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THE HYDROGEN UNITY PROJECT

Seizing Ontario’s opportunity to spark a national hydrogen economy

SUMMARY

Across the globe, hydrogen is emerging as an answer to the urgent need for enough clean energy to curb climate change. Hydrogen is an abundant fuel that emits no carbon, with the potential to replace fossil fuels in long-haul transportation, heavy industries and electricity markets. It can lower the carbon emissions used to heat buildings, or its power can be stored for later use. And hydrogen can be produced from many sources, including nuclear power and renewables, that produce what’s known as “green hydrogen.”

That flexibility in how it’s made and its wide variety of uses makes hydrogen an energy source all Canadians can embrace, wherever they are. Ontario’s already clean electricity grid — anchored by nuclear power — and the energy demand of its dense transportation and industrial sectors primes the province to lead a hydrogen transition. What’s

needed now are the policies, investments and regulatory climate to catalyze a national hydrogen economy.

TAKEAWAYS

- ▶ **National energy harmony:** Hydrogen can be produced across Canada from different sources, for different needs.
- ▶ **Low emissions:** Hydrogen can help solve the “toughest third” of carbon emissions in heavy industry, trucks and mass transit.
- ▶ **Ontario’s advantage:** A clean grid from nuclear power, renewables and hydro is primed to produce hydrogen.



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Why hydrogen. Why now.

The struggle to reduce carbon emissions and arrest climate change has been underway in earnest for over a quarter of a century. It continues to stumble. Global emissions of greenhouse gases (GHGs) are still rising. Almost all countries have been unable to meet the pledges made by their governments to reduce the amount of carbon dioxide and methane being pumped into the atmosphere. Adoption of renewable energy sources like solar and wind power, though growing, remains low overall.

Canada is no exception. It turns out that overhauling entire energy systems — in effect re-shaping the foundations of economies and societies — requires a mass mobilization that has been, so far, beyond our reach.

Yet the inescapable science and risks of climate change make it imperative to find viable alternatives to fossil fuels, not just incrementally reduce their use. That logic lies behind the new global focus on getting the world's economies to a state of “net-zero emissions.” This new call for carbon neutrality — usually with a target of reaching that goal by 2050 — means reducing human-caused GHG emissions as

close to zero as possible, then capturing or off-setting any remaining gases we produce. Net-zero is a new approach to tackling climate change, requiring decision-makers in government, industry and capital markets to set a realistic path to get there.

‘Many countries are already developing ambitious hydrogen strategies as a way to cut carbon emissions...’

The mathematical realities of net-zero account for the renewed interest in hydrogen as an energy source. The chemistry behind generating power from hydrogen is well-known, and hydrogen has historically had ephemeral periods of popularity that swiftly faded.

This time it may be different. Hydrogen is a versatile element that could replace the dependency on burning coal, oil and gas in a host of economic sectors that are hard to electrify, such as long-haul transportation and the chemi-

cal needs of heavy industries. Hydrogen can also be used as a way to store energy for later use, like a big battery, or blended with natural gas to reduce the GHG emissions in home heating.

The trick is that hydrogen does not exist on its own. It has to be extracted from something else, either from hydrocarbons like natural gas, or from water using electricity in a process called electrolysis.

That potential to deliver power at great scale accounts for the renewed interest in hydrogen development. Global investments in hydrogen are reaching into the billions of dollars, led by countries like Germany with an approximately CAD \$14 billion investment (€9 billion) for the expansion of hydrogen production, and CAD \$11 billion in investments (€7.2 billion) from France to build hydrogen production capacity. The ambitious hydrogen strategy released in July by the European Commission expects cumulative renewable hydrogen investments to amount to between CAD \$280 billion and \$730 billion (€180-470 billion) by 2050.

There are already abundant signs of a more aggressive push to hydrogen adoption around the world. French transportation company Alstom is delivering dozens of hydrogen-powered trains to replace diesel ones (supplied with hydrogen fuel cells by leading-edge Ontario company, Hydrogenics), having run successful tests with passenger

trains in Germany and now Austria. The United Kingdom is testing the viability of blending hydrogen with natural gas at a ratio of 1:4 for home heating in a pilot project in Leeds. And Australia has announced a strategic path to produce energy-gorging steel from green hydrogen, as well as for shipping liquified hydrogen to Japan, which is developing the world's first hydrogen shipping vessel.

