Pollution Probe

# Potential of Small Modular Reactors in Hard-to-Decarbonize Industries

APRIL 2022

## About

Pollution Probe is a national, not-for-profit, charitable organization established in 1969 that exists to improve the health and well-being of Canadians by advancing policy that achieves positive, tangible environmental change. Pollution Probe has a proven track record of working in successful partnership with industry and government to develop practical solutions for shared environmental challenges.

## Acknowledgment

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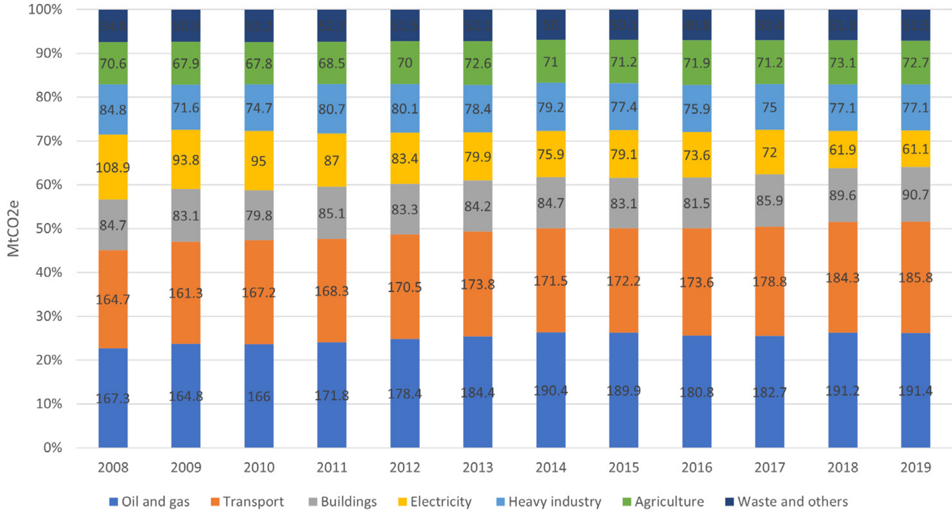
## TABLE OF CONTENTS

# CHAPTER 1: **INTRODUCTION**

Canada has committed to achieve a 40% reduction in greenhouse gas (GHG) emissions below 2005 levels by 2030, and to have net-zero emissions by 2050. These are ambitious targets and will require significant investments in non-GHG-emitting forms of energy.

After many years of setting targets, Canada's total GHG emissions have remained almost unchanged since 2007. Progress has been made by some industrial sectors, such as electricity generation, but this progress has been offset by emissions increases elsewhere, especially in the transportation and oil and gas sectors (see Figure 1).

## Figure 1: Canadian emissions by sector[1]




The 2050 target is intended to be a game-changer. It will no longer be sufficient to reduce emissions in the relatively easy industrial sectors while allowing the other sectors to perform far short of the target.

1 Government of Canada, Greenhouse gas emissions, 2021, https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html

Given Canada's resource-based industrial structure, achieving net-zero emissions poses an enormous challenge. It is a challenge so pressing that we need to consider all potential options that could help achieve Canada's net-zero emissions target.[2] While policymakers or the public may not support any given option in the end, it is important that the options be examined and discussed.

Small modular reactors (SMRs) have been proposed by the federal government and by four provincial governments[3] as a technological option to help in Canada's decarbonization efforts. These governments see SMRs providing low-carbon energy and electricity capacity services in many areas from traditional grid-connected applications, to off-grid communities, to industrial applications.

Pollution Probe believes it is in the public interest to consider all potential options that could help achieve Canada's net-zero emissions target. To understand how SMRs could contribute to Canada's decarbonization, Pollution Probe commissioned modelling on their potential roles and impacts. We then convened a workshop that engaged a range of industries which might use SMRs to reduce their GHG emissions. The workshop participants identified several barriers to SMR deployment, and they explored how those barriers might be addressed.

This paper contains the results of the modelling and the workshop, and also identifies some outstanding issues that would need to be explored. It is intended to stimulate informed discussion by governments, industry, and the public.

2 Canadian Institute for Climate Choices, Canada's Net Zero Future: Finding our way in the global transition, February 2021, https://climatechoices.ca/wp-content/uploads/2021/02/Canadas-Net-Zero-Future_FINAL-2.pdf

3 Alberta, Saskatchewan, Ontario and New Brunswick have signed a memorandum of understanding to promote SMRs. See John Gorman, Canadian provinces partner on SMR development and release feasibility study, Canadian Nuclear Association, April 16, 2021, https://cna.ca/2021/04/16/canadian-provinces-partner-on-smr-development-and-release-feasibility-study/

### *What are Small Modular Reactors?*

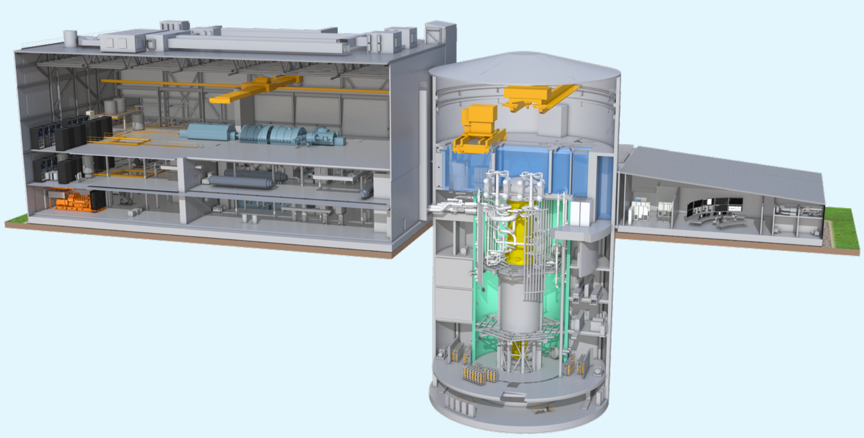
Small Modular Reactors, SMRs, are advanced nuclear reactors that are designed to be much smaller and more modular than current nuclear reactors.

Most current reactors are between 600-1,400 MW in size, while the largest SMR could be only 300 MW, and many SMR designs are much smaller, even down to 5 MW.

SMRs are modular in that they are designed for parts to be built in a factory, and then the parts are transported and assembled at the site.

The perceived benefits of SMRs are linked to them being smaller and modular. Unlike larger reactors, which are custom designed for the specific site, SMRs could be built on locations where you could not build a conventional nuclear plant. Prefabricating parts of SMRs in factories would it is assumed create economies of scale, thereby both driving down and providing certainty on costs. Their modularity could also allow for incremental deployment, where more reactors are added to an existing site as demand increases.

