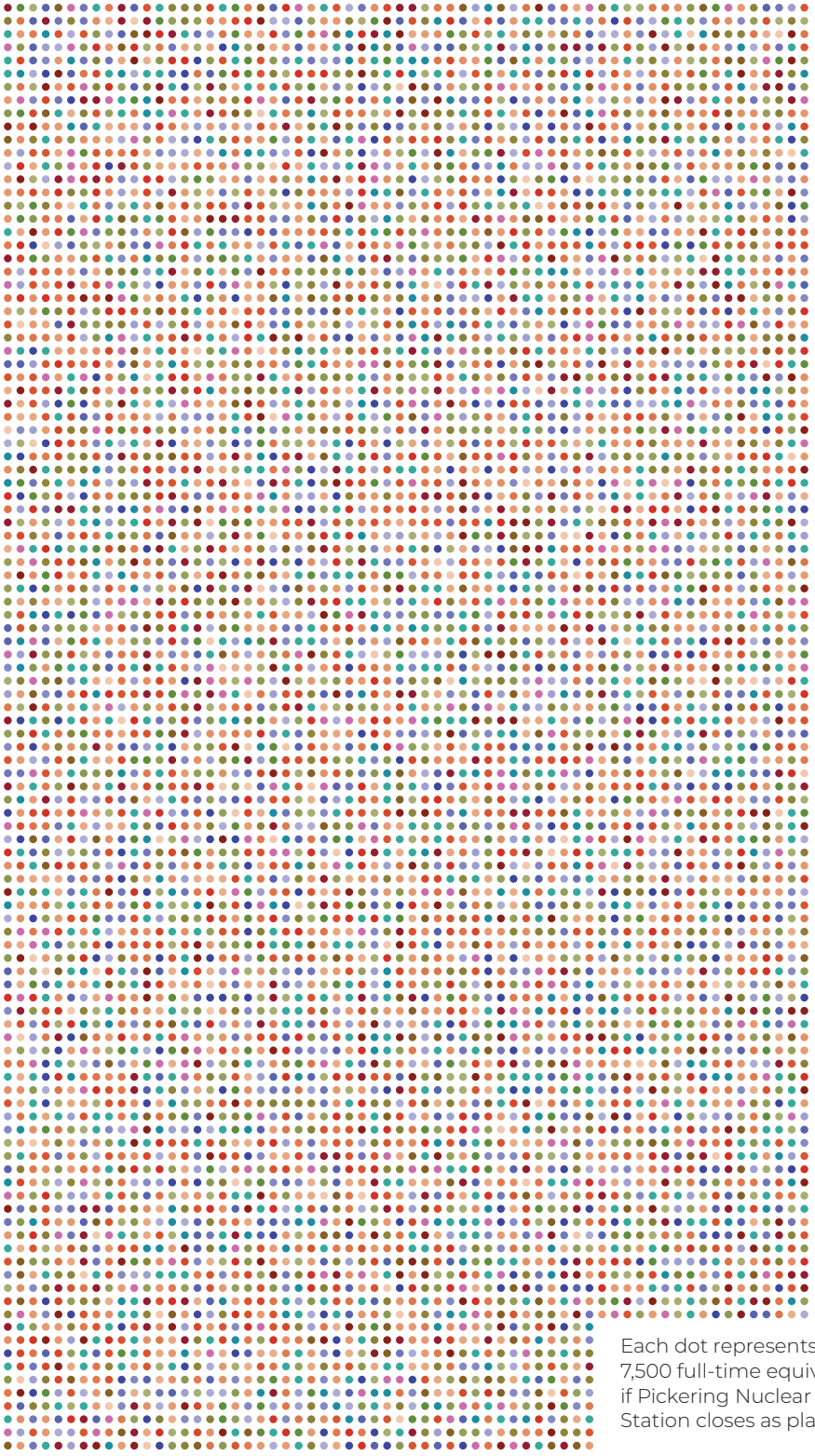
SAVE PICKERING

HOW ONTARIO CAN SAVE ITS CLEAN ENERGY FUTURE BY REFURBISHING PICKERING NUCLEAR GENERATING STATION



Each dot represents one of the 7,500 full-time equivalent jobs lost if Pickering Nuclear Generating Station closes as planned in 2025.

A REPORT from CANADIANS FOR NUCLEAR ENERGY

Save Pickering: How Ontario Can Save Its Clean Energy Future by Refurbishing Pickering Nuclear Generating Station

July 2022

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

Learn more at **c4ne.ca**

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The Time Is Now

Ontario faces an energy crossroad. Its world-class low-carbon grid is unprepared for the loss of 3.1 gigawatts of clean electric capacity from the Pickering Nuclear Generating Station. Yet Ontario Power Generation (OPG), the government-owned company that owns the plant, has pursued a plan to close it in 2025 despite a regulator-approved to refurbish it.

In this report, we argue that the continued operation of Pickering is of crucial importance to Ontario from an energy security, economic, and climate perspective.

The Government of Ontario must act now to secure Pickering's continued operation or else forfeit the province's climate leadership and strategic positioning as an economic and technological powerhouse for the world's electrified, low-carbon future.

Sincerely,

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

The Current Trajectory

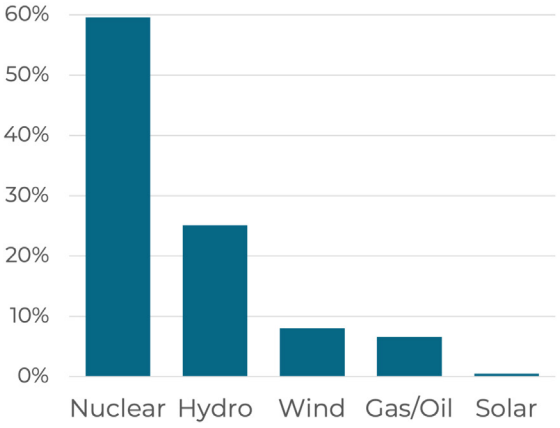
Losing the lead

Ontario was not always an energy role model. In 2005, thick coal smog blanketed the Greater Toronto Area for a total of 53 days,[2] and just two years later, the province's burning of coal contributed to Canada's all-time peak carbon emissions.[3] Today, however, smog days are long gone, and the climate progress that Canada has made since peak emissions can be largely attributed to Ontario's historic decrease in greenhouse gas (GHG) emissions.

What made Ontario a clean energy leader? Nuclear power. The restart of six CANDU nuclear units—four at Bruce Nuclear Generating Station and two at Pickering Nuclear Generating Station—provided 90% of the electricity needed to kick coal off the power grid by 2014.[4] Along with the Darlington Nuclear Generating Station, these plants today provide 60% of the province's electricity and constitute the bulk of Canada's nuclear sector, which sustains 76,000 direct and indirect high-quality jobs in STEM, business, and skilled trades. Refurbishments have played a large role in maintaining the strength and vibrancy of the sector.

Fig 1. Electricity Generation in Ontario, 2020

Transmission-connected generation only. Excludes behind-the-meter generation such as rooftop solar.



Source: IESO Year in Review

Despite its large population, Ontario outperforms all other provinces in terms of the carbon intensity of its electricity, save for those blessed with enough hydropower to cover 90% or more of their needs.[5] For carbon-intensive provinces without abundant hydropower, like Alberta, Nova Scotia, and Saskatchewan, Ontario's nuclear sector provides a model for scalable, deep decarbonization and energy security, while serving as a center of expertise for high-value nuclear projects.

And yet Ontario is at risk of losing its lead. In 2009, OPG, the government-owned company that operates Pickering Nuclear Generating Station, decided that by 2025 it would close rather than refurbish the plant's 3.1 gigawatts (GW) of generating capacity, which provides roughly 17% of the province's electricity.[6] This forgoes potential decades of reliable, carbon-free power at a time when securing such power is more important than ever.

