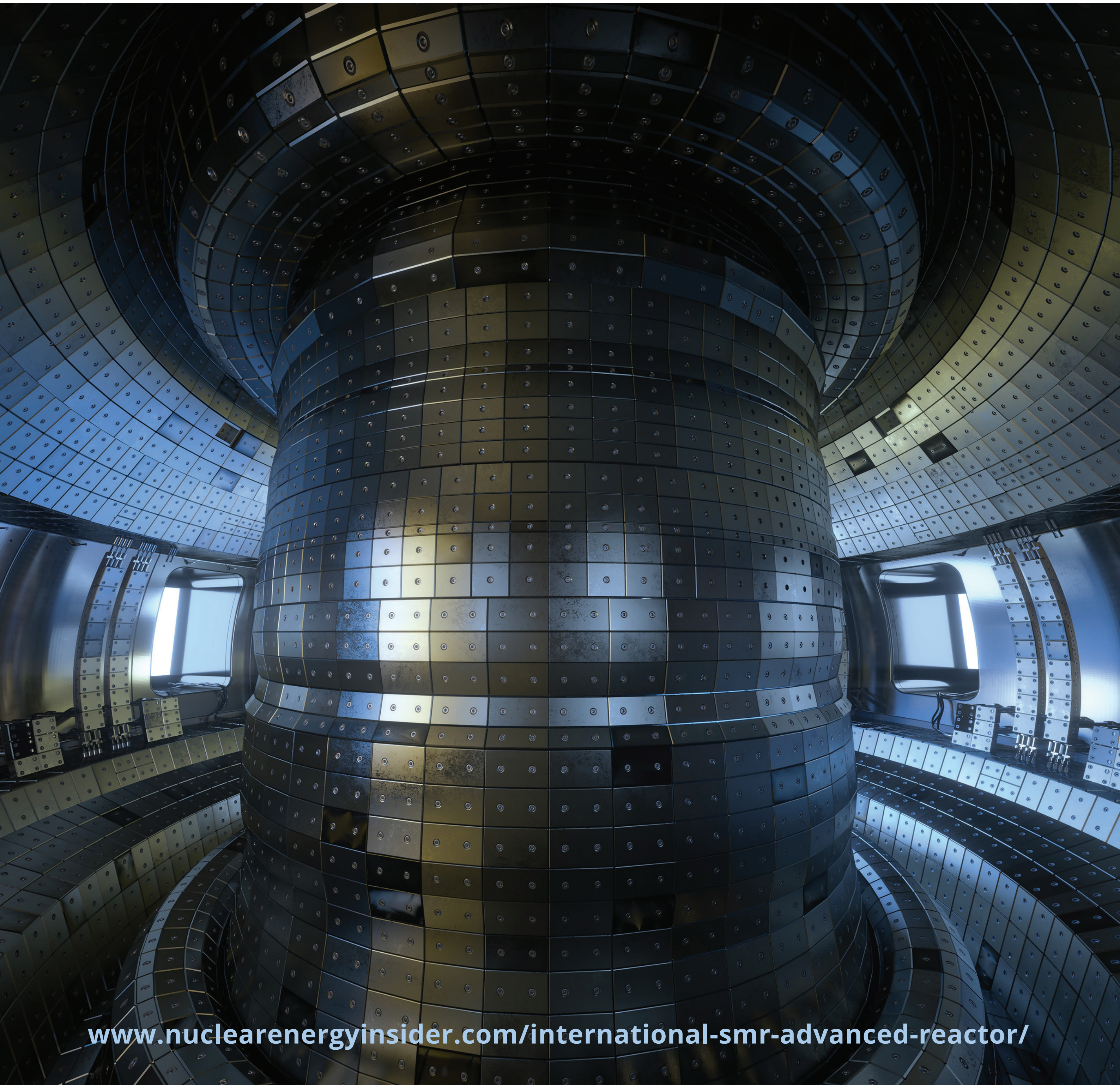
NUCLEARENERGY INSIDER

Analysis for the nuclear energy community

The future of small modular reactors and advanced reactors: off-grid market applications



Small Modular Reactors (SMR) and Advanced Reactors (AR) are now shaping a new nuclear energy landscape, with designs no longer just targeting electricity generation. Vendors are exploring markets outside electricity supply, which exploit reactor features not offered by conventional large-scale nuclear power plants (NPP).

