navius research

Identifying opportunities for small modular reactors to reduce greenhouse gas emissions in Canadian industry

Analysis prepared for Pollution Probe

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Summary of key findings

Summary | Introduction | Approach | Results

Small modular reactors (SMRs) are an emerging technology that have a variety of potential applications in Canada. This study focuses on their use in industry as a greenhouse gas emissions reduction solution. Key findings are summarized below.

Carbon policy will be a key driver of SMR adoption in industry.

The potential for SMR deployment in Canada is strongly tied to the level of climate mitigation effort. In the absence of new greenhouse gas abatement policy, SMR adoption is unlikely to be economical in most industries. However, if stronger carbon reduction policies are pursued – such as those that would put Canada on track to achieving net zero by 2050 – SMR adoption could increase rapidly after 2030, reaching into the tens of thousands of MW_{th} by mid-century and reducing GHGs by anywhere from 19 to 59 Mt CO_2e.

Where are the emissions reductions opportunities for SMRs in industry?

A variety of industries are attractive for potential SMR deployment in Canada. These industries all share one thing in common – a demand for high-grade process heat.

Key opportunities for SMR deployment are summarized in Table 1 and include:

1. Supporting the production of emerging low carbon energy carriers.

SMRs can minimize the life cycle carbon intensity of emerging fuels, such as second-generation biofuels and hydrogen, by providing low carbon electricity and/or heat for the fuel production process. Emerging fuels, in turn, are essential for decarbonizing certain sectors of the economy such as heavy-duty transportation.

Under the scenarios in which Canada achieves net zero, 2,540-5,603 MW_{th} of SMRs are deployed in the thermochemical production of second-generation biofuels and hydrogen production via steam methane reformation of natural gas. These are, however, not the only ways in which SMRs could be used for emerging fuel production. For example, other hydrogen production pathways using SMRs are also possible (e.g. water or steam electrolysis) and SMRs could even be employed to produce synthetic fuels (i.e., combining CO_2 from the atmosphere with hydrogen).

Summary of key findings

2. Helping decarbonize heavy industrial processes.

Many heavy industrial processes require high-grade heat, including steel production, metal smelting, and chemicals manufacturing. SMRs are one of the few potential options for meeting this heat demand other than combusting fossil fuels.

3. Providing a low carbon alternative to the use of diesel in the mining industry.

Mining operations require heat and power, but are often situated in remote locations far from the electricity grid. SMRs may be an attractive option for meeting these energy demands, especially when the alternative is diesel which is costly to transport.

4. Decreasing the carbon intensity of extracting and refining conventional fuels.

Extracting oil from the oil sands is relatively energy intensive, requiring substantial amounts of heat and steam. Presently, these energy services are provided by combusting fossil fuels. SMRs are an option for meeting these energy requirements which could help lower the carbon intensity of fossil fuel production. SMRs could also help reduce the carbon intensity of petroleum refining operations.

Under a scenario in which Canada achieves net zero by 2050, SMR adoption in the upstream oil extraction sector – predominantly the oil sands – and petroleum refining sector could reach into the tens of thousands of MW_{th}. This level of adoption would account for a large share of industrial SMR adoption across the country.

Nevertheless, the market potential for SMRs in fossil fuel extraction ultimately depends on the demand for Canada's oil. Under a scenario in which demand drops (i.e., consistent with a strong global decarbonization effort) and investment in the oil sands falls, SMR adoption could be minimal.

Table 1: SMR deployment and emission reduction opportunities in Canadian industry

Sector	Potential SMR deployment by mid-century (MW_{th})	Relative GHG reduction benefit
Low carbon fuel production	2,540-5,603	High
Heavy industry	2,815-6,322	Moderate
Mining	1,085-1,625	Low
Fossil energy extraction and refining	13,832-36,969	Variable*

*Source & notes: Potential SMR deployment based on Navius forecast using gTech, net zero scenario. *Depends on demand for Canadian oil and investment in the oil sands.*

Why small modular reactors?