The consequences will include a trifecta of rising emissions, reliance on imported natural gas, and dire capacity shortfalls. If Pickering goes offline as scheduled in 2025, emissions will rise by 8.7 megatonnes per year. The source of these emissions will be gas-burning power plants, some of which have sat mostly idle for a decade and are preparing to ramp up, and others which OPG spent $2.8 billion acquiring in 2020 in anticipation of Pickering's closure.[8] Yet this won't be enough to avoid capacity shortfalls. Ontario's grid operator, IESO, first identified coming supply gaps in 2013, and with the closure of Pickering this deficit could be as large as 3.6 GW by 2030. Factoring in goals to electrify the economy, this gap grows to a staggering 9.5 GW by 2030.[9]

Times have changed since 2009

OPG decided in late 2009 that it should forgo the refurbishment of Pickering Nuclear Generating Station B, in part to conserve resources for refurbishments at Darlington as well as an anticipated new CANDU build at Darlington B that was ultimately canceled in 2013. At the time, it looked like there were supply alternatives. The shale boom meant that Ontario could import natural gas from the United States cheaper than it could from Alberta and Saskatchewan, and since the province still burned coal, gas was considered a "cleaner" option. Hopes were also high for wind and solar energy following the 2009 Green Energy Act, which had not yet become the tens-of-billions-of-dollars policy disaster that continues to burden Ontario taxpayers even after the Act's repeal in 2018. OPG has since solidified its course with business decisions made under the assumption that Pickering would close, including the recent purchase of $2.8 billion of gas plants to replace Pickering's output and the formation of the subsidiary Laurentis Energy Partners to recycle the plant's heavy water.

We must change course

Facing new challenges, it no longer makes sense from a climate and electrification perspective to dismantle hard-earned, reliable, low-carbon energy infrastructure at a time when Ontario's secure energy future depends on crisis-level mobilization toward new capacity procurements. As the sole shareholder of OPG, the government of Ontario must provide the bold leadership needed to allow OPG to redirect its course. We offer **three major reasons** why Ontario must halt its decline as an energy leader by saving Pickering Nuclear Generating Station:

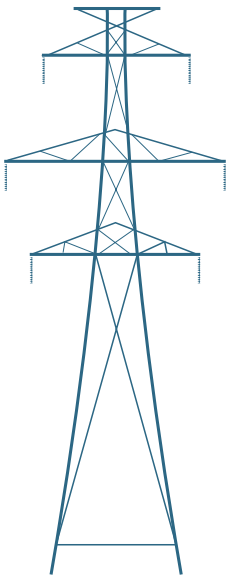
1 Pickering is needed to secure Ontario's **energy supply for an electrified economy**

2 Refurbishing Pickering **is the ultimate stimulus for the province's economy**.

3 **Climate action** requires not just preserving nuclear energy but building much more.

REFURBISHMENTS: POWERING THE NEXT GENERATION

Pickering Nuclear Generating Station is scheduled to close in 2024-2025, but the lifespan of the plant's "B" station, containing four reactor units of 515-525 megawatts each, could be extended by many years with a refurbishment. The refurbishment of Pickering B would be similar to the major component replacement and refurbishment at Bruce Nuclear Generating Station, requiring boiler and pressure tube replacements and control systems upgrades. The $8.8–10 billion investment required for the refurbishment is a cost-competitive way to maintain Ontario's low-carbon electricity and preserve the supply chain expertise and over 7,500 direct and indirect full-time-equivalent jobs that Pickering provides.[12]



Three Reasons to Save Pickering

1. Energy security and electrification

2. Economics and industry

3. Environment and climate

1. Energy Security and Electrification

Electricity demand on the rise

Mitigating climate change depends on our ability to: 1) reduce fossil fuel combustion for generating electricity, and 2) "electrify everything," that is, use electricity to power traditionally fossil-fueled sectors like transportation, heating, and industry.

"Electrify everything" is already underway in Ontario. Steelmakers like Algoma Steel and ArcelorMittal are swapping traditional blast furnaces for electric arc furnaces. And LG and Stellantis are moving forward on a massive battery plant to support electric vehicles. These investments could add 500 MW of near-constant electricity demand by 2030.

Combined with the loss of Pickering, rising demand has sent Ontario's grid operator, IESO, scrambling for new capacity, even loosening environmental and community consent practices for new project siting.[18] This paves the way for IESO to ramp up gas generation in order to meet demand.

Europe's experience during the winter of 2021-2022 has shown the risk of relying on gas imports for power and heat, with prices skyrocketing as high as $227 per megawatt-hour (MWh) in March 2022, compared to just $16 a year earlier.[13] That same month, owners of internal combustion engine vehicles in Ontario saw prices at the pump as high as 190 cents/litre, while the cost of charging an electric car stood at just 11 cents/kWh during off-peak times.[14] For comparison, fuel costs for a 100 km trip were $22 for a gasoline-powered Ford F-150, and just $3.20 for the electric Ford F-150 Lightning.

Moreover, Ontario's oil and gas is vulnerable to events out of its control, as the province imports nearly all of its supply from western Canada and the United States.[15] Over the last two years, US natural gas prices have quadrupled to their highest point since 2008,[16] and the country faces new supply challenges as it takes on the role of exporting gas to Europe to ease Russia's chokehold on supply.[17]

Ontario's nuclear assets are key to keeping money in the province while protecting it from the price volatility and geopolitical strings of energy imports.

The value of nuclear power is in its unique ability to produce **non-fossil, ultra-reliable, abundant,** and **affordable** energy.

Fig 2. US Natural Gas Futures, 2012-2022

Source: Trading Economics, 2 May 2022

Non-fossil electricity

If Ontario electrifies transportation, industry, and heating but does so with gas generation—precisely the result if Pickering is closed—then it is no more secure from price volatility and geopolitics than before. If the province *doesn't* electrify heating, then New England's experience shows, relying on gas for electricity risks winter blackouts, when Ontario's extensive use of gas for indoor heating gets priority on supply.[19]

Ultra-reliable electricity

For an electrified economy, reliability and dispatchability become criteria of the utmost importance for energy sources, as grid instability and blackouts threaten the economy's basic function. Unfortunately, weather-dependent, low-carbon options like wind and solar meet neither criterion. They have no ability to store fuel and present unforgiving periods of little to no output, which in Ontario have often coincided with humid summer heat waves or frigid cold snaps that cause energy demand to spike.

In contrast, nuclear energy promotes system reliability with high-inertia, rotating turbines and generators that can produce emission-free electricity for years non-stop. Pickering's world record of 894 days of continuous power output from a single unit stood for 22 years, eventually surpassed by Darlington Unit 1's world-record run of 1,106 continuous days of operation.[20]

Abundant electricity

With electrified heating, transportation, and industrial processes, the consequences of supply shortages go from economically severe to life-threatening. Concerningly, the Canadian Energy Outlook report, published by the Institut de l'énergie Trottier, foresees demand for electricity tripling by 2050.[57] An August 2021 report by Strategic Policy Economics finds the same, warning that even if Ontario makes significant efficiency gains in its use of electricity, its power generation must double or even triple by 2050 to support increases in demand while compensating for 11.4 GW of expiring contracts.[9] Given Ontario's sluggish action on new procurement, the decision to dismantle 3.1 GW of already-built, carbon-free power generating capacity at Pickering is a major setback to energy security.

Affordable electricity

Without cheap power, an electrified economy could make basic services less affordable. Despite the association of nuclear power with large upfront costs, it is a long-term investment that has borne fruit. Even with units at Bruce and Darlington offline for refurbishments, Ontario's nuclear fleet delivers the cheapest electricity after hydropower, at rates just 62% that of wind and 5 times cheaper than solar.[21]

Generation	***Price/kWh***
Hydro	5.8 cents
Nuclear	9.6 cents
Gas	12.5 cents
Wind	15.4 cents
Bioenergy	26.7 cents
Solar	49.8 cents

Source: Ontario Energy Board, 2021

COBALT-60

Pickering provides more than just electricity. Alongside production at Bruce, the plants produce half of the world's supply of Cobalt-60, a life-saving radioisotope used for cancer treatment and the sterilization of 40% of the world's single-use medical devices.[22]

Ontario's low-carbon nuclear grid

Pickering checks all the boxes for *non-fossil, abundant, affordable,* and *ultra-reliable* energy supply. Since the start of the coal phaseout in 2003, Pickering, Bruce, and Darlington have proven their ability to durably eliminate fossil fuels from Canada's most populous province, providing 60% of its power. In contrast, Germany, the model for the Green Energy Act and the world leader in wind and solar investments, relied on coal as the largest source of electricity on its grid in 2021 and has paid record prices to procure gas following its politically driven nuclear phaseout.[23]

The federal government has recognized the need for more nuclear power with its "SMR Action Plan." Small Modular Reactors, or SMRs, hold promise for electrifying less populous provinces and the far northern regions that rely on costly diesel generators. As for Canada's large population centers, the relatively small size of these reactors compared to existing CANDU technology does not lend itself to the heightened demand of an electrified economy. To date, the SMR Action Plan has resulted in a contract with GE Hitachi for a single 300 MW plant to come online in 2028 at the earliest.[24] We applaud OPG's involvement in this project and encourage an even greater ambition for new capacity, as ten of these new plants will be required to replace Pickering's output.