The Canadian government has taken notice. Natural Resources Canada is developing a hydrogen strategy as part of the Pan-Canadian Framework for Clean Growth and Climate Change. Canada is already a major hydrogen producer, almost all of it made from natural gas and used largely in oil and chemical production. Alberta's Natural Gas Vision and Strategy announced in October is also, partly, a hydrogen pathway, declaring the province's intention to develop technologies to capture, use or store the GHGs that are currently a byproduct of hydrogen production to create so-called "blue hydrogen." And Ontario is developing an environmental strategy that will likely address hydrogen issues.

Other provinces also have opportunities to produce clean hydrogen, whether from natural gas or the "green hydrogen" that comes from clean energy sources like nuclear power, hydroelectricity or renewables. That is especially attractive for Ontario, which has an electricity grid that

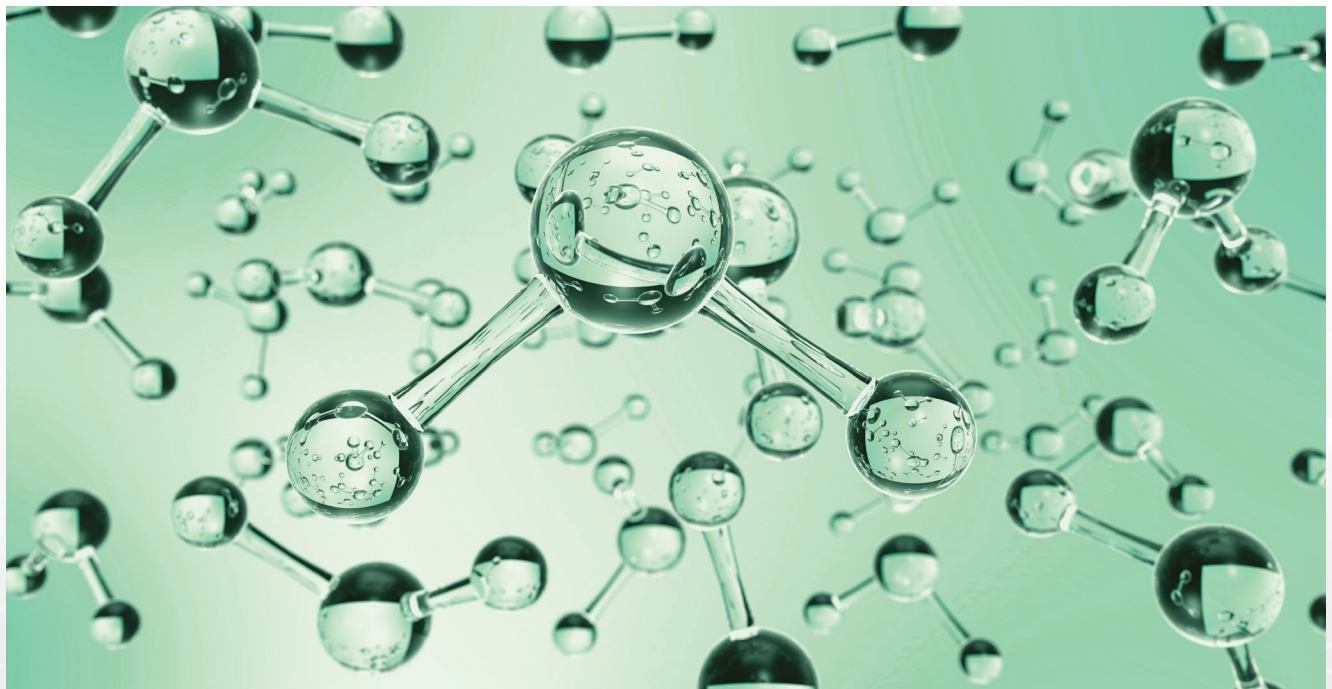


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is among the cleanest on the planet: 60 percent of the province's electricity comes from nuclear generation that emits no GHGs at all. And with the rest coming from a mix of hydroelectricity, solar, wind and natural gas, the province is already primed to be a leading producer of green hydrogen.