Background

The International Atomic Energy Agency defines small modular reactors (SMRs) as nuclear plants with a power generation capacity below 300 MWe. In contrast with larger nuclear plants, SMRs are anticipated to be less capital intensive and require less time to construct. They are also more readily deployable in brownfield sites thanks to their smaller footprints, making them well suited for meeting low carbon heat and power needs of industry.

This study builds on previous work[1] to explore the potential for SMRs to help decarbonize industry. It refines the representation of SMRs based on the Economic and Finance Working Group's SMR Roadmap[2] and considers the potential use of SMRs across a broader range of industries.

1. EnviroEconomics & Navius Research. 2021. Emission and economic implications for Canada of using small modular reactors in heavy industry. www.naviusresearch.com/publications/small-modular-reactors-2021/
2. Economic and Finance Working Group. 2018. SMR Roadmap. https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf

Objectives

The objectives of this analysis are to:

1. Quantify the potential for SMRs to reduce emissions in Canada's difficult to decarbonize industrial sectors.
2. Identify sectors and regions that could be prioritized for the development of SMRs as an emission reduction solution.

Structure

This deck:

- Describes the modeling approach and identifies key assumptions related to the potential cost and performance of SMRs.
- Presents results to answer the following questions:
  - What is the impact of carbon policy on SMR adoption?
  - What regions are most attractive for SMR development?
  - What sectors are most attractive for SMR development?
  - By how much could SMRs reduce GHGs?

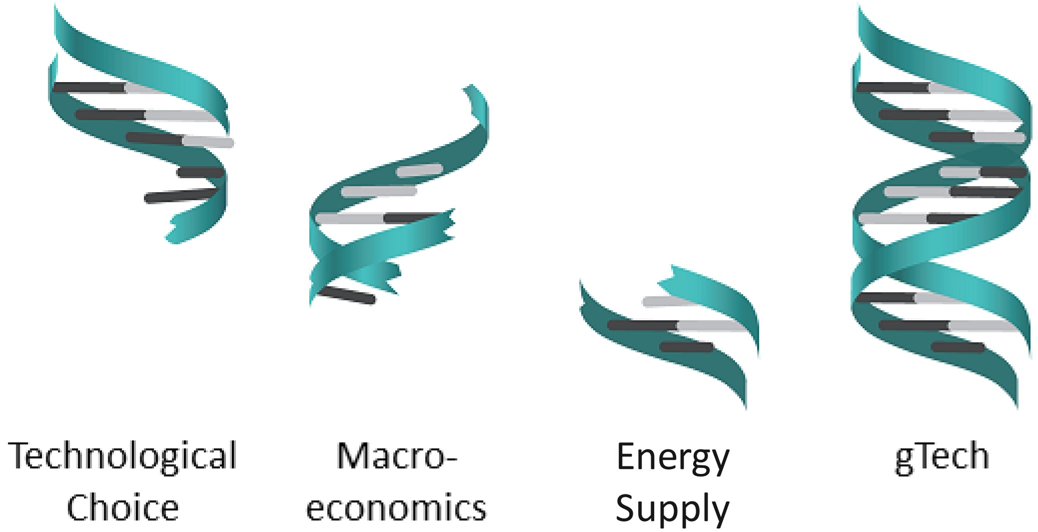
Our modeling toolkit

Introduction to gTech

This analysis uses gTech to quantify the potential adoption of SMRs across industry, as well as the impact of this adoption on greenhouse gas emissions.

gTech is ideally suited for this task because it provides a detailed accounting of low carbon technologies and fuels, allowing us to carefully characterize the cost and performance of SMRs across a range of applications. It also represents technologies that may compete with SMRs (e.g. natural gas boilers with carbon capture and storage), which is important because SMR adoption won't occur in a vacuum.