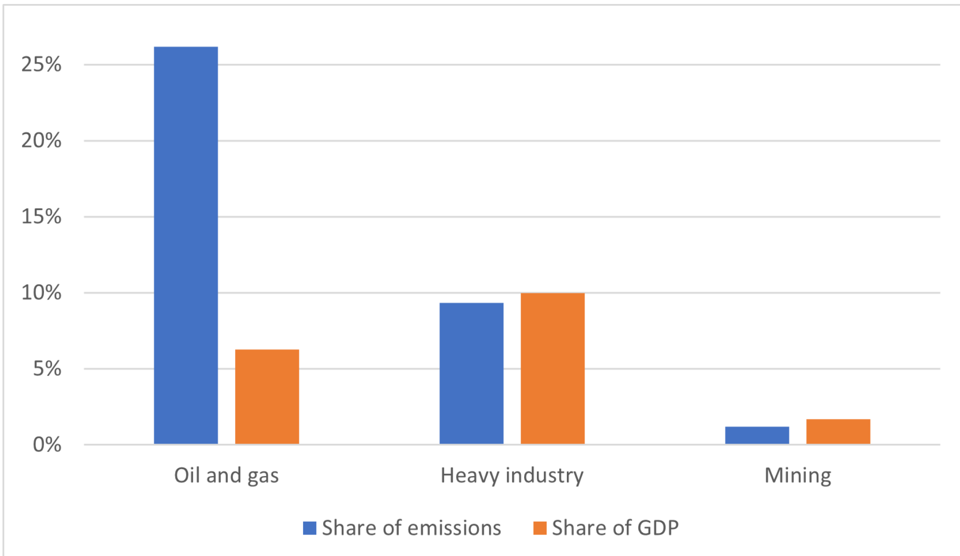
In Canada, SMRs are promoted by the federal government and by some provincial governments. Ontario Power Generation (OPG) has announced that it will build the first SMR in Canada at its Darlington Site. The 300 MW GE Hitachi BWRX-300 is expected to be operation by the end of the 2020s. New Brunswick Power is also considering SMR projects, and a number of other countries are considering SMRs. There is no one SMR design, and many different companies are proposing different SMR technologies. Appendix B has more details on different SMR designs.



# CHAPTER 2: THE NEED FOR INDUSTRIAL DECARBONIZATION

Heavy industry is responsible for a large percentage of Canada's Gross Domestic Product (GDP) as well as our GHG emissions (see Figure 2). This sector accounted for 10% of Canada's total emissions in 2019. When fossil fuel extraction and refinement, as well as mining, are included, industrial emissions discussed in this paper accounted for 37% of total GHG emissions.[4] In aggregate, these sectors also accounted for 18% of Canada's GDP.[5]

## Figure 2: Key industrial GHG emissions and GDP, by percent share of Canada's totals (2019)[6]




While a detailed breakdown of where Canadian industrial heat use comes from is not available, studies in other countries have shown that approximately 40% of their industrial emissions result from burning fossil fuels to produce high-quality heat.[7] For example, Figure 3 provides a breakdown of industrial energy usage in Europe.

4 Environment and Climate Change Canada, National Inventory Report 1990-2019: Greenhouse Gas Sources and Sinks in Canada, 2021, https://publications.gc.ca/site/eng/9.506002/publication.html

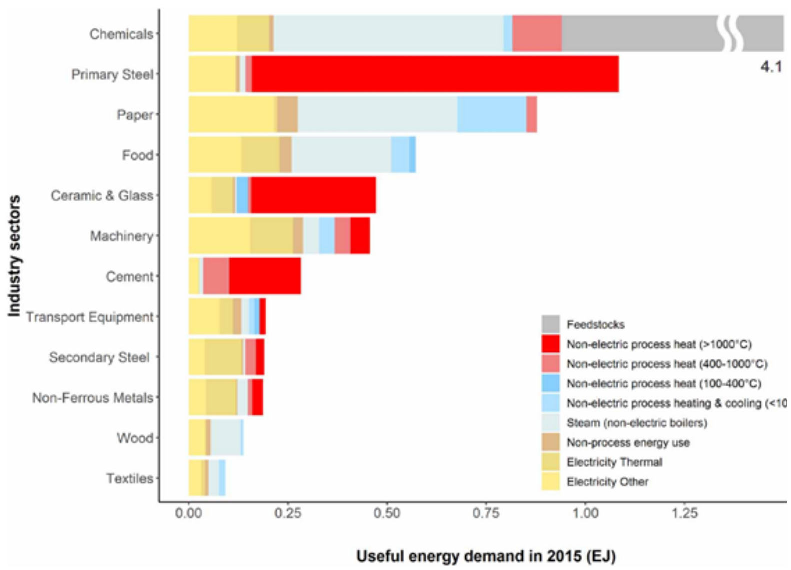
5 Government of Canada, Gross domestic product (GDP) at basic prices, by industry, annual average, https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3610043403

6 Government of Canada, Gross domestic product (GDP) at basic prices, by industry, annual average, https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=3610043403; Environment and Climate Change Canada, National Inventory Report 1990-2019: Greenhouse Gas Sources and Sinks in Canada, 2021, https://publications.gc.ca/site/eng/9.506002/publication.html

7 Julio Friedmann, Zhiyuan Fan, and Ke Tang, Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, And Costs Today, Columbia Center on Global Energy Policy, October 2019, https://www.energypolicy.columbia.edu/research/report/low-carbon-heat-solutions-heavy-industry-sources-options-and-costs-today

Industrial processes require large amounts of high-quality heat — generally more than than 300°C and as much as 1,100°C to 1,400° C for steel blast furnaces and cement.[8]

## Figure 3: Industrial energy usage in the European Union in 2015[9]




In the Canadian context, and apart from other industrial processes, the oil and gas sector creates a large thermal demand for refining and for in-situ oil production. Moreover, heat is crucial in many more industrial processes, and the required heat production often cannot be replaced by electricity. Hence, other non-emitting technologies that can provide heat need to be considered.