'Ontario needs a strategic path to develop the infrastructure, investment and talent for a hydrogen economy...'

Much work needs to be done for Ontario to drive a conversion of parts of the transportation and industrial sectors from burning carbon-emitting fuels to running on clean hydrogen. This NII Report is the first of many that will examine the opportunities for opening a hydrogen economy, from the need to grow our pool of specialized talent and expertise, to setting the policy conditions that get production and regulations right.

But it starts from solid ground. Hydrogen is an opportunity for Canadians to develop harmonized energy policies that allow regions to exploit their different strengths in developing paths to net-zero, such as Ontario's nuclear advantage. And it provides a hopeful alternative to the frustrations and impediments that have stymied our decarbonization efforts so far.

Hydrogen is an energy source all Canadians can embrace.

Energy policy has often been the burr in Canadian unity. The National Energy Program, created in a burst of Canadian nationalism amid a global oil crisis, aggravated the sense of alienation in Canada's West with such force that it remains a shorthand for grievance almost a half-century later. Newfoundland and Labrador carry their own bruises over long-ago signed hydroelectric contracts with Québec.



And we continue to litigate energy policy amongst ourselves, with some Canadians tying their political identity to the energy beliefs they hold. Should that pipeline be built and allowed to pass? Are we properly subsidizing the energy sources of the future? How do we treat the centres of fossil fuel production that have generated so much of our national wealth but now face a world focused on decarbonization?

Into this fraught environment comes the balm of hydrogen power.

Hydrogen holds the potential for rare agreement among Canada's regions and factions, a low-emission source that can be produced in different ways in different locations. It can unite all our energy sources — nuclear, hydroelectricity, renewables and fossil fuels. And it offers the potential to begin de-carbonizing what experts call the "toughest third" of total GHG emissions: long-haul trucking, steel and cement production, shipping and — some believe — even aviation. These are the economic sectors that have barely been scratched in the global push to reduce emissions.

And we're already in the game. Canada currently ranks among the world's top 10 hydrogen producers. Most of what is made here is used in oil refineries and for the production of chemicals and fertilizers. It is produced through a steam methane reforming process using natural gas.



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Unfortunately, this process emits a significant amount of carbon dioxide (CO₂). To make hydrogen production carbon neutral, advocates point to new technologies that show promise of being able to reduce emissions. By outfitting the process with carbon capture and sequestration technology (tucking it away in geological formations, for example), steam methane reforming production can potentially cut its emissions by up to 90 percent. Pyrolysis is another method being developed to produce hydrogen from natural gas that would yield solid carbon products instead of CO₂ emissions.

But while western provinces can rely on their natural gas resources to generate hydrogen, other provinces have their own energy sources that are already clean. Québec and Manitoba have hydroelectric power. And Ontario's world-leading clean grid, founded upon its strength in homegrown nuclear power, is a ready source of emissions-free energy for producing green hydrogen.

That's because hydrogen can be produced through electrolysis, a process of making it from nothing more than electricity and water. Electrolysis uses electricity to split water's two hydrogen atoms from the oxygen, leaving pure oxygen as the only byproduct. If the electricity used in the process is clean — as it is when it originates from Ontario's vast nuclear, solar, wind or hydroelectric assets — the result is green hydrogen that emits no GHG emissions at all.

In this model, electricity from a nuclear generation plant can be transmitted by the existing grid infrastructure to electro-

lyzers located on the sites where the hydrogen is needed.

As a low-emission fuel, hydrogen also presents export opportunities across Canada with export pathways that vary by region. In regions with natural gas infrastructure, hydrogen can be exported through pipelines, blended into the natural gas system for direct use or transport, or liquified at ports and shipped overseas. Elsewhere, it can be converted into high-value export products like ammonia.

'Hydrogen can create a harmonized Canadian energy policy, allowing each region to exploit its respective strengths...'