The closure of Pickering in 2025 would leave a painful, multi-year gap in nuclear generation before SMRs begin to produce power. The refurbishment and life extension of units at Pickering offer a clear solution to this gap. These investments will give the province some breathing room on GHG emissions, as well as buy time for the deployment of more CANDU units and the development of next-generation nuclear options. Keeping the Pickering plant as a licensed and active site also provides a significant future opportunity, as it is easier to add reactors to the site of an existing, approved nuclear plant than to find and win approval for a new site.

Maintaining Ontario's nuclear expertise is a significant economic opportunity as more provinces and countries seek to decarbonize their grids with nuclear power. Canada's hope of entering the blooming SMR nuclear export market and keeping alive the country's powerful nuclear sector lies with Ontario.

It isn't too late to save Pickering

The rationale for continuing the operation of Pickering has evolved over the last decade. OPG made the decision 13 years ago, when the heavy prices of wind and solar contracts from the GEA had only begun to set in; when the shale revolution had recently brought gas prices to new lows; when our burning of coal made cheap gas a "cleaner" option for Ontario; and when it was still expected that a new reactor at Darlington would count in the province's nuclear fleet. Fortunately, Ontario still has an opportunity to keep Pickering open.

NUCLEAR KNOW-HOW: KEEPING CANADA'S UPPER HAND

Unlike many other Western nations that have let their domestic nuclear labor force and supply chain atrophy by prioritizing novel designs over repeated build experience, Canada still has an ample, skilled labor force that is intimately familiar with CANDU technology and that is honing its craft at the Darlington and Bruce stations. Extending Pickering's operation presents an opportunity to maintain this strategic advantage among western countries, particularly as a promising SMR export market emerges.

The technical refurbishment

Any life extension of Pickering Nuclear Generating Station beyond its planned closure in 2025 will help alleviate short-term energy shortages. However, we believe a larger refurbishment of Pickering B merits serious consideration.

Ontario already has a regulator-approved plan for the refurbishment of the four units of Pickering B.[25] Additionally, Pickering A's units 1 and 4 were re-tubed in 1987 and 1993 and refurbished before their restarts in 2005 and 2003, when major components were swapped out for new ones. As a result, these two units have significant life left in them beyond their planned closure in 2025.

The refurbishment plan remains actionable, as the plant is licensed through 2028. But it must be put in motion soon. To limit interruptions and resulting cost overruns, work at Pickering should dovetail with the completion of refurbishments at Darlington, leveraging fresh experience in the workforce and supply chain, as well as avoiding layoffs of these skilled workers. For detailed recommendations on the refurbishment plan, see the ***Technical Recommendations*** section.

Well into the four-unit refurbishment project at Darlington, OPG has shown itself to be capable of undertaking refurbishments on-time and on-budget while upholding strict environmental and workplace standards.

A question of political will

The provincial ownership of OPG is an opportunity to change course, as the government has a broad responsibility to the well-being of Ontario's residents. Precedent for government action on important energy matters was firmly established by the coal phaseout, during which government-owned coal plants were directed to cease operation by their sole shareholder.[11,26]

Moreover, popular support is widespread. A majority of Canadians are open to supporting wider use of nuclear energy, in contrast to just 10% who oppose it, according to a 2020 poll conducted by Abacus Data for the Canadian Nuclear Association.[27] Investors also signaled their confidence in nuclear when demand for Bruce Power's $500 million bond issuance in November 2021 outstripped supply six to one.[28]

The unfulfilled promise of wind, solar, and Quebec hydropower

MPPs of all parties must understand that maintaining existing nuclear assets and starting to build more is the only viable route to low-carbon electrification in Ontario and provinces without abundant hydropower. Alternatives based on hydropower imports from Quebec are illusory, and attempted build-outs of wind and solar in Ontario have delivered low value for exorbitant prices.

Ontario cannot rely on Hydropower from Quebec

Imported hydropower from Quebec has been touted by groups such as the Ontario Clean Air Alliance as a one-stop solution to climate-friendly electrification.[29] This is misguided for several reasons.

1. Ontario already exports electricity to Quebec in the winter.

Since 2017, Ontario's IESO and Hydro-Québec have upheld a "seasonal capacity sharing agreement," in which Ontario imports 2 TWh of hydropower to displace gas generation during the summer but returns the favour in the winter to help Québec cope with its own generation shortfalls as their primarily electric heating causes demand to peak.[30] To replace Pickering solely with hydropower from Quebec, Ontario would have to quadruple its current hydropower imports. And to ensure year-round supply, it would have to effectively eliminate winter capacity sharing to Quebec.

2. Hydro-Québec is busy displacing coal and gas on other grids.

Hydro-Québec exports around 34 TWh annually,[31] 18% of which goes to Ontario. To compensate for Pickering's lost output using only hydropower from Quebec, Ontario would have to receive 85% of Hydro-Québec's total exports.

Furthermore, everywhere Hydro-Québec exports—New York, New England, Ontario, and New Brunswick—has factored Québec hydropower into its own decarbonization target. Ontario's electricity is already the least carbon-intensive of the bunch. From a climate perspective, Québec-Hydro should prioritize displacing coal in New Brunswick and gas in New England or New York, whose carbon intensity of 205 gCO2/kWh in 2020 was nearly 7 times higher than that of Ontario.[32]

3. Quebec's own carbon neutrality goals are straining their export ability.

In March 2022, Hydro-Québec revealed its Strategic Plan for 2022-2026, which notes that over 100 TWh of additional clean electricity will be required by 2050 to become carbon neutral. It announces that "energy and capacity balances are getting tighter," and that "additional electricity purchases will cost more" than in the past. Hydro-Québec has already pledge much of its remaining export capacity to New York and New England through contracts totalling 20 TWh.[33]

4. Required transmission upgrades could take 10 years and $1.4 billion.

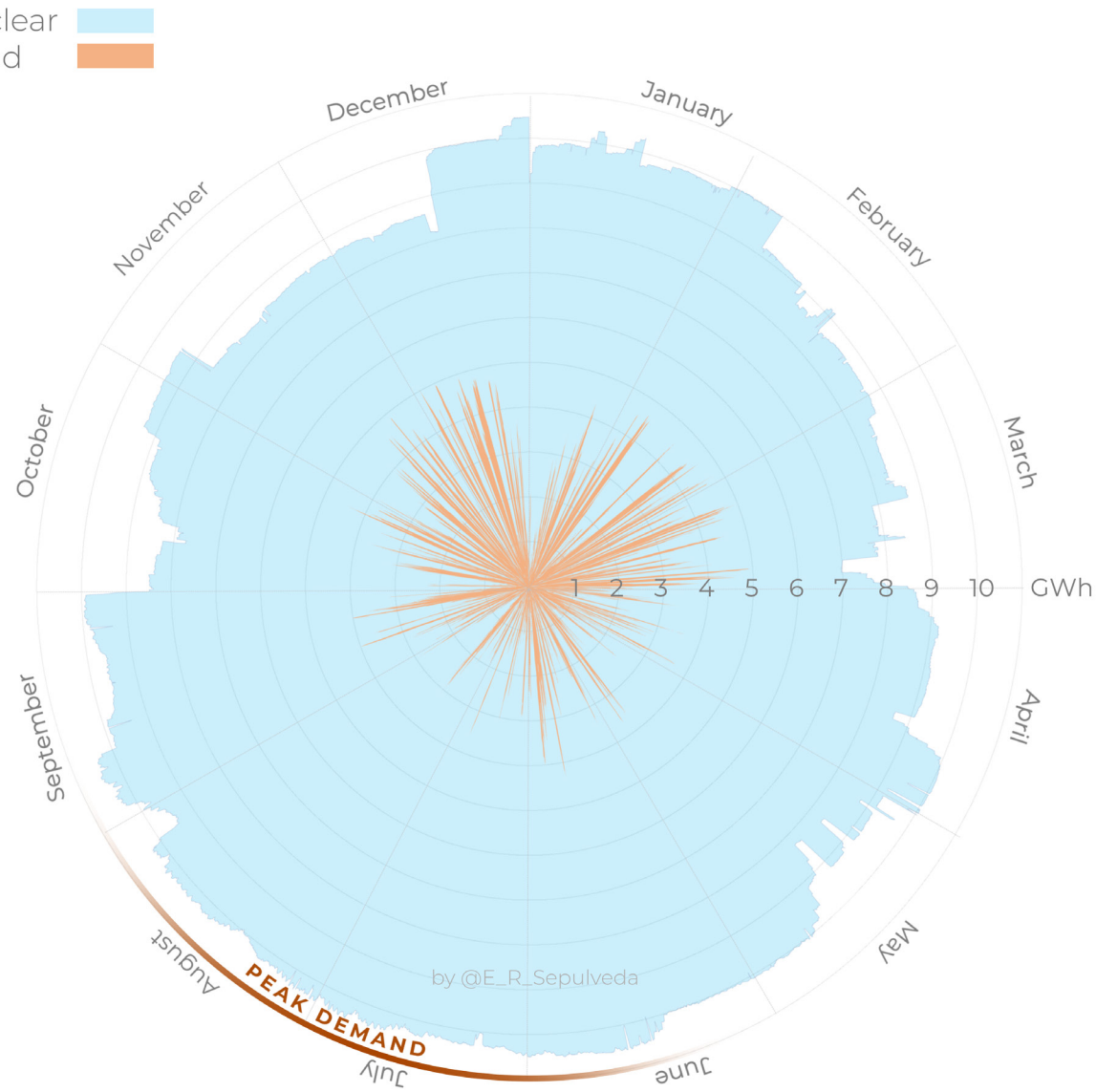
Even if sufficient Hydro-Québec imports to replace Pickering were possible or advisable, the IESO reports that transmission upgrades to transmit that power alone would cost $1.4 billion with construction lead times as long as 10 years.[34]

