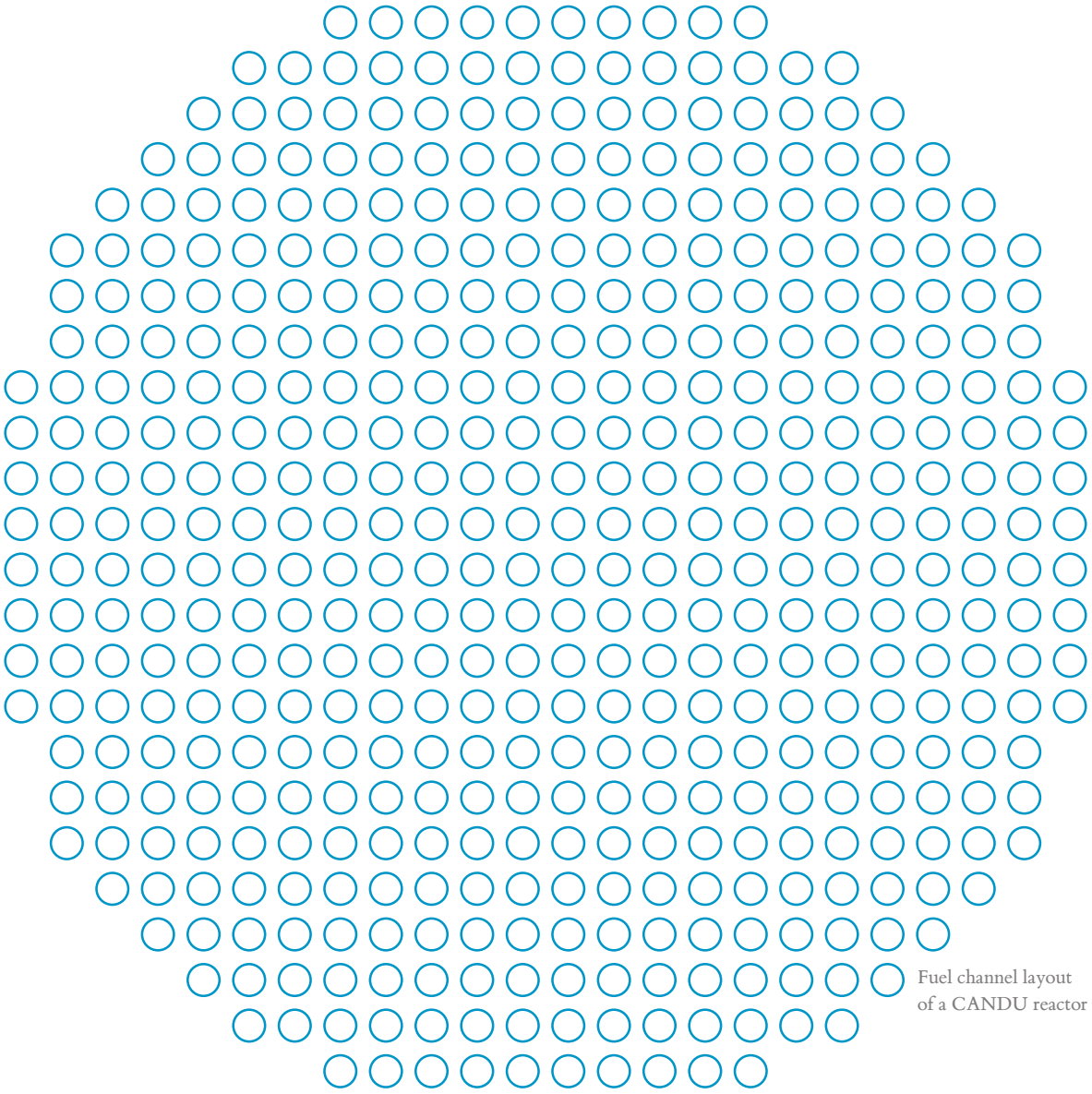
A report *from* Canadians for Nuclear Energy



Fuel channel layout
of a CANDU reactor

The Case for CANDU

Why Ontario's Homegrown Nuclear Technology Is The Province's Best Option In A Time Of Rising Electricity Demand

The Case for CANDU: Why Ontario's Homegrown Nuclear Technology Is Its Best Option In A Time Of Rising Electricity Demand
May 2023

Canadians for Nuclear Energy (C4NE) is a grassroots non-profit organization composed of Canadian energy workers, engineers, doctors, tradespeople, scientists, policy experts, and citizens.

Learn more at **c4ne.ca**

Contents

Seizing the Moment

Ontario faces energy challenges for which it has a proven solution and the opportunity to act.

Geared up from major refurbishments at the province's CANDU nuclear plants, a skilled workforce and supply chain trained on the technology create the ideal conditions to start new builds.

The pieces are in place. All that remains is to take the first step. To secure affordable energy for present and future generations, let's seize the moment and build new CANDU nuclear now.

Sincerely,

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

Executive Summary

This report answers the question "why build new CANDU reactors in Ontario now?" in three parts:

1. Coming electricity shortfalls have firmed up ambition for new nuclear capacity.
2. CANDU, our homegrown reactor technology, is far ahead of other options in terms of local economic benefit, fuel security, project risk mitigation, and a proven track record of success.
3. A window of opportunity created by ongoing CANDU refurbishments offers a smooth onramp to new builds.

Capacity shortfalls call for new large nuclear

Ontario is poised for rapid growth in electricity use without the supply to meet it. As policymakers search for solutions, a sober concern for energy security, fuel and technology independence, affordability, and emissions limits the available options. In this context, attention has again turned to nuclear energy as a proven way to meet clean electricity needs without sacrificing affordability or the stability of the grid.

CANDU is far ahead of the competition

Ontario's energy future depends, unavoidably, on delivering large power projects. Crucial to these efforts are: 1) lowering project risk, and 2) ensuring the end result meets the intended purpose (ideally with knock-on economic benefits).

We argue that CANDU is the lowest-risk, highest-benefit of Canada's large nuclear options. Lowering project risk are decades of construction and maintenance experience, a fully developed supply chain and trained workforce, proven economics, and ongoing success with new-build-scale refurbishments. Meanwhile, decades of affordable power, uninterrupted fuel supply, successful exports, local jobs, community benefit, and a track record of decarbonization prove that CANDU will meet the strictest criteria for new supply once built and will continue to do so for generations.

The window of opportunity is now

Refurbishment projects at the Bruce and Darlington Nuclear Stations are a $26 billion investment into CANDU assets and, just as importantly, into people with the skills to build, operate, and regulate them. Letting opportunities in CANDU lapse with the end of these refurbishments would be an irreparable loss to Ontario's jobs, economy, and clean energy. Alternatively, building new CANDU would preserve and grow Ontario's hard-earned legacy as a clean energy leader and signal its openness to business investment for the long-term.

What should be done?

With urgency to meet energy needs, Ontario should consider developing and executing an inclusive plan for new CANDU alongside the BWRX-300 at the Darlington New Nuclear Site, where an existing site license would speed up timelines by nearly a decade. Meanwhile, site development to support 10 new CANDU reactors is a "no regret action" that should begin promptly. Once firm plans are in place at the provincial level, nuclear operators and the Ministry of Energy could approach the federal government to discuss avenues of support, including funding for CANDU modernizations, heavy water production, and expedited licensing for new sites.