With its deep-water ports and established natural gas pipeline networks, Canada is well set up to export hydrogen globally. Canadian hydrogen could be exported to such markets as Japan, South Korea, California, and Europe. In Ontario, hydrogen technology could be exported to nearby jurisdictions and powered by clean energy exports from its nuclear fleet.

That offers the prospect of developing supply chains and the jobs that go with them across the country. Hydrogen's route to a low-emissions future based on regional strengths offers Canadians something rare: an energy pathway we can agree on.

Ontario's big, diverse economy is a recipe for hydrogen demand.

With its large population, dense transportation networks and strong industrial base, Ontario has energy needs that can spur economies of scale in hydrogen production and end-use technologies. By 2050, some estimates suggest hydrogen could supply up to 30 percent of all energy needs in Canada. By taking advantage of this scale, Ontario can be an early leader in a national hydrogen transformation.

Opportunities to develop hydrogen technologies and applications in Ontario include:

- ▶ **Refining & chemicals:** Ontario's petroleum refining and chemical manufacturing industries currently consume large quantities of hydrogen, which is produced using steam methane reforming. Emissions from hydrogen production account for roughly 10 percent and 8 percent of each industry's emissions, respectively, which could be eliminated using Ontario's clean electricity grid and hydrogen electrolyzers.
- ▶ **Home heating:** Ontario is one of the best places in North America to store hydrogen underground, and the extreme cold climate means households here use twice as much natural gas for home heating as the world average. Hydrogen could be added to existing natural gas storage caverns in the summer, and the blended fuel could then be delivered to homes in the winter through the natural gas distribution network.
- ▶ **Transportation:** Ontario has a large, urbanized population that needs mass transit, and is served by municipal vehicles like garbage trucks. Short-haul vehicles like these account for 16 percent of diesel fuel use in Ontario and many could be switched to clean-burning hydrogen, providing concentrated demand for electrolyzers.
- ▶ **Trucking:** Ontario is also home to one of the largest long-haul trucking sectors in North America thanks to its trade with the Great Lakes states and Québec along the Windsor-Montréal corridor. Sixty percent of all

US-Canada road trade goes between just three border crossings in Ontario. Powering these trucks with hydrogen could have a big impact on emissions for Ontario and its trading partners.

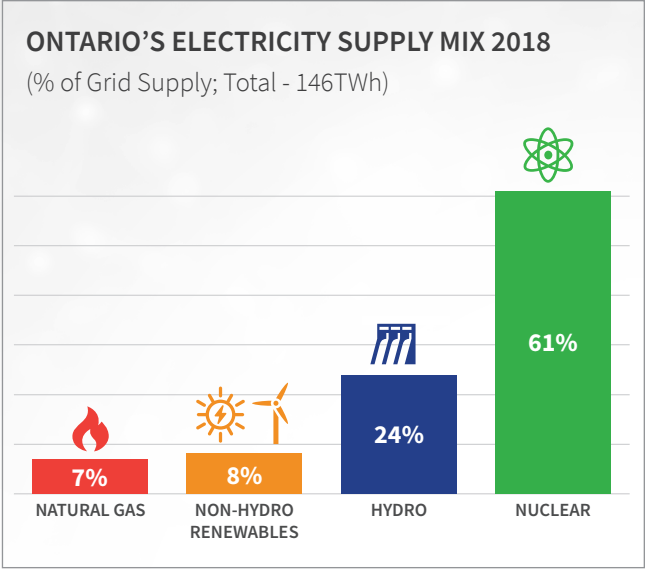
- ▶ **Industry:** Ontario is Canada's industrial heartland. Its manufacturing sector accounts for 18 percent of the province's GDP and employs one in eight workers in the province. Manufacturing has heat and energy needs that innovation in hydrogen technologies could provide.
- ▶ **Agriculture:** Hydrogen also plays an indirect but important role in agriculture as a key input to ammonia, which is used to make fertilizer. Ammonia production represented 40 percent of global hydrogen demand in 2018.

With strong demand for hydrogen across such diverse applications, and a clean electricity supply from nuclear power, Ontario has the potential to be home to a large-scale hydrogen economy.

HYDROGEN CAN BE USED FOR...