The low value of wind and solar in Ontario

Because Ontario already spends over $3 billion per year subsidizing solar and wind, we can answer the question: how do wind and solar perform in the province?[35] In 2021, wind accounted for 8.4% of electricity generation, no small amount.[36] Yet this generation was some of the most problematic from a grid operation perspective, with supply rising and falling starkly out of phase with demand at both a seasonal and hourly level.

Electricity demand peaks during Ontario's hot, muggy summers, when electric cooling ramps up (in contrast to gas-powered heating in winter that doesn't raise electricity demand).[37] Yet this is precisely when Ontario's wind generation falters. From June to September 2020, Ontario wind generation delivered less than 14% of its full capacity, down from its year-round average of 30%. A year earlier, wind generation was even worse, when during the hottest weeks it managed to produce just 6.87% of its capacity.

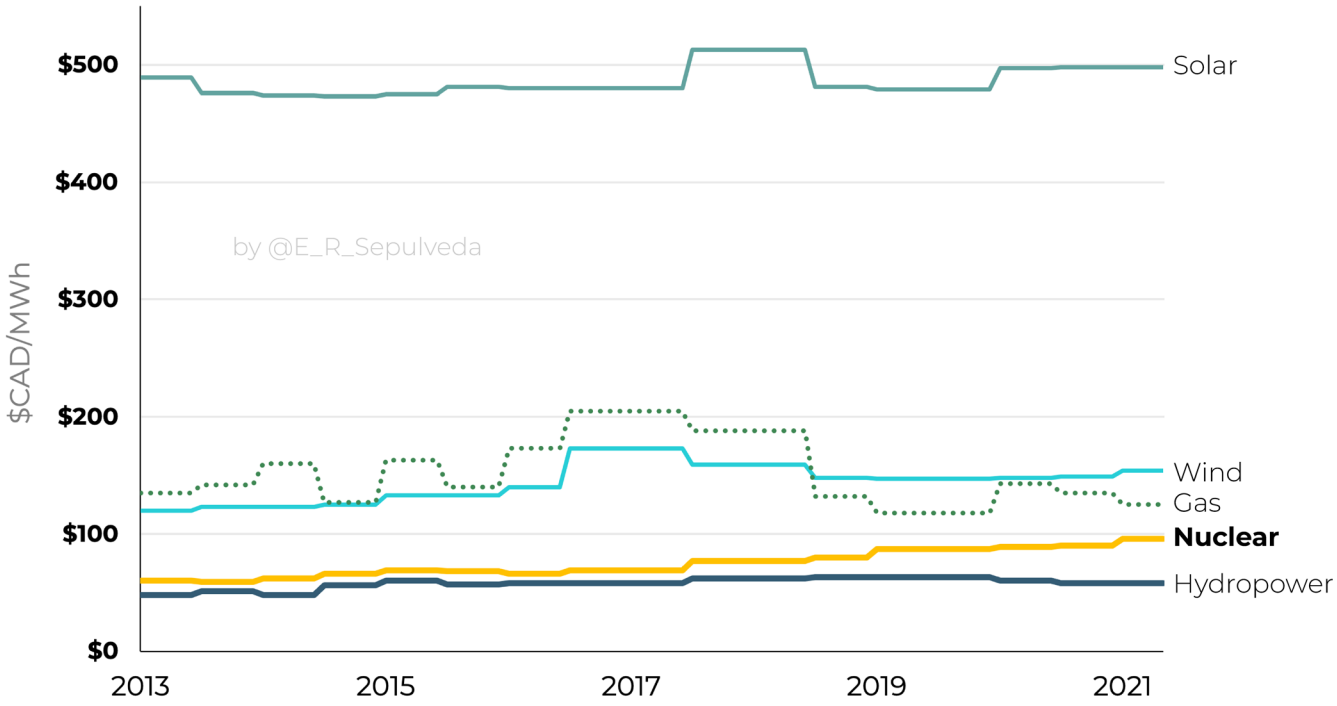
Fig 3. Hourly Wind and Nuclear Generation in Ontario, 2021



And yet with its under-performance come unpredictable spikes of wind generation liable to flood the electricity market. In times of low demand, this has forced Ontario to export wind power at a net loss (even at *negative prices*) or to curtail it altogether, for which generators still receive payment. In 2020, Ontario curtailed 2,300 GWh of wind generation, and Ontario residents paid full price as if it had been delivered, at a rate twice that paid to nuclear generators for far more reliable and predictable power.[38]

Solar generation in Ontario is even pricier than wind, receiving an average of 49.8 cents per kWh compared to 15.4 cents for wind and 9.6 cents for nuclear.[21] The province's commercial solar farms outperform rooftop installations, yet their lifetime capacity factor of 16% is still well below the U.S. average of 25%.[36,40]

Fig 4. Ontario Electricity Prices by Generation Source



Source: *Regulated Price Plan*, Ontario Energy Board

The Green Energy Act of 2009

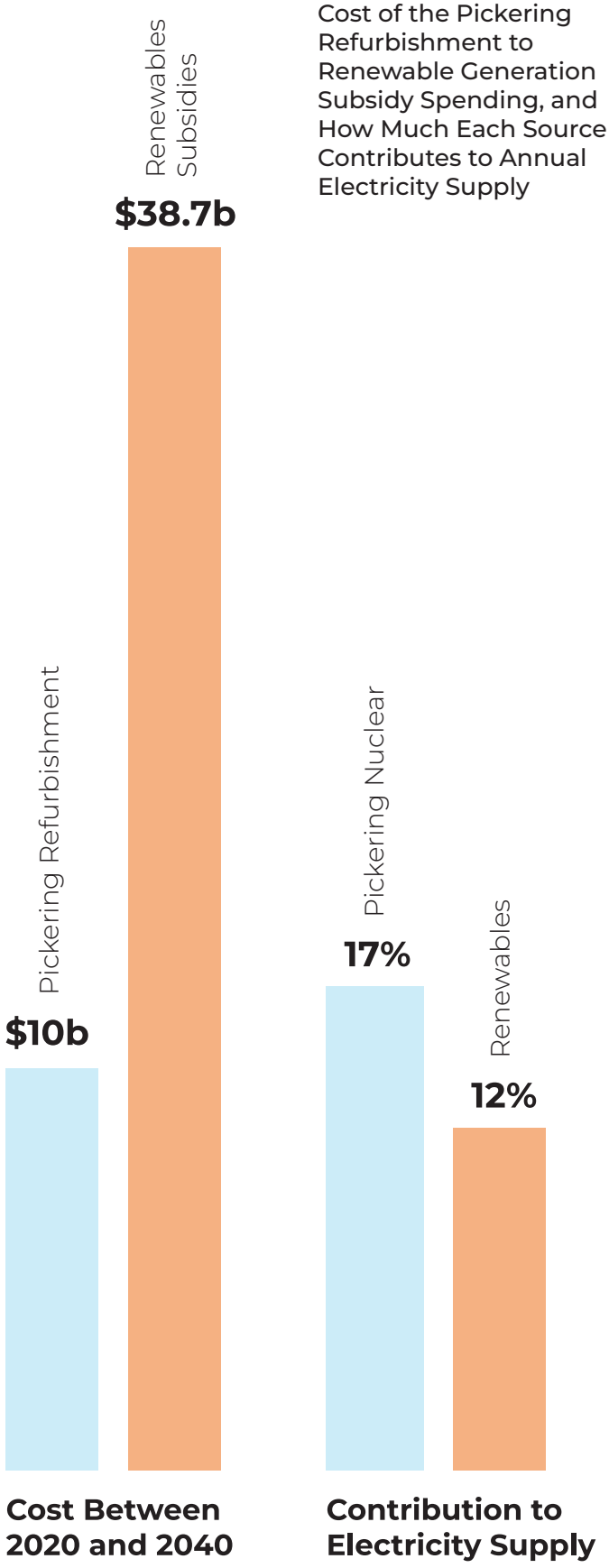
The steep price of wind and solar in Ontario is partly due to the Green Energy Act of 2009, which tried to incentivize clean energy in the footsteps of Germany's *Energiewende*. Following the act's passage, Premier McGuinty signed thousands of 20-year, fixed-price solar and wind contracts at rates as high as 80 cents per kWh at a time when nuclear generation in the province received just 5.8 cents per kWh.[41,42] Even worse, under these contracts, wind developers were promised full price for curtailed electricity.

