A Big Deal

Leveraging investment in CANDU as Canada negotiates the future of its nuclear sector

A report *from* Canadians for Nuclear Energy

A Big Deal: Leveraging investment in CANDU as Canada negotiates the future of its nuclear sector
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Canadians for Nuclear Energy (C4NE) is a grassroots not-for-profit organization composed of Canadian energy workers, engineers, doctors, tradespeople, scientists, policy experts, and citizens.

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Letter from the President

Canadians for Nuclear Energy is driven by an appreciation for the vast impact of nuclear energy on the people of Canada, our economy, and our energy goals. Since the "original technology choice" to design CANDU reactors, few decisions have been as consequential as the upcoming Bruce C technology selection.

In medicine, we hold that the patient has a right to know the risks, benefits, and alternatives of a recommended procedure. As Canadian ratepayers and taxpayers will be underwriting the Bruce C decision, we must strive to approach it with similar awareness, our eyes open to the possible outcomes.

This report doesn't wade into the technical merits of any one reactor over another. Instead, it highlights essential goals to secure regardless of the technology chosen—and how to secure them. Needed is a strong showing by Canadian nuclear technology, currently limited by the lack of a finished 1,000-megawatt CANDU design. It should be a top priority of the federal government to overcome this hurdle by funding the CANDU Monark.

Sincerely,

Chris Keefer, MD, CCFP-EM
President, Canadians for Nuclear Energy

Executive Summary

Canada's nationally important nuclear sector is at a crossroads. As electricity demand projections grow to record heights, 4,800 megawatts (MW) of new nuclear capacity is being considered at the Bruce Nuclear Generating Station. Breaking from past successful nuclear builds, the technology selection process at "Bruce C" is open to non-Canadian reactors.

Using competition to yield the best possible reactor is a wise choice. Concerningly, however, no Canadian technology is ready to build at the specs required, namely an economically advantageous 1,000+ MW capacity. To make sure the Bruce C technology selection works in Canada's best interests, it is imperative that the federal government support engineering and design work on the large-scale "CANDU Monark," thereby letting Canadian technology compete for the site.

With construction-readiness being a key criterion for the Bruce C decision, an unfinished CANDU Monark design limits the ability of a Canadian technology to drive serious competition around the three major pillars of Canada's continued strength in nuclear, namely:

1. Supply chain localization
2. IP ownership and export sovereignty
3. Social and political licence

Supply chain localization

Since the very first reactor, CANDU technology has given Canadian suppliers a natural high ground, assuring opportunity wherever work is to be done. The same is yet to be true for other types of reactors. Not only do other countries have existing supplier networks, but nuclear exports are sources of much-sought-after economic opportunity. As a result, ensuring maximal involvement by Canadian businesses and workers on imported nuclear technology could be a challenge that Ontario has rarely faced—and one that would take a strong negotiating position to solve.

IP ownership and export sovereignty

Complete ownership of CANDU lets Canadian engineers and scientists improve upon the technology without restriction and keep the fruits of R&D spending. Just as importantly, it gives Canada the ability to export its technology, which has sustained the sector as reactor sales in its relatively small domestic market paused. To prevent the eventual decline of the sector, Canada must secure its involvement in future exports of whatever reactor is chosen for Bruce C. Technology transfer and other guarantees are essential, since if CANDU isn't chosen, it will effectively end future export opportunities for CANDU.

Social and political licence

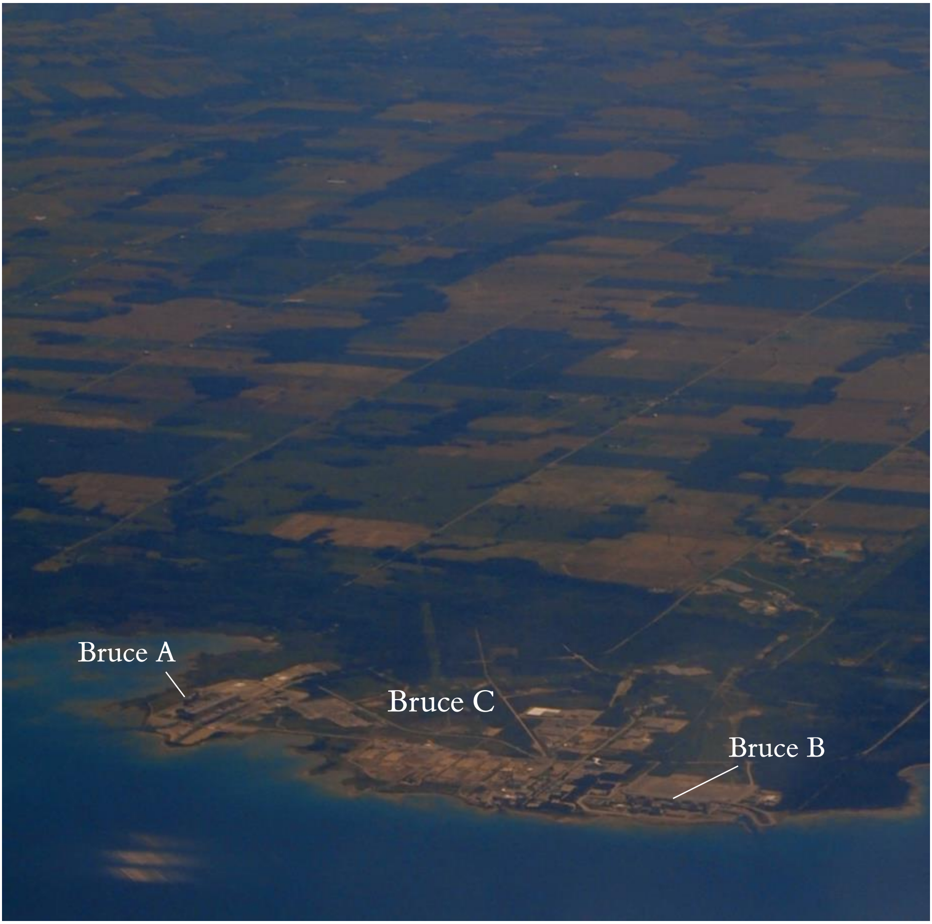
Long-duration, financially weighty projects like nuclear construction are sensitive to interference from any number of stakeholders. CANDU, however, has enjoyed cross-party social and political licence as a flagship achievement of high technology, a driver of world-renowned scientific and industrial research, and an intergenerational job-creator for 76,000 Canadians. The crucial task of garnering similar public support for a foreign technology could prove challenging, making strong guarantees for supply chain localization and technology transfer all the more important.

To keep these pillars amid a competitive technology selection, the CANDU Monark, the new 1,000 MW CANDU reactor announced by AtkinsRéalis, must be able offer a compelling bid for Bruce C. This would unlock the option of building Canadian technology while providing two other key benefits: 1) raising the bar for competition among all reactors along the lines of supply chain localization and IP ownership; and 2) strengthening Canada's negotiating position to secure these essential guarantees with foreign vendors — creating the option to go with high-quality Canadian tech if other offers fall short.

To be competitive, the CANDU Monark must first have a finished design. This will take the help of the federal government to develop a funding pathway for engineering and design work. We expect this work to cost a total of between $300 million and $600 million, with AtkinsRéalis asking the federal government to put up half of that cost. There is firm precedent for government support of reactor technologies. The United States, for example, funded the Westinghouse AP1000 design in the mid-2000s to the tune of $450 million in today's equivalent Canadian dollars. Moreover, the CANDU IP is a government-owned asset that is merely privately licensed. The investment, modest in comparison to subsidies for clean energy and innovation, would preserve and enable new returns on significant past R&D investment in CANDU.

Beyond getting the CANDU Monark ready for a competitive bid, the federal and provincial governments should take the role of making sure that supply chain localization, technology transfer, export involvement, and other strategic factors are properly valued as competitive criteria. One way to achieve this could be to vary the level of risk-sharing offered on the project based on these criteria, possibly benchmarked to the CANDU Monark.

With the 2024 Federal Budget coming up and the Bruce C decision approaching, the time to act now.



Aerial view of Bruce Nuclear Generating Station, Bruce County, Ontario. The site currently provides around 30% of Ontario's electricity. Bruce C's approximate future location is labeled

Photo by Haljackey, CC BY-SA 3.0, labels added

Canadian Nuclear: Past and Future

When Canada first chose to invent and build its own nuclear technology instead of buying it from the United States, it unlocked a future that has now become our present. Charting a distinct path, our nuclear sector stayed active as similar work elsewhere declined, the story of success fueling political support and social licence. Today, as nuclear in the West suffers from limited work opportunities, cost overruns, and steep rates of worker attrition,[1(pp30–31)] Canada is attracting skilled talent to clean energy. A range of new nuclear projects in Ontario alone include: the refurbishment of its CANDU fleet (proceeding on-time and on-budget); the West's first grid-scale Small Modular Reactor; and now, ambition to build 4 large units at a site in Bruce County, along Lake Huron.

At the "Bruce C" site, we face another choice that will shape future generations: *the selection of which reactor to build.*

No Small Decision

Nuclear plants are not just a way to make electricity. They are undertakings that shape economies for generations. Aware of this fact, CANDU engineers enshrined values of fuel security, economic development, and Canadian autonomy in the technology. Over the years, full ownership of the intellectual property (IP) and control over exports guaranteed work opportunities for Canadian suppliers, bringing unlikely success and respect to a small nation in a high-tech sector.

As we approach Bruce C, we must be aware: Canadian nuclear technology and foreign nuclear technologies were not built with the same supply chains, interests, or societies in mind. Similarities in their end services mask stark differences in how they run and who runs them. If we do not advocate—and negotiate—to keep supply chain localization, IP ownership, and export autonomy for whatever reactor is built, we might lose them, with grave consequences for a sector that has depended on such factors for over half a century.