This modeling framework also accounts for the economy at large, including how demand for energy carriers and services may evolve in response to various levels of greenhouse gas mitigation efforts. For example, this analysis considers how greenhouse gas abatement influences fuel choice (e.g. lower demand for refined petroleum products, greater demand for low carbon alternatives like bioenergy and hydrogen) as well as how changing levels of economic activity affect demand for goods and services (and the energy inputs required to produce them).



gTech builds on three of Navius' previous models (CIMS, GEEM and OILTRANS), combining their best elements into a comprehensive integrated framework.

SMR characterization

SMRs are characterized based on an “evolutionary” design.

The technology archetype used in this analysis is based on assumptions for on-grid SMRs in the Economic and Finance Working Group’s SMR Roadmap (please see Table 2). This archetype builds on current nuclear technology and is at a high technology readiness level.

A “revolutionary” archetype is also presented in the Roadmap – reflecting more novel technology that is at a low readiness level – but is not included in this analysis.

SMRs are assumed to become commercially deployable after 2030 and applicable for use in any industry that demands high-grade process heat.

To capture the potential for SMRs to provide heat only (as opposed to power), we modify the SMR Roadmap’s assumptions to account for 1) lower capital and operating costs due to the lack of a steam turbine and 2) a reduction in efficiency losses.

Lastly, to account for the uncertainty in technology costs, this analysis includes sensitivities on SMR capital costs based on high and low estimates provided in the SMR Roadmap (approximately 30% higher or lower).

1. Economic and Finance Working Group. 2018. SMR Roadmap. https://smrroadmap.ca/wp-content/uploads/2018/12/Economics-Finance-WG.pdf

Table 2: SMR technology archetype

	Units	Evolutionary archetype
Capital cost incl. decommissioning	2020 C$/kW$_e$	7,728
Fixed O&M	2020 C$/kW$_e$-yr	151
Variable O&M incl. fuel	2020 C$/MWh$_e$	9.1
Capacity factor	%	90
Plant life	Years	40
Levelized cost of electricity	2020 C$/MWh$_e$	93

Source & notes: SMR Roadmap. Levelized cost is illustrative and reflects the 6% discount rate used in the SMR Roadmap.

Scenarios

We explore four scenarios describing alternative levels of greenhouse gas constraints:

- Current policy. All major provincial and federal climate and energy policies that have been implemented remain in place. Notably, the federal carbon price rises to $50/t CO_2e by 2022 remaining constant thereafter (in nominal terms). The Current policies assumptions section describes current policies, relevant to this analysis, in more detail.
- $170/t by 2030 carbon price. The federal carbon price rises by $15/t annual increments between 2022 and 2030, reaching $170/t and remaining constant thereafter. All other current policies are maintained.
- $320/t by 2040 carbon price. The carbon price continues to rise in $15/t annual increments through to 2040, reaching $320/t and remaining constant thereafter. All other current policies are maintained.
- Net zero by 2050. Canada successfully achieves its net zero target by 2050 in the most economically efficient manner. We assume 110 Mt CO_2e of negative land use, land use change and forestry (LULUCF) emissions are achieved by 2050.

The development of emerging low carbon technologies, like SMRs, is uncertain. To account for this uncertainty, we conduct a sensitivity analysis that accounts for variation in:

- SMR technology costs. The cost of small modular reactors is uncertain because they have yet to be commercialized. We explore three cost sensitivities including reference, optimistic, and pessimistic costs as described on slide 6.
- Carbon capture and storage costs. An important low carbon alternative to SMRs in industry is likely to be natural gas-fired boilers and power plants equipped with carbon capture and storage (CCS). The competitiveness of SMRs therefore depends, in part, on the cost of CCS.
- Oil price. One of the larger demands for industrial process heat in Canada is from the oil sands. Since the level of production from the oil sands in the future has a bearing on potential SMR adoption, we vary oil price as a proxy for foreign demand for Canada’s oil.

How can policy impact the adoption of SMRs?

Carbon policy is a key driver of SMR adoption in industry.

The potential for SMR deployment in Canada is strongly tied to the level of climate mitigation effort.