8 Julio Friedmann, Zhiyuan Fan, and Ke Tang, Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, And Costs Today, Columbia Center on Global Energy Policy, October 2019, https://www.energypolicy.columbia.edu/research/report/low-carbon-heat-solutions-heavy-industry-sources-options-and-costs-today

9 Silvia Madeddu, et al., "The CO2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat)," Environmental Research Letters, Vol. 15, No. 12, November 2020. https://doi.org/10.1088/1748-9326/abbd02

# CHAPTER 3: INDUSTRIAL DECARBONIZATION AND SMRS

Navius Research conducted modelling for Pollution Probe on the potential roles and impacts of SMRs (see Appendix C). Using the modelling, Pollution Probe held a multi-sectoral virtual workshop in the winter of 2021 (see Appendix A for a list of organizations involved). The participants accepted the modelling results and identified the following sectors as priorities for exploring SMR development and use:

- Low-carbon fuels production
- Heavy industry
- Oil and gas
- Mining

It was recognized by the workshop participants that first-of-a-kind (FOAK) and early nth-of-a-kind (NOAK) SMRs will have higher costs than subsequent versions, assuming developers can gain experience in deploying SMRs, and as their manufacturing capacity increases. It was considered as important to target the four priority sectors for which SMRs offer the greatest potential added value to the industrial decarbonization effort. It is the ability of SMRs to generate low-carbon heat, as well as electricity, that supports their advantage over renewable energy technologies. While renewable electricity generation costs have declined rapidly and should continue to decrease, SMRs can supply firm energy, which runs continuously as opposed to intermittently.[10]

## 3.1 Low-carbon fuels production

SMRs can be used in the production of low-carbon fuels, such as next generation biofuels and hydrogen.

The benefits of low-carbon fuels include:

- providing backup fuels to industry to meet peak demands for electricity and/or heating
- providing fuels to other sectors, such as transportation, to assist in their decarbonization

10 Mark R. Weimar, et al., Techno-economic Assessment for Generation III+ Small Modular Reactor Deployments in the Pacific Northwest, Pacific Northwest National Laboratory, April 2021, https://www.pnnl.gov/news-media/small-modular-reactors-competitive-washingtons-clean-energy-future

The ability for low-carbon heat and electricity to be used for different purposes effectively leverages and increases the SMR decarbonization potential.

## 3.2 Heavy industry

SMRs are among a small number of low-carbon technologies that can provide high-grade heat to industry (see chapter 4).

While some industrial processes, such as steel making or cement, have higher-temperature heat requirements than SMRs can provide, there are many industrial processes for which SMRs could provide suitable heat. And through the production of low-carbon fuels, especially hydrogen, SMRs could also assist in decarbonizing processes that have elevated heat requirements. Steel makers, for example, are investigating using hydrogen to produce green steel.[11]

To date, the global chemicals industry has applied relatively few GHG emissions reduction technologies, and more innovation and concerted action will be required by this sector.[12] SMRs could be used to produce low-carbon hydrogen for making ammonia and methanol, among other products.[13]

## 3.3 Oil and gas

Extracting oil from the oil sands is an energy-intensive process. Using steam-assisted gravity drainage (SAGD) for in-situ oil production requires large amounts of thermal energy. Natural gas is burned to produce the steam that is directed underground to soften bitumen deposits, which are pumped to the surface for further treatment. After that, transportation by pipelines and other means, and then petroleum refining and processing are all energy intensive.

11 For information on other techniques for heavy industry decarbonization see Jeffrey Rissman, et al., "Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070," Applied Energy, Vol. 26, 2020, https://doi.org/10.1016/j.apenergy.2020.114848; see also Energi Media, Hamilton steel mill's shift from coal to electric part of global trend, February 22, 2022, https://youtu.be/FrNvcxQeUoc

12 International Energy Agency, Chemicals, 2021, https://www.iea.org/reports/chemicals

13 Julio Friedmann, Zhiyuan Fan, and Ke Tang, Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, And Costs Today, Columbia Center on Global Energy Policy, October 2019, https://www.energypolicy.columbia.edu/research/report/low-carbon-heat-solutions-heavy-industry-sources-options-and-costs-today

In-situ oil production using natural gas results in higher GHG emissions per barrel than other types of oil sands mining. And SAGD is expected to support most of the projected growth in western Canadian oil production. When the natural gas is burned to produce steam, electricity is sometimes also produced (in a combined heat and power arrangement) for use in the bulk electricity grid. Although gas-fired generation assists in coal phase-out as an energy source, in-situ mining oil production is still emissions-intensive.[14]

## 3.4 Mining

In 2016, Canada had more than 200 mines and 7,000 quarries, producing minerals and metals worth more than $41 billion.[15] Among them, 32 operating and planned off-grid mines were reliant on diesel generators. On average, the off-grid mines had power demands of between 5-30 MW.[16] One feasibility study concluded that very small modular reactors (roughly 10 MW in electricity generation) could provide 90% of these mines' energy needs, with an 85% reduction in GHG emissions.[17] It should be noted that many mining companies have announced net-zero emissions targets.[18]

14 For more information see Energy Exchange, The Oil Blog Series Part 3: In-Situ Production in the Oil Sands, June 25, 2020, https://www.energy-exchange.net/in-situ-production-in-the-oil-sands/
15 The Canadian Minerals and Metals Plan, Mining in Canada, 2022, https://www.minescanada.ca/en/content/mining-canada-0
16 F. Caron and J. Abols, Production of Electricity Using Small Modular Reactors (SMRs) for Off-Grid Mining and Other Applications, MIRARCO Mining Innovations, Laurentian University, 2020, https://mirarco.org/wp-content/uploads/ConferencePapers/Caron_and_Abols_CIM_2020_Accepted.pdf
17 Mirarco, Study shows vSMRs could reduce emissions by 85 per cent or more, June 22, 2021, https://mirarco.org/2021/06/22/small-reactors-could-power-far-north-mines
18 See, for example, "Teck Announces Expanded Net-Zero Climate Strategy," National Post, February 25, 2022, https://nationalpost.com/globe-newswire/teck-announces-expanded-net-zero-climate-strategy

## CHAPTER 4: OPTIONS FOR LOW-CARBON INDUSTRIAL HEAT

Low-carbon options are limited for replacing the high-quality industrial heat currently provided using fossil fuels. Five options are generally contemplated:

1. Renewable natural gas
2. Hydrogen
3. Carbon capture and storage with fossil fuels
4. Direct electrification
5. Nuclear heat production[19]

Each option has downsides, and there is not one choice that will satisfy all industrial, economic and climate considerations. Table 1 summarizes the options and their advantages and disadvantages. Additional details are provided following the table.

