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NUCLEAR POWER GENERATION:

KEEPING ELECTRICITY SECTOR EMISSIONS LOW

Ontario was able to end its dependence on coal-powered electricity generation and reduce electricity sector emissions to all-time lows by successfully deploying nuclear power in significant quantities. The only feasible option to keep electricity sector emissions low in the face of increased electrification is to expand our nuclear generating capacity.

NUCLEAR POWER GENERATION

For over fifty years, Ontario has relied on nuclear power to provide safe, reliable, and emission-free electricity. Nuclear power now supplies more than half of the province's electricity needs and is the primary reason Ontario was able to end its dependency on coal, lowering electricity sector emissions from a high of 43 megatons (Mt) per year in 2000 to just over 3 Mt in 2019. That reduction in carbon emissions is an important achievement.

Ontario's nuclear generating stations not only provide emission-free electricity to the province's electricity grid, they are also among the world's largest producers of life saving medical isotopes, including Cobalt-60, and soon they will also produce Lutetium-177 and Molybdenum-99, products critical to the medical community, and essential to cancer treatments.

Two of the province's nuclear generating stations – Bruce Power's Bruce Nuclear Generating Station (BNGS) and OPG's Darlington Nuclear Generating Station (DNGS) – are currently undergoing extensive refurbishment that will extend their useful life past 2050. The province's oldest nuclear generating station — Pickering Nuclear Generating Station (PNGS) — is scheduled to begin decommissioning in 2026. At the Government of Ontario's request, OPG recently began a feasibility study to determine whether it would be safe and economical to refurbish PNGS's Unit B reactors. If the government and OPG ultimately decide not to go ahead with refurbishment, decommissioning PNGS will remove approximately 3,100 megawatts (MW) of emission-free baseload power from Ontario's electricity grid, currently with no plan to replace it. Even if the refurbishment of the B Unit reactors goes ahead, PNGS's output will be reduced by more than 1,000 MW as the two remaining A Unit reactors are at the end of life and unsuitable for refurbishment.

In the absence of new nuclear generation to replace PNGS, carbon emissions from the province's electricity sector will rise over the next two decades. This will occur even without a major shift towards mass electrification, which has already begun, and will create significant new demand for electricity as we shift to electric vehicles and home heating. PNGS is critical for meeting the minimum amount of electricity Ontario currently needs daily. This minimum amount of electricity is known as "baseload" power. To continue meeting Ontario's current baseload energy needs should PNGS goes offline, the province will have to increase its use of natural gas. While some interest groups claim that Ontario could import power from other jurisdictions to meet this need, the evidence clearly demonstrates that natural gas is the only available alternative to nuclear[1]. The provincial government's forecast of how it will generate electricity to 2042 reflects this reality.

CANDU: UNIQUELY CANADIAN CLEAN TECHNOLOGY

In the 1950s, the former crown corporation Atomic Energy of Canada Ltd. (AECL) began developing the Canada deuterium uranium (CANDU) reactor. CANDU reactors use deuterium (heavy water) as a coolant and are fueled by unenriched uranium[2]. CANDU reactors have earned a reputation as one of the safest reactors in the world[3]. The success of Canada's CANDU technology has led to CANDU reactors being built in countries in Europe, Asia, and South America.

After creating the first prototype reactor near the AECL headquarters in Chalk River, Ontario, AECL built a larger prototype reactor at Douglas Point, Ontario. Shortly after the creation of the large prototype at Douglas Point, Ontario Hydro began construction of the Pickering Nuclear Generating Station, where the first commercial CANDU reactors came online in 1971. Ontario Hydro quickly followed up with CANDU reactors at the Bruce Nuclear Generating

1 https://www.ieso.ca/en/Learn/Ontario-Supply-Mix/Natural-Gas-Phase-Out-Study
2 https://world-nuclear.org/information-library/country-profiles/countries-a-f/canada-nuclear-power.aspx
3 https://sencanada.ca/content/sen/committee/371/enrg/rep/repintjun01part1-e.htm

Station – since transferred to private operation – with the first units coming online in 1977. More than a decade later, Ontario Hydro brought into commission the Darlington Nuclear Generating Station, with the first unit coming online in 1990. No new nuclear generating stations have been built in the 30 years since.