The impact of the Bruce C decision will extend beyond the one site, influencing every future nuclear build in Canada. Nuclear projects, for their size and complexity, are financially high-risk. A key way to reduce this risk is to replicate a fully completed, standardized design with a supply chain, workforce, and project management team that has done it before.[2–4] This is the path that Canada took, which enabled the commissioning of 22 CANDU reactors in just a 22-year time period. Given the importance of building a standardized fleet, it is likely that if CANDU is not chosen for Bruce C, then Darlington Nuclear Generating Station will remain the last CANDU plant ever built in Canada.

The technology selection at Bruce C is not, then, merely a question of what technology one private nuclear operator will pick for one site. It is a national question that will largely decide whether Canada's own CANDU nuclear technology, the product of 80 years of continuous investment, has a future.

Darlington Nuclear Generating Station, Ontario, completed in 1993

The public has a strong stake in the outcome of the Bruce C decision. The project itself will cost tens of billions of dollars, ultimately funded by ratepayers and taxpayers. The impact becomes even more pronounced when multiplied over the hundreds of billions of dollars that Canada must spend to triple its nuclear power by 2050, as pledged at COP28 in 2023.[5] To decarbonize Canada's economy by 2050, in line with federal commitments, the Royal Bank of Canada estimates $2 trillion of investment will be needed.[6] Over this vast sum, small differences in Canadian benefit between technologies widen into huge disparities.

ASKING THE RIGHT QUESTIONS

The question is not, however, how to block foreign vendors from building at Bruce C — an unproductive and harmful policy that merely limits Canada's options. The question is how to approach a competitive technology selection in a way that ensures a strategic outcome for Canada and avoids a "worst case scenario" outcome of foreign reactors being built under restrictive licensing terms and scanty involvement of the Canadian supply chain.

The reactor options

The leading options for Bruce C come from around the globe:

- the American AP1000,
- the American/Japanese ABWR,
- the Korean APR-1400,
- the French EPR, and
- the Canadian CANDU Monark

Competition must yield the best reactor for Canada. Yet there is a problem: the CANDU reactor is not ready to put its best foot forward, owing to an incomplete gigawatt-scale design. A CANDU unit of that size has never needed to be built. But for a country whose nuclear sector was until recently considered a "CANDU sector," this lack of design readiness, which amounts to poor timing, is a problem in need of a solution.

Big nuclear is in

For economic reasons, Bruce Power wants to maximize the output of the new site, which it is evaluating for up to 4,800 MW of electric capacity to add to the existing 6,500+ MW at the site.[7] This underlies a strong preference for reactors of at least 1,000 megawatts (MW). Ontario needs the power, which the IESO expects to grow by 60% over the next 25 years.[8] And as the costs of nuclear plant construction and operation do not scale linearly with its output, the larger the plant, the more profitable it typically is.[9(p404)]

However, the largest operating CANDU unit is about 880 MWe, in a discontinued four-pack configuration with three other such units at Darlington. The most recently built CANDU reactor, the CANDU 6, is approximately 700 MW. The difference in annual revenue between a 1,000 MW reactor and a 700 MW (at Bruce Power's current base contract rate of $84.72/MWh) is around $200 million — enough to matter.[10]

Enter the CANDU Monark

Eyeing Bruce C, AtkinsRéalis, the licence holder to nationally owned CANDU technology, has kicked off development work on the 1,000 MW CANDU Monark, as it chose to call it.[11] To cover expenses, the company has aimed to secure a cost-sharing agreement with the federal government. This is appropriate given that CANDU remains government-owned IP; other government spending on clean energy and industrial policy far exceeds this amount; and building a CANDU Monark at Bruce C is the best current opportunity to make further returns on past investment in CANDU.

Recognizing its stake in the development of the CANDU Monark, the Crown Corporation AECL has already signed a memorandum of understanding with AtkinsRéalis to collaborate on it.[12] But more investment is needed to ensure the prompt design of the CANDU Monark. We estimate this development work to cost between 300 and 600 million dollars.

Industrial policy for the competitive age

The completion of the CANDU Monark design—and its resulting ability to place a genuinely competitive bid for Bruce C—is essential for two reasons. One, it opens the possibility of continuing the strong CANDU legacy with guaranteed work for Canadian suppliers, the advantages of Canadian IP ownership, and export sovereignty. Two, it will have the effect of raising overall competition for the site with a “home team,” strengthening Canada’s negotiating position for IP licensing, export involvement, and supply chain localization even in the case that a foreign technology wins the bid.

As a corollary to this investment, the federal and provincial governments should use a policy “nudge” to make sure that factors like the use of Canadian suppliers, involvement in export opportunities, and IP licensing are given competitive weight. For instance, the government could pin such factors to the level of risk sharing offered on the project. Targets for these factors could be benchmarked to the CANDU Monark.

We should not shy away from competition. To have any chance in the reactor export market, Canada must have a technology that can succeed on merit. This is more reason to finish the CANDU Monark design, which will sharpen competition by creating more, better options for Bruce C.

The time is now

If the federal government fails to invest in the CANDU Monark design, the price to Canadians will far exceed that of the investment. But time is of the essence. The technology selection at Bruce C, to meet Ontario's growing energy demand and capitalize on broadly pro-nuclear policies, is moving quickly. If the federal government passes up financial support for the CANDU Monark and later regrets it, it will be too late.

The original technology choice

To understand the value of CANDU, it serves to understand two things: one, that Canada has had a highly successful nuclear sector, particularly as a small country; and two, that an open technology selection is a relatively new phenomenon.

Pickering Nuclear Generating Station in 1965, at the outset of construction for the first full-scale CANDU reactor

Photo from the Hydro-Electric Power Commission of Ontario, Public domain

The original technology choice was to design our own reactor. CANDU technology was thus born with special attention given to qualities that benefited Canada in ways that other reactors could not: total fuel security without uranium enrichment, no heavy forging so that local manufacturing could prevail, close collaboration with national labs doing heavy water research, and more.[13] As a result, the work of choosing the best technology for Canada was already done when Ontario Hydro and AECL built Pickering, Bruce, and Darlington — not through a competitive technology selection but through Canadian science, engineering, and industrial policy.

An open technology selection has been used before in Ontario but has yet to result in an operating reactor. From 2008 to 2013, a proposed new build at Darlington used a competitive procurement process. Initially considered were the AECL ACR-1000, Westinghouse AP1000, and Areva EPR. The search for a new reactor was paused after receiving non-compliant or too-expensive bids. It resumed to briefly consider further bids for the Enhanced CANDU 6 and AP1000 before the project was ultimately cancelled in 2013. More recently, in 2021 a competitive tech selection process was used for the new SMR project at Darlington. The chosen SMR, the BWRX-300, if completed, will be the first nuclear reactor in Canada chosen via an open technology selection.

This CANDU-focused strategy undeniably worked to maximize Canadian benefit. With a worldwide fleet of reactors and 19 operating units in Canada, CANDU technology globally generates around 135 terawatt-hours each year. This is enough to displace emissions from coal-fired generation equal to 20% of Canada's all-sector emissions.[14,15] Supplying 76,000 full time equivalent jobs in Canada, including tens of thousands in the skilled trades and STEM fields, the sector contributes $17 billion the country's GDP.[16] Some communities, particularly those around the Bruce Nuclear Generating Station, owe much of their development to nuclear plant operations, which engage hundreds of Canadian businesses in high-skilled work in manufacturing, construction, and engineering. CANDU electricity and power plant sales fund basic scientific research at our national labs, which have produced globally recognized innovations in medicine, materials science, precision manufacturing, and more, with vast carry-on benefits to the Canadian economy. A 2014 study by consultancy KPMG identified nearly $1 billion per year in economic activity from private commercial spinoff companies from AECL, with a third of this revenue coming from exports, bringing new money into Canada.[17] The sector has remained a rare hub of high-tech, high-value science and industry in Canada whose end service—baseload, carbon-free electricity—is the cornerstone of Canada's strategy for addressing climate change and energy security.[18,19]

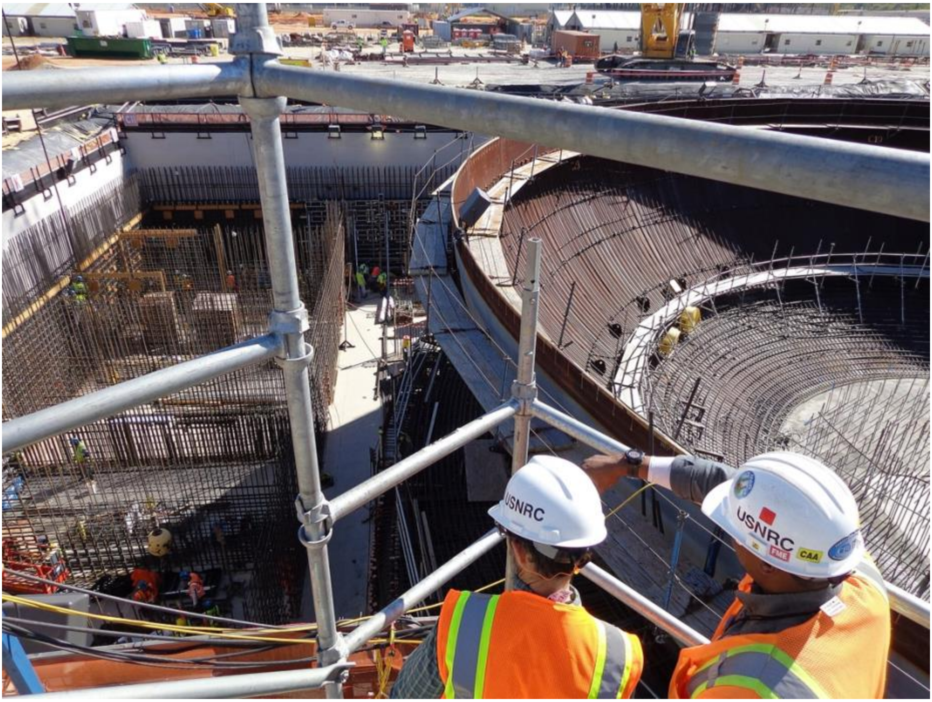
An unlikely success story

The "opportunity gap" between Canada and elsewhere in the West cannot be explained without CANDU. As much as strong Canadian nuclear institutions drove the development of a world-class technology, that technology also drove our nuclear institutions to ever higher levels of expertise and capability.