### Table 1: Potential low-carbon industrial heat options

| Option | Available temperature (C) | Technology advantages | Technology disadvantages |
|---|---|---|---|
| Renewable natural gas | 2,000 | - Infrastructure already place through the natural gas system<br>- High combustion temperatures | - Limited availability<br>- Competing demands for RNG use in other processes, such as heating |
| Hydrogen | 2,100 | - No GHG emissions at the point of combustion<br>- High combustion temperatures | - Low-carbon hydrogen may be expensive.<br>- If hydrogen is produced from hydrocarbons, there may be difficulty in capturing the carbon<br>- Storing and transporting hydrogen may be difficult |
| Carbon capture and storage with fossil fuels | 2,200 | - Can use existing infrastructure<br>- High combustion temperatures | - Not yet done at scale<br>- Best-case capture rate seen at 90%<br>- Difficulty in transporting and storing the carbon |

19 Julio Friedmann, Zhiyuan Fan, and Ke Tang, Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, And Costs Today, Columbia Center on Global Energy Policy, October 2019, https://www.energypolicy.columbia.edu/research/report/low-carbon-heat-solutions-heavy-industry-sources-options-and-costs-today

| | | | |
|---|---|---|---|
| Direct electrification | 1,800 | - Can use existing infrastructure | - May not provide heat for all industrial processes<br>- Potentially competing demands for electricity<br>- Only 100% clean if all grid resources are zero-emissions |
| Small modular reactors | 800 | - Can be installed on-site<br>- Can cogenerate low-carbon heat and electricity or produce low-carbon fuels | - Not yet done at scale and costs are unkown<br>-Social acceptance risk in communities new to nuclear<br>- Large up-front costs, so need policy certainity<br>- Need to manage nuclear waste |

Before switching to alternative heat sources, industries need to consider whether the replacement source can provide a similar quality of heat. The first consideration is the temperature — different industrial processes require different temperatures. In addition, low-carbon substitutes would need to provide comparable levels of reliability.

## 4.1 Renewable natural gas

Renewable natural gas (RNG) is gathered or created from renewable resources and is identical to conventional natural gas in terms of their methane content. RNG is generally captured from wet agricultural waste, as well as from landfill sites and wastewater treatment plants. Wood waste and other solid waste can also be converted to gas. While RNG can be produced from crops, that option would compete with other valued land uses and is not considered in this report. RNG is deemed low-carbon because it displaces the burning of fossil fuels, and it captures methane that might otherwise leak into the atmosphere from waste management facilities.[20]

20 See Canadian Biogas Association, Biogas Benefits, https://biogasassociation.ca/about_biogas/biogas_benefits; Pollution Probe, Future of Natural Gas, 2019, https://www.pollutionprobe.org/future-hold-natural-gas-report

Given that RNG methane is chemically identical to fossil gas methane, no technology changes are required for industrial use. However, there may be limitations on the supply of RNG. Studies have indicated that there is sufficient feedstock for RNG to supply up to 12% of current gas demand. While new technology may increase this percentage, many sectors may also demand the RNG, including for use in home heating and for industrial processes that require combustion.[21]

## 4.2 Hydrogen

Hydrogen is an alternate low-carbon fuel. It can be produced by two different methods. The most common and currently commercially viable way to obtain hydrogen is by using steam methane reformation to separate natural gas into hydrogen and carbon dioxide. If the CO2 is captured and stored, the hydrogen can be considered lower carbon (sometimes referred to as 'blue' hydrogen). It has been estimated that up to 90% of the CO2 can be captured, although the practicality of providing long-term underground storage depends on local geological conditions.

Another method for producing hydrogen is electrolysis, which uses electricity to split water into hydrogen and oxygen. When the electricity for electrolysis comes from clean sources, such as hydro, wind or solar, the resulting hydrogen may be considered zero-carbon (sometimes referred to as 'green' hydrogen). While this may not be the most efficient method of hydrogen production, it can be competitive if surplus electricity is available.[22]

Interest in hydrogen is growing, and the federal government has introduced a national hydrogen strategy. The government of Alberta announced a clean hydrogen facility in the summer of 2021, which is expected to be operational in 2024.[23]

## 4.3 Carbon capture and storage with fossil fuels

Carbon capture and storage (CCS) refers to the capture of carbon from the combustion of a fossil fuel, and then storing the carbon so that it does not contribute to global warming.

21 Pollution Probe, Future of Natural Gas, 2019, https://www.pollutionprobe.org/future-hold-natural-gas-report/

22 International Energy Agency, The Future of Hydrogen, June 2019, https://www.iea.org/reports/the-future-of-hydrogen

23 Government collaboration supporting the future of Alberta's clean hydrogen sector: News release, 2021, https://www.canada.ca/en/innovation-science-economic-development/news/2021/06/government-collaboration-supporting-the-future-of-albertas-clean-hydrogen-sector.htm

The primary benefit of CCS is that fossil fuels, as well as the existing infrastructure and industrial processes developed around them, could continue to be used. CCS could also be used to capture non-energy industrial process emissions, such as from cement, in which the process of creating the cement releases carbon dioxide.[24] The Oil Sands Pathways to Net-Zero initiative, a consortium of six large oil sands producers, is proposing to use CCS, among other technologies.[25]

Notwithstanding the potential benefits, there are several concerns about using CCS. For example, the ability to store carbon from small distributed industrial facilities is uncertain. In addition, no CCS system can capture 100% of the emissions. For hydrogen production from natural gas, 90% capture has been seen as possible by the International Energy Agency.[26] Another concern will be the long-term storage of carbon without leakages.

## 4.4 Electric heating

A significant amount of electricity is required to attain high temperatures. Electric heating is used in some industries, such as electric arc furnaces, which are used to recycle steel. Resistive heating temperatures have been pushed to as high as 1,800°C.[27]

It is important to note that on a life-cycle basis, electric heating is only as clean as the source of electricity being used. The overall GHG emissions intensity of the heat would thus depend on electricity sector decarbonization. Other limitations on the use of electric heating include the quality of the heat that can be generated, and the cost.

24 Julio Friedmann, Zhiyuan Fan, and Ke Tang, Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, And Costs Today, Columbia Center on Global Energy Policy, October 2019, https://www.energypolicy.columbia.edu/research/report/low-carbon-heat-solutions-heavy-industry-sources-options-and-costs-today

25 See Oil Sands Pathways to Net Zero initiative, https://www.oilsandspathways.ca

26 International Energy Agency, The Future of Hydrogen, June 2019, https://www.iea.org/reports/the-future-of-hydrogen

27 Julio Friedmann, Zhiyuan Fan, and Ke Tang, Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, And Costs Today, Columbia Center on Global Energy Policy, October 2019, https://www.energypolicy.columbia.edu/research/report/low-carbon-heat-solutions-heavy-industry-sources-options-and-costs-today

## 4.5 Small modular reactors

Traditional nuclear power involves building large, centralized facilities such as the 3.5 GW Darlington and 6.5 GW Bruce nuclear power plants in Ontario with each reactor sized between 700 and 1,000 MW.

These plants are massive one-of-a-kind engineering projects, and while costs can vary widely between countries, they are expensive and can take many years, and sometimes decades, to implement.