These "ironclad" contracts survived the act's repeal in 2019, keeping Ontario taxpayers on the line for an annual $3.1 billion "Renewable Cost Shift" to hide the excessive cost of these wind and solar contracts from energy bills.[43] The Financial Accountability Office of Ontario estimates that between 2020 and 2040 the cost of green energy subsidies will exceed $38 billion.[35]

Just 3 years of this Renewable Cost Shift could finance the refurbishment of Pickering, whose annual 23 TWh of output exceeds the roughly 15 TWh of actual combined output from the wind and solar generation secured under the Green Energy Act.

Maintaining its existing nuclear infrastructure and building more is Ontario's only option for securing a clean energy supply amid growing demand for electric services.

Fig 5. Comparing the Cost of the Pickering Refurbishment to Renewable Generation Subsidy Spending, and How Much Each Source Contributes to Annual Electricity Supply



2. Economics and Industry

Staying open for business

Rising electricity emissions and capacity shortfalls projected by the IESO send a bad signal to businesses.[59] To provide the reliable, affordable energy that businesses need to operate, with the low emissions that shareholders increasingly demand, Ontario urgently needs to build clean, firm electric capacity. There is no faster, more cost-efficient way to minimize energy shortfalls this decade than to extend the operating license of Pickering Nuclear Generating Station and refurbish the units at Pickering B, which could ultimately provide over 2000 MW of clean, 24/7 power using a fully licensed site with the transmission infrastructure to serve the baseload needs of the GTA.

The most economical path forward

The Electrification Pathways report by *Strategic Policy Economics*, which warns that Ontario must grow its grid by 2-3 times to meet electrification targets, finds that an energy path based on nuclear energy could be 25% cheaper to ratepayers than the province's current system and up to 10% cheaper than the lowest estimate for a natural gas and renewables-based solution.[9]

Cost and timelines of refurbishment

Refurbishing the four units at Pickering B will cost an estimated $8.8 billion over 10 years. Adding a $1.2 billion contingency budget, this comes to $10 billion total, or $2.5 billion per unit. Each unit would take an estimated 3-4 years to complete, with the start dates staggered by 2 years. Though this number may seem large, the average spending of $1 billion per year pales in comparison to yearly $3.1 billion the province spends to offset the steep cost of renewables contracts that in total deliver only 65% of the electricity that Pickering does, and at lower value.

The $10 billion cost estimate is based on similar refurbishment work completed during the major component replacements at Bruce Nuclear Generating Station. Units 1 and 2 were refurbished at a cost of $2.4 billion, while units 3–8 are estimated to cost an average of $2.17 billion, including contingency.[44] Refurbishments will continue to benefit from a well-practiced supply chain and workforce, and OPG can continue a downward cost trend as it gains experience from its highly successful ongoing refurbishments at Darlington Nuclear Generating Station.

Bruce Power has also shown that the cost of nuclear can stay low during refurbishments Even with temporarily elevated rates from the outage of two units for refurbishment, Bruce is delivering power at just 7.85 cents per kWh, a full 24% cheaper than Ontario's average supply cost of 10.34 cents per kWh.[21, 45]

THE NUCLEAR OPTION

The ongoing energy crunch in Europe and Asia has laid bare the essential role of nuclear energy in meeting climate and energy security goals, pushing leading economies such as France, Japan, and Belgium to reverse their prior stance on phasing out nuclear energy.[52–54]

The key to nuclear power's affordability is the huge amounts of electricity it produces to facilitate cost recovery. Even cost overruns present low risk to ratepayers, as the Financial Accountability Office found that a 50% cost overun for the province's ongoing refurbishments would only sway nuclear rates by 8.9%.[61] This means that even in such an event, the price of nuclear energy would remain lower than gas, wind, solar, and biomass.

Decommissioning

The alternative to refurbishing or life-extending Pickering is to decommission it, which includes the removal and long-term storage of fuel and the dismantling of all radiologically exposed components. The fund set aside to cover the expected cost of nuclear decommissioning country-wide is $20 billion, roughly $8 billion of which is set aside for Pickering.[46] An analyst at the Ontario Ministry of Energy estimates that decommissioning and spent fuel storage for Pickering could cost as much as $9.5 billion in 2016 dollars.[47] Put simply, refurbishment and decommissioning have a similar price tag, but one option sustains Ontario's abundant low-carbon power and high-quality jobs, and the other does not.

The ultimate economic stimulus

One would be hard-pressed to find any investment with a greater return for Ontario's citizens than nuclear power.

The made-in-Ontario nuclear supply chain

The province is home to 96% of the supply chain, ensuring that every dollar spent on Pickering's continued operation stays in Ontario, generating stable jobs and economic activity on top of its energy benefits. An independent analysis commissioned by OPG estimates that for every $1 spent on CANDU refurbishments, Ontario enjoys $1.40 of economic activity.[49]

As we head into a green economy, these are the high-paying, high-skilled, intergenerational jobs that Ontario wants to create and keep. The refurbishment of Pickering will maintain the made-in-Canada nuclear supply chain while generating the hands-on experience that drives costs down and improves Canadian nuclear refurbishment opportunities in other markets.

Pickering's Workforce

On the heels of the COVID-19 pandemic, a decision must be made: either eliminate 7,600 full-time-equivalent jobs sustained by Pickering, or guarantee these workers high-skilled, family-supporting, community-building employment. The Ontario Chamber of Commerce estimates the GDP contribution of Pickering's operation to be $1.54 billion annually.[12] These jobs secure the skills, learning, and supply chain foundation for the expansion of CANDU and SMR technology.

FORGING AHEAD WITH CANADIAN INDUSTRY

Nuclear is a cornerstone of Ontario's manufacturing industry. More than 190 businesses in Oakville, Toronto, Peterborough, Cambridge, Bowmanville, and elsewhere handle mining, the forging of steam generators and pressure tubes, plant maintenance, engineering, and spent fuel storage.[50]

3. Environment and Climate Change

Ontario led Canada's overall climate gains with nuclear energy

Ninety percent of Ontario's coal phaseout was powered by nuclear energy, including the restart of two units at Pickering.

If not for Ontario, Canada's total yearly emissions would have increased by over 30 megatonnes between 2005 and 2019.[3] Instead, Canada's emissions have held steady thanks to Ontario's historic progress on emissions. The closure of Pickering will have national consequences, sending Canada's emissions well above 2005 levels, which served as the baseline for the country's emissions reductions promised under the Paris Climate Agreement.

Ontario's climate goals need Pickering

A clean electricity grid serves as the backbone of Ontario's efforts to reduce emissions by electrifying transportation, heating, and industry. Electric vehicles and electric arc steelmaking furnaces are only as clean as the electricity that powers them.