By population, Canada is the smallest of the nuclear export countries, yet our technology is synonymous with one of just three major classes of reactor to reach a broad international market, the other two being light water reactors (LWRs) with origins in the United States. Existing customers are doubling down on CANDU, with Romania moving forward on plans to build two new CANDU 6 units and South Korea announcing the refurbishment of its CANDU units at Wolsong.[20,21]

Thanks to an unbroken chain of work on CANDU in Canada and abroad, Canada's nuclear sector is still bustling. With just one-fifth the total market for electricity generation and one-ninth the population of the United States, we nevertheless have more new nuclear projects active or planned. And in contrast to delays, cancellations, and cost-overruns in the U.S., Bruce Power and OPG are delivering CANDU refurbishment megaprojects on-time and on-budget.[22,23]

Today, facing a rapid growth in projected electricity demand,[8] Ontario is again seeking to build new nuclear capacity. But where once the choice would have been CANDU by default, the door has been opened to others.



AP1000 reactor construction at Vogtle Electric Generating Plant, USA

ABWR reactor at Kashiwazaki-Kariwa Nuclear Power Station, Japan

APR-1400 reactors at Barakah Nuclear Power Plant, United Arab Emirates

EPR-1750 reactors at Taishan Nuclear Power Plant, China

Photo courtesy of EDF Energy, Public domain

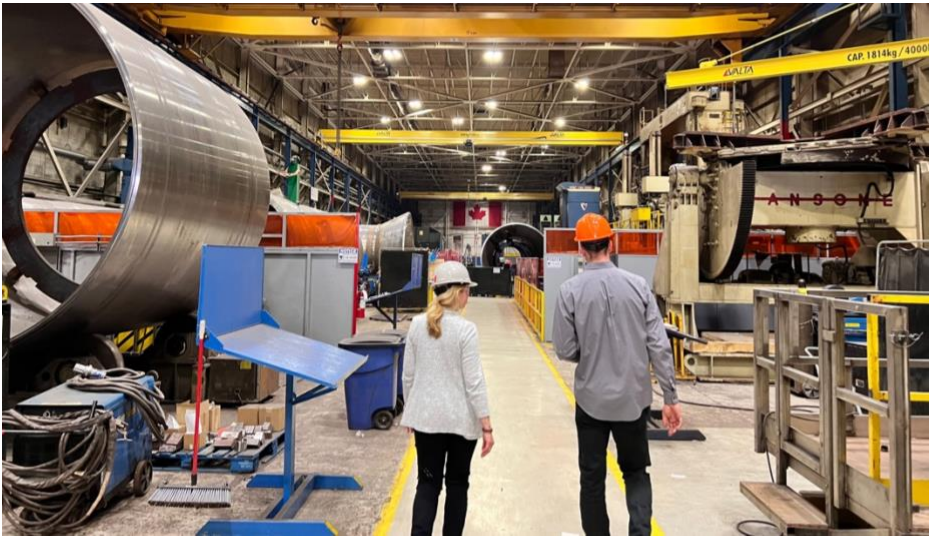
Three Pillars of a Strong Sector

A key question is: can Canada switch to a foreign technology and keep the strength and autonomy of its nuclear sector? To answer this question, we identify three major areas that have underpinned Canada's unusual strength in its nuclear sector:

1. Supply chain localization
2. IP ownership and export sovereignty
3. National identity and social licence

1. Supply chain localization

Because CANDU technology differed in basic ways from other reactors, it created a natural high ground for Canadian suppliers. We stayed competitive and all-involved on CANDU services, keeping industry at home as other sectors, like automotive, aerospace, and telecoms, bled work offshore. This translated into large economic multipliers for CANDU operations — according to the Conference Board of Canada, $1.40 of added GDP activity for each $1 spent, owing to "the extensive supply chain and economic footprint" of CANDU operations and "low import content" on high-value work.[24(p5)] Even among nuclear sectors, Canada has achieved an outstanding retention of high-caliber suppliers and facilities. BWXT Canada's facility in Cambridge, ON is just one such example, manufacturing steam generators, CANDU feeder tubes, dry storage containers, and other critical CANDU components. The company, along with other supply chain members like Kinectrics, has endorsed a campaign by AtkinsRéalis to promote CANDU technology.[25,26]



BWXT Canada's manufacturing facility in Cambridge, Ontario

The CANDU Monark would almost certainly preserve the dominance of Canadian suppliers. The design of the reactor core is based on that of the Darlington units. Because Canadian suppliers are actively rebuilding those units, they are already tooled up for the exact work that would be required for a Monark new build. Decades of hands-on familiarity with CANDU grants these suppliers, as well as plant workers, an added competitive edge during construction, maintenance, and operations—not one that must be fought for with domestic policy, but one that flows naturally to the sector because of its greater experience with the technology.

CANDU EXPERTISE: A DOUBLE-EDGED SWORD

Decades of laser focus on CANDU means it will take significant investment and focus to retool suppliers and build similar expertise on LWRs. Absent firm negotiations for local content, enabling suppliers to gear up for a new technology, this could translate into fewer opportunities on a per-reactor basis.

Some aspects of LWRs will always require Canada to seek outside help, for example, with fuel. Whereas CANDU uses natural uranium fuel made in-country, LWRs use enriched fuel, which Canada does not produce. This means that fueling LWRs will entail mining and processing uranium in Canada and then sending it abroad for enrichment and fuel fabrication before re-purchasing it at a higher price. Avoiding this arrangement is a deliberate feature of CANDU that makes for lower fuel costs and greater security of supply. The importance of fuel security has become obvious in the context of Russia's invasion of Ukraine and its weaponization of energy exports.[27] As nuclear operators around the world seek to reduce their dependence on Russian enrichment (which in 2020 accounted for nearly half of the global supply),[28] alternate sources for uranium enrichment have become strained. This has prompted billions of dollars in crash funding for uranium enrichment and conversion capacity by the "Sapporo 5," including United States, Japan, France, the United Kingdom, and even Canada (though Canada will not enrich uranium itself).[29] Because Canada mines its own uranium, CANDU fuel is unaffected by these world events.

Early signs of missing out

The BWRX-300 Darlington SMR project has already shown some displacement of traditionally Canadian work. Nuclear-specific engineering work, more specialized than the remainder of the work on the more conventional thermal generation equipment, is being handled not by Canadian nuclear companies but by GE Hitachi and American subcontractor Sargent & Lundy. Refueling outages, unnecessary for CANDU reactors with on-power refueling, will likewise be undertaken by roaming work crews from the United States.

Troubleshooting and engineering will also look different for LWRs than for CANDU. During the operation of systems as complex as a nuclear reactor, there is constant problem-solving to do. On CANDU reactors, this is often done in-house or through organizations like the CANDU Owners Group, which efficiently draw on the expertise and capabilities of a tight-knit network of CANDU operators around the world with decades of amassed experience that Canada is allowed to both use and share. On the other hand, troubleshooting for LWRs will take bureaucratic engagements and third-party permission slips, albeit to access a large global knowledge pool.

Manufacturing experience for LWRs likewise gives incumbent foreign suppliers an edge, particularly on highly specialized parts like control panels and skids. Buying components from a supplier that has made these parts before typically streamlines their procurement compared to transferring that work to a new supplier. This puts pressure on vendors and EPCs to bring their supplier networks from build to build if possible. The result is that much of the work that for a CANDU reactor would naturally land within Canada, generating GDP and tax dollars, would, for foreign reactors, tend to land elsewhere.

Compared to an economic multiplier of 1.4 for CANDU operations at Darlington, an analysis by the Conference Board of Canada pinned the economic multiplier of the BWRX-300 in Canada at 0.82 over the life of the project.[30] This is still a net positive for the province, but it is no CANDU.

Competent suppliers: a source of hope

Despite added challenges, the Canadian supply chain is far from hopeless on LWRs. It may not have manufactured various LWR components, but it does possess excellent fabrication abilities, bright minds, and experience with demanding nuclear quality standards. Canada is also geographically well-suited to supply major nuclear components to the growing U.S. market via the Great Lakes. In a win for supply chain localization, a major component of the first BWRX-300, the reactor pressure vessel, is set to be manufactured by BWXT Canada.[31] This is an unmistakable sign of confidence by a foreign vendor in Canada's ability to expand its nuclear repertoire. Supplier networks in other Western countries are, moreover, underdeveloped due to a lack of recent (or successful) experience, making a gap for Canadian suppliers to fill. Quality concerns on components for recent American, French, and Korean builds only widen this gap.[32–35] If it is able to negotiate for supply chain localization and favourable IP licensing terms to Canadian entities, Canada has a real opportunity to gain a foothold in the supply chain for whatever reactor it builds.

