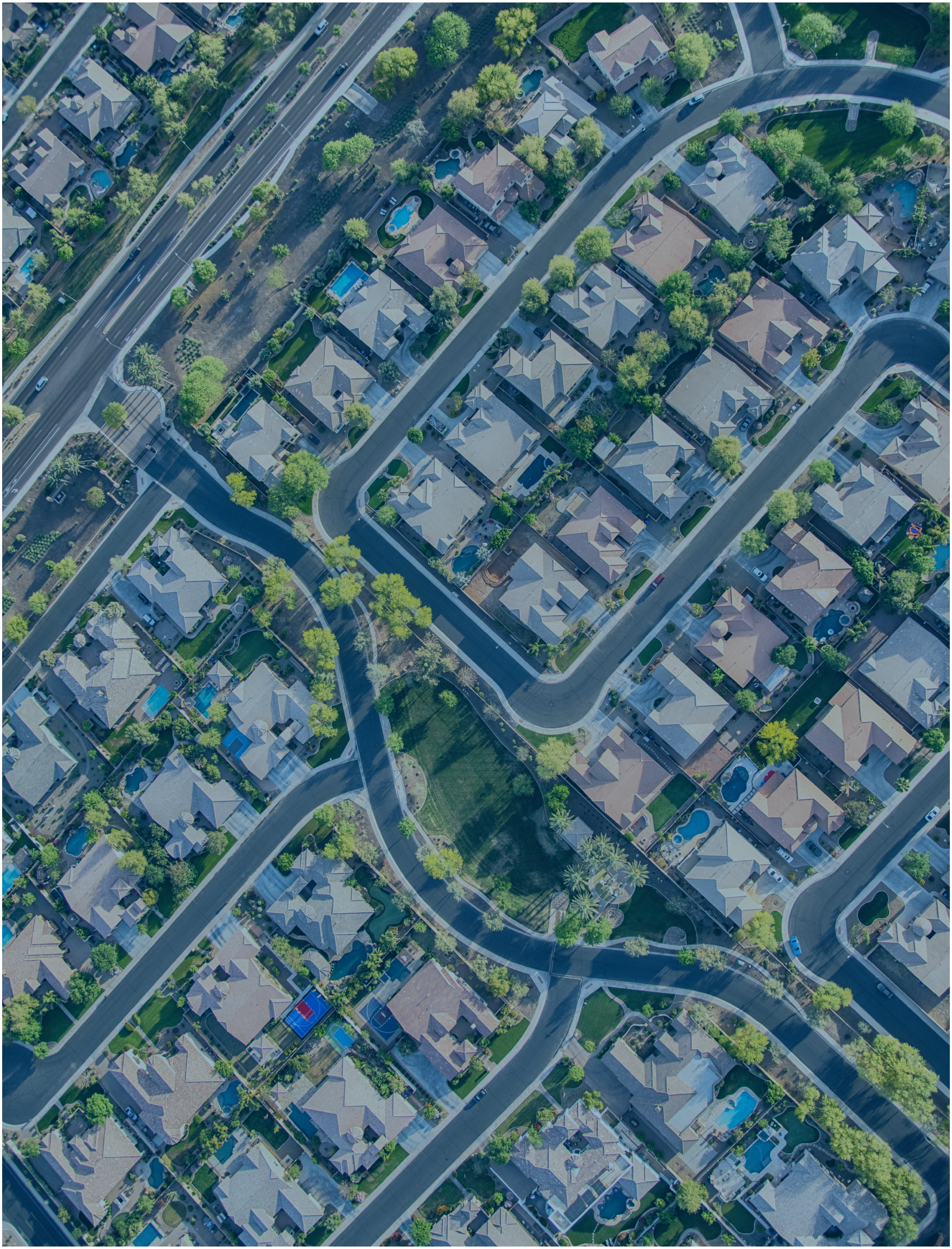
Developing a sustainable approach to hydrogen deployment in Canada

H2GO CANADA



Why you should read this report

In jurisdictions around the world, hydrogen technologies and infrastructure are being deployed according to plans co-developed and implemented by governments and industry stakeholders. These deployments are a feature of deliberate efforts to develop hydrogen as a supporting option in the broader pursuit of transition pathways to less carbon-intense economies.

As these plans drive growth in hydrogen system investments, internationally, Canada is participating in an ad hoc and reactive manner, mainly as an exporter of hydrogen technology and expertise. Should the decision be made to develop a strategic approach to cultivating hydrogen opportunities in Canada, this report provides guidance from the perspective of a range of private sector organizations representing diverse sectors of the national economy and regions of the country.