SMRs are smaller and modular in nature, which means that various components of SMR facilities could be manufactured at a central location, then delivered and assembled at the final site. This can allow costs to be reduced through mass production, and the on-site work can be completed much faster.

Table 2 compares different SMR technologies. Appendix B provides more detail on the range of SMR models, as well as some proposed projects.

### Table 2: Comparing SMR models[28]

| Reactor technology | Size range | Investments | Potential for heat production |
|---|---|---|---|
| Water-cooled reactors | ≥ 30 MWe | The most common type of reactor deployed. GE-Hitachi's BWRX-300 has been selected for development at Darlington. | Limited potential for heat production |
| High-temperature gas-cooled reactors | ≥ 4 MWe | Projects in China and Japan. Proposed project in the US and at Chalk River research labs in Canada. | Potential for high heat production |
| Sodium-cooled reactor | ≥ 100 MWe (although smaller is possible) | Project under development in Wyoming, and proposed for New Brunswick. | No experience with the technology in Canada |
| Molten salt reactors | ≥ 100 MWe | Proposed for New Brunswick. | Potential for high heat production |
| Heat pipe reactors | ≤ 15 MWe | NASA is investigating, and a Westinghouse eVinci reactor is under development. | Potential for high heat production |

28 SMR Working Group, Canadian SMR Roadmap: Technology Working Group Report, October 2018, https://smrroadmap.ca/wp-content/uploads/2018/12/Technology-WG.pdf

# CHAPTER 5: **MODELLING SMALL MODULAR REACTOR POTENTIAL**

To identify the efficacy of SMRs to reduce emissions, Navius Research modelled the potential for SMRs to be used in industrial decarbonization.[29] For this paper, the results from the net-zero GHG emissions scenario are presented. Details on the different scenarios modelled are presented in Appendix C.

In the Navius modelling, four industries were identified which have significant GHG emissions, face limitations on the use of alternative low-carbon technologies, and are compatible with using SMRs. The industries included:

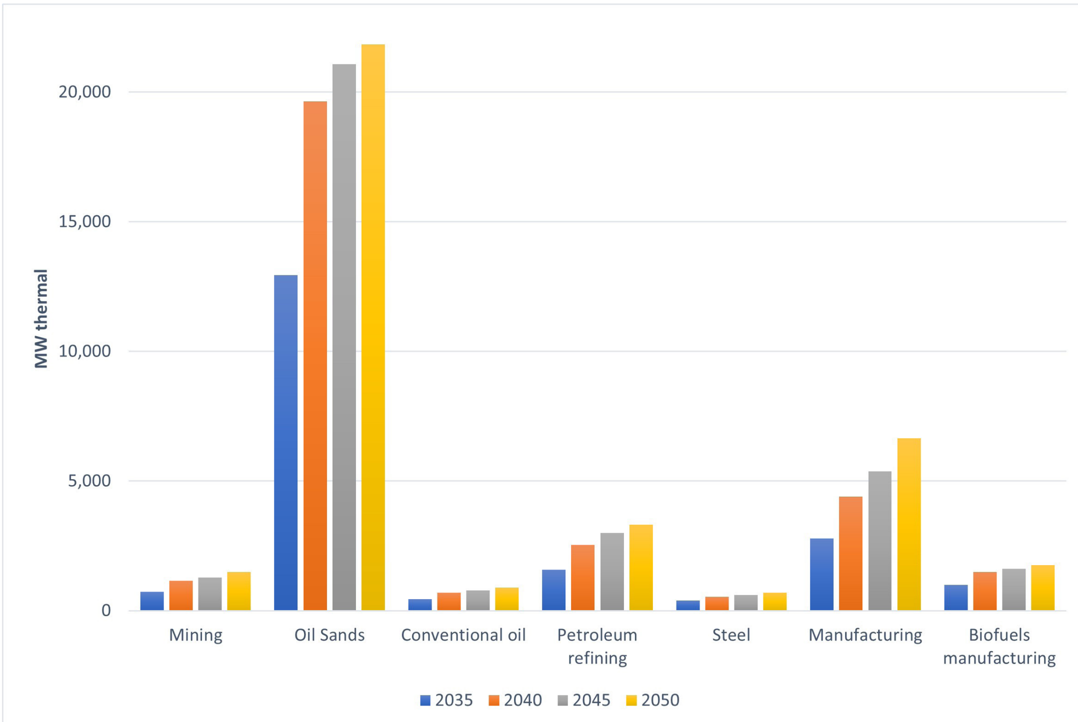
- Low-carbon fuels production
- Heavy industry
- Mining
- Fossil fuel extraction and refining

Natural gas-fired boilers and power plants equipped with carbon capture and storage (CCS) are prominent low-carbon alternatives to using SMRs in industry. Moreover, given the potentially large role that SMRs are being considered for in the oil and gas sector, the future price of oil, and hence future oil and gas production, were also analyzed by Navius (see Appendix C for details).

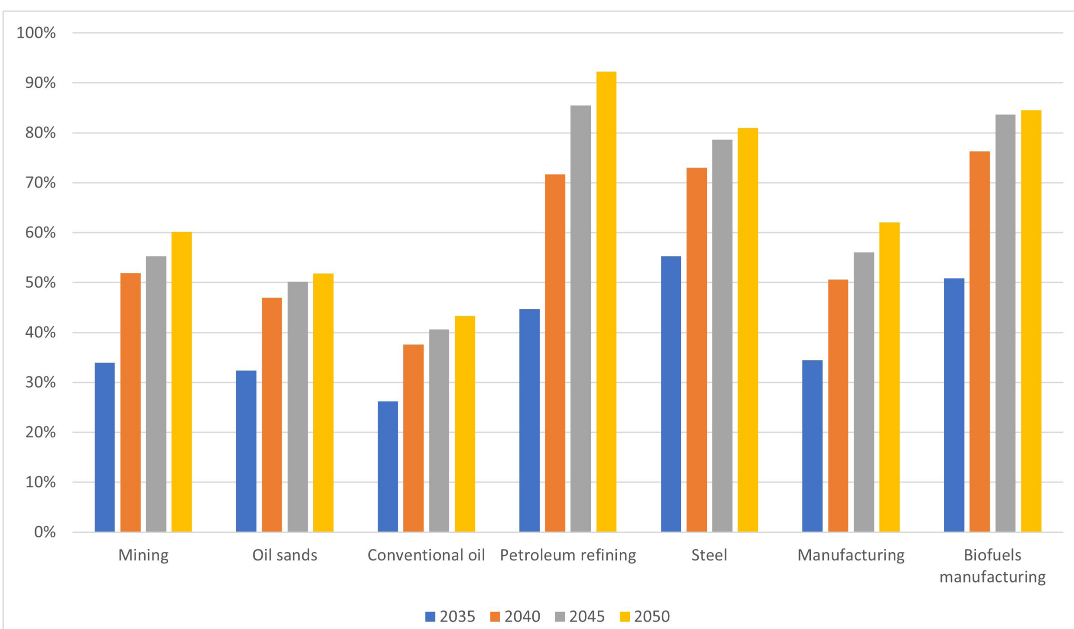
Under a net-zero scenario, the modelling projected that the deployment of SMRs would grow rapidly in the oil sands and manufacturing sectors (see Figure 4). By 2050, SMRs would account for a large majority of the heat supply for petroleum refining, steel, and biofuels manufacturing, as well as a significant portion for manufacturing and mining (see Figure 5).