POWERING CANADIAN JOBS

Nuclear power's need for high-skilled labour, and unique, 96 percent Canadian supply chain, make it a significant boon to the Canadian economy. The Canadian nuclear industry directly accounts for 30,000 high-quality jobs and contributes an additional 30,000 indirect jobs in communities supported by the nuclear industry[4].

Jobs directly created by Canada's nuclear industry range from uranium mining in Saskatchewan, to workers supporting the nuclear supply chain, nuclear scientists and researchers, and the thousands of highly skilled workers operating Ontario's nuclear generating stations.

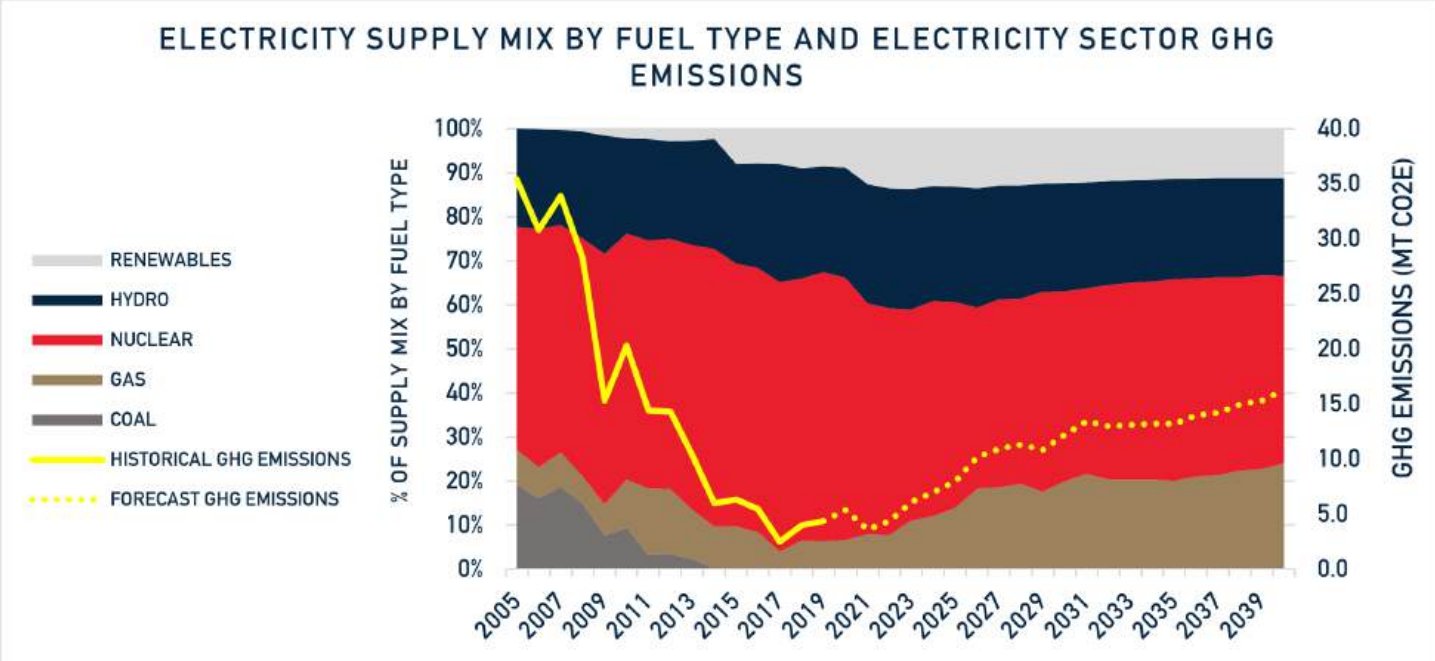
Additionally, the refurbishment of BNGS and DNGS will have an even greater economic impact, both during the refurbishment process and in the decades to come. A report by the Conference Board of Canada estimated that the DNGS refurbishment project alone will create an average of 14,200 new jobs per year during the more than 30 years of additional lifespan at the Darlington Generating Station. Additionally, the report estimates that the refurbishment will generate an additional $9.3 billion in revenue for the provincial government, $13.8 billion in federal revenue, and $356 million in revenue to local municipalities over the additional span of operations at the Darlington Station[5].