This does not mean that supply contracts will go easily to Canadian companies. Commercial opportunities on nuclear exports are closely guarded. In requesting export financing, vendors often stress the benefits of nuclear exports to domestic industry — benefits they are expected to deliver. Local content guarantees are common in international reactor marketing, but only to the extent that they increase the attractiveness of an offer, confer other tradeoff benefits to the vendor, or are negotiated. For Canada's own CANDU exports, licensing terms and local content have played a major role in negotiations and, ultimately, winning bids.[36(p13)]

To localize the supply chain for a potential LWR build, Canada must make doing so a priority, using available means to increase its negotiating position. This, above all, means fielding a construction-ready CANDU Monark reactor that generates true competition to engage Canadian suppliers.

When CANDU was the only reactor in town, Canada never had to fight to ensure supply chain localization. That could change in the technology selection for Bruce C. Rather than shy away, Canada should have confidence that it can succeed.

2. IP ownership and export sovereignty

Total ownership of CANDU IP has sustained the Canadian nuclear sector in two key ways: 1) by enabling unrestricted innovation and iteration on the CANDU reactor, and 2) by enabling total sovereignty over when, where, and how we export the technology.

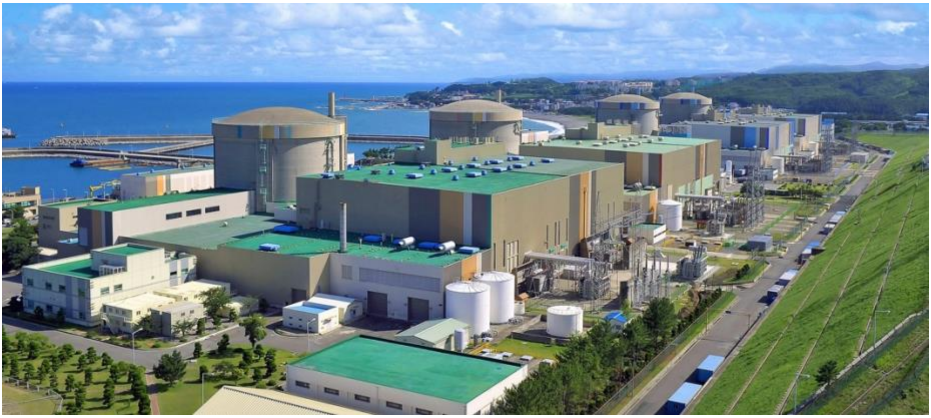
Constant improvement of the CANDU did not happen automatically. It was the result of decades of R&D and deliberate incorporation of feedback from plant operators. Canada's operating fleet, as well as versions of the CANDU like the export-oriented CANDU 6, the Advanced CANDU Reactor, the Enhanced CANDU 6, and the forthcoming CANDU Monark all benefitted, or will benefit, from the freedom to maintain a cutting-edge design without bumping up against licensing restrictions.

For exports, ownership of the IP allowed Canada to leverage licensing agreements, boosting the appeal of CANDU in the face of tough competition from larger vendor countries. Even more importantly, IP ownership gave Canada the sovereignty to export CANDU in the first place.

EXPORTS: A LIFELINE FOR THE SECTOR

Exports have been crucial for sustaining Canada's nuclear sector as reactor sales ebbed and flowed in its relatively small domestic market. As historian Duane Bratt writes of CANDU exports to South Korea:

> [Wolsong 2 to 4] provided a litany of commercial benefits to Canada, but these benefits, as important as they may have been, were outweighed by the fact that… if Canada had lost the sale, it could very well have been the end not only of Canada's reactor export program, but also of all government support for the domestic nuclear industry.[36(p13)]



CANDU-6 reactors at Wolsong Nuclear Power Plant, South Korea

Exports were thus essential in forming the unbroken chain of productive work in the Canadian nuclear sector during the time between new builds and the refurbishment megaprojects in the CANDU sector today. A lack of work, particularly in demanding fields like nuclear megaprojects, makes sectors rusty — a major cause of the calamitous delays and cost overruns faced on the AP1000 units at Vogtle (USA) and EPR units at Olkiluoto (Finland), Flamanville (France), and Hinkley Point C (England).[1(p30)] Had Canada been unable to support its domestic nuclear sector with work abroad, it is quite possible that its nuclear sector would have declined considerably and that it would not be leading the way on new large nuclear today.

It is, therefore, imperative that Canada secure bulletproof technology transfer agreements and strict guarantees for work on all future exports of the reactor it ultimately chooses. After all, to build a foreign reactor at Bruce C is to trade in nearly all prospects for new CANDU in Canada and abroad.

Export controls: beholden to others

The risk of export interference after weak IP transfer is not hypothetical. In a recent 2023 lawsuit, Westinghouse tried to block Korean nuclear vendor KEPCO from submitting a bid to build APR-1400 reactors in Poland.[37] The basis for the suit, Westinghouse argued, is that the APR-1400 is based on a common ancestor with the AP1000, the System 80+ to which Westinghouse holds the rights. By submitting a detailed bid to

Poland, the American company argued, KEPCO would be engaging in the unauthorized transfer of American nuclear IP to a third party in violation of U.S. export control laws in 10 CFR Part 810. Dismissed by a U.S. court that said only the U.S. Attorney General may invoke 10 CFR Part 810, the move nevertheless showed vendors' willingness to weaponize IP ownership and export control laws.

Despite the dismissal of the suit by the U.S. court, which Westinghouse is appealing, tech licensees are not in the clear. Nuclear reactors are typically bought and sold not by companies but by countries. Given the importance of nuclear exports to national foreign policy, it is easy to imagine a scenario where a U.S. Attorney General might invoke export control laws. After all, the international nuclear market is rapidly expanding, and many countries, including the United States, are looking to export their technologies to secure high-stakes, strategic, long-duration commercial partnerships with other countries.

In 2018, the Trump administration did just that when it tightened export controls against China specifically regarding AP1000 technology. Under a 2007 technology transfer agreement, China obtained the rights to build and iterate upon AP1000 reactors, which became the basis for its CAP-1000 and CAP-1400 reactors. While the new policy allowed for continued domestic use of the technology in China, it mandated "a presumption of denial" of approval for further exports when in "direct economic competition with the United States."[38]

Export controls are not just a threat to future exports, either. They impact daily operations. On the BWRX-300 at Darlington, for instance, Iranian-Canadian workers, several of whom hold distinguished project director roles with successful hands-on experience with CANDU refurbs, will face barriers to working on the project, not because of Canadian laws but US policy governing IP of U.S.-origin. CANDU is not entirely free from export controls on certain computer codes developed in the U.S., but it is burdened by export-related restrictions to a much lesser degree than foreign reactor technologies.

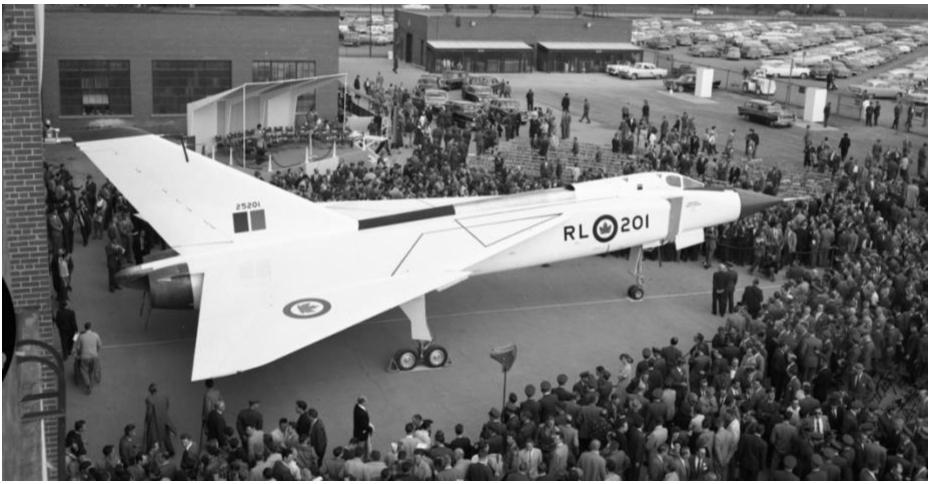
Technology Transfer is a Minimum

While a foreign reactor design would require Canadian workers to retrain and suppliers to retool, sufficient IP licensing terms could ensure that Canadian workers gain firm opportunities in engineering, design, manufacturing, and construction, not just on domestic but international builds. Such an agreement should include the ability to initiate exports and retain IP for future iterations on the technology. Canada itself has offered generous licensing terms during exports and so is familiar with possible terms for such agreements.

To keep a strong nuclear sector, Canada must either build its own technology or secure IP rights and deep supply chain involvement on whatever it chooses. Either case comes within reach only when the Canadian reactor option is no longer *de facto* uncompetitive because of an incomplete design.

3. Identity and social licence

A harder-to-quantify benefit of Canadian ownership of its nuclear technology is the social and political licence it has enjoyed for decades. For many, CANDU is a source of pride and identity, as their service in the sector underpins Canada's prominence in a high-tech sector. CANDU is one of the last great Canadian innovations to resist transfer to foreign interests, bucking an all-too-common trend from the discovery of insulin to creation of the Bombardier C-Series.[39]



Unveiling of the Avro Canada CF-105 Arrow, October 1957. To many, the cancellation of the Avro Arrow in 1959 symbolizes a missed opportunity for Canadian innovation and leadership in a high-tech sector

Photo: Robert Lansdale. Federal News Photos. Library and Archives Canada, CC BY 2.0

"Technology agnosticism" disavows sentimentality in picking a reactor design. But public opinion, political support, and even storytelling are crucial aspects of success on long-duration megaprojects.[40] This is particularly true in Canada, where politics has historically had a leading role in energy planning and projects. A project as large as Bruce C, lasting several years and costing tens of billions of dollars, will require an unassailable political backing and a compelling story with which to manage and engage a broad range of stakeholders.