This whitepaper examines potential off-grid market applications of SMRs and ARs that could provide more than just power to remote communities and mining projects in Canada, as well as to U.S. military operations.

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Written in conjunction with the
10th Annual International SMR & Advanced Reactor Summit
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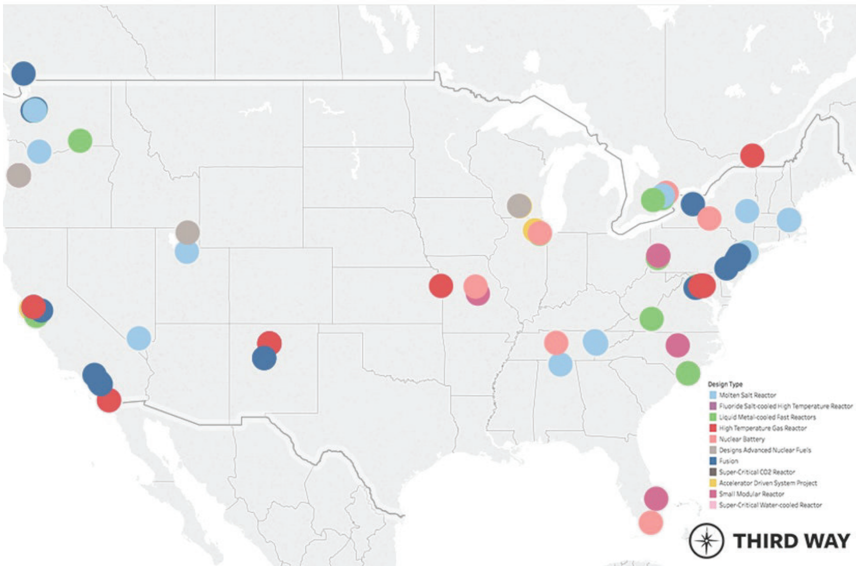
OVERVIEW

Argentina, China and the Russian Federation are on course to begin commissioning the world's first SMRs by 2020, and around 12 more designs are advancing through licensing and construction. North America will likely be the next to deploy an SMR, as the U.S. is looking to 2026 for the start of operations while Canada pursues its progressive regulatory regime to start up demonstration reactors in the same year.

As SMR and AR deployments become commercial realities, potential off-grid markets are opening up off the back of reactor applications that go beyond electricity supply. Russia's KLT-40S pressurized water reactor (PWR) has been developed for deployment on a floating nuclear power plant. However, its design also enables cogeneration of power and heat to remote, off-grid communities, power generation on oil rigs, as well as desalination. Likewise, China's ACP100 is designed for deployment in remote areas that have limited energy supply options or a lack of industrial infrastructure. Its applications also include desalination, cogeneration and district heating, as well as steam production

Other off-grid sectors are also engaging with the nuclear industry and the range of applications is expanding. In addition to providing heat and power to remote communities, SMRs provide a cheaper, more reliable and sustainable energy source to mining and oil sands operations. Similarly, the commercial shipping industry has expressed interest in SMRs due to its consumption of expensive fossil fuels that results in high running costs, as well as contributing to global environmental pollution and carbon emissions.

Finally, one sector that is revisiting the concept of using SMRs and ARs as mobile power sources is the U.S. military. Recognizing the constraints imposed by lack of power when conducting military operations in the field, the U.S. Department of Defense (DOD) is now actively pursuing the deployment of mobile nuclear reactors to accompany the U.S. Army deployed to remote and/or off-grid regions.



Advanced Nuclear Industry: The Next Generation. A map showing advanced nuclear projects across North America. Credit: THIRD WAY

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A Map Showing the Locations of Remote Communities in Canada. Credit: Canadian Nuclear Laboratories

UNIVERSITY OF SASKATCHEWAN

Dr Ken Coates, *Professor and Canada Research Chair in Regional Innovation, Johnson Shoyama Graduate School of Public Policy, and Musk Senior Fellow,* **Macdonald-Laurier Institute**

Ken Coates co-authored the Northern Indigenous Peoples and the Prospects for Nuclear Energy report, published by the Sylvia Fedoruk Canadian Centre for Nuclear Innovation.