BASELOAD POWER: The minimum amount of electricity needed to be supplied to the electrical grid at any moment. Baseload power must be supplied by constant and reliable sources of electricity.

PEAKING POWER: Electricity required by the grid when demand exceeds the baseload supply. Common peaking periods might include hot summer days when air conditioners are used. Peaking power supply is dispatchable, meaning they can be turned on or off and their output can be changed.

4 https://cna.ca/2012/10/19/economic-impact-study-launch-a-canadian-strategy-for-energy-jobs-and-innovation-2/

5 https://www.opg.com/document/continued-operation-of-the-darlington-

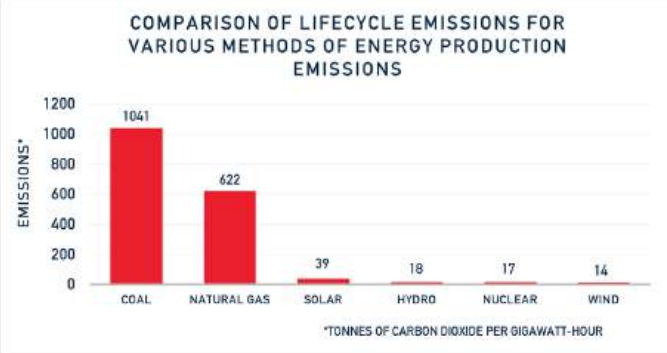


GREENING THE GRID

Over the last two decades, Ontario has taken great strides in eliminating carbon emissions from its electricity grid by removing the primary source of carbon emissions: coal-fired generation. In 2005, coal accounted for 19 percent of electricity generated in the province, and as a result, electricity generation emitted almost 34 Mt of CO2, accounting for 17 percent of the province's total emissions.

By 2014, coal-fired generation was completely removed from Ontario's electricity grid. In 2020, the only GHG-emitting form of electricity generation is the 6 percent of electricity generated by natural gas to provide peaking power. In 2018, the province's electricity system emitted 3.8 Mt of GHG emissions, or only 2.3 percent of total GHG emissions in the province.

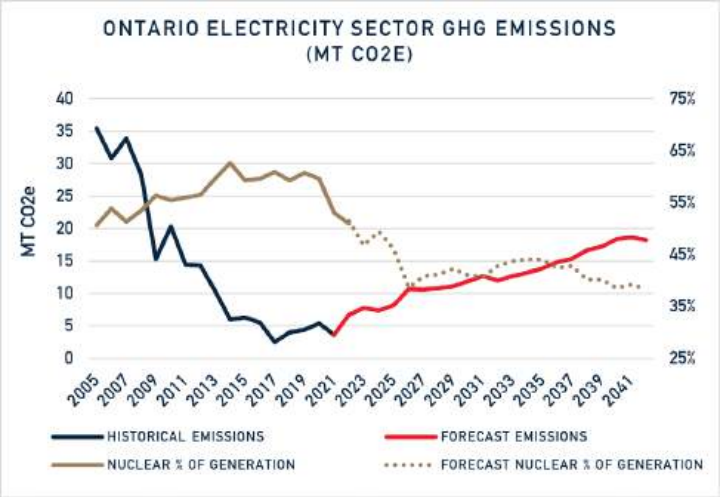
The province was able to end its dependence on coal-powered generation and slash electricity sector carbon emissions because of the province's three nuclear



generating stations. Immediately following the closure of the last coal generating stations in Ontario, nuclear power supplied over 60 percent of the province's electricity needs, and electricity sector emissions reached an all-time low, at only 2.5 Mt.

The drastic reduction in emissions should come as no surprise considering that when we compare lifecycle emissions of various methods of energy production, nuclear power is among the lowest emitting energy sources available. Nuclear power's lifecycle emissions are just 1.6 percent of coal power emissions and 2.7 percent of natural gas emissions.

In recent years, nuclear power's share of generation has



dipped slightly to just over 50 percent as units at DNGS and BNGS temporarily came offline for refurbishment.

However, if PNGS is fully decommissioned in 2026, nuclear power's share of electricity generation will drop significantly, to 35 percent of Ontario's power needs.