Three reasons to build new CANDU

1

Electricity shortfalls call for new large nuclear

2

CANDU is far ahead of the competition

3

The window of opportunity is now

1. Electricity shortfalls call for new large nuclear

Demand at the Doorstep

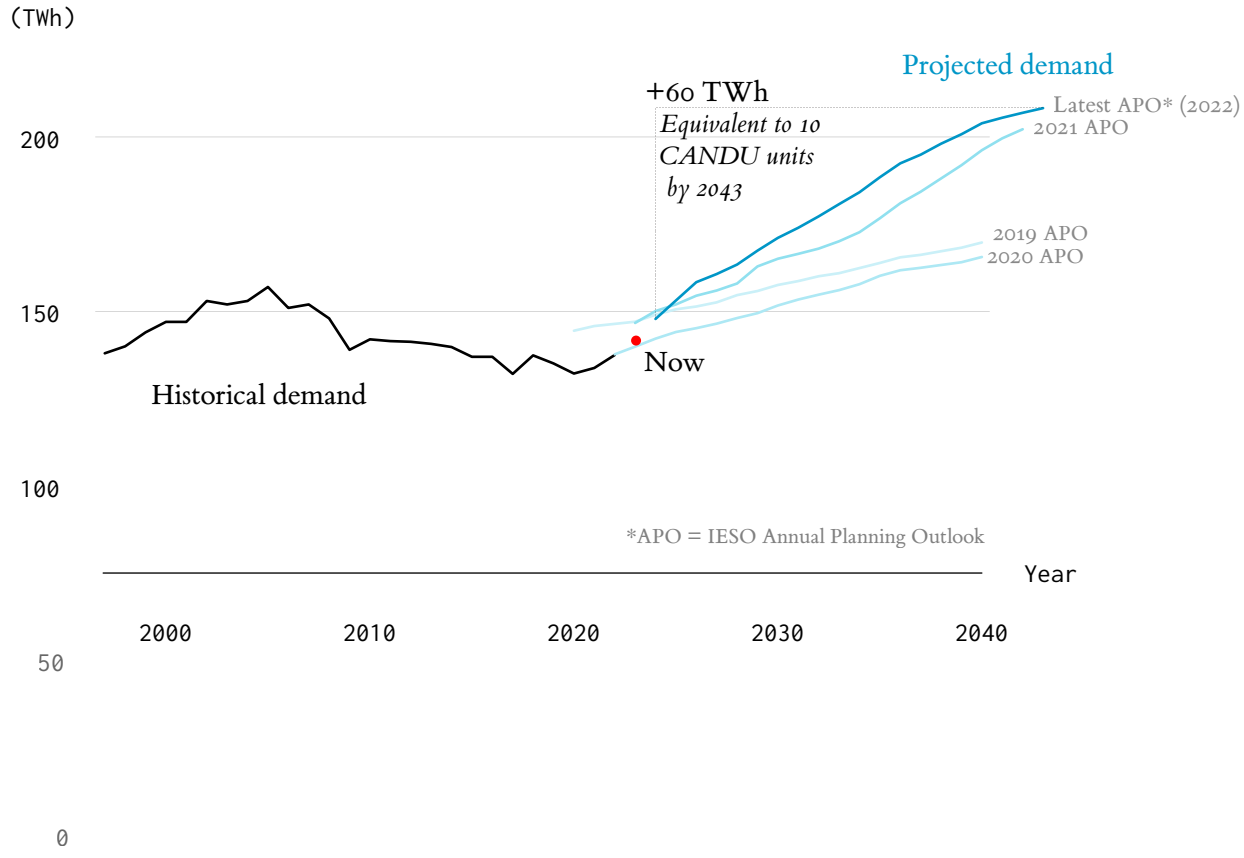
For the first time since 2005, Ontario's electricity demand is rising. To meet it, provincial and federal leaders have put new nuclear on the table—a shift from the last decade of energy planning.

The return of manufacturing and industry, the conversion of industrial processes to use electricity, rapid population growth, federal electric vehicle mandates, and more have led the Independent Electricity System Operator (IESO) to raise demand projections to record levels as usage trends clarify.[1–4]

10 new CANDU reactors

Under *current policy*, the IESO expects 60 terawatt-hours (TWh) of new annual demand by 2043, enough to require adding 10 new CANDU reactors to the current fleet of 18.

Fig 1. Ontario Electricity Demand Projections Reach New Heights



If decarbonization goals advance, this number shoots even higher. In its *Pathways to Decarbonization* report, the IESO shows the need for nearly 18,000 megawatts (MW) of new nuclear by 2050 to reach net zero, or about 25 CANDU reactors[5]—a rate of construction unseen since Ontario's CANDU buildout between the 1960s and 1990s. New capacity must also overcome the lost output from expiring contracts and facilities over the next two decades, which make one-fifth of the province's electricity from solar, wind, and natural gas.[6]

A shift for Ontario's energy use

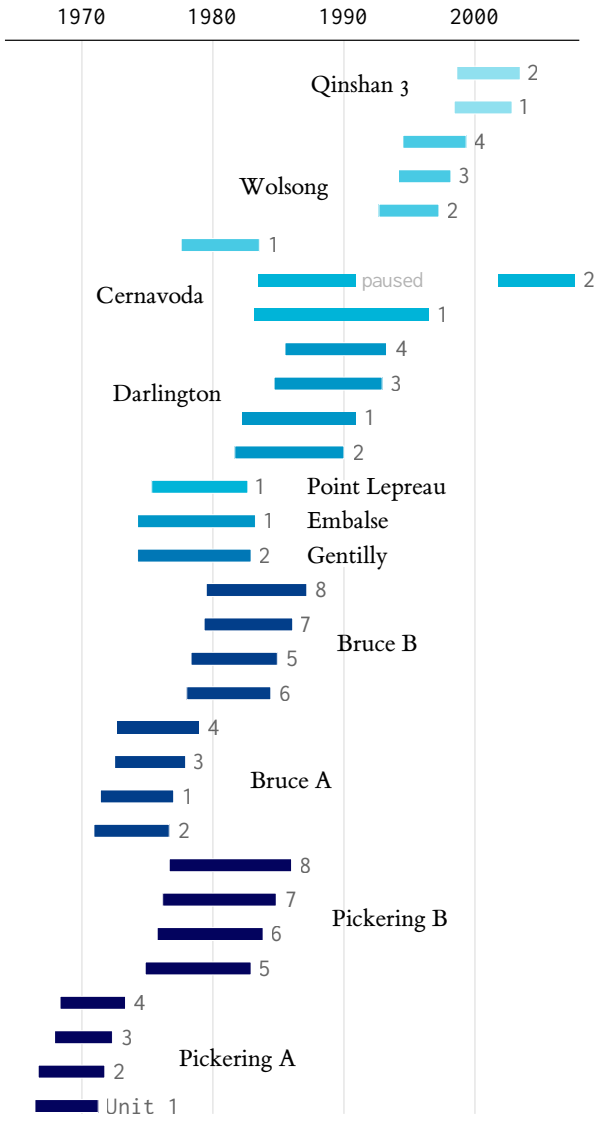
Since the 1990s, the province has had little need for new power sources. Demand modestly rose to a peak in 2005, after which declining manufacturing combined with energy efficiency drove down electricity use year after year.[73] Meanwhile, the nuclear plants and hydro dams built by Ontario Hydro prior to its 1990s restructuring continued to meet most electricity needs. These facilities still make over 80% of Ontario's electricity today.[7]

The makeup of the electric grid has indeed changed in recent decades, but these changes came from policy, not necessity. The coal phaseout, a historic environmental win, was made possible by the restart of existing CANDU reactors at the Bruce and Pickering nuclear stations.[8] The Green Energy Act of 2009 (GEA) brought on new wind and solar capacity, but these contracts cut into gas generation and drove up electricity exports rather than increase the province's overall power use.[9] And the refurbishment of nuclear stations, though massive projects, are to preserve capacity rather than build more.

Repeating success

To avoid energy shortfalls, Ontario must learn from the success of its CANDU nuclear buildout—the only time the province has managed to build power capacity at the speed and scale currently needed—and repeat it.

Fig 2. Timeline of Global CANDU Construction



Locations: Qinshan 3, China; Wolsong, South Korea; Cernavoda, Romania; Embalse, Argentina; rest Canada

IT'S GAS OR NUCLEAR

Amid growing electricity demand, when spare supply is no longer a given, the criteria for new capacity tighten. World events have combined to give energy planners a new appreciation for:

- **energy security** amid global energy shocks,
- **fuel and technology independence** amid supply chain disruptions and trade disputes,
- **carbon emissions** amid climate change, and
- **affordability and local economic development** amid inflation.