Canadian ownership: always a good story

During the 2009 new nuclear bidding process at Darlington, a powerful constituency—labour—made clear just how large a political advantage the CANDU reactor had. Before the Natural Resources Committee on October 28, 2009, Michael Ivanco, then vice-president of the Society of Professional Engineers and Associates (SPEA), explained the union's support for the continued stewardship of CANDU. He argued that hard-won nuclear expertise on a national technology was worth preserving:

> "There are few areas in which Canada can compete on an equal footing with the United States, Japan, France, and Russia, but the nuclear industry is one of these." [41]

At the same meeting, Howard Shearer, as president and CEO of Hitachi Canada Limited, echoed the support for government backing of Canadian technology via strong domestic policy:

> A vision is needed… for nuclear's future in Canada, a vision that embraces the creation of long-term, high-paying, skilled technology jobs related to IP created by Canadians…. To realize such a vision, nuclear technology must be proven at home to have any chance of acceptance abroad…
>
> …In casting our sights on the potential that international markets offer, we must never lose sight of the fact that international nuclear projects are very competitive…. Every major player received and had the backing of their home government, local stakeholders, community, and supply chain.
>
> Domestic policy is critical to global success, whether it be the Olympics or large high technology projects such as nuclear plants. Why should Canada expect differently? This represents the challenge facing Canada. I maintain that such support is crucial if Canada has any chance of getting its fair share of the very real nuclear renaissance…
>
> …Customers, domestic and international, need to believe that the Canadian supply chain, supported by strong vision and domestic public policy, will be there in the long term, or they will not engage with Canadian technology.

The story of Canadian ownership as a tool for public and political support is not lost on Bruce Power, Westinghouse, or other vendors (though it may be lost on Framatome, whose

Canadian Nuclear Association 2024 conference booth read in bold letters: "The French industry with the European nuclear supply chain ready to support the Canadian nuclear ambitions"). In a foray in 2008 to Alberta to explore building two large reactors, Bruce Power got exclusive rights from AECL to build CANDU technology in Alberta. Then company president Duncan Hawthorne said that Bruce Power would "compare and contrast" reactor options on the market but clarified, "we are an all-Canadian company and the impact on Canadian jobs will be a big part of our decision-making process."[42]

Is Westinghouse Canadian?

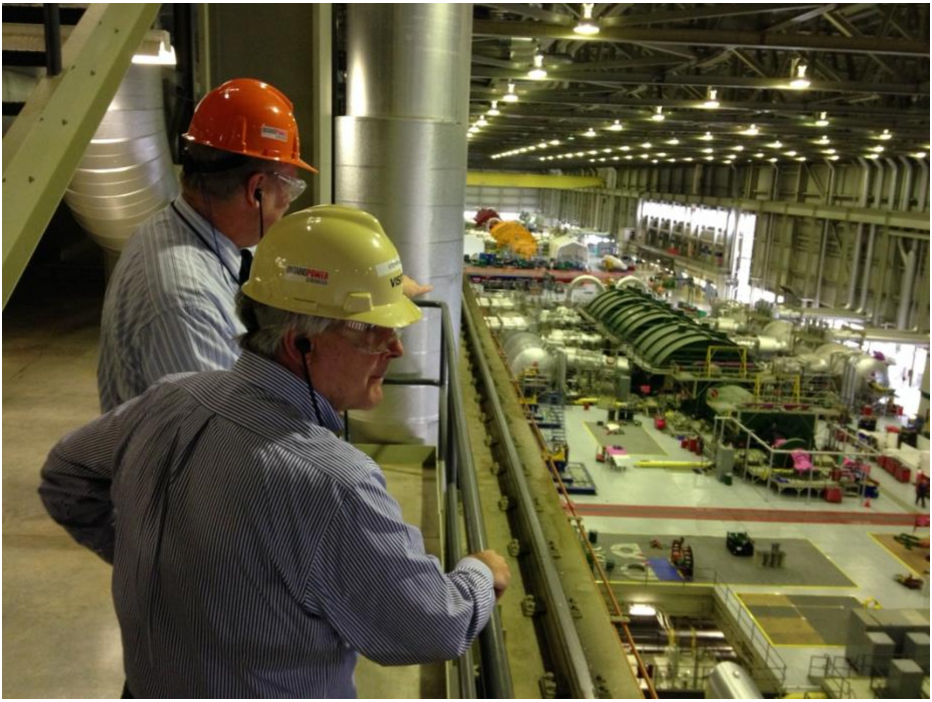
Westinghouse, too, has begun to market itself as a Canadian company, emphasizing its ownership by CAMECO and Brookfield Renewable Partners, two Canada-based companies, after the 2023 acquisition. However, Westinghouse still has deep American roots. The AP1000 technology remains of U.S. origin. Through Westinghouse Electric Company's initial sale to British Nuclear Fuels in 1999, to its sale to Japanese company Toshiba in 2006, to a subsidiary of the Canadian company Brookfield Corporation in 2018, and to CAMECO and another Brookfield subsidiary in 2023, its headquarters have remained in Pennsylvania, U.S. Likewise, exports of the AP1000 to China are clearly considered American rather than British, Japanese, or Canadian. In 2005, the U.S. Export-Import Bank approved a preliminary ask from Westinghouse for nearly $5 billion to export AP1000 reactors to China, though this funding source was not ultimately used.[43] Under Brookfield ownership, it tried to invoke U.S. export controls against KEPCO in 2023. That same year, at the ceremony for a "historic" Westinghouse engineering services agreement with Poland to begin work on AP1000s, no Canadian leadership was present. At the event, the U.S. Ambassador to Poland said, "This is one of the most significant steps forward to date in U.S.-Polish civil nuclear cooperation."[44] An Assistant Secretary at the U.S. Department of Energy said the Department "has long looked forward to this day… This collaboration will stretch out for multiple decades and prove to be a cornerstone of our enduring strategic and commercial partnership."

This is not to say that Westinghouse's current Canadian ownership is irrelevant. In fact, it could boost Canada's efforts to localize a potential AP1000 supply chain, that is, if Westinghouse remains under Canadian ownership, breaking from its trend of a new international acquisition at least once per decade. But there remains a long way to go before Westinghouse can claim that the AP1000 is a Canadian reactor on par with CANDU technology.

Reviving social licence with foreign tech

As powerful as the social licence of CANDU has been, it would be a mistake to think that no such support could be found for a foreign reactor technology. If Canada can ensure the localization of the supply chain, there is no reason that being a key supplier hub for a globally competitive reactor technology should not spark pride in the Canadian sector, even if the technology were not originally conceived within our borders. In France, the recovery of national pride in the nuclear sector was aided by IP transfer let them take the lead on future design changes to the American PWR technology.[45(p293)] This indeed led to the very EPR design that Areva bid to Darlington in 2009 and is bidding to Bruce C today.

What would be most damaging is if CANDU is never seriously in the running because of an incomplete design. It would be better for our national technology to be considered and passed up for well-considered and clearly articulated reasons (along with significant IP and supply chain guarantees) than to be excluded from the processes outright, Canadian technology having no chance even to prove its mettle.



Former NRC Chairman Stephen Burns (right) stands with Brian Duncan, retired Senior Vice President at the Darlington nuclear power plant in Ontario, Canada, examining the turbine building during a tour of the plant

Photo from U.S. Nuclear Regulatory Commission

A Balancing Act

The above pillars are necessary for a strong and sustainable Canadian nuclear sector, but they are not sufficient. Simply mandating CANDU Monark reactors to be built at Bruce C may cause Canada to miss the most important pillar of all: having the best reactor, which open competition is most apt to produce. Conversely, being content with only foreign vendors and leaving out all considerations of supply chain localization, technology transfer, integration with Canadian research labs, etc. would all but ensure that other pillars aren't met.

Both too much and too little domestic policy would create a missed opportunity. The right balance, however, could be transformative. This balance takes funding the CANDU Monark, a modest investment with huge upside that doesn't harm competition but improves it.

The age of competition

The strength of Canada's nuclear sector was built by invention and industrial policy. But although IP ownership and supply chain involvement are as relevant as ever, times have changed. Ontario cannot afford to bypass competition for the Bruce C site, nor does it need to.

Although CANDU technology is well-established and past investments and learnings will be retained in forthcoming reactors, the design for the latest 1,000 MW iteration has not been finalized. Betting Ontario's energy security on the successful, on-time completion of the design, licensing, and constructability assessments for the CANDU Monark is too steep a risk. To handle this risk, we need alternatives. Bruce Power's Request for Information, which received over 20 responses from vendors in early 2024, began to engage such alternatives.[46]

Competition is Good for CANDU, too

CANDU needs competitive pressures as well. As the sector learned from hard-fought reactor exports when its domestic sales paused, it is not enough to have a technology that Canada wants to build. Others must want to build it, too. In an era of vast competition from Russia, China, the United States, and Europe, CANDU must be kept sharp. If it cannot succeed amid competition in its home country, it is unlikely to live up to its promises anyway, namely the sustained growth of the Canadian nuclear sector. And it certainly won't if the CANDU Monark isn't ready in time.

It is worrying to think, given the stakes, that the Bruce C technology selection could proceed without a finished Canadian reactor option. If this remains so, it creates a "worst of all worlds" scenario in which Canada has neither the option to build its own technology nor the leverage to secure vital contract terms.

MUST HAVE: FINISHED DESIGN

The reason that the CANDU Monark is not yet "competitive" is not due to a bad design or a poor operational history of CANDU. The CANDU has in fact been quite competitive with large LWR designs. Its only "sin" is that there is still a significant amount of engineering and design work to do on a standalone 1,000 MW unit.