If Ontario is to be a national and global leader in hydrogen, it needs a critical mass of companies, talent, investors and policymakers to sustain it. Several Ontario enterprises, such as Next Hydrogen, Dana Canada and Hydrogen Optimized, are among world leaders in hydrogen-related industries. Toronto-headquartered Greenfield Global and Hy2Gen Canada have announced a joint venture to produce green hydrogen in Varennes, Québec. Hydrogenics has supplied fuel cell power systems for Alstom's hydrogen commuter trains in Germany, the first hydrogen-powered commuter trains in the world, and also produced the world's largest electrolyzer for Air Liquide's hydrogen manufacturing plant in Bécancour, Québec, producing hydrogen for industrial and mobility markets in North America.



Ontario also exports its expertise in hydrogen technologies, demonstrating the opportunity for growth and deployment on an international scale.

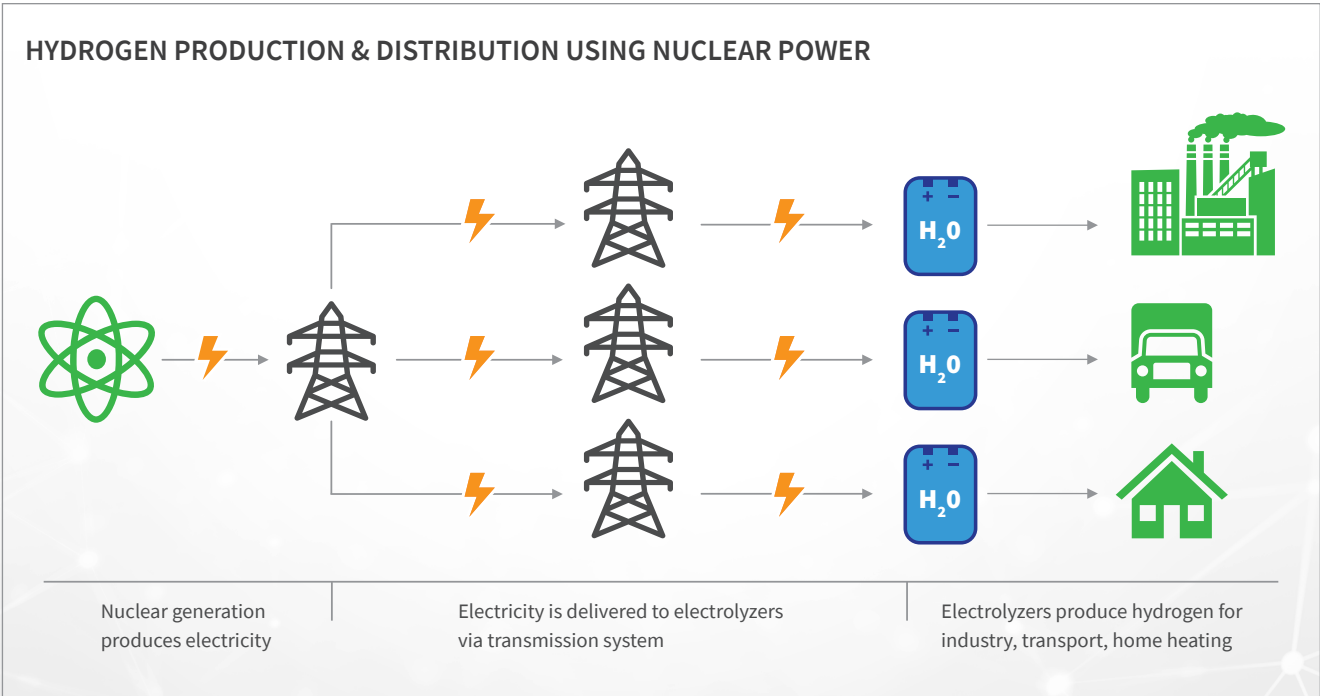
A focused Ontario strategy would help ensure that these companies are operating in an environment that sets them up for global success. They need a pipeline of engineers, researchers and investors with the sophistication to innovate on the supply side, and hydrogen expertise spread through other industrial sectors to promulgate understanding of

hydrogen's benefits in a net-zero economy. And Ontario needs public and private sector cooperation to develop the lead markets, first-users and infrastructure that can create the demand side of the hydrogen equation.