These crucial considerations mean that the options for meeting capacity shortfalls are fewer than we might like.

Renewables, like wind and solar, make around 9% of the power supplied to the Ontario grid.[75] However, intermittency limits their ability to provide reliable power without 1-to-1 backup. Additionally, their availability often misaligns with Ontario's demand. Unpredictable output spikes at odd hours regularly force the province to curtail power or rapidly offload it to neighbouring grids, even if that means selling at negative prices.[10] Research from Queen's University pins the cost to the province of such wind-induced market disruptions at $1 billion per year.[11]

Equally problematic, the high-pressure weather systems that bring heat waves and cold snaps (and with them seasonal demand peaks) cause the wind to still, leading to extended supply dips when power is most needed. From June to September 2020, for example, Ontario's wind power fell to just 14% availability. The year prior, during the hottest two weeks wind power averaged just 6.87% availability.[9,12] Solar, though more predictable, is liable to make virtually no power during winter, leaving assets and transmission infrastructure underused for months.[6]

Hydroelectricity has been largely tapped out. In the last 20 years, the IESO has been able to contract only about 1,500 MW of hydroelectric capacity through 129 separate contracts averaging a mere 13 MW each, and 80 of these were renewed contracts with existing sites.[13] Large hydroelectric opportunities on the scale of the two Sir Adam Beck Generating Stations at Niagara Falls (still smaller combined than any of Ontario's CANDU nuclear stations) are nowhere to be found. Reflecting this in its Annual Planning Outlook, the IESO foresees hydropower to remain level through 2040.[1]

Imports from Quebec have also been touted as a solution to Ontario's energy needs. However, the proposal to lean on Quebec could not withstand scrutiny even before our neighbouring province tightened exports to focus on its own energy goals.[14] Hydro-Québec exports around 34 TWh annually, only 18% of which goes to Ontario.[15] To match the output of a single 4-unit CANDU station, Ontario would have to monopolize Quebec's exports and in doing so strip New Brunswick, New England, and New York—all higher carbon grids—of their access to Quebec hydropower. This would still fall short of ensuring firm capacity year-round, as Ontario already sends power to Quebec to help with its winter demand peaks.[16]

Of the remaining options, coal is banned by law;[17] grid-scale geothermal, though a potential source of electricity in the future, has no foothold in Ontario and is limited by geography; and efficiency gains, though important to make, are overshadowed by demand growth in IESO projections.

That leaves natural gas and nuclear energy.

Absent new nuclear, Ontario's default course is natural gas. The province has several thousand MW of installed gas capacity that could fill in for gaps in the short term, and last year the IESO launched an expedited process to procure more.[18]

Although gas generation is dispatchable, it scores low on energy security, fuel independence, and carbon emissions. Reliance on natural gas has left scars in recent memory, showing itself to be the most price volatile of all energy sources, with fatal consequences for businesses across Europe.[19] Additionally, Ontario produces almost none of its own gas supply, tying the province to imports from the United States and western Canada.[20]

Embracing NUCLEAR ENERGY is not a "lesser of evils" decision. It is a strong energy option in its own right, as governments and expert bodies around the world are explicitly recognizing. For instance, a landmark report by the United States Department of Energy (DOE) states that:

> "Regardless of level of renewables deployment... the U.S. will need... additional clean, firm capacity to reach net-zero; nuclear power is one of the few proven options that could deliver this at scale, while creating high-paying jobs with concentrated economic benefits for communities most impacted by the energy transition." [21]

ONTARIO IS IN THE KNOW

Provincial and federal leaders know that we need large scale nuclear.

Prime Minister Trudeau, in a discussion with the President of Germany at the University of Ottawa just days after the European country closed its own nuclear plants, told students: "We're going to need a lot more energy, and we are going to have to be doing much more nuclear over the coming decades."[22] Days earlier, Finance Minister Chrystia Freeland told press at the Pickering Nuclear Generating Station that "nuclear energy will play a very important role in our clean economy, especially here in Ontario."[23]

In its 2023 budget, the federal government extended funding to large nuclear projects, something it had previously left out.[24] At the provincial level, the IESO, in its Pathways report, left no doubt that large nuclear additions would be needed to meet climate goals.[5] And actions by the Ontario Minister of Energy, such as stopping the sale of the valuable potential nuclear site at Wesleyville, show that the province has put nuclear development beyond the Darlington SMR project on the table.[25]

Part proud, part concerned

So, as we turn our attention from options among energy sources to options among specific nuclear technologies, we are equal parts proud and concerned: proud of Ontario's immense advantage in the form of CANDU nuclear, and concerned that we may pass up the opportunity to make further use of it.

2. CANDU is far ahead of the competition

Ontario's Nuclear Waste Problem

Ontario has no current plans to build new CANDU reactors. If it continues without them, it will indeed have a nuclear waste problem:

that of wasted opportunity.

Keeping the CANDU advantage

For 50 years, Ontario's nuclear sector has been a CANDU sector. By committing to new CANDU, the province would benefit from decades of experience and investment in every aspect from mining and fuel fabrication to component manufacturing, workforce development, construction, operation, maintenance, project management, and the handling of used fuel for the intermediate and long term.

Switching to new reactor designs, the province would lose significant ground having to:

- retrain workers
- retool the supply chain
- relearn regulation on a new reactor
- rework the Deep Geological Repository, designed exclusively for CANDU fuel bundles
- move fuel contracts overseas since non-CANDU reactors take enriched uranium
- leave behind the vast CANDU-specific progress from refurbishments and construction over the last several decades.

In the end, the extra work (and extra risk) to build a new style of reactor would not result in any real improvement over CANDU.

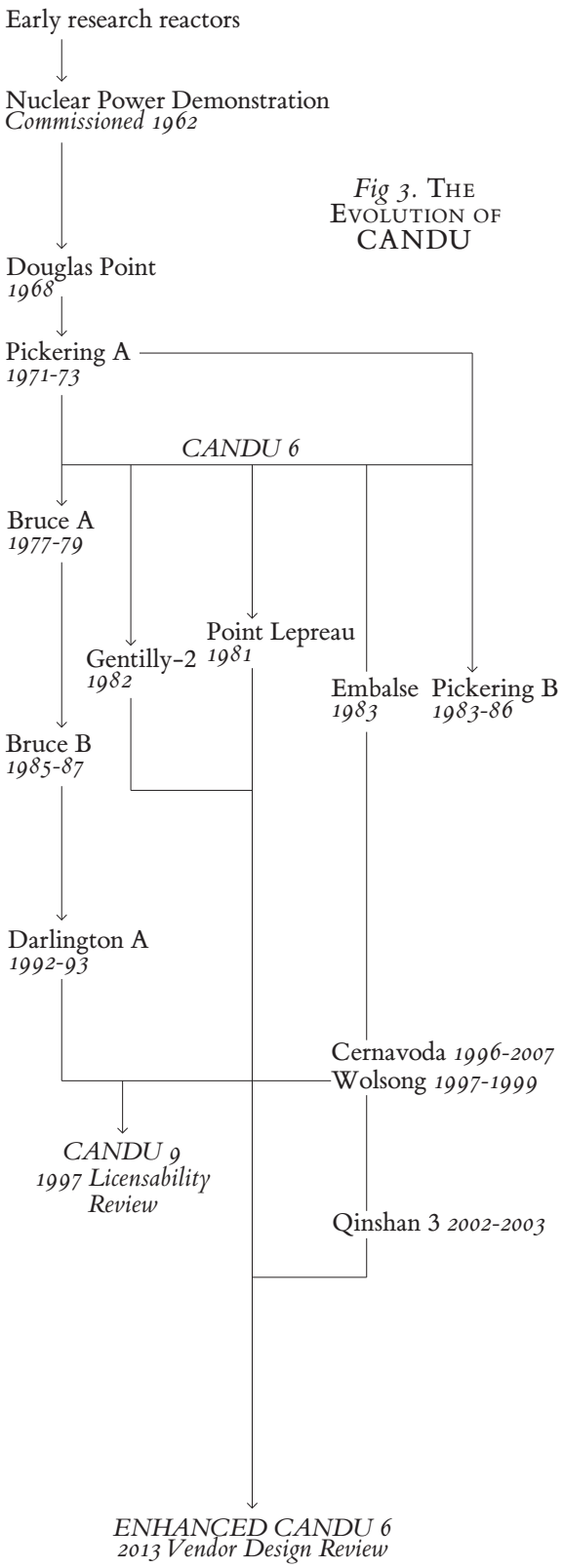


Fig 3. The Evolution of CANDU

CANDU: MORE THAN A GOOD BRAND

CANDU is a stellar nuclear technology. Named one of Canada's top engineering achievements,[26] it is the only reactor that checks all three of the following criteria.