Yet the closure of Pickering will quadruple the emissions from Ontario's electricity sector, from roughly 3 megatonnes per year to 12 megatonnes.[10] This is because the only near-term alternative is to burn more gas, which has a carbon footprint 100 times that of nuclear power.[60]

Fig 6. Change in Provincial Electricity GHG Emissions Since Year 2000

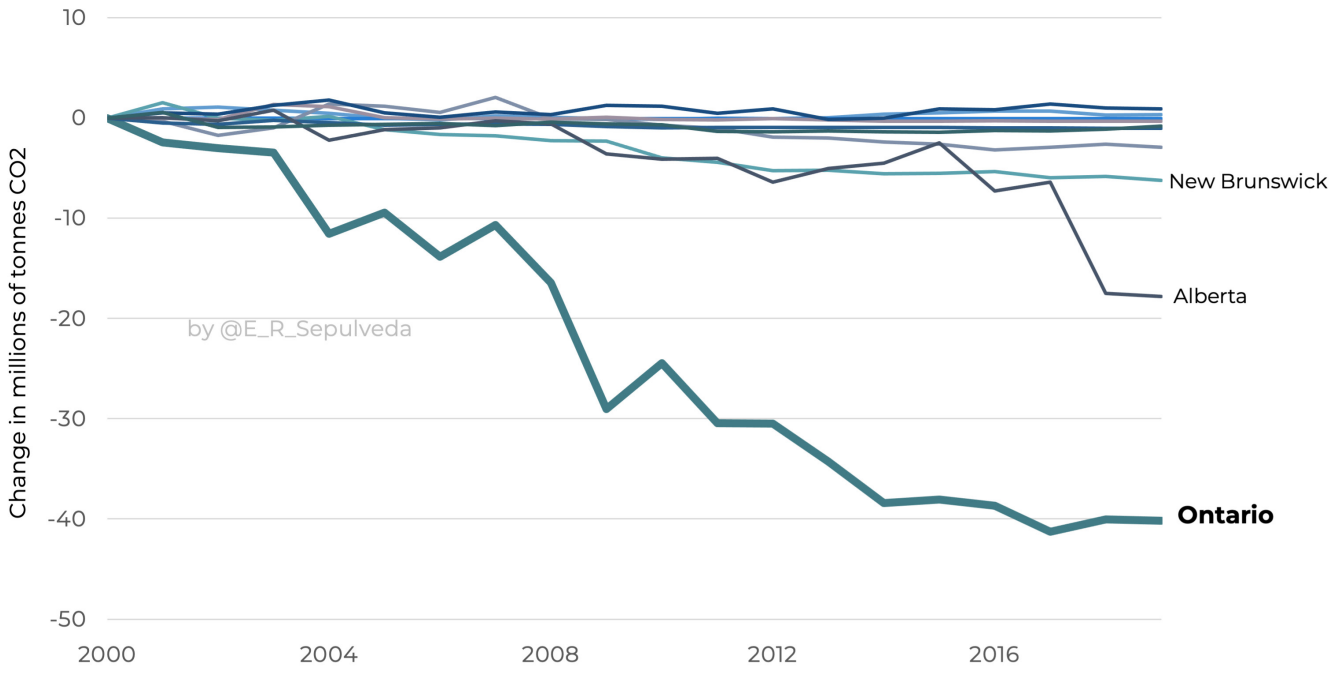
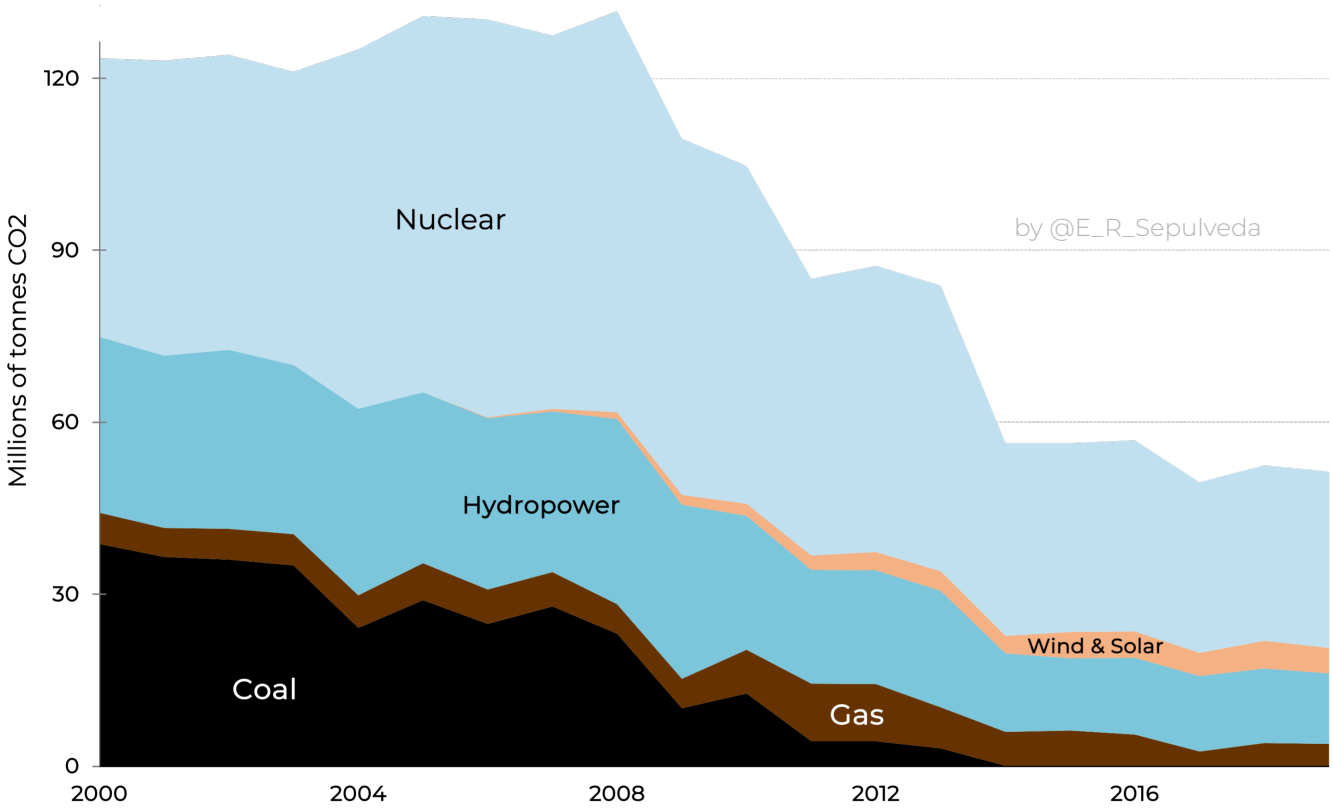


Fig 7. Actual and Avoided Emissions in Ontario

Coal and Gas represent **actual emissions**. Nuclear, Hydropower, and Wind & Solar represent **estimated avoided emissions** resulting from the use of these low-emissions technologies.



Avoided Emissions

By displacing fossil fuels, Ontario's nuclear fleet has avoided as much as a billion tonnes of carbon dioxide emissions since 2000. These nuclear plants provide more than twice as much clean power as Ontario's hydro dams.

When Pickering is decommissioned, Ontario will lose a source of low-carbon power 50% larger than Niagara Falls, a symbol of clean power in Canada.

IPCC Illustrative Pathways

Nuclear energy plays a prominent role in all credible decarbonization pathways because of its irreplaceable attributes as a reliable, low-carbon energy source. In 2015, the Intergovernmental Panel on Climate Change (IPCC) published four illustrative pathways to limit average global warming to 1.5°C, all of which call for a global increase in nuclear energy ranging from 98 to 501%.[51] The IPCC, an intergovernmental body of the United Nations composed of scientists from 195 member states, represents the scientific consensus on climate change and climate action.

Radiation

Continuous radiological surveying shows that Pickering contributes to less than one-tenth of one percent (>0.01%) of the annual radiation dose received near the plant. The other 99.99% comes from naturally occurring background radiation, air travel, and life-saving medical imaging and therapies. In fact, due to geological variations in background radiation, the Pickering site actually experiences a lower annual effective dose of radiation than the Canadian average.[55] Built instead of a 4 GW coal plant, Pickering Nuclear Generation Station is not a public health threat but a public health hero.

Used Nuclear Fuel

Used nuclear fuel has been framed by anti-nuclear interest groups as an environmental hazard. In fact the opposite is true. Only the nuclear sector accounts for every gram of its waste stream using proven and sophisticated handling and storage techniques. Worldwide, there have been no serious injuries caused by the used nuclear fuel from commercial power reactors.

In the long term, new reactor designs are expected to make use of the used fuel's remaining energy. For this reason, stored fuel is an asset with incredible value and potential for Ontario's energy future. Canada's Deep Geological Repository efforts by the Nuclear Waste Management Organization also offers a long-term storage solution that presents no environmental or health risk even under extremely conservative risk assessments.