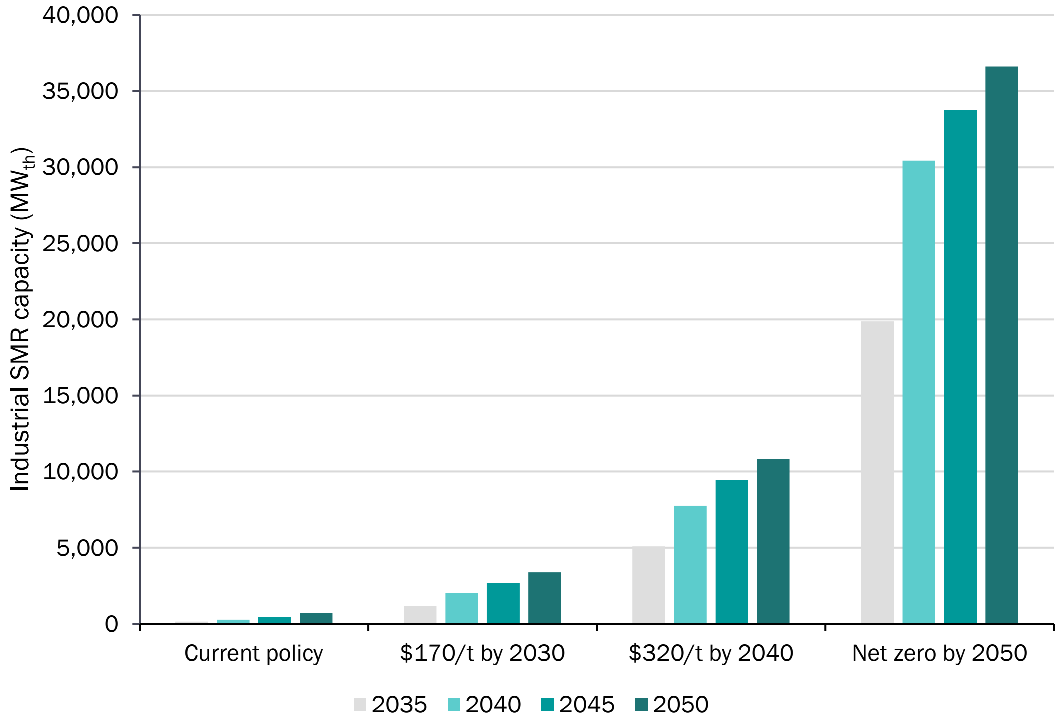
In the absence of new climate mitigation policy, SMR adoption increases to 713 MW_{th} of thermal capacity by 2050. SMR capacity additions are relatively minimal because without stronger carbon policy, more conventional and greenhouse gas intensive technologies out-compete SMRs in most industrial applications, such as natural gas-fired boilers.

Potential SMR adoption increases with stronger climate policy.

SMR adoption increases to 3,384 MW_{th} by 2050 if Canada's carbon price rises to $170/t by 2030. It increases further to 10,822 MW_{th} by 2050 if the carbon prices continues rising at $15/t increments, reaching $320/t by 2040.

Lastly, under a scenario in which Canada achieves net zero by 2050 (as defined on Slide 7), SMR adoption increases further still to 36,629 MW_{th}.

Various other factors beyond climate policy are also likely to influence SMR adoption, some of which are discussed in the following slides. Nevertheless, it's clear that stronger climate policy will increase the competitiveness of SMRs and boost potential adoption across industry.



Source & notes: Navius forecast using gTech, using baseline assumptions for low carbon technology costs & assuming a WTI oil price of ~ USD 2015$ 66/barrel. The figures shown on subsequent slides focus on the net zero scenario.

What regions are most attractive for SMR deployment?

The largest potential market for SMRs in industry is Alberta, though the size of this market is uncertain.