1. **Built by and for Canadians**, maximizing energy security and economic benefit
2. **Proven to supply affordable**, clean power at scale to Canadian provinces
3. **Future proof**, out-competing advanced designs and giving Ontario a competitive edge in exports

The result is a low-risk, high-benefit reactor specifically suited for Canada's needs.

1. Built by and for Canadians

CANDU is the only Canadian-designed nuclear power reactor. So strongly is it embedded in Canadian businesses, labour, research laboratories, and universities, that despite successful exports to Romania, Argentina, South Korea, and China, the CANDU supply chain never left Ontario.[27]

Building new CANDU ensures the highest degree of control over our nuclear technology, allowing us to drive innovation to serve Canada's needs, whether through the continued use of natural uranium fuel, localization of manufacturing and jobs, flexible sizing of units to meet the needs of various provinces, or leading the booming medical isotope market.

We highlight two features of CANDU that, by design, prioritize **local economic opportunity** and **energy security** for Canadians:

- Completely local manufacturing through the avoidance of massive forged pressure vessels
- The use of natural, unenriched uranium fuel

Local Economic Opportunity

At CANDU's origin, Canada lacked—as do most Western economies today—the heavy forging capacity to make pressure vessels, giant stainless steel tanks used to increase the pressure, and therefore boiling point, of the water used to cool the reactor. By splitting the pressure system into smaller pressure tubes, Canada bypassed the need for massive vessels and retained its ability to handle all of the manufacturing in-province.[28,29(p1)] Continued local opportunity has made Ontario home to the only manufacturer of large nuclear components left in North America.[30]

In addition to keeping jobs local, the pressure tube configuration makes the reactor core fully rebuildable, boosting employment at mid-life to give units 3 to 4 decades of extended, safe operation (and potentially much more, as the core could theoretically be rebuilt multiple times providing the concrete structures of the plant remain fit-for-service).[31] Such refurbishments are ongoing at the Bruce and Darlington nuclear sites. Creating 35,000 jobs in the skilled trades, they are a major contributor to the vibrancy of Ontario's nuclear sector and its preparedness for new builds.[32,33]

Local benefit was felt from the very beginning. One historian describes the atmosphere during the construction of Douglas Point, the first CANDU-type reactor in Bruce County:

> "All of a sudden jobs were plentiful and people were busy. The prestige of having such a unique development as nuclear power began to interest the people. Perhaps the 'big times' had once again come to Bruce. Not since the days of the great timber and fishing harvests had Bruce seen so much activity, excitement and employment." [34(p208)]

Today, Bruce County is as alive as ever, and CANDU supports no fewer than 60,000 high-quality, largely unionized jobs and 200 local businesses in Ontario alone (*Fig 5)*. This contributes to a thriving middle class that keeps wealth within the province rather than sending it out.[35] Local spending means that every dollar invested in CANDU adds around $1.40 to the Ontario GDP.[36]

Energy Security

As shown by the European energy crisis of the last two years, energy is only as secure as its fuel supply.

CANDU has a leg up on other reactors because it uses natural, rather than enriched, uranium thanks to unique heavy water physics. No other reactor option is able to use natural uranium, meaning CANDU is our only opportunity to keep fuel supply domestic.

Although Canada is a major uranium producer (22% global market share), we do not enrich uranium per international treaty.[37] No matter how much uranium we pull from mines in Saskatchewan, using enriched fuel will require buying it from a small handful of countries. Atop the list of uranium-enriching countries is Russia, with nearly a one-half global market share.[38]

Table 1. World Commercial Uranium Enrichment

Country	Company	Share (2020)
Russia	Tenex	46%
Germany/Netherlands/UK	Urenco	22.8%
France	Areva	12.5%
China	CNNC	10.5%
USA	Urenco	8.1%
Other		0.1%
Total		**100%**

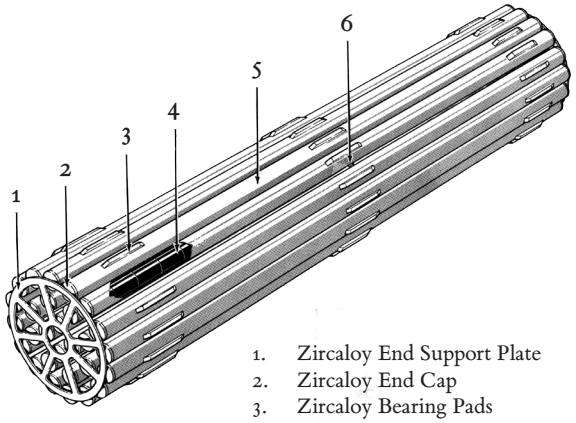
Source: World Nuclear Assocation

Inherent fuel security was a major selling point for early CANDU builds, when the alternatives were coal imports from the United States or else buying enriched uranium from foreign vendors.[39(p190)] In the time since, the advantage of CANDU's fuel sovereignty has only become clearer. Since Russia's invasion of Ukraine, half of the world's nuclear fleet realized it depends for fuel on a country willing to weaponize its energy exports.[40]

All other large nuclear options for Canada, including the French EPR, American AP-1000, or Korean APR-1400, use enriched uranium. As countries around the world seek vendors to replace Russian fuel enrichment, Canada can do its part by relying on natural uranium via CANDU rather than cutting into a limited supply of non-Russian-enriched uranium to fuel light water reactors.[41,42]

Fig 4. CANDU Natural Uranium Fuel Bundle

Fully made in Canada and the size of a piece of firewood, each CANDU fuel bundle makes around 1,100 MWh of electricity, enough to power 100 homes for a year.



1. Zircaloy End Support Plate
2. Zircaloy End Cap
3. Zircaloy Bearing Pads
4. Natural Uranium Pellets
5. Zircaloy Fuel Sheath
6. Interelement Spacers

Fig 5.
Ontario's CANDU Supply Chain

Source: Ontario Power Generation, Bruce Power

Stouffville
Stanmore Equipment Inc.

Deep River

Pickering
AREVA NP Canada Ltd.
Black & McDonald Ltd.
CALM Management Consulting Inc.
Durham Instruments
Ian Martin Group
Nucleom
RCM Technologies Canada Corp.
Tetra Tech
TRC Ltd. Industrial Sales & Manufacturing
UCC Industries International

Ajax
Jag Mohindra Consutling Services

Whitby
AeroTek Manufacturing Ltd.
BDI Canada Inc.
Fastenal Canada
Forterra Pipe & Precast Ltd.
Hard-co Sand & Gravel Ltd.
Linde Canda Ltd.
Pottinger Gaherty Environmenal Consultants Ltd. (PGL)
Quantum CNC Inc
Rivett Architectural Hardware Ltd.
Sargent & Lundy
StonCor Group

Port Perry
Luchka HydroVac

Peterborough
BWXT Nuclear Energy Canada Inc.
Rolls-Royce Civil Nuclear Canada Ltd.

Clarington
B&D Tractor Services
Black & McDonald Ltd.
Crossby Dewar Inc.
Ontario Power Generation
Worley Parsons Canada Services Inc.

Bowmanville
A&C Tool Inc
Coco Paving Ltd.
Detox Environmental Services Ltd.