According to the IESO's forecasts, if the 3,100 MW of baseload power generated from the PNGS comes off the grid, it will be almost entirely replaced with natural gas. This shift towards reliance on natural gas to provide baseload power is almost directly responsible for the forecasted increase in GHG emissions from the province's electricity grid, which would triple over the next two decades.

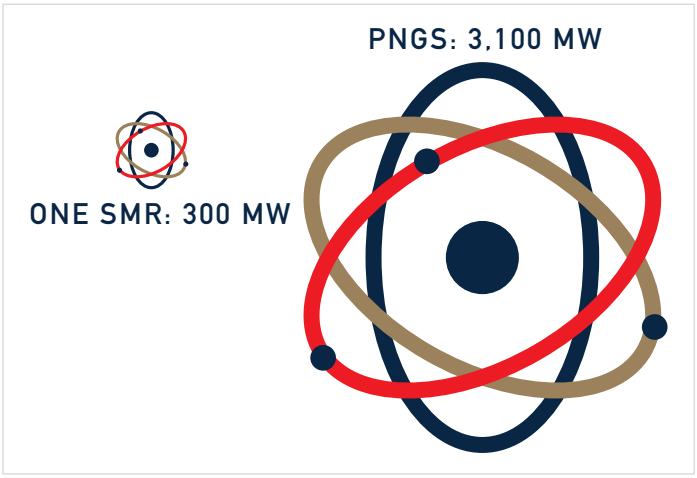
These forecasts are based on the IESO's assumptions of a modest increase in electricity demand over the next two decades. However, significant shifts towards the electrification of transportation, home heating, and industry would double or triple electricity demand. For electrification to help Ontario and Canada meet its zero-emission goals, Ontario must continue to keep carbon emissions from electricity generation to the absolute minimum. This means investing in the next generation of nuclear power.

nuclear-generating-station-an-impact-analysis-on-ontarios-economy/

NEW NUCLEAR IN ONTARIO: 300 STEPS FORWARD, 3,100 STEPS BACK?

About a decade ago, Ontario Power Generation (OPG) received a license from the CNSC to build a new, large-scale nuclear generating station at its Darlington B site, near the existing DNGS. The Darlington B site is the only site in Canada currently approved by the Canadian Nuclear Safety Commission (CNSC) to construct a new nuclear operating facility. However, despite the CNSC's approval, OPG has not proceeded with the construction of a full-size nuclear generating station.

The future of nuclear power in Ontario isn't so much two steps forward, one step back, but rather 300 steps forward, 3,100 steps back. 3,100 megawatts is the generating



capacity of PNGS[6]. The Pickering Station, which supplies about 14 percent of Ontario's energy needs, is set to be decommissioned in 2026 (though a feasibility study on a partial refurbishment was recently announced). Fully decommissioning PNGS in 2026 would remove over 24 terawatt hours (TWh) of emission-free baseload power from the electricity grid each year. Meanwhile, the IESO forecasts that with a modest uptake of electric vehicles (EVs) by 2042, the charging demand for EVs alone will require an additional 24 TWh per year. This means that EVs alone will add about as much electricity demand as Pickering currently supplies in a year, while Pickering could be retired with no plans of replacement. This is effectively a net loss of 48 TWh of capacity.

There is currently no plan to replace PNGS with a new, full-size, nuclear generating station. A feasibility study is being conducted into potentially refurbishing Unit B at Pickering, which could keep approximately 2,000 MW of power on the grid. However, that still means the province's power grid can expect to lose about 1,000 MW of baseload power from the grid PNGS Unit A is decommissioned. Losing Unit A will come at a time when demand for electricity is expected to increase significantly.

Refurbishing PNGS Unit B is necessary to meet the increased intensity of demand in the years to come, but refurbishment alone will not allow Ontario to meet baseload power needs during the coming period of electrification. The province needs to look to build a new, full-size CANDU generating station. However, at this time, OPG is only proceeding with plans to build its first Small Modular Reactor (SMR) at the Darlington site, which will produce approximately 300 MW of emission-free power – less than one-tenth of what Pickering currently generates, and less than one-third of the power that will be lost when PNGS Unit A is decommissioned.

SMALL MODULAR REACTORS

Small Modular Reactors represent a significant development in nuclear power generation. While small reactor technology isn't new – they have been powering naval vessels like submarines and icebreakers for more than half a century – SMRs seek to address one of the primary barriers to new nuclear generation.