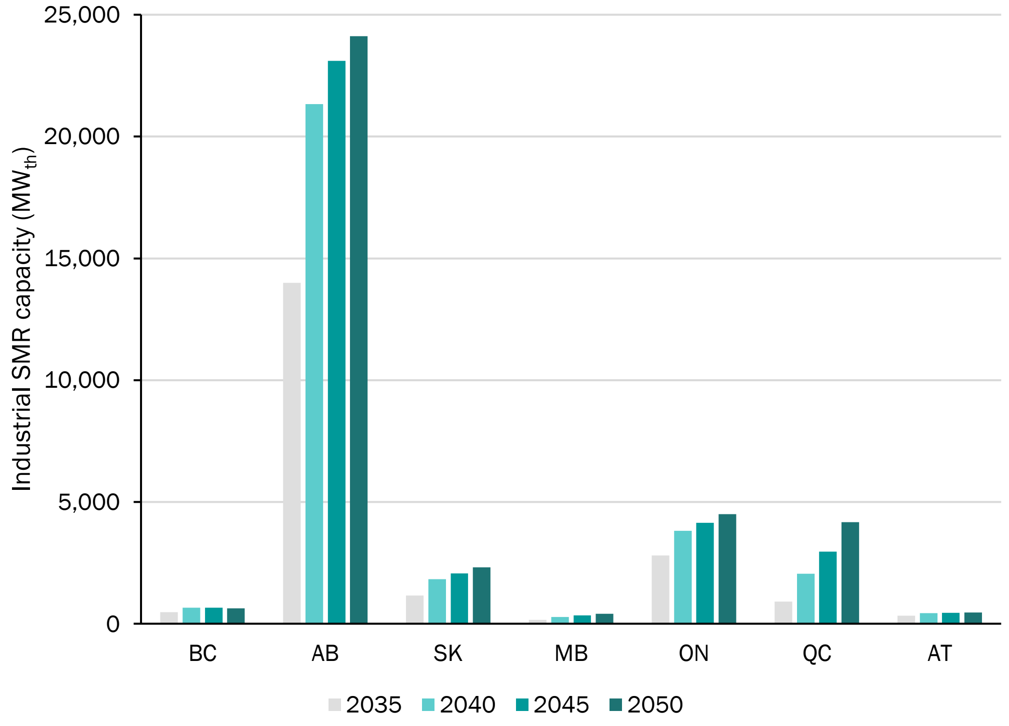
Potential industrial SMR adoption is higher in Alberta than all other provinces combined. For example, under the scenario in which Canada achieves net zero as shown here, SMR adoption in Alberta accounts for 24,126 MW_{th} of total Canada-wide adoption by mid-century.

The potential for SMR adoption in Alberta, however, depends on foreign demand for oil. Lower demand for Canadian oil would result in lower SMR adoption in Alberta oil sands, as discussed on the following slide.

A large potential market for SMRs in industry also exists in Ontario, Québec and Saskatchewan.

SMRs are adopted in most Canadian provinces across all net zero scenarios, starting in the 2030s. Other large potential markets including Ontario, Québec and Saskatchewan. SMR adoption in these three provinces reaches 10,994 MW_{th} by 2050 under a scenario in which Canada achieves net zero.

The specific industries associated with this potential are reviewed on the following slides.



Source & notes: Navius forecast using gTech, net zero scenario, using baseline assumptions for low carbon technology costs & assuming a WTI oil price of ~ USD 2015$ 66/barrel.

What sectors are most attractive for SMR deployment? (1 of 2)

The oil sands represent a large potential market for SMR deployment.

Extracting oil from the oil sands is relatively energy intensive, requiring substantial amounts of heat and steam. Presently, these energy services are provided by combusting fossil fuels.