When the Canadian Nuclear Safety Commission reviewed and approved the environmental assessment for the Pickering refurbishment in 2009, it concluded that the continued operation of the plant posed no significant risk of adverse environmental effects.[58]

What needs to be done?

The Government of Ontario should direct OPG to extend the life of Pickering Nuclear Generating Station.

To avoid near-term supply shortages, there is a clear imperative to extend Pickering's operation at least until the licensed 2028 date and ideally significanly longer by refurbishing Pickering B.

The informed decision to close or save Pickering belongs to the Government of Ontario. Instead of asking OPG if it wants to refurbish Pickering, a question it answered 13 years ago, the Government of Ontario must ask what doing the refurbishment will take. While OPG provides unmatched expertise on the material requirements of Pickering's continued operation, as a corporation it is not accountable to wide-ranging and devastating impacts of the plant's closure to Ontario's economy, energy security, and climate targets.

A secondary option is for the province to lease the plant to a qualified third party to maintain and operate it beyond 2025 under an arrangement similar to the province's successful public-private partnership with Bruce Power.

The cost of decommissioning Pickering far exceeds the price of refurbishing it. Ontario's businesses and residents, current and future, cannot afford to lose the invaluable asset that is Pickering Nuclear Generating Station.

Technical Recommendations for the Pickering Refurbishment

1. Build on the existing plan
2. Cost Estimate for the Pickering refurbishment
3. Dovetail the refurbishments at Darlington and Pickering
4. Ensure the timely procurement of needed components
5. Optimize the lifespans of existing assets
6. Project Risks

Any life extension of Pickering Nuclear Generating Station through the 2020s will help alleviate short-term energy shortages. However, we believe a larger refurbishment of Pickering B merits serious consideration.

1. Build on the existing, already approved refurbishment plan

Ontario already has a regulator-approved plan for the refurbishment of the four units of Pickering Station B. Both the overall strategy and environmental assessment for this plan were submitted by Ontario Power Generation in 2009 to the Canadian Nuclear Safety Commission, which reviewed and approved it.

The plan for the refurbishment of Pickering Station B is very similar to the major component replacement (MCR) refurbishment at Bruce Generating Station in terms of its scope as it requires boiler replacement, control systems upgrades, and pressure tube replacement. The plan for Pickering should also include capacity upgrades to the turbines to bring all units in line with Unit 5, which is already capable of 550 MWe. This involves replacement of the existing turbines with modern ones that are more efficient and produce more power. In total, this would increase output by 100 MWe, equivalent to almost 60,000 homes, based on OPG assessments.

Increasing the site's capacity not only enhances Ontario's ability to respond to the increased power demand of an electrified economy. It also helps keep amortization time down and thus expedites cost recovery. In addition, replacement of the station's 1970s analogue control systems with modern digital equivalents will allow for more reliable operation, better control and, crucially, the ability to perform some of the testing and validation while units are online. Currently, these units have to be shut down in order to perform this testing and validation, interrupting service. Due to unified control across the two stations, the already refurbished Station A Units 1 and 4 cannot be run if the Station B side of the plant is shut down. Thus refurbishing the Station B units also means that the full lives of Pickering A Units 1 and 4 will be realized instead of shutting down 1030 MWe of clean generating capacity prematurely.

If the refurbishment is performed by OPG, this means that the organization will be able to continue to spread all refurbishment costs across both Darlington and Pickering going forward, which will lower their rate rider requirement. This describes an additional per kWh payment placed atop the base rate to cover costs that are above and beyond operating expenditures (this exists because as public assets cannot make a profit, they can only cover operating costs).

Alternately, Bruce Power, which operates the Bruce Generating Station independently of OPG, might consider an agreement to take over the Pickering site, either as an extension to their existing operator license or as part of a new agreement with a fixed-price compensation scheme similar to what they currently enjoy. This would allow Bruce Power sufficient means to

recoup the cost of the project. We have calculated that a ~$0.095/kWh rate should enable sufficient profit to recover the refurbishment costs based on an anticipated refurbishment budget of $10 billion.

2. Cost Estimate for the Pickering Refurbishment

The scope of the refurbishment work at both the Darlington and Bruce Nuclear Generating Stations includes all inspection, testing, design, engineering, construction, procurement, management, installation, commissioning, training, and other work related to calandria and pressure tube replacement, Primary Heat Transport (PHT) feeder pipe replacement, and electronics upgrades. For Bruce, the refurbishment also includes the refurbishment of the PHT pump and valves and the removal and replacement of the steam generators.

Work at Pickering B would be similar to the Bruce station, but the number of calandria, pressure tubes and feeder pipes would be less (380 versus 480). However, there are twelve steam generators at Pickering B compared to eight at Bruce, which would need to be removed and replaced through the Equipment Access Hatch. Considering these factors, refurbishing the four units at Pickering B is estimated to cost $8.8 billion over 10 years or $2.2 billion per unit. This $8.8 billion estimate is based on the current Bruce Power estimate of $13 billion total, or $2.17 billion per unit, for the refurbishment of six units.

This refurbishment estimate is also dependent on the work beginning at Pickering B as the work at Darlington winds down. Dovetailing these two projects will ensure the recent experience of the workforce, the supply chain and the lessons learned will benefit the Pickering B refurbishment. For instance, ensuring sufficient experienced management staff and skilled tradespersons are available, ensuring detailed engineering work is completed and a detailed cost estimate is prepared, and the combined pressure and calandria tube removal technique perfected at Darlington, will be used to dramatically reduce the time and effort required for this task at the Pickering B units.

Realizing that with any large infrastructure project there are risks, such as unforeseen planning errors, equipment delivery delays or physical interferences the cost estimate needs to have a contingency. Typically, for large projects the contingency ranges from 10-15%, based on a reliable cost estimate. For this reason, a contingency of $1.2 billion is added to the estimated cost for a total cost of $10 billion for the Pickering B refurbishment. This preliminary cost estimate, which does include engineering and planning, would have to be significantly refined to ensure it has sufficient detail to meet the requirements of an AACE Class 3 cost estimate.

3. Dovetail the refurbishments at Darlington and Pickering

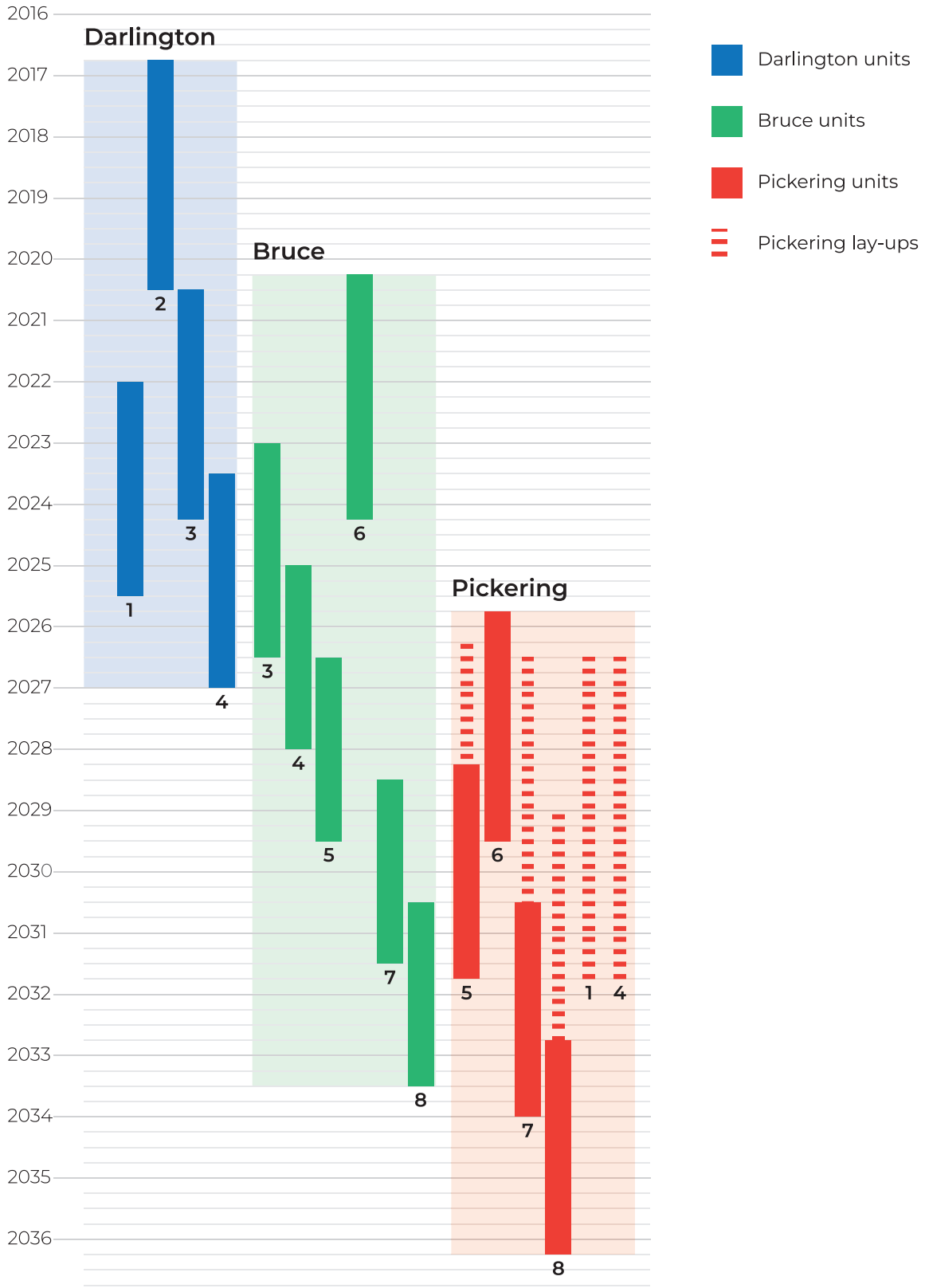
Key to making the plan work with limited interruptions and consequent cost overruns is to ensure that work begins on Pickering Station B as work on the refurbishment of the Darlington Generating Station winds down.