29 For the cost of SMRs, Navius used the figures from the SMR Economic and Finance Working Group (adjusted to 2020 dollars). For more information, and the full results, see Appendix A. For this report, the "Evolutionary" trajectory was chosen, with a 40-year lifespan and 90% capacity factors were chosen to be conservative. A longer lifespan and higher capacity factor are possible. It was assumed commercial introduction in 2030.

## Figure 4: Projected SMR deployment in a net-zero scenario (in MW thermal)




## Figure 5: SMR market share for heat by industry in a net-zero scenario



In terms of GHG emissions reduction, Table 3 shows how much SMRs might reduce emissions in select years in a net-zero scenario (the emissions reductions are for each indicated year and are not cumulative).

**Table 3: Reduction in annual emissions in hard-to-decarbonize industrial sectors due to SMRs in the net-zero scenario (Mt CO2e in each year)**

| Sector | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|
| Mining | -1.0 | -1.6 | -1.7 | -1.6 |
| Oil Sands | -10.9 | -15.5 | -16.4 | -17.1 |
| Conventional oil | -0.5 | -0.8 | -0.2 | -0.7 |
| Petroleum refining | -4.7 | -7.5 | -10.5 | -11.1 |
| Steel | -0.4 | -0.5 | -0.5 | -0.4 |
| Manufacturing | -4.3 | -6.4 | -7.2 | -7.4 |
| Biofuels manufacturing | -1.1 | -1.7 | -1.9 | -1.5 |
| Total | -22.8 | -34.1 | -38.4 | -39.9 |

The contribution of SMRs to industrial decarbonization would be two-fold. First, SMRs can directly reduce GHG emissions in the sectors noted above. What is not captured in Table 3 is that SMRs can also facilitate emission reductions in other sectors, through the production of low-carbon fuels can be used to displace fossil fuels. Thus, low-carbon fuels can be valuable in reducing the net-GHG emissions from other hard-to-decarbonize sectors.

# CHAPTER 6: IMPLICATIONS FOR POLICY AND FUTURE ACTION

The Navius modelling results indicate that SMRs could play a significant role in support of Canada's net-zero GHG emissions commitment, through advancing industrial decarbonization. However, the deployment of SMRs faces several challenges. During the Pollution Probe workshop, the participants created a matrix of action items highlighting some of the things that would need to be done if SMRs were to become a significant part of Canada's approach to reducing GHG emissions (see Table 4).

Governments have seldom got involved in the issue of industrial heat. While this is changing due to the imperative of decarbonization (recent government funding for the steel industry is a good example there is not a lot of policy support for heating-related initiatives). Industrial heating needs tend to be spread across wide geographic areas, and there are many small industrial sites that use a variety of fuels, as compared to electricity generation or steel production, which have historically involved building large, centralized plants. Hence, widespread distribution and industrial variety make effective government intervention difficult. But there are still many actions that can be taken by governments, industries, and civil society to support industrial heating initiatives.

At the same time, there are potential advantages to SMR deployment. SMRs developed for industrial loads could also assist in wider decarbonization efforts through providing low-carbon electricity in addition to the heat, or by producing low-carbon energy carriers such as hydrogen, while at the same time producing low-carbon heat or electricity. That flexibility is unique for SMRs.

Common actions that were highlighted by the workshop participants included the need for government financial support and policy clarity. However, while financial support can help, what industry really needs is policy clarity and certainty on future decarbonization pathways. It is not clear, for example, if the federal government supports the development of new nuclear, technologies.[30] And without such clarity, industry is unlikely to invest in new technologies with multi-decade paybacks.

30 See for example, nuclear energy was not included in the federal government Green Bond framework in early 2022. See Government of Canada, Canada Publishes Green Bond Framework in Advance of Inaugural Issue, March 3, 2022, https://www.canada.ca/en/department-finance/news/2022/03/canada-publishes-green-bond-framework-in-advance-of-inaugural-issuance.html. See also Heather Scofield, If nuclear power is the key to Canada's green future, Ottawa needs to say so now, Toronto Star, January 14, 2022, https://www.thestar.com/politics/political-opinion/2022/01/14/if-nuclear-power-is-the-key-to-canadas-green-future-ottawa-needs-to-say-so-now.html

Workshop participants also highlighted the need to develop effective supply chains for equipment and for skilled workers. The nuclear industry needs to a play a large role in workforce training to ensure that apprenticeships and so on are available. The nuclear industry, for its part, needs to demonstrate that significant cost-redutions in SMR manufacturing can be achieved, and that SMRs are safe and reliable.

Community engagement needs to begin years before an SMR facility is built, or even proposed. The nuclear industry needs to recognize the valid reasons why some communities may be concerned about nuclear energy, and nuclear waste. The nuclear sector must demonstrate that it has a good track record with safety, and it needs to work with potential SMR host communities to build understanding and trust.

When the existing large nuclear plants in Canada were built, Indigenous communities were not meaningfully consulted, and they did not benefit as much as other communities. The nuclear industry needs to learn from industries like mining, hydropower, and oil and gas, which have found ways to help Indigenous communities participate in regulatory and permitting processes, and in some cases to play key roles in project development and implementation. Today, nuclear facilities could only be built in willing communities, and support for SMR projects that may be proposed in the traditional territories of Indigenous communities is essential to their success.

| Areas of action | | | | |
|---|---|---|---|---|
| Policy and regulatory | Technical | Community engagement | Finance | Supply chain |
| • Increased federal leadership and support for SMRs<br>• Clarity of future policy pathways to net-zero<br>• Clarify and improve permitting and the regulatory processes<br>• Prepare a waste plan | • Provide training for industry to be able to manage SMRs<br>• Assess technical feasibility for industry-specific applications<br>• Successful demonstration project to gain buy-in<br>• Supporting research development programs and collaboration<br>• Reduction in cost and reliability needs to be demonstrated | • Start engagement and communication as early as possible, even during feasibility study<br>• Early and often engagement with Indigenous communities<br>• Employment and training opportunities<br>• Improve existing nuclear communication to show SMRs potential roles<br>• Provide information on benefits<br>• Work with the Nuclear Waste Management Organization | • Support from federal/provincial governments to transition away from fossil fuels<br>• Federal funding to better research, approaching communities, and engaging<br>• Incentives for training and skills development and the frameworks to then support increased employment in the sector | • Develop supply chains here for export<br>• Develop skills training strategies<br>• Develop nuclear fuel supply chain |

