. • Advanced manufacturing techniques, 3D Printing, modularisation and other methods to make manufacturing of components more efficient and cost effective. Includes developing lab-scale or pilot-scale manufacturing to validate the manufacturing processes.
REGULATORY IMPLICATIONS	• Improving uncertainty of the licensing process to achieve predictable cost and duration.
SOCIAL LICENCE	• Issues around public policy, public acceptance of technology including automation and remote control, community relations.

Outside of the developers, most respondents placed a high emphasis on the need to research these areas. While many of these ideas were put forward by potential service providers as areas where they could support CNL, these areas were also identified as items that warrant research and analysis efforts, since they represent key considerations in bringing SMRs successfully to market, as discussed in earlier sections. Some respondents suggested the creation of an advanced manufacturing centre of excellence. It is worth noting that the CNSC is already actively engaged in addressing the regulatory implications[12].

Most of the technical R&D needs were identified by reactor vendors and technology developers. In addition to interest in deploying a demonstration reactor at a CNL site, respondents also indicated which of CNL's listed Science & Technology (S&T) capabilities were of potential value to them. The majority of such respondents have interest in the broad S&T categories of:

- Advanced Nuclear Fuels & Material Research
- Nuclear Safety, Security & Risk Management
- Nuclear & Systems Engineering
- Nuclear Chemistry Applications

12 Canadian Nuclear Safety Commission, "Small Modular Reactors: Regulatory Strategy, Approaches and Challenges", Discussion Paper DIS-16-04, May 2016, and the "What We Heard Report- DIS-16-04", http://nuclearsafety.gc.ca/eng/acts-and-regulations/consultation/completed/dis-16-04.cfm

Of particular interest were CNL's capabilities for:

- Post-Irradiation Examination (PIE)
- Instrumentation, Control and Software
- Materials Characterization
- System Thermalhydraulics
- Advanced Fuel Cycle Analysis
- Fuel Characterization
- Fuel Development
- Fuel Fabrication and Assembly
- Materials and Components Examination
- Corrosion and Electrochemistry

CNL's differentiating capabilities with advanced nuclear fuels were of clear interest to reactor vendors and technology developers.

While most of CNL's current capabilities have been identified as of interest, the differences between the reactor technologies will require many of these capabilities to be tailored for use by a specific technology. For example, different fuel forms and materials will require different adaptations to current equipment and expertise. Also, depending on the reactor type, the need for fuel R&D capabilities could vary as a function of the design readiness level, maturity and existing supply chains.

Beyond the R&D activities listed above, many respondents expressed the desire or need for additional facilities:

- Multiple expressions of interest were received for a dedicated fuel preparation or manufacturing facility at CNL, ideally co-located with a demonstration SMR.
- Specialized hot cells with fuel handling equipment co-located at the demonstration reactor building.
- Several respondents also expressed interest in siting a non-nuclear or electrically heated demonstration facility at CNL. Such a facility would be used for material and component testing, transient simulations, and operator training.
- Interest in dedicated operator training facilities was also common among respondents. Several put forward the idea of deploying training simulators, either software-driven or utilizing a non-nuclear demonstration at CNL. In some cases, developing the simulator would utilize CNL's capabilities in instrumentation, control and software as well as human performance.

> Because of the inherent conservatism in the industry and a long period of retrenchment in R&D, the nuclear sector has gone from being a technology innovator to a follower. SMRs represent an opportunity to reintroduce innovation.
>
> **Dalton Nuclear Institute, The University of Manchester**

POTENTIAL SMR DEMONSTRATIONS
FOR CNL-MANAGED SITES

Nineteen unique reactor vendors or technology developers submitted technical descriptions of SMRs. Sixteen expressed interest in deploying a prototype or demonstration plant at a CNL site (the remaining three were considering commercial deployment in Canada, but not siting a demonstration reactor). The majority of these expressed interest in a first-of-a-kind demonstration, which would produce power as well as demonstrate the technology. In total, 19 different SMR concepts were described by those respondents interested in demonstration siting.

The 19 proposed SMR demonstrations have been grouped into several broad categories of reactor type[13] (Figure 14), and include:

- Water-cooled Reactors
- High-Temperature Gas-cooled Reactors
- Sodium-cooled Fast Reactors (SFR)
- Lead-cooled Fast Reactors (LFR)
- Gas-cooled Fast Reactors (GFR)
- Molten Salt Reactors (MSR)
- Fusion Reactors

As indicated in Figure 14, the majority of interest came from developers of non-water-cooled reactor technologies.