Dovetailing the two projects will leverage the recent experience of the workforce and supply chain. In essence, the workforce should move “hammer in hand” from Darlington to Pickering. At this point, the necessary components should already be on site. Canada does not have sufficient labour with training and experience in refurbishment to run both projects in parallel, a reason cited in 2009 for forgoing the Pickering B refurbishment when it was believed this work would begin early enough to overlap substantially with the Darlington refurbishment, which is no longer the case.[58]

The impact of Units 1 and 4 requirements and other unit lay-ups (shutdowns in preparation for either refurbishment or decommissioning) are shown on the refurbishment timeline in Figure 8. These represent mandatory shutdowns due to the current Equivalent Full Power Hour (EFPH) limits (see Project Risks below) being reached. Therefore it is critical to address these points as part of the preparation for this project.

Fig 8. Refurbishment Timeline by Nuclear Station and Unit Number

Shutdowns for refurbishments are shown in solid color. Lay-ups, or shutdowns in preparation for refurbishment or decomissioning, are shown in stripes. Unit numbers are indicated underneath each block. Lay-ups are shown in accordance with the current 295,000 Equivalent Full Power Hour (EFPH) limit. The lay-up timeline could be made more favourable by extending the EFPH limit to 300,000.



Pickering Station A's units 1 and 4 were refurbished in 1987 and 1993, when their old pressure tubes were swapped out for new ones. Secondary, less complex refurbishments in the early 2000s included the division of a single fast shutdown system that had covered both units into two systems that can function separately. As a result, these two units have significant life left in them past the scheduled closure date for the plant as a whole in 2025.

4. Ensure the timely procurement of needed components

Ontario has successfully built a large nuclear component supply base in the province to support refurbishments at both the Bruce and Darlington. This is another nuclear advantage that Canada has over other jurisdictions where, absent domestic demand, the supply and delivery chain has withered. This made-in-Ontario nuclear component supply advantage can keep costs down for a Pickering refurbishment, making the most of the learning and efficiencies these suppliers have achieved in the production of components such as steam generators and fuel channel components.

The refurbishment of Pickering faces unique requirements due to a plant design that relies on a large number of small components working in parallel rather than fewer, larger components as seen in later CANDU designs.

Each of Pickering B's four units requires 12 new steam generators for a total of 48. Each of these would be fabricated in Cambridge, Ontario, by BWXT, a domestic supplier of nuclear components. While these steam generators are significantly smaller than their equivalents at Bruce Nuclear Generating Station, Pickering requires more of them. To reduce the chance of delays, there should be enough new steam generators ready to go for the first unit at the commencement of the project.

The procurement of other components necessary for the refurbishment—such as turbines, if they are being upgraded, and control systems—will also need to be set in motion beforehand for the same reasons. Suppliers such as BWXT are already producing components for both Bruce and Darlington, so setting them to work on supplies for Pickering as the Darlington refurbishment winds down would take advantage of that experience and of the established supply and delivery chain.

5. Optimize existing asset lifespans

The Equivalent Full Power Hours (EFPH) limit on pressure tubes must also be kept in mind with respect to a timely, delay-free start to the Pickering project. In the reactor, the pressure tubes contain the fuel bundles and primary coolant, which for CANDU is heavy water.

Hydrogen uptake, measured by Hydrogen Equivalent Concentration (Heq), is the main driver of pressure tubes aging because it introduces embrittlement, as above a certain threshold there is an increased probability of hydride blistering. Bruce and OPG were able to demonstrate that a 120ppm Heq limit was safe, but Pickering's current EFPH limit is based on the old Heq limit of 100ppm. Increasing the limit is what allowed Bruce to keep their units online. That same limit applied to Pickering would buy those plants a significant amount of time because the plant's hydrogen uptake rate is lower than Bruce or Darlington due to lower levels of flux in the core.

6. Project Risks

Part of OPG's hesitancy to refurbish Pickering has undoubtedly been the relative complexity of the design and the perceived risk to the company's reputation in the case of schedule and cost overruns.

As with any large infrastructure project, there are risks. Hydroelectric dams, offshore wind farms, high-altitude wind turbines, tidal barrages, and arrays of wave energy converters, as well as the utility-scale energy storage and additional often-continental transmission required to integrate high levels of intermittent renewables,

all contain their own choke points, particularly at the gargantuan scale of build-out required to, for example, double generating capacity. There is no clean energy transition pathway that avoids such risks. In all cases, such risk items can be addressed with proper planning, and extending the operation of Pickering is no different.

EFPH Pressure Tube Limits

Currently, the Pickering B units are licensed for 295,000 Equivalent Full Power Hours (EFPH) while Bruce is licensed for 300,000 EFPH. The units will run past their licensed maximum allowable operating hours part way through the refurbishment. This would force shutdowns prior to refurbishment unless the EFPH limit is extended. Pickering's units have fewer fuel channels (380 in Station B plant compared to 480 at the Bruce and Darlington plants), fewer fuel bundles, and these bundles themselves have fewer elements. In essence, this means that they have a lower power density than the units at Ontario's other nuclear plants. We see ample justification for increasing the EFPH limit for Pickering to keep the other units operating during refurbishment with limited need for shutdowns.

Steam Generator Replacement

To replace steam generators, the old ones must be extracted from the containment structures. Bruce Nuclear Generating Station has a flat roof atop a square building, so the extraction process using holes cut into the roof is relatively straightforward. In contrast, Pickering's containment structures are dome-shaped, with no flat roofs, complicating the logistics of the extraction. We believe it is still possible, due to the smaller boiler size, to use the Equipment Access Hatch for this task, which avoids cutting the containment. If it turns out they do not fit through these hatches, extraction through the dome via crane would be necessary. It should be noted that the original OPG refurbishment plan included steam generator replacement.

Steam Turbine Replacement

The output of Unit 5 was significantly increased by the replacement of the original 1970s turbine with a higher power, more efficient turbine. The unit has run at up to 560 MWe, though this is stretching beyond its intended typical operating range. The realistic operating ceiling would be around 550 MWe. Three new turbines would need to be procured and readied as part of the refurbishment for the three other units, whose turbines have not been replaced.

A Units 1 and 4, B Unit Dependence

In the early 2000s, when it was decided that Pickering A Units 2 and 3 would not return to service, the separate control systems for the two stations were consolidated. Documentation from OPG indicates that as part of this consolidation, some safety systems for Station A Units 1 and 4 are dependent on a minimum of two of the units from Station B operating at any given time. This means that if the refurbishment of any two units at Pickering B overlaps, an outage for standard maintenance purposes at one of the other units would force the shutdown of Pickering A. Indeed Pickering recently experienced such an occurrence, dropping down to a single B unit with no A units online. Therefore, it is not unprecedented.

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Acknowledgments

Special thanks to the talented members of C4NE who volunteered their time and expertise to this report, including Christopher Adlam, Edgardo Sepulveda, Tom Hess, Steve Aplin, Paul Hader, Scott Luft, and Dr. Chris Keefer. The report was written and designed by Dylan Moon.

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