Herein the qualities of hydrogen that make it attractive are presented, as well as the challenges to adoption. An approach is suggested, along with a set of principles to consider, such that the needs of the market are met and conditions for success are established.

About H2GO Canada

H2GO Canada is a not-for-profit entity that serves as a collaborative, partnership-building conduit bringing together public and private sector resources in support of the strategic, sustainable deployment of hydrogen systems in Canada. The organization is structured to catalyze and mobilize hydrogen supply and demand, raise awareness through education and facilitate market demonstration projects of hydrogen systems.

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We also thank the many more organizations that participated in the consultations but are not named here, as formal permission was not received at the time of publication.

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Executive summary

In December 2018, H2GO Canada began consulting with a diverse array of private sector organizations about the prospects for increasing hydrogen production, distribution and use in Canada. The goal was to identify the barriers and opportunities to deploying hydrogen systems that could support deep, long-term reductions in greenhouse gas emissions, and do so in a manner that is economically and socially practicable. This report presents the perspectives gathered through the consultation process in a narrative format.

The interest of industry in the hydrogen option stems from three key characteristics:

1. It is versatile – hydrogen is a non-carbon energy commodity, capable of meeting society's demands for heat, power and mobility;

2. It is accessible – hydrogen can be produced from a wide range of developed sources, the supply chains for which can be progressively decarbonized; and

3. It can integrate with current systems – hydrogen works with existing infrastructure and distribution channels.

In exploring the implications of these characteristics, three compelling benefits were identified that are particularly relevant to Canada's circumstances:

First, hydrogen offers a pathway to decarbonization that is *highly inclusive*. Crucial roles must be played by established companies in resource extraction, power generation and manufacturing, among others, as well as by technology innovators and entrepreneurs.

Second, existing infrastructure and industrial assets need not be stranded, since hydrogen integrates with current systems. Hydrogen technologies build onto these systems, using them in ways that create new value as opposed to marginalizing their role or advancing their displacement.

Third, as a consequence of the previous two benefits, the hydrogen pathway is an option that can *preserve* current employment and create *new jobs*.

Notwithstanding the potential benefits, scaling up hydrogen faces many practical barriers, including the maturity of the supply chain, alignment of finance and policy, and a need to build knowledge and understanding. A coordinated approach is advised, involving public- and private-sector collaborations. Seven principles are presented as guidance for the development of a Canadian plan:

1. Prioritize a **net gain in employment**

2. Be guided by **analytical rigour**, basing deployment decisions on full life cycle analysis of sustainability criteria

3. Focus on the **development of markets** to accelerate scale-up

4. Build on international leadership to **secure growth in exports of technology**, services and expertise

5. Use hydrogen to help mobilize **Canada's resources for export**

6. Showcase the application of hydrogen to **integrated community energy system** design

7. Deliver **clean air** benefits to the public

INTRODUCTION

In December 2018, H2GO Canada launched a process of consultation with private sector organizations on the prospects for increasing hydrogen production, distribution, and use in Canada. The purpose was to qualitatively identify the barriers and opportunities to achieving a vision of hydrogen use in Canada that supports decarbonization of energy systems and reductions in greenhouse gas emissions. Hydrogen can be used in many industrial and commercial applications, and it can be produced from a diversity of sources. Accordingly, the consultation team – assembled by Fasken and PricewaterhouseCoopers with the support of Natural Resources Canada – worked to engage companies representing a wide range of industrial sectors.

Nearly 50 companies were initially invited to participate in the consultation process, of which more than 35 chose to engage. Most were large, established employers whose activities are expected to profoundly influence the evolution of Canada's energy system in the coming decades. This is not a large subset of industry, but the diversity of sectors represented is an important quality of the process.

Following the circulation of an engagement package, one-on-one interviews were scheduled and conducted – mainly during December 2018 through March 2019. The collective input gathered through the interviews was synthesized into a draft report, which was shared with participating organizations in a series of regional workshops held in Burnaby, Calgary and Toronto, in April. In these workshops, the interview findings were further discussed, with an eye toward developing basic guidance for government and industry stakeholders in deploying hydrogen systems that are sustainable and scalable. This report is the outcome of that dialogue.

Herein the collective perspectives of the private sector organizations engaged in the consultation process (i.e., stakeholders) are presented. This is not a verbatim report, nor is the text attributable to any specific company. It represents the best efforts of the consultation team to reflect the spirit of the input gathered in a coherent, narrative format. No part of this document should be considered as obliging the stakeholders to any action, nor be construed as promise or covenant. Rather, the value of this document is as a source of vision and guidance, voluntarily submitted by industry stakeholders, regarding the challenge of developing a successful hydrogen deployment plan for Canada.