If Bruce Power has learned from international experience, it will make a completed reactor design a top criterion before beginning construction — a lesson learned the hard way by Areva on its recent EPR builds and by Westinghouse, Southern Company, and many others on construction for the AP1000s at Vogtle.[47] Without the completion of the CANDU Monark design, it is virtually impossible that Canadian technology wins Bruce C, and rightly so.

Aerial view of the Vogtle Nuclear Power Plant in 2011. Units 1 and 2 are operational; AP1000 reactors for Units 3 and 4 are in the early phases of construction, at which time the reactor design was not yet finalized. The lack of a finalized design was at the root of major delays and cost-overruns.

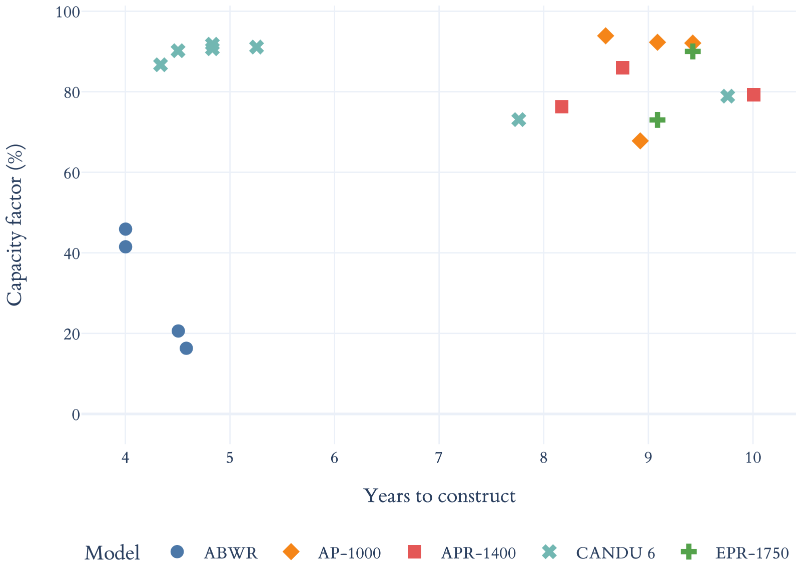


Figure: Capacity factor vs. construction duration for select reactor types. The CANDU 6 reactor (turquoise) has demonstrated excellent build times and capacity factors. NOTE: In the absence of CANDU Monark builds, data for CANDU 6 units were used. ABWR units have low capacity factor owing to post-Fukushima shutdowns in Japan. Data for Vogtle AP1000s not shown.

Data source: IAEA PRIS Database, 2022

AtkinsRéalis, licence holder to the government-owned CANDU IP, has requested that the federal government help fund the needed design work on the 1,000-MW CANDU Monark, which we estimate will cost in total between $300 million and $600 million. Gary Rose, the Canada EVP for

AtkinsRéalis, told *The Globe and Mail* that the company expects to finish design work in 2027 if it gets adequate financial partnership from the government.[48]

Why now?

Ideally, a 1,000 MW CANDU reactor would already be designed and buildable. But its absence is not so much from a lapse of stewardship as it is poor timing and circumstance. In the time since the failed Darlington bid, for which AECL had begun design work on the CANDU-inspired ACR-1000, there had been little demand for new nuclear construction. And when it appeared, it strongly favored SMRs owing to a lack of assured electricity demand growth, initiatives like the federal SMR Action Plan, and the initial exclusion of large nuclear reactors from the Clean Electricity Investment Tax Credit.[49,50] Renewed interest in new large nuclear construction caught off-guard not only AtkinsRéalis but much of the Canadian nuclear sector after years of focus on SMRs and, for years before that, on nothing new.

It's not too late

Although the delay in having a completed design is unfortunate, streamlined regulatory approvals for CANDU technology versus LWRs may help compensate for lost time. As of publication, the CNSC has never licensed a non-CANDU power reactor design for construction and operation in Canada.

All else being equal, this means that CANDU technology can expect faster, more efficient, and more competent regulation than first-in-country LWRs.

Specific CANDU expertise within Canada could also expedite construction of the CANDU Monark compared to other designs with which we are less familiar, even though other reactors may have reference plants. The conventional "balance of plant," consisting of the steam turbines, generator, and other non-nuclear-specific components—will be similar to that of competing designs with little variation in risk. The nuclear side of the CANDU Monark, however, will consist of very similar components to the existing CANDU reactors at Darlington. Nuclear operators are currently rebuilding these units, thereby gaining invaluable hands-on experience and even developing novel time-saving techniques. Thus, tough jobs in CANDU nuclear construction have been done many times over during refurbishments and in much more challenging circumstances than greenfield builds. In a refurbishment, pressure tubes and feeder tubes must be removed and replaced within very tight spaces and amid relatively high levels of background radiation. With a new build, these components are installed without the space limitations of a refurbishment and with no background radiation. The same goes for valve replacements, cable replacements, and more. Notably, these refurbishments are proceeding on-time and on-budget thanks to skilled workers, able suppliers, and project management talent. The importance of this experience in reducing risk cannot be overstated.

The investment is worth it

Government funding for the CANDU Monark is worth the investment, whether through a cost and revenue-sharing agreement likely favoured by AtkinsRéalis, a simpler loan structure, or any other way that ensures the completion of the design with proper accountability. Assuming engineering and design costs of between $300 million and $600 million, a matched-funding arrangement with the federal government would command between $150 million and $300 million.

The Canadian nuclear sector generates around $2 billion yearly in tax revenue for federal and provincial governments, primarily from operations and maintenance of its 19 operating CANDU units.[51] An additional 4,000 MW at Bruce C would constitute a one-third increase in Canada's installed nuclear capacity and the associated tax revenue opportunity. At these levels, if investment in the CANDU Monark raises local content guarantees at Bruce C by even 10%, increased tax revenue could pay back the cost of the investment in just 5 years.

Even in the case that the CANDU Monark isn't selected for Bruce C, increased leverage to secure technology transfer, supply chain involvement, and export opportunities will yield large returns in boosted GDP and tax revenue, let alone the long-term benefits to national interest. In the case that the CANDU Monark is chosen, it would yield direct royalties in addition to abundant tax revenue.

Stewarding Past Investment

Financially, the cost of design work on the CANDU Monark is a fraction of the cumulative taxpayer and ratepayer investments in CANDU R&D that it will preserve.

R&D spending on CANDU has spanned over 70 years. In its first 50 years of developing and building the CANDU reactor, Atomic Energy of Canada Limited (AECL) received and spent around $7.5 billion in real terms.[36(p4)] For development work on the ACR-1000, which the CANDU Monark builds upon, AECL received in 2009 upward of $150 million.[52] CANDU Owners Group, a non-profit organization of worldwide CANDU operators founded in 1984, funds about $75 million of CANDU R&D every year. Not to mention, ongoing refurbishments in Ontario, costing $26 billion, are resulting in major innovations and CANDU-specific work experience.

Given past investments, passing up funding for the CANDU Monark would not so much save taxpayer money as prevent returns on taxpayer and ratepayer money already spent.

Putting the Spend in Context

Government support for nuclear reactor designs is ubiquitous. Even the United States, typically more private sector-led than Canada, has signed massive checks for design work on the Westinghouse AP1000. In the mid 2000s, the U.S. Department of Energy (USDOE) provided US$218 million toward the

AP1000 standard plant design on a 50% cost-sharing agreement, equivalent to around CA$450 million today.[53] The USDOE also funded the AP1000's precursor, the AP600, in the 1990s.

Assuming that a similar cost-sharing investment is needed to finish the CANDU Monark as was needed to scale up the AP600 to the AP1000 (CA$450 million), if the CANDU Monark makes full use of the $150 million already invested in the ACR-1000, then a remaining $300 million is needed.

Funding CANDU Monark to the tune of $300 million is a drop in the bucket of existing incentives by the federal government for projects to advance innovation and decarbonization goals. The Canada Budget 2023 announced $83 billion in funding for low-carbon initiatives, with $70 billion in the form of investment tax credits, according to an analysis by consultancy PwC.[54] Direct investment in innovative technologies through the Strategic Innovation Fund has totaled over $8 billion since 2017.[55] The most stark comparison is perhaps that of the subsidies for electric vehicle battery plants by Northvolt, Volkswagen, and Stellantis-LGES in Ontario and Quebec. These subsidies are expected to reach $43.6 billion dollars over the next decade, with around $27 billion of that coming from the federal government.[56] The funding needed for the CANDU Monark is a small fraction of this cost, and it will play a crucial role at the intersection of decarbonization, energy security, and economic development, making sure that Canadian interests are represented in one of the largest industrial decisions for Canada this century.

The Bruce C site selection will be highly competitive as it is. For any vendor, to build a reactor at Bruce C is a once-in-a-generation opportunity. It is not just the most imminent sale for a large nuclear reactor in North America at a time when such deals are scarce. The context of the site is also ideal, including policy alignment on support for nuclear energy, excellent social licence, a talented and active local supply chain that understands the rigorous quality assurance and control required for nuclear projects, a location adjacent to an operating nuclear plant and accessible via the Great Lakes, and highly capable project managers with proven megaproject successes. Understandably, there is huge motivation for vendors to win Bruce C.

This makes a good negotiating position for Bruce Power, but there remains the task of putting proper weight on factors that aren't strictly financial or operational. In the case that the heavy involvement of Canadian workers and suppliers raises costs compared to using existing foreign suppliers, Bruce Power may have trouble taking on the added costs and risks. Those with the greatest incentive to protect supply chain interests, technology ownership, and future export potential are the broad coalition of Canadian taxpayers, skilled tradespeople, and businesses. The federal and provincial governments should make sure these interests are properly represented and so must be ready to assume some of the added initial costs and risk-sharing needed to kick off supply chain localization.