Courtice
Black & McDonald Ltd.
Crossby Dewar

Port Hope
Cameco

Cobourg
CAMMDA Corp.
McMaster-Carr Supply Co.

Colborne
Dufferin Concrete/Holcim Canada Inc.

Scarborough
Avon Fluid Systems Technologies Inc.
Interline Wholesale Hardware Distributors

Deep River
Canadian Nuclear Laboratories Ltd.

Arnprior
GE Hitachi Nuclear Energy Canada
Nu-Tech Precision Metals Inc.

Oshawa
Acklands Grainger Inc.
Badger Daylighting Inc.
Coco Paving Inc.
Crane Supply
Desco Plumbing & Heating Inc.
Dufferin Construction Co.
Dulux Paints/PPG Architectural Coatings Canada Inc.
G&K Service Canada
Guillevin International Co.
Hertz Equipment Rental Ltd.
Peacock Lumber Ltd.
Ryder Truck Rental Canada
United Rentals of Canada
Westburne/Rexel Canada Electrical Inc.

Arnprior

Ottawa

Belleville
Westburne
Tenaquip Limited
Kleton

Kingston
Anvil International
Fastenal
Praxair
Nedco
Eastern Fluid Power Inc.
Advanced Solutions Inc.
Acklands-Grainger

Cornwall

Ottawa
BuildForce Canada
BWXT Medical Ltd.
Nordion

Cornwall
Sumtotal Systems Inc.

Peterborough

Kingston

Belleville

Port Hope

Colborne

Cobourg

Clarington

Bowmanville

Toronto
Aecon
Amec Foster Wheeler
ASA Alloys/Canadian Speciality Metals USD
Avensys Solutions
Burns & McDonnell
Bremar
Deloitte LLP
Eckler Ltd.
EllisDon Corp.
Faithful + Gould Inc.
Globotech Inc.
Granitetown Services Inc.
Hanford Lumber Ltd.
Hydro Aire
Hydro One
Information System Architects Inc.
Jensen Hughes Consulting Canada
Kiewit
Kinetrics Inc.
Knightsbridge Human Capital
KPMG Law LLP
McCarthy Tetrault
National Concrete Accessories
Nuvia Canada Inc.
Shawcor
Sierra Systems Inc.
Tundra Technical Solutions

Stoney Creek
Dynarack Inc.
Liburdi Automation Inc.
TOSHIBA International Products-Canada (TIPCA)

Hamilton
Crane Supply
Dalpro Technologies Inc.
Pitton Plumbing & Heating Inc.
R.E. Glover Inc.
Resource Equipment Ltd.
Stern Laboratories Inc.
Unified Engineering
University Network of Excellence in Nuclear Engineering (UNENE)

Burlington
ABB Automation Inc.
Aerotek
Air Liquide Canada Ltd
Applus+
Clean Harbours Canada Inc.
CTSNA Commissioning & Technical Services Ltd.
GE Power
Gerrie Electric Wholesale Ltd.
Konecranes Canada Inc.
Laker Energy Products Ltd.
Laveer Engineering Ltd.
Marsh Metrology/Accredited Calibration Services Inc.
Platecon Projects Ltd.
Seals Unlimited
Stern Laboratories Inc.
Toshont Power Products

Oakville
Acuren Industrial Services
High Reach Inc.
Hooper Welding Enterprises
Javelin Technologies Inc.
Laker Energy Products Ltd.
Levitt-Safety Ltd.
Promation Nuclear
Redirack Storage Systems/ Econo Rack Inc.
Redrock Ltd.
TISI (Team Industrial Services) Canada Inc.

Milton
Prothane Inc.

Georgetown
Howell Pipe & Supply/Dasco Ltd.

Brampton
ABB Inc.
Complete Survey Solutions
FJL & Associates Inc.
Senior Flexonic (Canada) Ltd.
Texcan Division of Sonepar Canada Inc.
Uline Canada Corp.
Energy Solutions Canada

Etobicoke
Triumph Gear Systems

Mississauga
Atlas Copco Canada Inc.
Canadian Bearings
Air Products Ltd.
Canadian Plate & Profiles Inc.
Canadian Springs/Aqua Terra Corp.
Candu Energy
Comco Pipe & Supply/ Russel Metals Inc.
CPUS Engineering Staffing Solutions Inc.
Eaton Industries Canada
Easy Access Storage Co.
Energy Solutions Canada
Gilbert Steel Ltd.
GN Johnston Equipment Co. Ltd.
Golder Associates
Hatch
Hilti (Canada) Corp.
Hite Engineering Corp. Inc.
Integrated Networking & Systems Inc.
KONE Canada
Lakeside Process Controls
McCann Equipment Ltd.
Mississauga Electrical Supply Co.
Newman Hattersley Ltd.
Motion Electric Motor Services
Nilfisk Advance America Inc.
RN Tooling Corp.
Roan International Inc.
Rubberline Products Ltd.
SGS Canada Ltd.
SNC-Lavalin
Staples Advantage Canada/ Corporate Express Canada Ltd.
Stuart Hunt and Associates Ltd.
Tetra Tech
Try Hard Industrial Supply Co. Ltd.

North York
Algal Engineering Ltd.
Conval Equipment
Deltek Inc.
Giffin Sheet Metals Ltd.
Morningstar Industries Ltd.
Jacobs Engineering Group
Triump Gear Systems

Richmond Hill
Arcadis Canada Inc.
Compugen
Johnson Controls
Record Technology & Development/ Zodar Tool & Die Ltd.
Wise Environmental Solutions Inc.

Not all suppliers are listed

2. A proven solution

Despite the novelty of today's energy challenges, CANDU offers a proven solution. Decades of experience have built CANDU's resume of:

- Affordability
- Rapid capacity additions at scale
- World-record reliability
- Emissions reductions with a just transition for workers

No technology can promise these qualities without proven experience. Whereas alternative and first-of-a-kind reactor options present technology risk or unproven economics, CANDU removes these uncertainties: we know that if we build it, it will meet the rigorous criteria for supplying affordable, stable, low-emissions, bulk power.

Affordability

Throughout its history, the affordability of CANDU power, combined with its reliability and low emissions, has attracted businesses to Ontario. As offshored manufacturing and supply chains return to the province, building new CANDU sends a strong signal that Ontario is open to business investment for the long term.

Decades of operational data prove that CANDU makes economical power. Even with units at Bruce and Darlington offline for refurbishment (adding temporary costs), CANDU delivers the cheapest power in Ontario after legacy hydroelectric dams, at rates 89% that of natural gas, 65% that of wind, and just 20% that of solar.[43]

Although Canada has no direct experience with non-CANDU reactors, international benchmarking of Ontario Power Generation's (OPG) fleet from 2016 found that:

> "On a cost performance assessment, Pickering and Darlington compare very favourably to PWR/BWR [light water] reactors by reference to TGC [total generating cost] per unit. Pickering's performance, similar to Darlington, is that it is **among the lowest cost nuclear generators in North America**." [44] (emphasis added)

Despite relatively larger staffing requirements for CANDU (which increases operating costs in the form of high-quality jobs), there are several avenues for savings compared to Light Water Reactors. For example, the efficient use of non-enriched uranium means that CANDU fuel costs are effectively the lowest of any nuclear reactor in the world.

Table 2. OEB Regulated Rates by Electricity Source

Source	Rate (cents/kWh)
Hydropower	6.1
Nuclear	10.1
Natural Gas	11.3
Wind	15.4
Bioenergy	25.8
Solar	50.2

Source: Ontario Energy Board, Regulated Price Plan Report 2022. [43]

CANDU's affordability can withstand construction hiccups. Although it is clearly preferable for projects to come in on-time and on-budget, the Financial Accountability Office of Ontario (FAO) found that a 50% cost overrun on every current refurbishment project (totaling $13 billion extra) would raise CANDU costs to consumers by less than one cent per kilowatt-hour (kWh).[45] Even in this unlikely case, Ontarians would still pay less for nuclear power than for natural gas, solar, wind, or biomass.