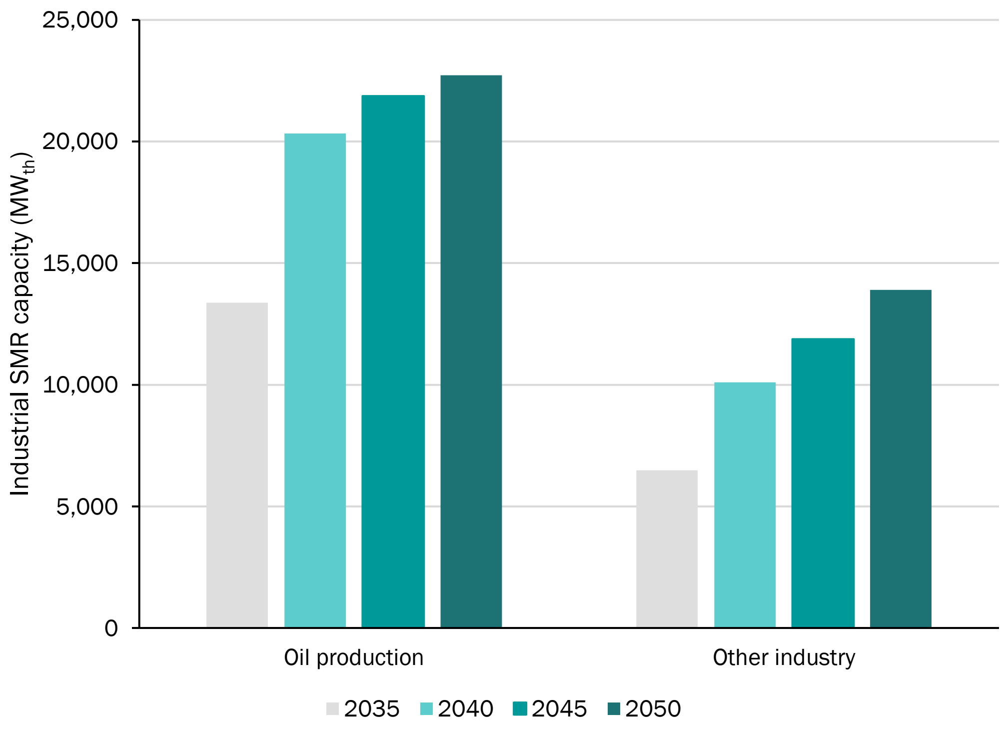
SMRs are a low carbon option for meeting these energy requirements. Provided stronger carbon policy is in place, SMRs represent an economical way of producing less carbon intensive oil from the oil sands that could compete with other technologies like carbon capture and storage.

Under a scenario in which Canada achieves net zero, SMR adoption in the upstream oil extraction sector – predominantly the oil sands – could reach in the range of 22,731 MW_{th} in 2050. This level of adoption would account for a large share of industrial SMR adoption across the country.

The market potential for SMRs in the oil sands ultimately depends on demand for Canada's oil.

The deployment of SMRs in the oil sands is tied to sector activity, which in turn depends on how much demand there is for petroleum products from the oil sands.

This analysis demonstrates that SMRs can facilitate decarbonization of production from the oil sands. However, long-term demand for Canada's oil is uncertain. Under a scenario in which demand drops (e.g. consistent with a strong global decarbonization effort, simulated using an oil price of USD 2015$ 26/barrel in 2050), SMR adoption in oil production is much lower (126 MW_{th} in 2050).