Dr Coates' areas of interest include regional innovation, aboriginal rights and land claims, science and technology policy, as well as northern governance and development. He has served at universities across Canada and at the University of Waikato in New Zealand, which is internationally renowned for its work on Indigenous affairs.

The SMR has great potential to bring stable and sustainable energy to hundreds of remote, off-grid communities in the provincial north of Canada, a region that runs from British Columbia to Labrador. All but one or two of these communities use very high-cost energy sources since most are in areas without ready access to transportation networks and bringing in diesel fuel is expensive. These communities endure extreme cold weather onditions for the majority of the year and they are seriously concerned about the increasingly urgent need to secure reliable and affordable energy. Although renewable energy sources are also possible long-term solutions, hydroelectric power is an expensive proposition while early solar power installations in the far north have not worked due to the accumulation of snow and ice. Similarly, the geography and geology do not easily lend themselves to installing wind power. Therefore, even though the SMR is not yet a practical solution to meeting energy demand in Canada, it has potential to provide a cheap and reliable long-term solution to remote northern communities.

Further to issues raised during initial consultations with stakeholders and potential SMR end-users reported by the Canadian Small Modular Reactor Steering Committee in its roadmap published in 2018, some communities are now reaching out and actively looking for engagement with the government and private industry. People living in the remote north are attending industry conferences and asking for more information and support to learn more about SMR technology. Government agencies are engaging in conversations about a full range of potential solutions, which include but are not exclusively about nuclear power.

In addition, SMR vendors and private companies are cultivating interest in SMRs rather than cultivating markets. Conversations between remote communities and industry are still in at a preliminary stage rather than exploring new features or tailoring designs to meet specific needs. Industry is anxious not to over-sell and is proceeding at an appropriate pace that ensures the science, regulations and economics are right. The latter is a fair concern due to the capital expenditure necessary to install an SMR, which is not yet a proven technology. It is likely that the first implementations will be for remote mining companies and other potential end-users will watch the SMR at work for a year or two before confirming it is a real solution.

Alternative applications are being actively explored, with heat generation almost equal to electricity in terms of the potential benefits of SMRs. Heat is central to people living in temperatures that drop 40C to 50C below zero during winters that stretch from end-September to end-May. There is also a lot of interest in natural resource development in the remote north and an SMR could dramatically change the economics in the region for projects including hydroelectric development, mining, and oil sands development.

The interesting challenge in the case of the north is that because all the energy has been so dear for so long and people are heavily reliant on diesel, there is not yet an entrepreneurial culture waiting to exploit all the SMR opportunities. The high cost of electricity and inconsistency of supply makes it really expensive to live in the north. However, the overall cost of living will diminish with a reliable, safe and cheaper supply of energy and electricity. Also, current business opportunities to develop food factories or greenhouses to grow fresh produce are limited to the ability to capture waste heat from buildings. The dynamics change completely if there is an SMR and a flood of interest and creativity is likely once the standard and

obvious uses of the reactor have been justified and proven.
The most important part of the route to installing an SMR in a remote community is that it controls the project. This is a big issue for First Nations generally in that they are tired of relying on everybody else all the time. The other part of the process relevant to most places is that there is pressure on so many issues beyond power and energy that although people are very interested in the energy side of an SMR, they are not far enough along to be looking at nuclear as part of the puzzle overall.

MIRARCO Mining Innovation

Dr François Caron, *Director of the Energy Sector and Bruce Power Chair for Sustainable Energy Solutions*

Mining Innovation Rehabilitation and Applied Research Corporation (MIRARCO) is a not-for-profit corporation that is engaged in five core research domains: geomechanics, safety, decision support software, sustainable energy solutions and climate adaptation.

MIRARCO has been developing solutions that address mining industry challenges since 1998 and, in April 2018, it signed a memorandum of understanding with Bruce Power and Laurentian University that will enhance strategic research opportunities including the long-term potential for SMRs (Small Modular Reactors) to generate clean, low-cost and reliable energy in remote Canadian regions.