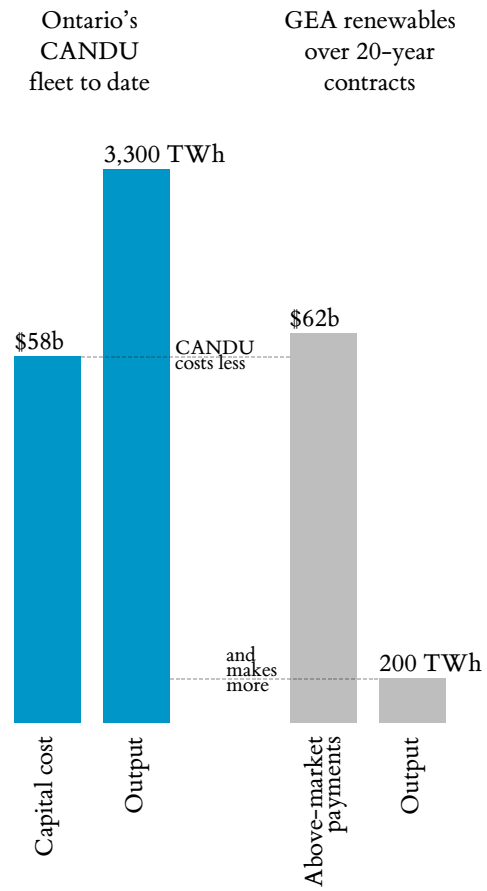
More evidence of CANDU's bulletproof affordability is Darlington. Construction at Darlington came as electricity demand growth tapered off in the early 1990s, and low projections led to an expensive two-year pause on construction.[46] During this time, the site racked up billions in interest payments that totaled 40% of the end project cost. And as a 4-unit site compared to the 8-unit Bruce and Pickering stations, its electricity sales would be fewer with which to recoup costs. Yet when completed in 1993, it right away joined Ontario's fleet of low-cost generators, operating at just 3.7 cents per kWh in 2014, prior to refurbishments.[44]

How is that possible? It is sometimes said that nuclear reactors are an expensive way to make affordable power. Indeed, what sound like (and are) large upfront costs become affordable to consumers because of the sheer volume of electricity sales, around-the-clock for decades, over which to spread these costs.

For comparison, the capital cost of Ontario's CANDU fleet and the lifetime costs of the GEA renewables contracts are roughly equal (both around $60 billion in 2021 dollars). However, at mid-life the CANDU fleet has already produced 3,300 TWh—over 16 times the electricity that the renewables contracts will make over their full combined lifetimes (200 TWh). For the same price as the GEA contracts, which make roughly 10 percent of the province's electricity, Ontario could double its CANDU fleet, which already makes 60 percent of it.[47,48]

And CANDU will keep generating for decades. By the time its contract expires in 2064, the Bruce station will have made over 6,000 MW of nearly continuous power for just shy of a century, enough to cover about 25 years of Ontario's total electricity use at current levels. A long-term, fixed-rate contract of just 8.07 cents per kWh (significantly below the average supply cost) is allowing Bruce Power to absorb the cost of a $13 billion refurbishment project while guaranteeing decades of price-stable power to Ontario's citizens and businesses.[49]

Fig 6. Comparing CANDU and GEA Costs

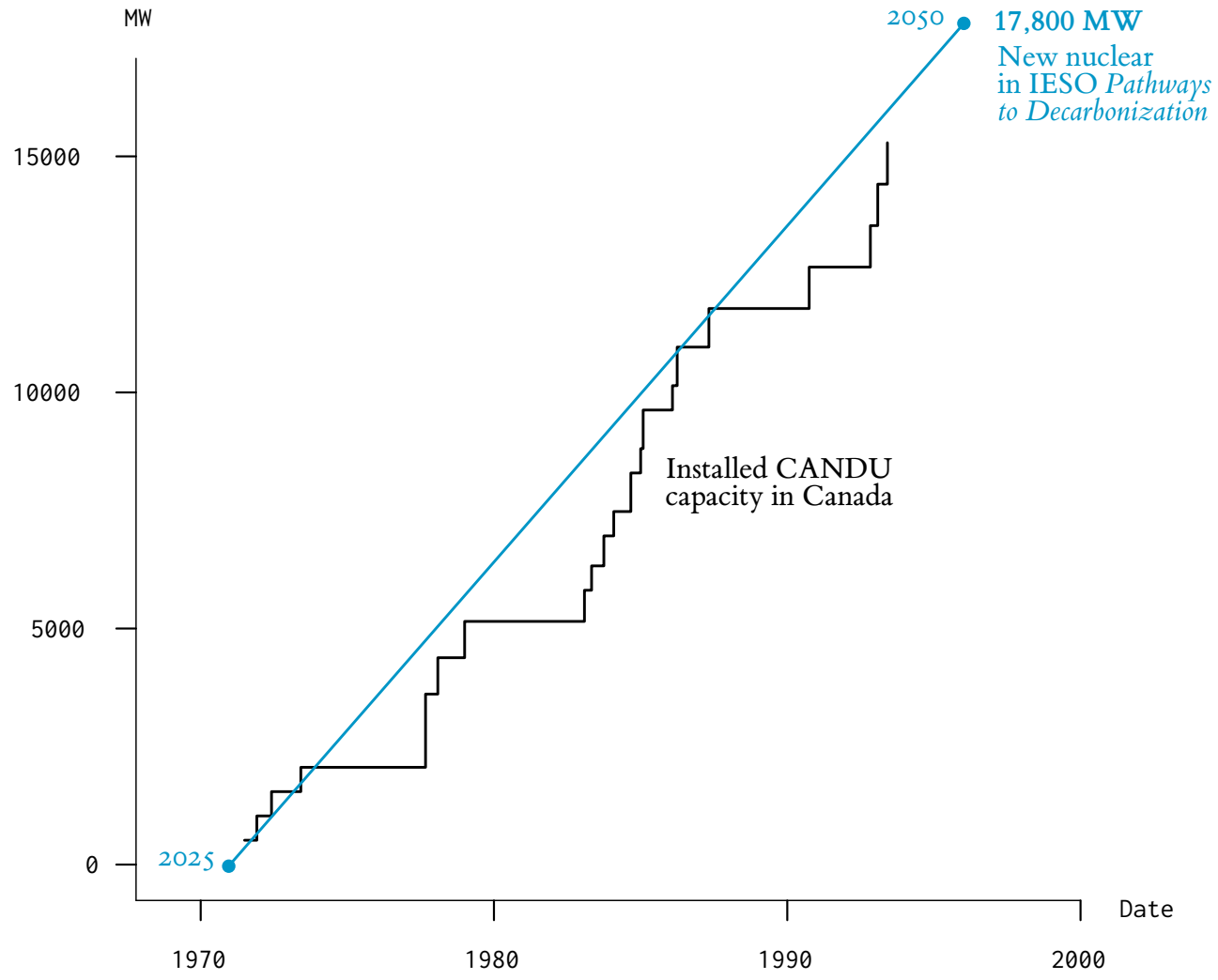


Dollar amounts in 2021 CAD

Rapid capacity additions at scale

With urgency to meet electricity demand, speed and scalability are obvious considerations. Ontario need not rely on hypotheticals to know whether CANDU can meet needed capacity additions at speed. Between the late 1960s and early 1990s, Ontario's CANDU buildout matched the pace of the IESO's highly ambitious *Pathways to Decarbonization*. As the result of cohesive industrial policy, Ontario Hydro and Atomic Energy of Canada Limited commissioned, within Canada alone, 22 CANDU units in 22 years: 20 in Ontario, 1 in Quebec, and 1 in New Brunswick. Within the career of a single worker, Ontario went from having zero nuclear power to having a low-carbon grid powered two-thirds by nuclear plants that could offer employment to the worker's great-great-grandchildren.