The primary benefit of SMR design is the ability to build and service nuclear reactors in a standardized, factory-like way. This will lower upfront capital costs, construction timelines, and long-term maintenance costs compared

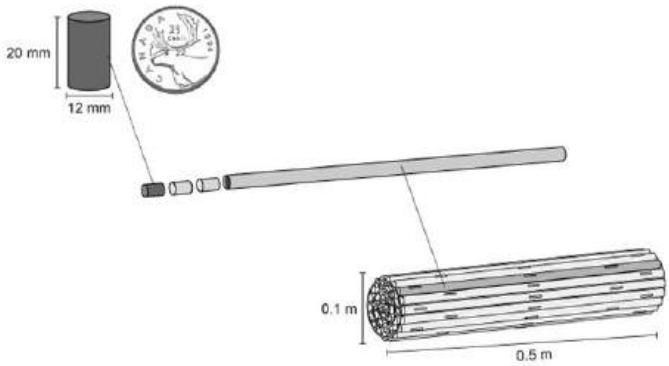
6 https://www.opg.com/powering-ontario/our-generation/nuclear/pickering-nuclear-generation-station/

to traditional nuclear power plants[7]. The modular nature of SMR design would create economies of scale for the small reactors, allowing standardized designs to be manufactured offsite, and assembled at its final location. The standardized design will also create economies of scale with regards to the operation of reactors, lowering long-term maintenance costs.

Manufacturing SMR components offsite for installation at the final operating site means SMRs can be easily installed in areas where clean electricity is needed most, like in northern communities and mining sites, many of which rely on carbon-intensive diesel fuel to power electricity generators. And, as a load-following[8] form of electricity – that is, power generation that can quickly alter its output to meet changes in demand – SMRs can effectively replace natural gas as a support fuel for intermittent power generation, like wind and solar.

However, as exciting as SMR technology is, the reality is the small reactors will not provide the scale of electricity needed in Ontario in the decades to come. Even if PNGS only has its Unit A decommissioned in 2025, the province will lose 1,000 MW of emission-free baseload power. Grid-scale SMR can provide about 300 MW of power, meaning the province would need four SMRs to fully replace Pickering Unit A. Simply maintaining the capacity of Ontario's energy system isn't enough to facilitate the transition to the net-zero carbon emissions economy. The IESO forecasts that 6.6 million EVs in Ontario will increase electricity demand by about the 3,100MW that PNGS currently produces in a year from its Units A and B. If Ontario wants to ensure EVs aren't powered with natural gas, the province would need an additional five to 10 SMRs. More SMRs would be needed as EV adoption increases or if there is significant fuel switching in home heating. It is unreasonable for Ontario to expect to site and build at least a dozen SMRs when the province has yet to even get one SMR fully licensed by the Canadian Nuclear Safety Commission let alone built.

Rather than go through the process of choosing a location for each of the many SMRs Ontario would require and then undergoing the full licensing process for each SMR, Ontario could pursue a single new, full-sized nuclear generating station. With an entire supply chain that already exists to build, operate and maintain CANDU nuclear generating stations, Ontario is ideally positioned to pursue this option.



Uranium dioxide fuel pellets, about the size of a quarter, are encased in zircaloy "fuel pencils", and welded together into 24 kg fuel bundles.

Source: NWMO

Small modular reactors can play a crucial role in greening grids across Canada, and the technology can help limit natural gas use in Ontario by providing a load-following alternative that can work in conjunction with intermittent wind and solar power. However, given the scale of Ontario's electricity needs, SMRs alone are insufficient. The only opportunity Ontario has to limit electricity sector carbon emissions in the looming shift towards electrification is to build new, full-size nuclear generating stations.

7 https://smrroadmap.ca/wp-content/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf?x64773

8 ibid

MANAGING WASTE

One of the most common concerns with nuclear power is the safe disposal of radioactive waste. Radioactive waste is primarily divided into two categories: low-level and high-level.

Low-level waste includes items that have been exposed to radiation or have been contaminated with radioactive material[9], like shoe covers and mops used in nuclear generating facilities, or medical equipment exposed to radiation as part of their use. This waste represents approximately 90 percent of all radioactive waste, by volume[10]. Low-level waste can be safely stored at near-surface disposal facilities while radiation decays.