**Legend**

Government Industry Civil Society (Includes academics and NGOs) Other

# CHAPTER 7: WORKSHOP KEY FINDINGS AND CONCLUSION

The key findings from the modelling and the workshop include:

| | |
|---|---|
| **SMRs can play an important role in decarbonization** | Modelling shows that SMRs could play an important role in Canada reaching its 2050 net-zero target. In hard-to-decarbonize sectors, SMRs could help reduce emissions at a lower cost than potential competitors. |
| **Decarbonizing heat has not been recognized as an essential element of emissions-reduction strategies** | Reducing emissions from heat production, especially high-grade industrial heat, has not been a priority of policymakers, despite heat production's large share of emissions. One of the reasons for this could be the relative lack of low-carbon options for producing industrial heat, compared to a larger number of options for other sectors. |
| **SMRs' ability to produce heat and electricity is an important asset in decarbonizing a wide variety of sectors** | Modelling demonstrates the different sectors that SMRs could contribute to. Also, the ability to produce heat and electricity allows for SMRs to help decarbonize two areas at the same time. Heat could be used in industry, while the electricity could be supplied to the grid, or used to produce hydrogen, or vice versa. This ability could make SMRs even more cost-effective when it comes to decarbonization, and could help reduce the overall investment to get to net-zero. |
| **Business and regulatory models need to change** | Current business and regulatory models were designed for the large-facility nuclear power development of the 1970s and 1980s. Given their modularity and size, SMR development will require different business and regulatory models. Regulators will still need to ensure that there is both public safety and public confidence in SMRs. |
| **Certainty on future net-zero policies and regulations is needed** | Modelling shows that significant SMR deployment will depend on a range of policy measures, such as carbon pricing. In particular, before investment, industry needs policy certainty about government support for nuclear deployment. |
| **Valid concerns around safety and waste need to be addressed** | While the nuclear sector has a good safety record in Canada, many communities remain concerned about nuclear reactors. In addition, radioactive waste management is a valid concern. It needs to be properly addressed. |
| **The nuclear industry needs to demonstrate their ability to realize the purported costs savings while providing reliability** | SMR development is contingent upon reductions in the cost of developing SMRs, through modularity and scale of manufacturing, as well as regulatory certainty. Historically, the nuclear sector has not demonstrated the cost-effective development of new reactors. The nuclear sector needs to demonstrate cost certainty, and that those costs are justifiable to other comparable low-carbon options. The reliability of SMRs will need to be demonstrated to industrial sectors that have not had experience with nuclear. |

| | |
|---|---|
| **Public engagement needs to be ongoing** | Nuclear energy is an emotive issue, and just repeating facts and static talking points is unlikely to garner the public acceptance of development that is needed. The nuclear sector has improved its engagement in recent years, but more can be done to develop long-term relationships to build trust with communities.<br><br>In addition, Indigenous engagement needs to begin early. The nuclear sector has improved its approaches in this area, such as in the engagement around the proposed deep geologic repository for used fuel, new nuclear at Darlington, and Global First Power's commercial demonstration project at Chalk River. For SMRs to be successfully deployed, the industry will have to build off of these learnings and develop a portfolio of best-practices, as well as build coalitions of support in parts of Canada that are new to nuclear. |
| **More work is needed on the potential for further decarbonization through secondary energy carriers** | One of the largest benefits of SMRs is their ability to directly contribute to industrial decarbonization, while at the same time producing low-carbon energy carriers, such as hydrogen, that can be used to decarbonize other sectors, such as heavy-duty transportation vehicles. |

Achieving net-zero by 2050 will require new technologies, new business and regulatory models, new ways of engaging with the public, and new ways of making the required materials. The scale of the challenge requires us to consider all options that can help us get there need.

The modelling work by Navius as well as the Pollution Probe workshop have shown that SMRs have the potential to play a role in the range of options that Canada can use to achieve net-zero GHG emissions in specific contexts.

But the development of SMRs is not inevitable. SMRs need to be compared to potential alternatives, and any barriers need to be addressed. In addition, Pollution Probe has identified five barriers to the widespread deployment of SMRs, and which require further work and discussion by industry, governments, and civil society:

- Assurance on the safety and reliability of new designs
- Safe and effective disposal of nuclear waste
- Demonstration of cost-effectiveness of SMR manufacturing and deployment
- Open engagement with potential host communities, and with the broader public
- Early consultation and engagement with Indigenous peoples and communities

## APPENDIX A: WORKSHOP ATTENDEES

Algoma Steel
Canadian Manufacturers and Exporters
Canadian Steel
Cedar Water Strategy
Chemistry Industry Association of Canada
Electricity Canada
Government of Saskatchewan
Indigenous Clean Energy
Laurentian University
Mining Innovation, Rehabilitation, and Applied Research Corporation (MIRARCO)
Natural Resources Canada
Navius Research
NB Power
Nova Chemicals
Ontario Power Generation
Queens University
RMC Kingston
Suncor Energy

# APPENDIX B: OVERVIEW OF SMALL MODULAR REACTORS

## B.1 Water-cooled reactors

Water-cooled reactors have the advantage of being well documented as they comprise the majority of existing large-scale and small nuclear reactors.[31]

GE Hitachi Nuclear Energy is developing the BWRX-300, a 300 MWe boiling water reactor. The reactor was selected by OPG for its first Darlington SMR project.[32] NuScale has developed an integrated pressurized water-cooled SMR with passive safety features.[33] A similar integrated preserved water-cooled reactor, the RITM-200 (50 MWe), is currently working on a Russian icebreaker, and a second, the Argentinean CAREM-25 (27 MWe), has begun construction.[34] Rolls-Royce Nuclear is also developing a water-cooled SMR based on its experience with nuclear submarines, and is receiving support from the UK government.[35] However, water-cool reactors do not have the potential to provide large amounts of heat.