The number of different nuclear fuel types were equally varied, and included (but were not limited to) traditional oxide fuel, coated particle fuel (i.e. TRISO[14]), and liquid salts (Figure 15). Some vendors proposed that a potential demonstration would include more than one type of fuel, or that a demonstration reactor would contain a different type of fuel than the reference (commercial) design. Of particular note is that only four reactors make use of uranium enriched to less than 5% ^{235}U (i.e., typical water-cooled reactor fuel). The remainder make use of higher enrichments (<20% ^{235}U) or plutonium-bearing fuels, with the exception of the fusion reactor which uses no heavy elements.

The relationship between a plant's thermal power and electrical output is dictated by the features of its design, such as the coolant outlet temperature. The different proposed reactors possess different thermal to electrical conversion efficiencies depending on the design choices of the developer. With only a few exceptions, the respondents view electrical power as the primary output of a demonstration plant at a CNL site. The need to connect the demonstration to the electrical grid was either explicit in the response or could be inferred by considering electricity as an output.

The power outputs of the various SMRs range from 5 MWth to 2,500 MWth and 2 MWe to 1,000 MWe. For the purposes of this summary, if a vendor did not specify that a demonstration would output a different power than a commercial reactor, it was assumed that the demonstration would output the same as the commercial reference design. Also, if the reference commercial plant consisted of multiple reactor units, it was assumed that a demonstration would consist of a single unit. Demonstration and commercial power outputs (including multi-unit reference plants) are summarized in Figure 16.

13 These categorizations are consistent with different types of nuclear power reactors identified by the World Nuclear Association (WNA), International Atomic Energy Agency (IAEA) and Generation IV International Forum (GIF)