Government risk sharing

Long-term strategy for Canada's nuclear sector will take light-handed industrial policy — not to predetermine technology choice but to urge that real value be placed on supply chain localization, IP transfer, and commitments to involve Canadian suppliers in future exports. One obvious way to do this is to link such outcomes to varying levels of government risk-sharing offered on the project.

Government will almost certainly be asked to share risk on the project. The government of Ontario itself, alongside that of New Brunswick, Saskatchewan, and Alberta and utilities in each of these provinces, stressed the importance of government finance and risk sharing in its joint strategic plan for SMR deployment in Canada.[57,58] The same reasoning applies to new large nuclear builds. If government finance is important for the deployment of small and micro reactors totaling around 3,000 MW by the 2040s (assuming 8 BWRX-300 units between Ontario and Saskatchewan, Moltex and Arc Clean Energy reactors in New Brunswick, and a handful of microreactors), how much more important is government involvement in a 4,000+ MW project at Bruce C totaling tens of billions of dollars?

Who will own Bruce C?

There is another way in which the province could negotiate for supply chain localization, IP transfer, export guarantees, and other strategic factors: if the province of Ontario owns that plant via Ontario Power Generation (OPG), the current owner of the Bruce site. At Bruce C, it is an open question which entity will end up buying and owning the reactors.

Although Bruce Power is leading the RFI, private ownership of a nuclear asset would be a first for Canada. Canada has no experience with privately owned nuclear assets. In Ontario, every unit is owned by the province via OPG. Even when Bruce Power became the private operator of the units at Bruce A and Bruce B, it only licensed the site, the ownership of the reactor and the land remaining with the province. In Quebec and New Brunswick as well, reactors are likewise owned by provincial utilities. If the province of Ontario ultimately owns the reactors at Bruce C, then factors such as supply chain localization become natural territory for competition between vendors.

OPG has indicated that it is taking an "observer role" in the Bruce C technology selection,[59] but this could easily change as the project progresses from early stages to practical implementation. Understanding the value of bringing Canadian technology to the conversation on new large nuclear in Canada, OPG is actively engaging AtkinsRéalis regarding the development of the CANDU Monark, offering lessons from hands-on CANDU operations.[59]

Inaction: the most expensive option

The worst of all outcomes would be to take a passive role in negotiations for the technology choice, failing to steward CANDU and thereby doing little to improve Canada's negotiating position when we had the chance. Can we expect the United States or France or South Korea or Japan to simply give Canada, as an importer of their technology, terms that will allow Canada to replicate the success it has had with its own domestic nuclear technology? Will foreign vendors hand over lucrative supply contracts, export controls, international relations opportunities, and intellectual property? Not if Canada has already lost those things by failing to put forth a finished domestic reactor design for the Bruce C technology selection. If Canada has lost these advantages anyway, what grounds does it have to request them from foreign vendors?

Appearing strong for our leadership on new nuclear sites, we are in fact in a position of weakness without CANDU. We are about to shoot the starter gun for a very important race with our star athlete still in the locker room. But we must understand that we have a star athlete that, once in the race, can win on competitive grounds. We need not call off the race or rig the results. We just need to finish tying our shoes and get to the starting line.

What should be done?

It is beyond the scope of this report to detail the specific mechanisms by which to finance the development of the CANDU Monark and to give competitive weight to supply chain localization and IP transfer. But for the Bruce C technology selection to return the greatest long-term benefit for Canadian jobs and energy security, this must be a priority of the provincial and federal government.

Fund the Monark design in a way that holds AtkinsRéalis accountable

The first step is to make appropriations in the Canada budget for funding for the CANDU Monark of approximately $300 million, constituting a high-end estimate of government funds needed to finish design work.

More detailed arrangements for disbursing the funds would follow. The possibilities for how to structure such funding are many, ranging from a matched-funding and revenue-sharing agreement with AtkinsRéalis and AECL or the federal government, to a simpler loan offering, to a multi-party agreement with various Canadian suppliers.

Whatever the structure used, it should have as its primary goal the prompt completion of the CANDU Monark design while ensuring accountability from all companies involved. As the most vital step toward improving the otherwise competitive case for CANDU technology, such funding should be arranged soon, the natural delay created by forthcoming design work already impacting the Bruce C technology selection process.

Ensure that supply chain localization and IP transfer are key competitive considerations

There are likewise several ways to ensure that supply chain localization and IP transfer are made key criteria in the competitive evaluation of each vendor's offerings. Though it is beyond the scope of this report to prescribe the specific mechanisms by which to do this, we broadly recommend an approach that pairs a domestic policy "nudge" with the primary strategy of fielding a genuinely competitive CANDU bid that naturally excels in bringing about domestic benefit.

The federal government, province, and utilities should enter discussions to find a mechanism by which technology transfer with foreign vendors and countries could be facilitated. The answer to this question will undoubtedly overlap with that of another open question: that of who will indeed take ownership of the plant.

References

1. Julie Kozeracki, Chris Vlahoplus, Katheryn Scott, et al. *Pathways to Commercial Liftoff: Advanced Nuclear*. US Department of Energy; 2023. Accessed August 7, 2023. https://liftoff.energy.gov/advanced-nuclear/
2. Berthélemy M, Escobar Rangel L. Nuclear reactors' construction costs: The role of lead-time, standardization and technological progress. *Energy Policy*. 2015;82:118-130. doi:10.1016/j.enpol.2015.03.015
3. Roche B. Lessons Learned from Standardized Plant Design and Construction. In: IAEA; 1999.
4. The benefits of standardisation for nuclear projects. *World Nuclear News*. https://www.world-nuclear-news.org/RS-The-benefits-of-standardisation-for-nuclear-projects-22091601.html. Published September 22, 2016. Accessed March 27, 2024.
5. Canada NR. COP28: Declaration to Triple Nuclear Energy (2023). Government of Canada. Published December 20, 2023. Accessed March 27, 2024. https://natural-resources.canada.ca/energy/resources/international-energy-cooperation/cop28-declaration-triple-nuclear-energy-2023/25591
6. *The $2 Trillion Transition: Canada's Road to Net Zero*. Royal Bank of Canada; 2021. Accessed March 27, 2024. https://thoughtleadership.rbc.com/the-2-trillion-transition/
7. *Bruce C Project: Planning for the Next Generation*. Bruce Power; 2023. Accessed March 27, 2024. https://www.brucepower.com/wp-content/uploads/2023/11/230527A_BruceCProjectPublication_R000-AX.pdf
8. *Annual Planning Outlook: Ontario's Electricity System Needs: 2025-2050*. Independent Electricity System Operator; 2024. https://www.ieso.ca/Powering-Tomorrow/2024/Six-Graphs-and-a-Map-2024-Annual-Planning-Outlook-and-Emissions-

Update#:~:text=The%20IESO's%202024%20Annual%20Planning,sustainability%20of%20Ontario's%20electricity%20system.

9. Carelli MD, Garrone P, Locatelli G, et al. Economic features of integral, modular, small-to-medium size reactors. *Progress in Nuclear Energy*. 2010;52(4):403-414. doi:10.1016/j.pnucene.2009.09.003

10. Delivering Transparency and Trust. Bruce Power. Accessed April 3, 2024. https://www.brucepower.com/who-we-are/delivering-transparency-and-trust/

11. AtkinsRéalis introduces 1,000 MW CANDU® MONARK™ Reactor; Nuclear Power for a Net Zero, Energy Independent Future. AtkinsRéalis. Published November 28, 2023. Accessed March 27, 2024. https://www.atkinsrealis.com/en/media/press-releases/2023/28-11-2023

12. AtkinsRéalis and AECL enter into Memorandum of Understanding to collaborate and expand intellectual property agreement, accelerating development of CANDU® MONARK™ reactor. AtkinsRéalis. Published February 22, 2024. Accessed March 27, 2024. https://www.atkinsrealis.com/en/media/press-releases/2024/2024-02-22

13. Brooks GL. A Short History of the CANDU Nuclear Power System. In: ; 1993. https://www.osti.gov/etdeweb/biblio/169829

14. Greenhouse gas sources and sinks in Canada: executive summary 2023. Environment and Climate Change Canada. Published April 14, 2023. Accessed April 10, 2024. https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/sources-sinks-executive-summary-2023.html

15. *Nuclear Power Reactors in the World*. International Atomic Energy Agency; 2023. Accessed April 10, 2024. https://www.iaea.org/publications/15485/nuclear-power-reactors-in-the-world

16. Caplan M, Kitchen H, Boyd C. *Benefits of Nuclear Energy for Canadians*. MZ Consulting Inc; 2019. Accessed March 27, 2024.

https://cna.ca/wp-content/uploads/2019/11/MZ-Consulting-Benefits-of-Nuclear-Energy-for-Canadians.pdf

17. *A Report on the Contribution of Nuclear Science and Technology (S&T) to Innovation*. KPMG; 2014. Accessed January 11, 2024. http://cins.ca/docs/Nuclear%20ST%20Innovation.pdf

18. *Canada's Energy Future 2023: Energy Supply and Demand Projections to 2050*. Canada Energy Regulator; 2023. https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2023/

19. Ramzy M. Trudeau says Canada is "very serious" about reviving nuclear power. *The National Post*. https://nationalpost.com/news/politics/trudeau-says-canada-is-very-serious-about-reviving-nuclear-power#:~:text=OTTAWA%20%E2%80%94%20Prime%20Minister%20Justin%20Trudeau,country's%20reliance%20on%20fossil%20fuels. Published April 24, 2023.