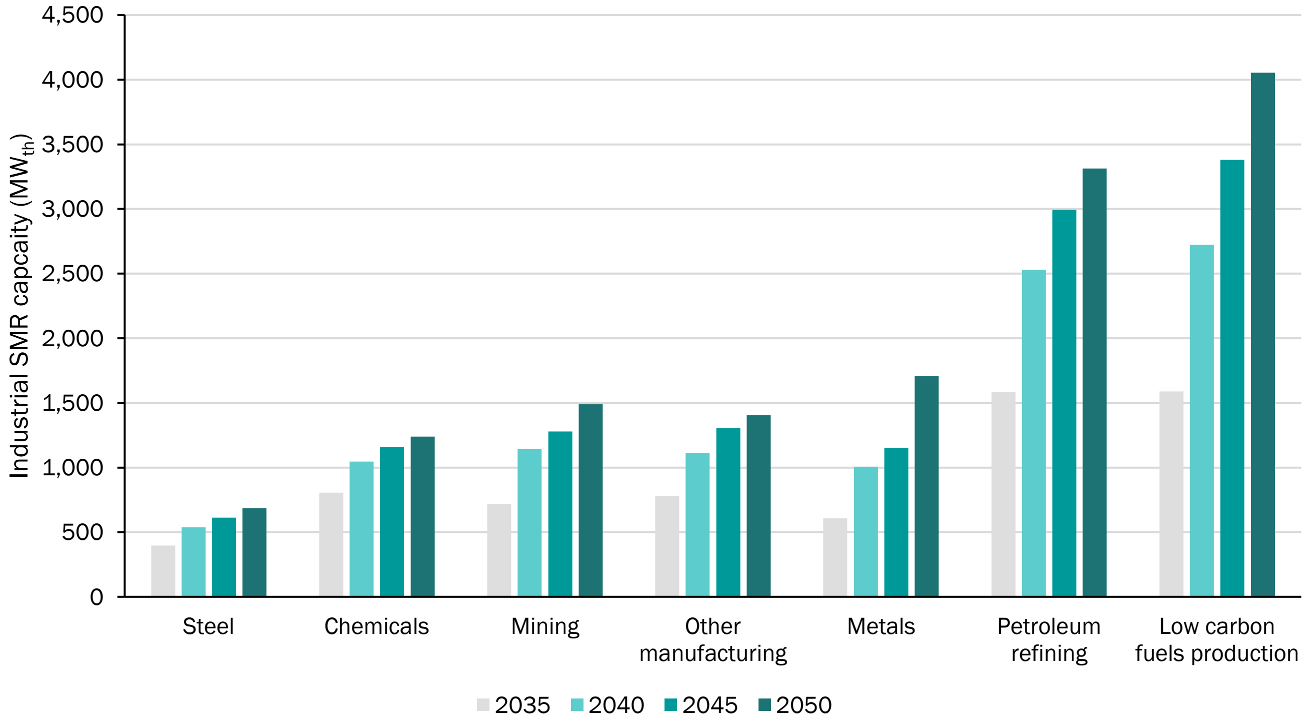
Source & notes: Navius forecast using gTech, net zero scenario, using baseline assumptions for low carbon technology costs & assuming a WTI oil price of ~ USD 2015$ 66/barrel.

What sectors are most attractive for SMR deployment? (2 of 2)

A variety of other industries are attractive for potential SMR deployment. These industries all share one thing in common – a demand for high-grade process heat.

Under a scenario in which Canada achieves net zero, SMRs:

- Contribute to the production of low carbon fuels (4,054 MW_{th} by 2050), helping to decarbonize other sectors of the economy such as transport:
    - SMRs provide heat that is necessary for the thermochemical production of second-generation biofuels, such as renewable diesel. SMRs could also be used in the production of synthetic fuels (i.e., combining CO_2 from the atmosphere with hydrogen).
    - SMRs provide heat required for hydrogen production via steam methane reformation of natural gas. Other hydrogen production pathways using SMRs are also possible: using electricity only (water electrolysis) electricity and heat (steam electrolysis) and a small amount of electricity and heat (thermochemical processes).
- Lower the carbon intensity of petroleum refining (3,312 MW_{th} by 2050).
- Provide heat necessary for heavy industrial processes in steel production (688 MW_{th}), metal smelters and foundries (1,707 MW_{th}) and chemicals manufacturing (1,240 MW_{th}).
- Meet low carbon energy needs in mining operations (1,491 MW_{th} by 2050), many of which are off-grid and would otherwise rely on diesel which is costly to transport.



Source & notes: Navius forecast using gTech, net zero scenario, using baseline assumptions for low carbon technology costs & assuming a WTI oil price of ~ USD 2015$ 66/barrel.

By how much could SMRs reduce greenhouse gas emissions?