There are some promising signs:

- ▶ **Electricity:** IESO is piloting hydrogen power-to-gas systems for ancillary services by controlling the output of Hydrogenics' electrolyzers at the Markham Energy Storage Facility, taking surplus power from Ontario's electricity grid and using it to produce hydrogen. The Markham facility is the first of its kind in North America.
- ▶ **Transportation:** Metrolinx found it would be technically feasible and cost-effective to run Ontario's GO Transit network using hydrogen fuel cell-powered rail vehicles.
- ▶ **Warehouses:** Canadian Tire has deployed hydrogen-fueled forklifts for two of its locations in Ontario and has placed a third order for an electrolyzer from Next Hydrogen for one of its Ontario warehouses.

The initial steps provide a ramp for developing a made-in-Ontario hydrogen strategy that can build the network of talent, companies and investment required for global success.



Ontario's nuclear advantage makes it a ready source of green hydrogen.

With a clean grid built on nuclear, hydro and renewables, Ontario has the low-carbon electricity that is key to economic hydrogen production. Delivering over 60% of this supply, nuclear anchors this clean electricity advantage.

Ontario's nuclear generation operates 24/7, and this consistency enables high-capacity factor electrolyzer operation needed for hydrogen production. As well, new small modular reactor designs provide high-temperature outputs that could provide another avenue for production. Ontario Power Generation and Bruce Power are supporting the development of high-temperature reactors in collaboration with Terrestrial Energy (a Canadian company), X-energy, GE and Westinghouse.

That local nuclear power is delivered into an extensive electrical transmission system grid that provides Ontario with another key asset to deliver electricity to wherever hydrogen electrolysis is needed. This allows Ontario to get started in



rolling out hydrogen without requiring new investments in transmission infrastructure. Hydrogen production can be coordinated by the electricity system during periods of peak demand to optimize the use of the electricity system and hydrogen assets.

Nuclear power gives Ontario a path to developing a secure, stable supply of hydrogen that can meet the potential demand for great swaths of the provincial economy. It must be part of a made-in-Ontario strategy to get there.



What's needed next.

The world has awoken to the hydrogen opportunity. The most abundant element in the universe, hydrogen — once it is teased out of water, fossil fuels or other materials — can help meet the biggest challenge of our generation: decarbonizing the global economy to avoid the worst ravages of climate change.

For Canada, this marks an inflection point in which Canadians can come together over energy issues in a way that lets each region respond to the opportunity hydrogen presents according to its strengths, all in pursuit of the common goal of a net-zero economy.

For Ontario, it is an opportunity to develop a made-at-home solution to powering its industrial sectors and transportation, leveraging its existing strength in clean energy from nuclear power. Nuclear can provide the shoulders upon which Ontario can develop the innovations, technologies and expertise to transition to the next generation of energy systems.

This brief makes the case that these advantages must be nurtured. The catalyst is a combination of policies, regulations, market conditions and investment that creates the conditions for success. ▶▶▶



The **Nuclear Innovation Institute (NII)** is an independent, not-for-profit organization that provides a platform for accelerating the pace of innovation in the nuclear industry.

Nuclear energy is a powerful force for decarbonization. It creates good jobs, drives economic growth and produces radioisotopes that are used - among other benefits - for cancer detection and therapies that save lives in Canada and around the world. The Institute is founded on the belief that the industry can enhance these vital contributions by adopting a structured approach to fostering innovation.

www.nuclearinnovationinstitute.ca

BRUCE POWER CENTRE FOR NEXT GENERATION NUCLEAR

Based within the Nuclear Innovation Institute, the **Bruce Power Centre for Next Generation Nuclear** nurtures a deeper understanding of the role of nuclear power in developing new energy technologies that can help forge Canada's path to a net-zero economy.

Initially operating as a research/think tank, the Centre examines the market and technology challenges facing energy sources such as hydrogen, new nuclear technologies such as small modular reactors and fusion energy. The Centre will also explore opportunities for Bruce Power assets to be optimized and leveraged to maximize the impact they will have on Canada's clean energy future.

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