20. Canada offers CAD3 billion finance for nuclear in Romania : New Nuclear - World Nuclear News. World Nuclear News. Published September 20, 2023. Accessed April 10, 2024. https://www.world-nuclear-news.org/Articles/Canada-offers-CAD3-billion-finance-for-new-nuclear

21. Jo JH, Lee J eun. Exclusive: South Korea to extend lifespan of Wolseong nuclear power plant units 2, 3 and 4. The Chosun Daily. Published April 1, 2024. Accessed April 10, 2024. https://www.chosun.com/english/industry-en/2024/04/01/5Z73RBHF3NBALDJFWDDO4APQWA/

22. Unit 6 MCR construction complete on-time and on-budget, focus shifts to return to service. Bruce Power. Published May 4, 2023. Accessed March 27, 2024. https://www.brucepower.com/2023/05/04/unit-6-mcr-construction-complete-on-time-and-on-budget-focus-shifts-to-return-to-service/

23. McClearn M. Ontario's Darlington nuclear station is on time, on budget and learning from past mistakes. *The Globe and Mail*. https://www.theglobeandmail.com/business/article-darlington-

nuclear-generating-station-refurbishment/. Published July 15, 2023. Accessed March 27, 2024.

24. Owusu P, Bond S, Antunes P. *Continued Operation of Darlington Nuclear Generating Station: An Impact Analysis on Ontario's Economy*. The Conference Board of Canada; 2016.

25. Kinectrics Joins Canadians for CANDU Campaign. Kinectrics. Published March 28, 2024. Accessed March 29, 2024. https://www.kinectrics.com/media-center/news-releases/kinectrics-joins-canadians-for-candu-campaign

26. BWXT Canada Joins Canadians for CANDU® Campaign. Published April 11, 2024. Accessed April 11, 2024. https://www.bwxt.com/news/2024/04/11/BWXT-Canada-Joins-Canadians-for-CANDU%C2%AE-Campaign

27. Finley M, Mikulska A. Wielding the Energy Weapon: Differences Between Oil and Natural Gas. Published online June 2023. doi:10.25613/G9P2-3F78

28. Uranium Enrichment. World Nuclear Association. Published October 2022. Accessed April 8, 2024. https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx

29. The United States Announces Key Measures to Jump Start Deployments of Advanced Nuclear Energy Systems and to Secure Nuclear Fuel Supply Chains, Accelerating the Contribution of Nuclear Energy to Net Zero Goals. United States Department of State. Published December 5, 2023. Accessed April 8, 2024. https://www.state.gov/the-united-states-announces-key-measures-to-jump-start-deployments-of-advanced-nuclear-energy-systems-and-to-secure-nuclear-fuel-supply-chains-accelerating-the-contribution-of-nuclear-energy-to-net-z/

30. *Economic Impact Analysis of Small Modular Reactors (SMRs)*. The Conference Board of Canada; 2023. https://www.opg.com/documents/cboc-economic-impact-analysis-of-smrs-pdf/

31. BWXT Awarded Engineering Contract from GE Hitachi for BWRX-300 Small Modular Reactor. BWXT. Published March 21, 2023. Accessed March 28, 2024. https://www.bwxt.com/news/2023/03/21/BWXT-Awarded-Engineering-Contract-from-GE-Hitachi-for-BWRX-300-Small-Modular-Reactor

32. NRC Responses to NNSA Regarding AP1000 Design Issues. NRC. Published March 2014. Accessed March 27, 2024. https://www.nrc.gov/docs/ML1322/ML13224A192.pdf

33. Areva reports flaw in nuclear reactor vessel. Power Engineering. Published April 7, 2015. Accessed March 27, 2024. https://www.power-eng.com/nuclear/areva-reports-flaw-in-nuclear-reactor-vessel/

34. Irregularities concerning components manufactured in its Creusot Forge plant. Autorité de sûreté nucléaire. Published May 4, 2016. Accessed March 27, 2024. https://www.french-nuclear-safety.fr/asn-informs/news-releases/irregularities-concerning-components-manufactured-in-its-creusot-forge-plant

35. Andrews-Speed P. South Korea's nuclear power industry: recovering from scandal. *The Journal of World Energy Law & Business*. 2020;13(1):47-57. doi:10.1093/jwelb/jwaa010

36. Bratt D. Candu or candon't: Competing values behind Canada's nuclear sales. *The Nonproliferation Review*. 1998;5(3):1-16. doi:10.1080/10736709808436716

37. US court dismisses Westinghouse case against Korea. *World Nuclear News*. https://www.world-nuclear-news.org/Articles/US-court-dismisses-Westinghouse-case-against-Korea. Published September 19, 2023. Accessed February 20, 2024.

38. Kerr PK, Nikitin MBD. New U.S. Policy Regarding Nuclear Exports to China. *Congressional Research Service*. Published online December 17, 2018.

39. Mandel-Campbell A. *Why Mexicans Don't Drink Molson: Rescuing Canadian Business From the Suds of Global Obscurity*. D & M Publishers; 2009.

40. Ninan J, Sergeeva N. Mobilizing Megaproject Narratives for External Stakeholders: A Study of Narrative Instruments and Processes. *Project Management Journal*. 2022;53(5):520-540. doi:10.1177/87569728221102719

41. Evidence - RNNR (40-2) - No. 36. Published online October 28, 2009. Accessed March 12, 2024. https://www.ourcommons.ca/DocumentViewer/en/40-2/RNNR/meeting-36/evidence

42. Bruce Power to prepare Alberta site. *World Nuclear News*. https://www.world-nuclear-news.org/it-bruce_power_to_make_important_announcement_130308.html. Published March 14, 2008. Accessed March 19, 2024.

43. Bowen M, Apostoaei A. *Comparing Government Financing of Reactor Exports: Considerations for Us Policy Makers*. Columbia SIPA Center on Global Energy Policy; 2022. https://www.energypolicy.columbia.edu/publications/comparing-government-financing-reactor-exports-considerations-us-policy-makers/

44. Historic Contract Paves the Way for Site Work on Poland's First Nuclear Power Plant. Westinghouse Electric Company. Published September 27, 2023. Accessed March 19, 2024. https://info.westinghousenuclear.com/news/historic-contract-paves-the-way-for-site-work-on-polands-first-nuclear-power-plant

45. Hecht G. *The Radiance of France: Nuclear Power and National Identity after World War II*. MIT Press; 2009.

46. Bruce Power to launch RFI and Advisory Panel to evaluate options to grow Ontario's nuclear capacity and strengthen economic development. Bruce Power. Published November 22, 2023. Accessed March 27, 2024. https://www.brucepower.com/2023/11/22/bruce-power-to-launch-rfi-and-advisory-panel-to-evaluate-options-to-

grow-ontarios-nuclear-capacity-and-strengthen-economic-development/

47. Leipner C, Murray JM, Maxwell A. Mixed Milestone: What Vogtle can teach us about the future of U.S. nuclear energy. Clean Air Task Force. Published September 5, 2023. Accessed March 27, 2024. https://www.catf.us/2023/09/mixed-milestone-vogtle-teach-about-future-us-nuclear-energy/

48. McClearn M. AtkinsRéalis, Atomic Energy of Canada to partner on development of new Monark nuclear power reactor. *The Globe and Mail*. https://www.theglobeandmail.com/business/article-atkinsrealis-atomic-energy-of-canada-to-partner-on-development-of-new/. Published February 22, 2024. Accessed February 23, 2024.

49. Canada's Small Modular Reactor (SMR) Action Plan. Natural Resources Canada. Accessed March 27, 2024. https://smractionplan.ca/

50. Canada releases long-awaited draft legislation for tax credits supporting the clean energy sector. Osler, Hoskin & Harcourt LLP. Published August 9, 2023. Accessed March 27, 2024. http://www.osler.com/en/resources/regulations/2023/canada-releases-long-awaited-draft-legislation-for-tax-credits-supporting-the-clean-energy-sector

51. The Canadian Nuclear Industry and its Economic Contributions. Published December 19, 2016. Accessed April 10, 2024. https://natural-resources.canada.ca/energy/energy-sources-distribution/uranium-nuclear-energy/nuclear-energy/canadian-nuclear-industry-and-its-economic-contributions/7715

52. *2009 Annual Financial Report*. Atomic Energy of Canada Limited; 2009. Accessed March 12, 2024. https://publications.gc.ca/collections/collection_2009/eacl-aecl/CC1-3-2009E.pdf

53. U.S.-Chinese Agreement Provides Path to Further Expansion of Nuclear Energy in China. U.S. Department of State, The Office of Electronic Information, Bureau of Public Affairs. Published December

16, 2006. Accessed April 7, 2024. https://2001-2009.state.gov/p/eap/rls/prs/77962.htm

54. 2023 Federal Budget analysis. PwC. Published March 28, 2023. Accessed March 25, 2024. https://www.pwc.com/ca/en/services/tax/budgets/2023/2023-federal-budget-analysis.html

55. Investments: Strategic Innovation Fund. Government of Canada. Published December 21, 2023. Accessed March 27, 2024. https://ised-isde.canada.ca/site/strategic-innovation-fund/en/investments

56. Giswold J. *Costing Support for EV Battery Manufacturing*. Office of the Parliamentary Budget Officer; 2023. https://distribution-a617274656661637473.pbo-dpb.ca/eaafeb418199ab141962f0b62dae824e9ab2efa95e5baddd1fb5ad774a3fe984

57. A strategic plan for the deployment of small modular reactors. Ontario Ministry of Energy. Published March 2, 2022. Accessed March 19, 2024. http://www.ontario.ca/page/strategic-plan-deployment-small-modular-reactors

58. A Call to Action: A Canadian Roadmap for Small Modular Reactors. *Canadian Small Modular Reactor Roadmap Steering Committee*. Published online November 2018. https://smrroadmap.ca/

59. Chafee P. OPG's Dykxhoorn on New Nuclear in Ontario and Beyond. *Nuclear Intelligence Weekly*. 2024;18(10):8-11.

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