14 TRIstructural ISOtropic

Figure 14

PROPOSED SMR DEMONSTRATION REACTORS

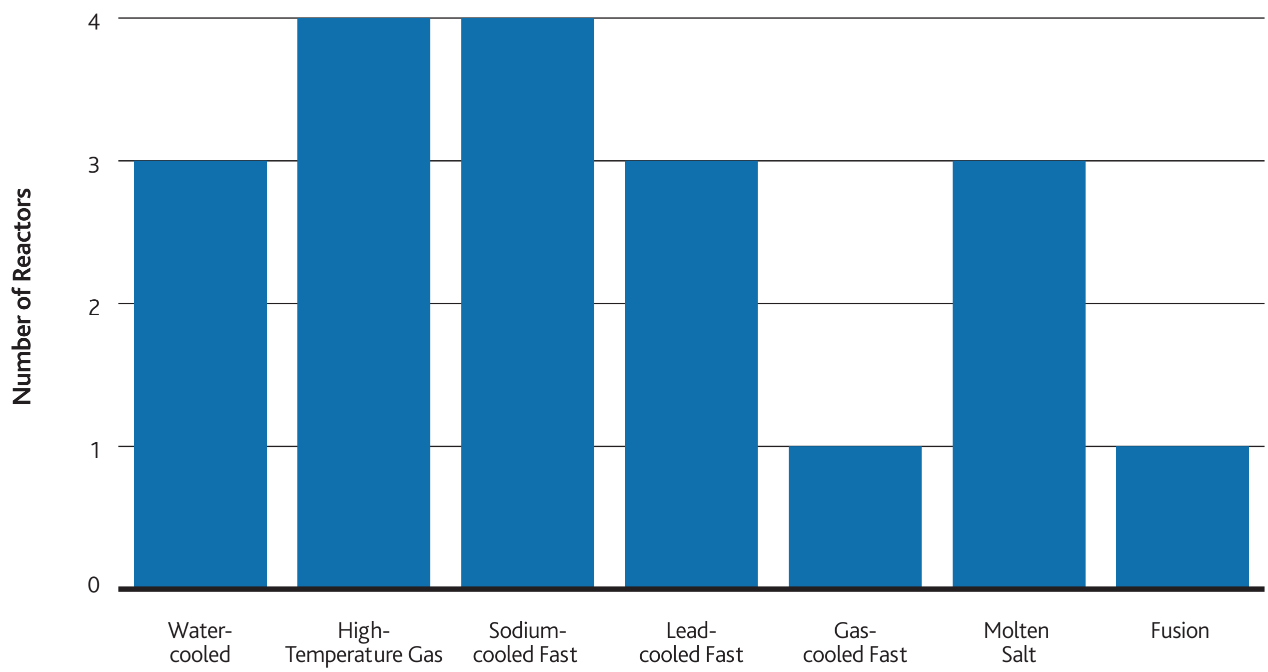