High-level radioactive waste, which is primarily the spent fuel from nuclear power generation, contains a much higher level of radioactivity than low level waste. The radioactivity of high-level waste will decrease over time, but the potential health risk of exposure to spent fuel will remain for hundreds or thousands of years,[11] making the safe disposal of nuclear waste a paramount concern for nuclear power generators and the federal government. That's why the government created the Nuclear Waste Management Organization (NWMO), to oversee the safe, long-term management of used nuclear fuel.

Currently, spent fuel waste is stored in onsite storage facilities and consists of two phases: wet storage and dry storage[12]. The wet storage phase involves storing used fuel in water pools that cool the fuel and shield the radiation. After seven to ten years in wet storage, the spent fuel from Ontario's nuclear reactors is transferred to dry storage containers made of reinforced concrete and carbon steel[13]. The dry storage containers have a design life of at least 50 years, after which time, the life of the container can be extended, or the fuel can be repackaged.[14]

In Canada, the long-term management of high-level nuclear waste is the responsibility of the NWMO. The NWMO's plan for the long-term disposal of high-level nuclear waste is the construction of a Deep Geological Repository (DGR). The DGR would be an underground storage facility for used nuclear fuel containers. The repository, built 500 to 800 metres underground,[15] will use a multiple barrier system of engineered and natural barriers to safely contain used fuel to protect people and the environment.[16]

Deep Geological Repositories have become the most widely favoured solution to the long-term management of high-level nuclear waste.[17] Finland is currently finishing construction on the world's first DGR to be licensed for the disposal of spent nuclear waste, which will become operational in 2023.[18]

The NWMO is currently exploring options for a site to host the DGR project. NWMO will only place the site in an area with an informed and willing host community, and with acceptance from First Nation and Métis communities in the area.

The storage of high-level nuclear waste is not without risk, however with the oversight of the NWMO, these risks are manageable. The alternative to nuclear waste is greater reliance on fossil fuels, the byproduct of which is increased carbon emissions. Manageable nuclear waste is far less risky than the real and irreversible threat to our planet posed by catastrophic climate change.

9 https://www.nrc.gov/waste/low-level-waste.html
10 https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/storage-and-disposal-of-radioactive-waste.aspx
11 https://www.nwmo.ca/en/Canadas-Plan/Canadas-Used-Nuclear-Fuel/How-Is-It-Stored-Today
12 http://nuclearsafety.gc.ca/eng/waste/high-level-waste/index.cfm#other
13 ibid
14 https://www.nwmo.ca/en/Canadas-Plan/Canadas-Used-Nuclear-Fuel/How-Is-It-Stored-Today
15 https://www.nwmo.ca/en/A-Safe-Approach/Facilities/Deep-Geological-Repository
16 https://www.nwmo.ca/en/A-Safe-Approach/Facilities/Deep-Geological-Repository/Multiple-Barrier-System
17 https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/storage-and-disposal-of-radioactive-waste.aspx
18 ibid

A PATHWAY TO DECARBONIZATION

In their recent report, Pathways to Decarbonization, the IESO considered the necessary shifts in the province's electricity sector in order to reach net-zero electricity sector carbon emissions by 2050, and assuming significant policy-driven electrification in the transportation, building, and industrial sectors.

In the report, the IESO assumes aggressive electrification by 2050 would more than double annual energy demand from current levels. In the net-zero emissions scenario they propose, the use of natural gas generation will be completely phased out by 2050, leaving only carbon-free forms of generation available to meet the rise in demand.

The IESO predicts that even with a 3000% increase in wind power, and more than 1000% increase in solar, the province still needs to double the existing nuclear capacity by 2050 – an increase that will have to come from a mix of SMRs and new, full-sized nuclear reactors.

Considering the long lead-time for nuclear construction, and the expected increase in electricity demand in the coming decades, IESO recommended a series of "no regret" actions that should be taken immediately given Ontario's short- and medium-term electricity needs. These actions include beginning to plan and gain regulatory approval for new nuclear infrastructure that will accelerate the work to decarbonize Ontario's economy. ■

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