MIRARCO and collaborators continue to pursue an SMR design and delivery model that would provide significant economic benefits to mines operating at remote sites, as well as supplying a carbon-free and reliable source of energy. The model includes transporting an SMR to site where it would produce power with cost savings of CAN $0.15/KWh for a typical 20-year mine lifecycle. By switching from diesel, a typical mine could save around CAN $300 million across two decades of mining operations.

The ease of deployment is central to the delivery model. More than one vendor is being considered since mining companies are interested in the possibility of an SMR with maximum portability at a certain price point. In addition, they want established nuclear operators with experience in running a nuclear reactor and in licensing. This is especially pertinent since the reactor can be removed, recycled and replaced by the nuclear operator, who can also deliver further modules should there be a demand for increased power at the mining site.

A nuclear operator will also be very useful with respect to nuclear regulatory processes. The model currently being pursued by MIRARCO involves the mining client entering into a power purchase agreement (PPA) with a nuclear operator. The mining company and nuclear power company each have their own set of specific regulations for which they have the expertise and knowledge to manage individually, while the agreement enables them to come together to work on those regulations that can be done jointly.

Timelines to deployment vary from the mid- to late-2020s in Canada. More precise dates depend, among others, on the progress of vendor reviews at the Canadian Nuclear Safety Commission (CNSC) and potential demonstration units getting up and running at the Canadian Nuclear Laboratories (CNL). There is considerable optimism, however, since there are a number of favorable factors that are converging to realise commercial operations.

For example, clients are looking to take advantage of the economy of smaller multiple reactors as opposed to having a large station generate power. More widely, the demand for power in remote areas is very strong especially as consumers look to saving on not only financial costs but also to reducing their carbon footprint. There is a set of possibilities offered by installing an SMR including electricity production, district heating used to produce food, for example, in greenhouses in remote northern areas of Canada.

Mining companies could also tap into the potential of using direct heat generated by the reactor for processes rather than producing electricity to heat up a process. Although somewhat confined by the ultimate reactor design, there is a wide range of potential applications that include having the SMR integrated into an energy park at the mine site. This would be a feature for clients located in more northerly locations that interested in other sources of green energy such as wind or solar since these types of power sources are not always as reliable or available as diesel or nuclear.

Pacific Northwest National Laboratory

Kerry A Mccabe, *Research Scientist*

The U.S. Department of Defense is working with the U.S. Department of Energy (DOE) research labs, including Pacific Northwest National Laboratory (PNNL), supporting efforts to prototype micro-SMR. PNNL research scientist, Kerry Mccabe, co-authored a study on the use of mobile power plants for ground operations in remote locations.

A desire for inexpensive, stable, sustainable electric power generation to support military operations at remote and inaccessible sites led the U.S. Army to create the Army Nuclear Power Program in 1954. One of the program's noteworthy efforts was the prototype development of a mobile, low-powered nuclear power plant, intended to furnish electrical power in remote locations.

The ML-1 prototype was a trailer-mounted system employing a gas-cooled, water moderated reactor, coupled to a compact closed-cycle gas-turbine power conversion unit. Designed to produce 300-500kW of electricity, the system was transportable by air, sea, rail or truck. The ML-1 program was terminated in the early 1960s as resources were diverted to the Vietnam War effort. However, the U.S. Government, specifically the DOD, has recently begun to re-examine nuclear power generation for military operations.

The emergence and utility of SMRs for military operations was recently identified by the Defense Science Board in a 2016 report on Energy Systems for Forward and Remote Operating Bases. In response, the Army Deputy Chief of Staff for Logistics (G-4) conducted further study of the topic in 2018. The Army study assessed the political, economic, social, technological, environmental and legal/regulatory/licensing issues surrounding the use of nuclear energy and particularly very small modular reactors (vSMRs) for mobile nuclear power plants (MNPPs) that generate electricity in support of ground operations.

Energy supply imposes limits on military power and maneuverability. The delivery, storage and handling of conventional liquid fuel is costly, time consuming and can come with a significant cost to lives, as liquid fuel logistics is a military target. Leveraging the density of nuclear power enables operational flexibility and supports a ground force's maneuver options, while reducing its fuel supply vulnerabilities. Using MNPPs to provide electricity at forward and remote locations negates the need to continually resupply fuel, providing energy assurance and resiliency in austere locations.