## B.2 High-temperature gas-cooled reactors (HTG)

HTG reactors are graphite moderated and helium cooled. Current use of gas-cooled reactors are predominantly in the United Kingdom. HTGR reactors have high heat production and could therefore be useful for industrial heating needs.[36]

US-based X-energy is developing an 80 MWe HTGR reactor, the Xe-100, and the Xe-100 was proposed for the Darlington project but was not selected.[37]

31 SMR Working Group, Canadian SMR Roadmap: Technology Working Group Report, October 2018, https://smrroadmap.ca/wp-content/uploads/2018/12/Technology-WG.pdf

32 OPG, OPG advances clean energy generation project, December 2, 2021, https://www.opg.com/media_releases/opg-advances-clean-energy-generation-project/; GE, The BWRX-300 Small Modular Reactor, N.D., https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/bwrx-300; GE, GE Hitachi Nuclear Energy and BWXT Canada Enter into Agreement to Support BWRX-300 Design and Commercialization, October 2021, https://www.ge.com/news/press-releases/ge-hitachi-nuclear-energy-and-bwxt-canada-enter-into-agreement-to-support-bwrx-300?_ga=2.162554364.1563629195.1637791899-535582264.1637791899

33 NuScale, technology overview, 2021, https://www.nuscalepower.com/technology/technology-overview

34 SMR Working Group, Canadian SMR Roadmap: Technology Working Group Report, October 2018, https://smrroadmap.ca/wp-content/uploads/2018/12/Technology-WG.pdf

35 Rolls-Royce Nuclear, Why Rolls-Royce Nuclear?, 2021, https://www.rolls-royce-smr.com/why-rolls-royce-smr

36 International Atomic Energy Association, Gas-cooled Reactors, 2021, https://www.iaea.org/topics/gas-cooled-reactors

37 Xenergy, Xe-100, 2021, https://x-energy.com/reactors/xe-100; X-Energy Canada, Canada Can Lead the Charge to Net-Zero, 2021, https://x-energy.com/update/canada-can-lead-the-charge-to-net-zero

Global First Power is commercial demonstration project at Chalk River Laboratories site in Ontario using the Ultra Safe Nuclear Corporation developed HTGR Micro Modular Reactor, producing 5 MWe and 15 MWth.[38] China has deployed a HTG reactor (HTR-PM), with two twin 100 MW reactors first reaching criticality in November 2021.[39] The Ultra Safe Nuclear Corporation is developing an HTGR Micro Modular Reactor, producing 5 MWe and/or 15 MWth.[40] Canadian Nuclear Laboratories (CNL) is planning on deploying a pilot of the reactor with Global First Power.[41]

## B.3 Sodium-cooled reactors (SCR)

Sodium-cooled reactors are cooled by liquid sodium metal and operate at near atmospheric pressure. They also operate at a higher temperature.[42]

A number of proposed SMRs are SCRs. The Natrium sodium-cooled fast reactor with molten salt storage is under development in Wyoming. TerraPower is developing the project with GE-Hitachi, and the US Department of Energy is funding 50% of the project. Once completed, PacificCorp will own and operate the plant.[43] In addition, the ARC Clean Energy Canada ARC-100 SMR is being considered by NB Power.[44]

## B.4 Molten salt reactors (MSR)

Molten salt reactors (MSRs) use molten fluoride salts as primary coolant and can be operated at low pressure. Molten salt reactors were first developed in the 1960s, but little progress was seen until recently. MSRs have several advantages, including the ability to use a variety of fuel sources including uranium, thorium, and plutonium, or even re-use waste fuel from other reactors.[45] In addition, MSRs are seen as safe as they operate at atmospheric pressure and reduce power as they are heated. MSRs are also good for providing process heat. However, molten salts are corrosive, and hence to build a reactor would require stringent controls.[46]

38 Ultra Safe Nuclear Corporation, USNC Micro Modular Reactor (MMR Block 1) Technical Information, 2021, https://usnc.com/assets/media-kit/[022989][01]%20MMR%20Technical%20Information%20Document.pdf?v=c-3819e0ac7: Ultra Safe Nuclear Corporation, USNC Micro Modular Reactor (MMR Block 1) Technical Information, 2021, https://usnc.com/assets/media-kit/[022989][01]%20MMR%20Technical%20Information%20Document.pdf?v=c3819e0ac7; Global First Power, Proposed Project at Chalk River, Ontario, https://www.globalfirstpower.com/proposed-project-at-chalk-river-ont

39 Dual criticality for Chinese demonstration HTR-PM, World Nuclear News, November 12, 2021, https://www.world-nuclear-news.org/Articles/Dual-criticality-for-Chinese-demonstration-HTR-PM

40 Ultra Safe Nuclear Corporation, USNC Micro Modular Reactor (MMR Block 1) Technical Information, 2021, https://usnc.com/assets/media-kit/[022989][01]%20MMR%20Technical%20Information%20Document.pdf?v=c-3819e0ac7

41 Canadian Nuclear Laboratories, CNL successfully fabricates advanced Small Modular Reactor fuel, April 13, 2021, https://www.cnl.ca/cnl-successfully-fabricates-advanced-small-modular-reactor-fuel/

42 SMR Working Group, Canadian SMR Roadmap: Technology Working Group Report, October 2018, https://smrroadmap.ca/wp-content/uploads/2018/12/Technology-WG.pdf

43 Wyoming Advanced Energy, Project Details, 2021, https://wyomingadvancedenergy.com/project-details/

44 NB Power, Small reactors, Big Opportunities, 2021, https://smrnb.ca

45 World Nuclear Association, Molten Salt reactors, May 2021, https://world-nuclear.org/information-library/current-and-future-generation/molten-salt-reactors.aspx

46 SMR Working Group, Canadian SMR Roadmap: Technology Working Group Report, October 2018, https://smrroadmap.ca/wp-content/uploads/2018/12/Technology-WG.pdf

Several projects are being developed in Canada. Oakville, Ontario-based Terrestrial Energy is developing a molten salt reactor and was one of the candidates that OPG considered for its initial development. NB Power is also looking into a molten salt reactor developed by Moltex Energy.[47]

## B.5 Heat-pipe reactors

Westinghouse is currently developing the eVinci Micro-Reactor, a very small modular reactor (1-5 MW) for decentralized remote applications.[48]

47 Matthew McClearn, "Governments, utilities and the nuclear industry hope small modular reactors will power Canada's future. Can they actually build one?," Globe and Mail, 2021, https://www.theglobeandmail.com/business/article-governments-utilities-and-the-nuclear-industry-hope-small-modular

48 Westinghouse Nuclear, eVinci Micro-reactor, https://www.westinghousenuclear.com/new-plants/evinci-micro-reactor

## APPENDIX C: MODELLING

Modelling available at :
**https://www.pollutionprobe.org/wp-content/uploads/2022/04/SMR-GHG-Reduction-Potential_2021-12-03.pdf**