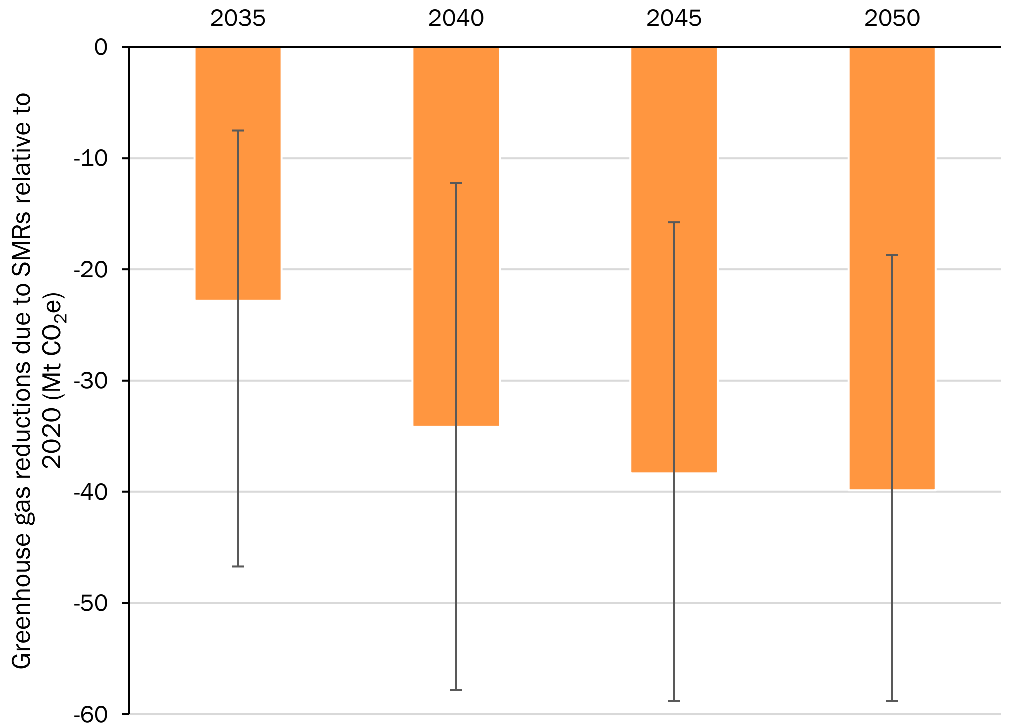
The adoption of SMRs in industry can reduce direct emissions as well as facilitate emission reductions in other sectors.

The adoption of SMRs can reduce industrial greenhouse gas emissions in two ways.

- First, SMRs can directly reduce GHGs in the industrial sectors in which they are adopted. For example, a metal smelter will reduce its emissions if it uses an SMR to meet its process heat requirements rather than fossil fuels.

  This analysis finds that SMRs could reduce industrial GHGs by between 19 and 59 Mt in 2050, measured relative to 2020. This wide range reflects uncertainty in various factors, including SMR costs, oil prices and CCS costs.

- Second, SMRs can help produce low carbon energy carriers, facilitating emissions reductions in other sectors. Through a variety of pathways, SMRs can be employed to produce second generation biofuels, synthetic fuels and hydrogen. These fuels are critical to decarbonizing transport (especially trucking, marine, air and rail) among other applications.



Source & notes: Navius forecast using gTech, net zero scenario, using baseline assumptions for low carbon technology costs & assuming a WTI oil price of ~ USD 2015$ 66/barrel. Error bars capture uncertainty in SMR costs, oil prices and CCS costs as described on Slide 7. Emissions reductions measured relative to 2020.

About us

Navius Research is an independent and non-partisan consultancy based in Vancouver. We operate proprietary energy-economy modeling software designed to quantify the impacts of policy on energy use and greenhouse gas emissions. We have been active in this field since 2008 and have become one of Canada's leading experts in modeling the impacts of energy and climate policy. Our analytical framework is used by our clients across the country to inform energy and greenhouse gas abatement strategy.

We are proud to have worked with:

- Most provincial and territorial governments, as well as the federal government
- Utilities, industry associations and energy companies
- Non-profit and research organizations with interests in energy, climate change and economics