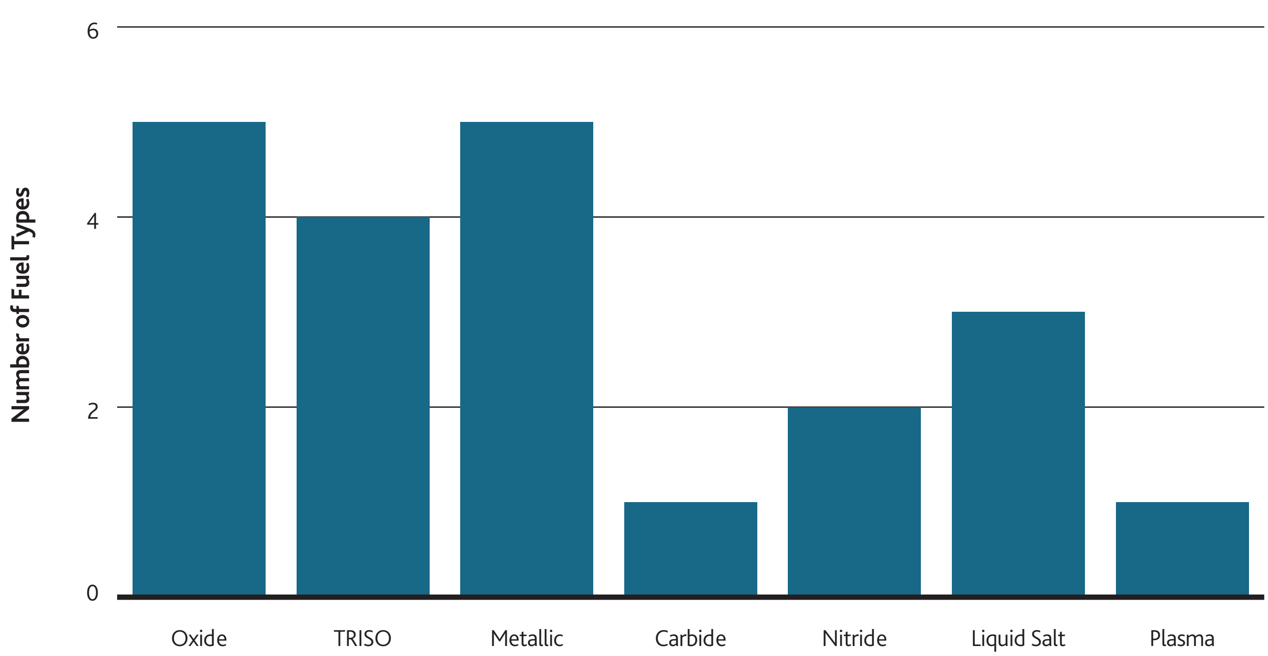


Figure 15

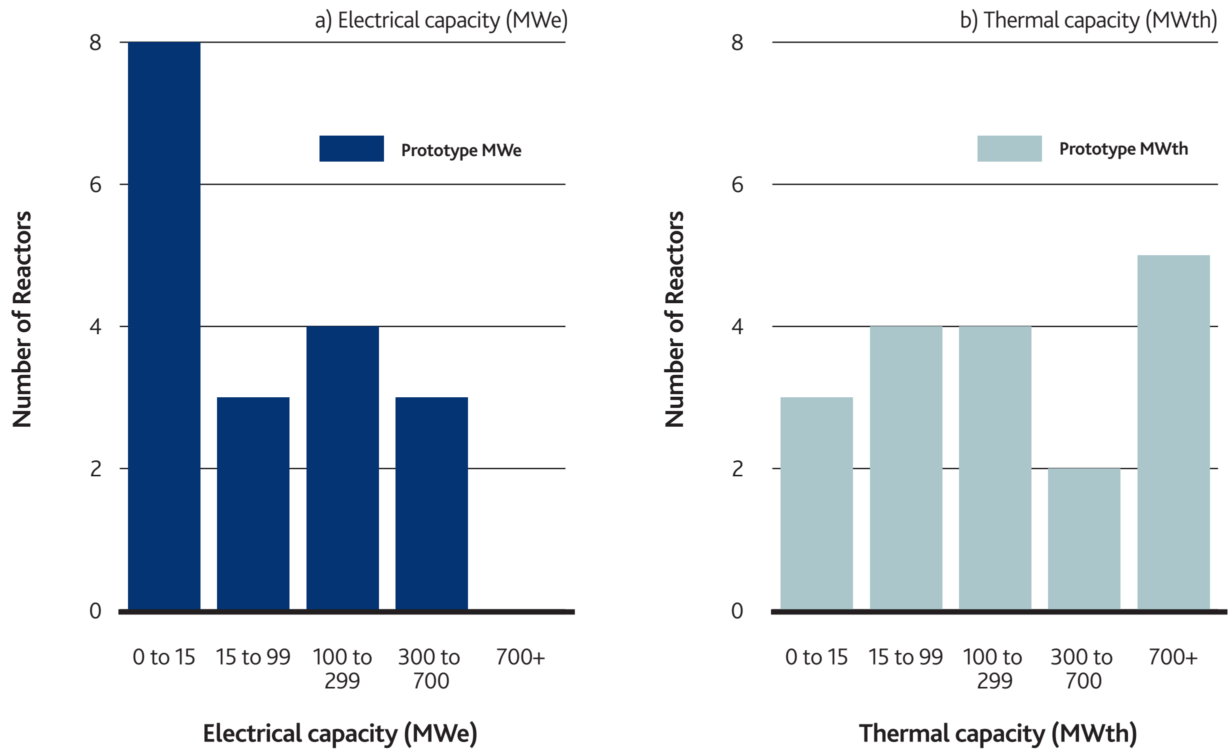
NUCLEAR FUEL TYPES PROPOSED FOR DEMONSTRATION REACTORS[15]