The MNPP micro-reactor is designed with robust design and emphasis on transportability, enabling it to be rapidly moved multiple times during its operating life. Future efforts aimed at miniaturization of the reactor and components are expected to improve mobility and expand the utility of nuclear power for both military operations, as well as other functions such as humanitarian and disaster relief.

The DOD prototype effort is examining design options, trade-offs and their impacts on military doctrine, transportability, staffing, training and life cycle support. An example of this is an examination of the utility and potential impact of a segmented design (involving two 20ft containers separately carrying the reactor and power conversion unit, which would be coupled together at the site) against an all-in-one design with everything in a single 20' or 40' container.

Safety is also being examined in detail to influence key design characteristics necessary for success when operating in a military environment. The DOD target for prototype design is 2023, with immediate operation and testing to follow. Shutdown and movement from the development/test site to a remote operational setting where the MNPP would provide power for a period of time, is envisioned as the prototype programs capstone event.

The MNPP effort is examining and assessing avenues for nuclear industry involvement in commercialization of the capability. Supply chain issues are being examined to understand how to best engage and support the market place in delivering low cost, high quality reactors, components and fuel over the long term. A desired outcome is the creation of a business model that can keep costs down while supporting a healthy industrial base to meet both military and civilian mobile power demands for decades.
Developing a commercial market for vSMRs is pivotal to ensuring commercial business and DOD costs are kept at a reasonable level, while facilitating a successful path through regulatory and licensing requirements. The plan is for the DOD's Strategic Capabilities Office (SCO) to enable reactor designs selected for potential adoption to be commercialized by their vendors.

The DOD selection and development program for reactor designs has two phases. The down-select for the first phase has been completed, with the most promising designs now being taken to a preliminary design review. An expert panel will next evaluate each preliminary design against criteria to qualify for phase two. The field will be narrowed further in phase two for completion of a detailed design and eventual development and construction.

The prototype reactor will be licensed and regulated by the DOE. Eventual military acquisition of an MNPP capability would likely see the devices licensed under DOD authorities. Close coordination with the Nuclear Regulatory Commission (NRC) on the project assists with potential commercial licensing of future vSMR and SMRs. The NRC will be brought into the process during the preliminary and final design phases, as will other entities to conduct nuclear health and safety assessments and provide input and guidance to the prototyping effort. While DOD is only building a prototype at this point, it is interesting to think of potential applications and opportunities a spin-off commercialized small mobile power plant could create in business areas such as mining, oil and gas exploration and remote communities.

CONCLUSION

SMRs and ARs present the nuclear industry with diverse market opportunities, especially for those vendors willing to engage with potential end-users so designs can be tailored to specific applications. Business models that include reactor innovations which adapt to and exploit those niche off-grid sectors with an urgent need for safe, reliable and sustainable energy, have a head start in the market place. Bringing down costs will also prove attractive to clients and consumers, while additional features will enhance the commercial viability of SMRs and ARs. Once the benefits of off-grid applications are clearly demonstrated, demand is likely to grow rapidly.

On an international scale, governments, industries and communities that are actively seeking carbon-free energy sources to reduce their carbon emissions have an expanding range of advanced reactor technology that not only meets their demand for power, but also offers a widening range of applications. SMRs and ARs have the potential to secure a long-term future for the nuclear industry and its supply chain if the technology can be proven in a rapidly evolving energy landscape. This future will be further enhanced if alternative applications are fully developed to attract more alternate end-users.

LIST OF ACRONYMS

AR	Advanced Reactors
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
DOD	(U.S.) Department of Defense
DOE	(U.S.) Department of Energy
MNPP	mobile nuclear power plants
NRC	(U.S) Nuclear Regulatory Commission
NPP	nuclear power plant
PNNL	Pacific Northwest National Laboratory
PPA	power purchase agreement
PWR	pressurized water reactor
SCO	Strategic Capabilities Office
SMR	Small Modular Reactor
vSMR	very Small Modular Reactor

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