Fig 7. Canada's CANDU Buildout vs. IESO's Pathways to Decarbonization



The scale of the buildout proved that large amounts of nuclear can keep the electric grid healthy. In contrast, a less than 15% share of variable renewables has already led to major grid operation challenges, indicated by the need to export massive amounts of electricity to cope with sudden off-peak spikes. Between 2004 and 2014, as wind power was introduced, Ontario's net electricity exports rocketed from virtually none to as high as 20 TWh per year—nearly a Pickering Nuclear Generating Station's worth of electricity that Ontarians are forced to pay for but cannot use (the selling cost is far below what wind generators are contractually paid).[50]

Beyond its track record for speed, CANDU also has a material headstart on other designs. The Enhanced CANDU 6, the latest iteration of CANDU, and a larger variation, the ACR-1000, are the only new designs to have passed all three stages of the extensive Vendor Design Review (VDR) by the Canadian Nuclear Safety Commission (CNSC).[59, 74]

Decades of reliable electricity

Reliable power is essential for attracting and keeping businesses in Ontario, and CANDU delivers.

Several unique features contribute to CANDU's world-record uptimes. Among them is on-line refueling. Whereas other reactors have to shut down at regular intervals to load fresh fuel, CANDU allows for continuous refueling at full power (another benefit of the pressure tube design). This led Pickering Nuclear Generating Station to hold, for over 20 years, a world record among nuclear plants for 894 days of non-stop power generation until Darlington Unit 1 ran for 1,106 days.[51]

A number of efficiencies arise from on-line refueling. Freedom from regular outages means more flexibility to schedule maintenance, ensuring electricity demand is always met, even when some units are temporarily down for upkeep beyond everyday maintenance.

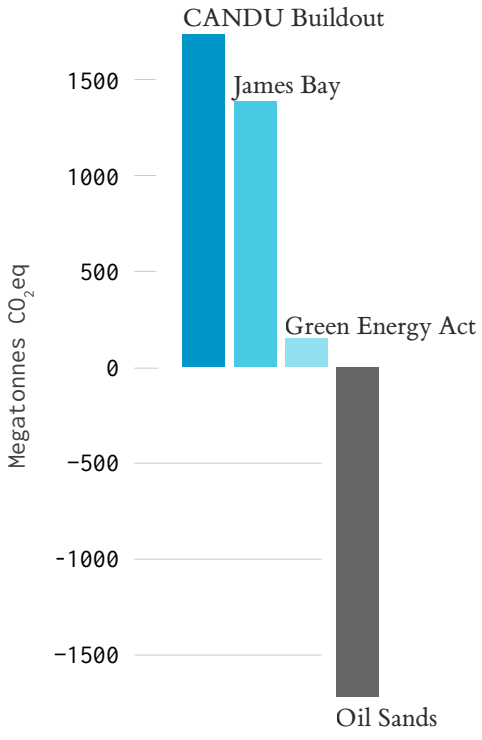
Climate hero

Ontario is in a small club of industrialized economies to have decarbonized their electric grids, and we did it with CANDU.

The CANDU buildout was the largest clean energy initiative in Canadian history, surpassing the annual output of the colossal 17,000 square kilometre James Bay hydroelectric project on a sector footprint smaller than 20 square kilometres, mining and fuel processing included.

If assumed to displace gas generation, CANDU reactors in Canada alone offset emissions from the Athabasca Oil Sands, the country's largest emitter, responsible for 10% of yearly total greenhouse gases.

Fig 8. Avoided Emissions from Canada's Largest Energy Projects



Note: Shown are avoided emissions from displaced gas generation (hypothetical) over project lifetime to date. Negative values indicate real emissions from oil sands projects.

Authorized Nuclear Operator Dan Campbell stands in front of steam turbine at Bruce Nuclear Generating Station Unit 4, Decouple Media

From the early days, CANDU avoided coal. The very pricing agreement for the first four units at Pickering factored in the avoided costs from the 4,000 MW coal plant that would have been built in its place (and been the largest coal plant in North America).[28] Each new CANDU secured clean bulk power that kept emissions low and set the stage for the coal phaseout. Then, from 2005 to 2014, the restart of reactors at Pickering and Bruce made 90% of the electricity needed to permanently oust coal from Ontario. With this, CANDU made a major contribution to ending smog days in the Greater Toronto Area, of which there were over 50 in 2005.[8]

Ensuring a Just Transition

When CANDU displaces fossil fuels, it does not displace jobs. In 2013, many of the operators and skilled workers at the recently-closed Nanticoke coal station, Ontario's last, brought their years of expertise to CANDU nuclear plants. Not only did the transition provide income security and better working conditions, but it kept valuable human capital within the energy sector.

In a short film by *Decouple Media* on nuclear power in Ontario, Dan Campbell describes his transition from being an operator at Nanticoke to one at Bruce Nuclear Generating Station:

> *Interviewer:* You went from being the problem to being the solution, but doing very similar work.
>
> *Dan Campbell:* Yeah, and unknowingly to me at the time. I was concerned about how I was going to provide for my family. I was just appreciative to have the opportunity to make more money, become better trained, get a better job, and have that financial security. [52]

3. Future-proof

CANDU has always been a reactor ahead of its time. Even today, a list of its features sounds like an advanced theoretical reactor concept.

- Can run natural uranium, advanced fuels, and the spent fuel of other reactors.[53]
- Makes a large portion of the world's medical isotopes, used to treat cancer, make diagnoses, sterilize medical instruments, ensure food safety, and more. Continuous research and implementation is helping CANDU meet a quickly growing market for medical and other isotopes.[54,55]
- Has flexible sizing, able to be built for various markets with standardized components, from the 300 MW range of SMRs to the gigawatt-scale of large reactors.[56]
- Enjoys factory fabrication of critical reactor components.[57]
- Has inherently large safety margins thanks to reactor physics and layout.[58]
- Has had no major accidents in over 50 years of operation.

The difference between CANDU and other advanced or first-of-a-kind reactors is that there are over 25 full-scale CANDU units worldwide, with decades of R&D spending, real-world innovation, construction, and operations experience under their belt. A living design, CANDU has become more, not less, competitive with the years and will remain so far into the future.

Fully modern

The latest iteration of CANDU, the Enhanced CANDU 6 (EC6), is a 700 MW reactor that embodies 50 years of learning and improvements. Past the VDR (and design-certified more recently than the AP-1000) the EC6 is a state-of-the-art reactor ready to build.

Funding for further modernizations, whether provincial or federal, could accelerate Enhanced CANDU reactors of larger sizes that would still benefit from standardized components.

Don't short the export

Canada's export position also benefits from CANDU. While state-backed corporations flood the reactor export market with light water designs, the heavy water reactor market remains underserved. Countries like Romania, Argentina, and India have specifically sought CANDU exports for the fuel flexibility, a feature that has become even more attractive as countries seek independence from Russian uranium exports.[41]

CANDU not only carves out a niche for Canada but enables fuel supply agreements unavailable for light water reactors. Standard course for Russia and China, fuel agreements would boost the competitiveness of Canada's export package and create added revenue.

Romania is eager to add two new EC6 units to its Cernavoda site, which already hosts two CANDU 6 units.[71] With shared international financing, this project represents a low-risk path for the federal government to re-enter the export market with the latest generation CANDU at the request of an international partner.[72]

3. The window of opportunity is now

To meet capacity shortfalls and avoid a surge in natural gas, work on new CANDU should begin promptly. Fortunately, Ontario is in an excellent position. Refurbishments at Bruce and Darlington have geared up the CANDU supply chain and workforce as well as proven Ontario's ability to deliver CANDU megaprojects on-time and on-budget. To preserve and make use of this high degree of readiness, we must seamlessly transition our nuclear sector from refurbishments to new CANDU builds.

A $26 billion headstart

CANDU refurbishment refers to the replacement of key parts, such as feeders, pressure tubes, and steam generators, allowing a unit to run safely for another 30 to 40 years. Constant research, engineering, and iterative learning (for instance, with new metal alloys or advanced quality inspection techniques) means reactors are returned to a better-than-new condition.