15 Number of fuel types may be larger than the number of reactors, as some designers are considering different fuel types, or are considering changing the fuel type during the lifetime of the prototype

Figure 16

CAPACITY OF DEMONSTRATION SMRS A) ELECTRICAL CAPACITY AND B) THERMAL CAPACITY



Most interest (11 of 18 responses)came from vendors with very small proposed demonstration SMRs (0 to 99 MWe). Nevertheless, there was substantial interest in SMRs in the 100 to 700 MWe range.

The vast majority of respondents envisioned that their first demonstration plant would be fully operational within eight to thirteen years (2025 to 2030). The most optimistic or aggressive estimates were full operation as early as 2022.

TECHNOLOGY READINESS LEVELS

Technology Readiness Level (TRL) is a scale used to measure the maturity of a technology. It ranges from TRL 1, where only the basic scientific principles have been observed and reported, to TRL 9, indicating successful operational deployment[16]. For the purposes of this summary, these nine levels have been grouped into three broader categories:

- TRL 1 to TRL 3: Fundamental principle and proof-of-concept testing
- TRL 4 to TRL 6: Component or subsystem validation in a laboratory or simulated environment
- TRL 7 to TRL 9: Demonstration or operational deployment

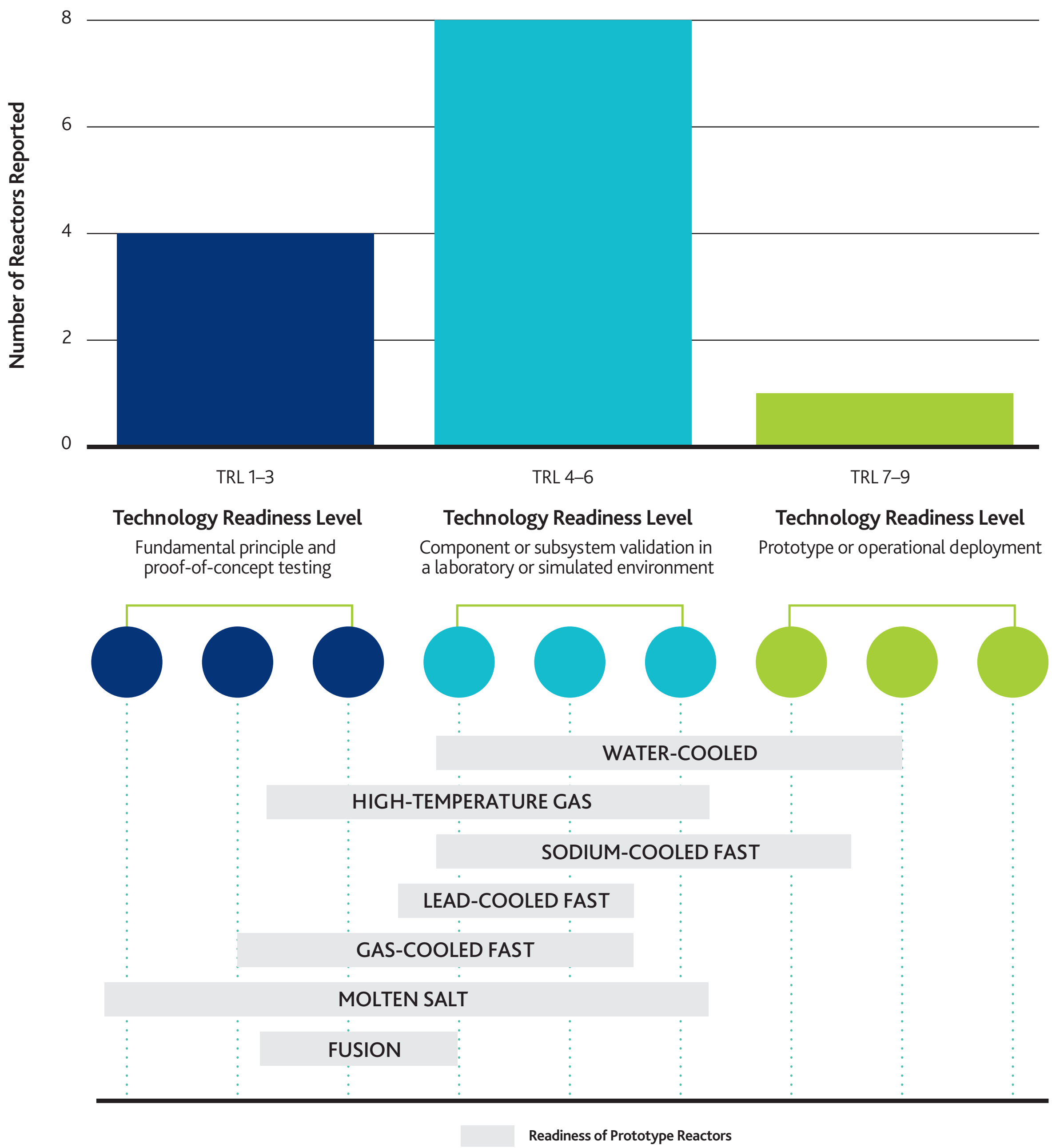
The majority of respondents reported a TRL for either the entire system or for individual components. In the case of the latter, the minimum TRL reported for any component was taken as representative of the system as a whole. This does not necessarily represent the magnitude of the R&D effort necessary to bring the technology to commercialization, but it does illuminate the need for additional R&D. As shown in Figure 17, most technologies have had, at the least, component or subsystem validation. Additional R&D would mostly be focussed on integrating the different subsystems and components into a demonstration plant.

According to respondents, the readiness of the demonstration reactors in order of average TRL level are: water-cooled reactors, sodium cooled fast reactors, high temperature gas cooled reactors, lead-cooled reactors, molten salt reactors.

16 The original definition of Technology Readiness Level is attributed to the National Aeronautics and Space Administration (NASA). This report considers the definition of TRL provided by Public Works and Government Services Canada, which is consistent with other definitions used around the world.

Figure 17

MINIMUM TRL REPORTED BY REACTOR VENDORS AND TECHNOLOGY DEVELOPERS



CONCLUSION

The volume and quality of the responses received from this RFEOI show that there is significant interest in an SMR industry in Canada, and in testing technologies through a demonstration at CNL. Through this exercise, CNL now has better information on what the needs are of an SMR industry, and of an SMR initiative at CNL. Over the coming months we will include the information obtained through this RFEOI to help shape CNL's SMR initiative.

The responses have helped clarify what SMRs technologies are of interest, and why there is global interest in developing these new technologies for low-cost, clean energy. It is clear that Canada offers many advantages to help accelerate the development of SMRs, not the least of which is CNL's licensed sites and the respected regulator, the CNSC.

The requirements for SMRs to be successful in Canada and the challenges that will have to be overcome in order to create a pathway to market are evident. These will require a determined and well-considered strategy that includes a material role for government. Government's most important role is to provide consistent political and policy support to create a stable investment environment and to build public awareness and confidence proactively.

The CNL sites are well suited to meeting the needs of most developers, but it is not only research into the technical requirements and creation of the demonstration facilities that are required. Substantial effort is also required to establish the financeable pathway to market.

CNL believes that the results of the RFEOI are an important contribution to the fact base as the SMR opportunities in Canada continue to be evaluated.

Canada was a world leader in nuclear technology. With this government and its priorities, the environment, reducing GHG's, support for science and innovation, investing in northern and remote communities paired with strong federal provincial relations, we have an enormous opportunity in Canada to develop this technology and establish ourselves again as a world leader. If we do not seize this opportunity it would be lost for a generation

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