Refurbishments are similar to new builds in both scale and scope, creating full-scale practice for new CANDU. This also means that the hundreds of millions of dollars spent by Bruce Power and OPG on refurbishment R&D can be directly leveraged to improve new units.

Economics likewise benefit. Because the same components are needed for refurbishments and new builds, instead of retooling their shops, suppliers can simply increase the quantity of orders already underway, driving down unit costs.

In some ways, refurbishments are even more difficult than new builds, making their success all the more impressive; unlike new construction, refurbishments occur within the tight confines of existing concrete structures, sensitive equipment, and radiation.

Refurbishments are a huge vote of confidence in CANDU that is paying off. As the largest ongoing infrastructure projects in Canada, they will last a planned 17 years, costing $26 billion and creating over 30,000 jobs.[45] To proceed on-time and on-budget with any project of this scale is a feat of project delivery, yet Ontario is succeeding. Six years in, despite the challenges of the COVID-19 pandemic, both projects are not only on-budget but ahead of schedule thanks to meticulous planning, execution, and real-time learning by OPG, Bruce Power, and their network of local contractors.[60,61]

An investment in people

Refurbishments are a $26 billion investment not just in assets to make clean power for decades, but in people with the skills to build, operate, and regulate them. If opportunities in CANDU end with refurbishments, it would constitute a major setback to jobs, energy security, and emissions.

While jurisdictions like the United States are seeing their nuclear workers retire without replacement,[62] CANDU refurbishments are attracting young people to the skilled trades. In the last 5 years, the portion of CANDU workers under age 26 has quadrupled, and all are beginning their careers with irreplaceable hands-on experience with the technology.

No design can compensate for an unpracticed workforce. Despite proven construction of the AP-1000 in China, for example, the first two builds in the U.S. turned into a decade-long, high-publicity saga that saw Westinghouse file for bankruptcy. An analysis by the DOE traced the challenges at Vogtle back to several causes, including a shortage of experienced labor, supply chain delivery issues, poor risk assessment, and limited understanding of the design—all unanticipated.[21]

Why experience matters

The importance of the CANDU refurbishments and their vitalizing effect on Ontario's nuclear sector cannot be overstated. It is not merely a nice bonus; it materially derisks all aspects of construction, operation, regulation, supply chain and workforce coordination, and fuel management.

Compared to novel reactor designs—as well as designs that Canada has never built, maintained, or regulated—CANDU has few unknowns, which translates to:

- Minimal technology risk
- More certain cost estimates
- Faster, higher quality construction
- Relatively efficient regulation

Even the simplest nuclear reactors are complex projects sensitive to public opinion that face an uphill battle to secure financing. Lowering project risk through every possible avenue is needed to attract finance, build momentum through repeated builds of a standardized design, and contribute meaningfully to a strong energy future.

Heavy water

Heavy water, or deuterium oxide, can be used indefinitely, meaning refurbishments do not require additional heavy water production. The drawback is that Canada, therefore, no longer makes heavy water at the scale needed for new CANDU builds.

In the near-term, the heavy water contained in Pickering Units 1 and 4 (coming offline in 2024), combined with existing inventory at the Canadian Nuclear Laboratories, should be sufficient to begin construction on new units.

Building 10 CANDU units, however, will require new facilities for heavy water production. Plans for new CANDU builds must factor this in, and preparation for such facilities should begin soon.

The case for new heavy water production is broader than CANDU. A fast-growing market is being driven by new applications in long-lasting OLED screens for smartphones and televisions, microchips and semiconductors, improved pharmaceuticals, fiber optics, and frontiers in lab biology, chemistry, and physics.[69] To tap into this market, Atomic Energy of Canada Limited (AECL) has partnered with Ontario-based companies to market existing supplies. Foreseeing supply shortages, these partnerships have taken recent steps toward new production,[70] which should be further accelerated.

Darlington New Nuclear Site

The Darlington New Nuclear Site, adjacent to the active Darlington site, is home to the farthest-along Small Modular Project in the West, a collaboration between GE Hitachi and OPG to build a BWRX-300.[63] The BWRX-300 is a 300 MW light water reactor, designed by the American-Japanese partnership GE Hitachi, with first operation planned at the site for the late 2020s.

The project has garnered welcome international and federal attention (and funding) for Ontario as a first-mover on SMRs, though OPG is far from the only customer of GE Hitachi, who has signed agreements with the United States, Poland, Estonia, Czech Republic, and others.[64,65]

CANDU + BWRX-300

Whereas CANDU refurbishments have materially prepared Ontario's nuclear sector for new builds, the Darlington SMR project has brought renewed political and financial intrigue.[66] By leaning into both CANDU and BWRX-300, Ontario can capitalize on the advantages of both, maintaining a durable and prestigious nuclear sector far into the future.

Just as valuable to the province as the BWRX-300 project is the land beneath it. As the only new site in Canada to have passed environmental permitting and received site preparation licensing by the CNSC, the Darlington New Nuclear Site is one of the most valuable properties in North America.[67] Repeating the licensing process for other sites, though it will be necessary to accommodate 10 CANDU reactors over the next two decades, can take 7 to 10 years per site under the federal Impact Assessment Act.[68] Expediting the impact assessment process for sites adjacent to licensed nuclear sites, such as a potential Bruce C site, would significantly boost Canada's energy security and climate progress.

With the urgency of building CANDU, the province should consider making use of the Darlington New Nuclear Site for the construction of the first new CANDU reactors. The site being licensed for 4,800 MW, it has more than enough room to fit two 700 MW or larger CANDU units alongside two BWRX-300 units. Doing so would secure the countless advantages of our homegrown reactor technology, shave a decade off the regulatory process to start construction, and more than double the utilization of the site compared to only building SMRs, while still reaping the benefits of first-mover status on a promising SMR design.

Building new CANDU at Darlington reduces project risk in multiple ways. For one, the location next to an operating site enables the shared use of facilities, suppliers, and workers, making construction cost less and move faster compared to more distant sites. Second, by avoiding the long process of developing a new site, Ontario bypasses vulnerabilities that could delay or jeopardize a new project, including lobbyist and activist obstruction.

The times are quickly changing

The decision to pursue SMRs at Darlington was made prior to the dramatic increase in demand projections and before federal and provincial support for new nuclear was so forthcoming. OPG has ample justification to incorporate new CANDU into its plans for the Darlington New Nuclear Site, and we believe it would receive broad coalition support for doing so.

What should be done?

If Ontario hopes to secure its supply of affordable, clean energy heading into fast-rising demand, **it should build new CANDU**. To do so, many pieces must align, requiring the careful planning that OPG, Bruce Power, and the IESO have shown themselves capable of through their refurbishment programs.

CANDU is bigger than any one company. Building new CANDU stands to unite industry, labour, and government behind a shared vision. To reflect this in practice, an enhanced design for CANDU, implementing the latest experience from operators, could be transferred back to an industry-led, pan-Canadian consortium. This would ensure broad benefit not just from the end-product (affordable, clean power) but from construction and licensing as well, while gaining from the diverse capabilities and financial depth of our domestic manufacturing base.

The provincial government should also consider leveraging its ownership of OPG—one of the most capable entities in the Western world for delivering large nuclear projects—to take a forward role and ensure the benefits of CANDU are properly valued.

To do so, Ontario's Minister of Energy should consider the following:

1. Urge OPG and Bruce Power to develop new sites for nuclear construction.

More than one site will be needed to accommodate a minimum of 10 CANDU reactors over the next two decades. Such development should begin soon, as the lead time can be several years.

2. Prepare firm plans alongside OPG for CANDU at the Darlington New Nuclear Site.

Firm orders are needed to break free from the stalemate between finance, vendors, and buyers all hesitant to take the first step.

3. Send a joint letter from nuclear operators and the Ministry of Energy to the federal government to open discussions on support for new CANDU projects.

There is no shortage of ways in which the federal government could support new CANDU, including:

- funding for modernizations
- accelerated heavy water production
- an expedited impact assessment process

As the federal government has provided funding and other support for novel reactor technologies across Canada, there should be no hesitation to provide similar investment in CANDU.

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