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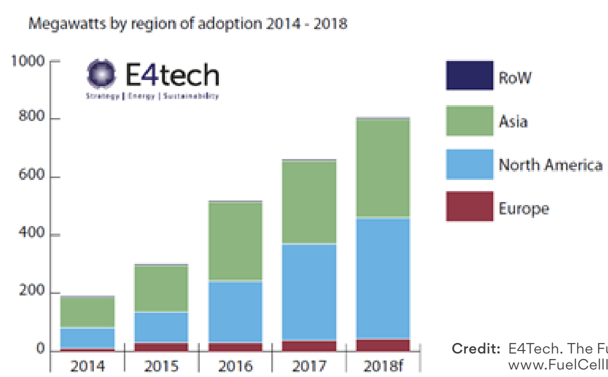
WHY HYDROGEN?

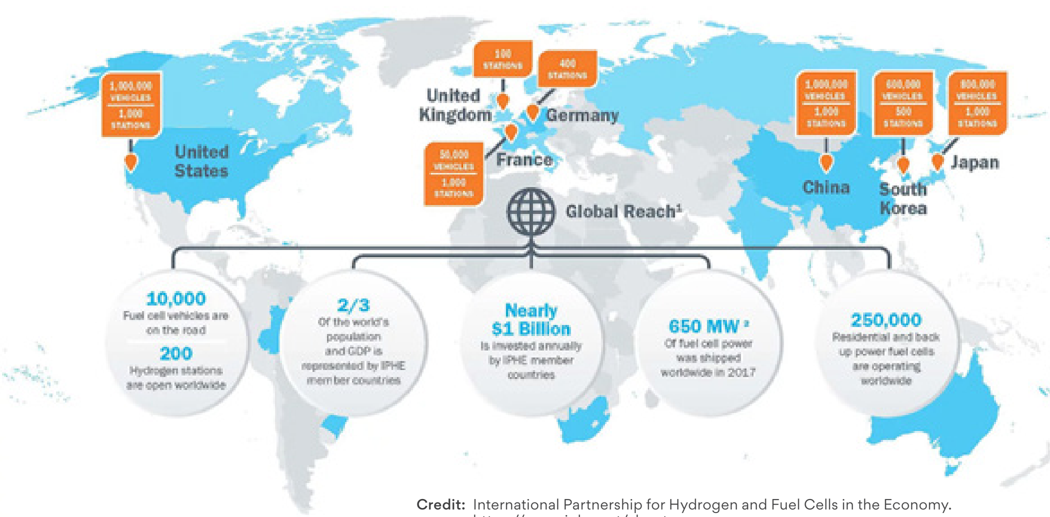
Establishing context for the interest in hydrogen

Interest in hydrogen is growing. This is observable by the growth in global investments made in hydrogen technologies and infrastructure in recent years, as well as the projected rates of adoption expressed in ambitious declarations by governments and industry alike. The images below illustrate these indicators. The first shows the recent, global growth in installed capacity of fuel cells – just one type of hydrogen technology – according to publicly reported data. The other shows recent levels of unit and system deployments worldwide, as well as the targets among leading countries for hydrogen powered vehicles and refueling stations. Each image is a snapshot – a recently-captured instant-in-time – of a rapidly evolving landscape.

The interest in hydrogen arises from the imperative to reduce concentrations of greenhouse gases in the atmosphere, globally, as the primary, long-term solution to the problem of climate change. The governments of many national and subnational jurisdictions around the world, including in Canada, are establishing targets and timelines for the reduction of emissions of greenhouse gases – chiefly, carbon dioxide – aiming to forestall the worst impacts of global warming. Achieving these goals is the orienting principle of many new and emerging policies of government, including regulations promulgated under law; in particular, those concerning the production, distribution and use of energy.



Credit: E4Tech. The Fuel Cell Industry Review 2018. www.FuelCellIndustryReview.com



Credit: International Partnership for Hydrogen and Fuel Cells in the Economy. https://www.iphe.net/about

Private sector organizations – especially larger, more established companies that employ millions of Canadians and invest significantly in the country's economic growth – are confronted with the challenge of contributing to climate change objectives while fulfilling obligations to their stakeholders and commitments to their communities. In this context, *options* are highly valued: options for corporations to decarbonize their internal processes, as well as the larger energy systems of which they are a part (and on which they rely); options among which to compare risks and contrast benefits; and, perhaps most importantly, a choice between options that *work*.

Indeed, not every pathway to a lower-carbon future is a practical option for every organization or community to follow. Some involve fundamental trade-offs that are untenable, either because the application of the relevant technologies is infeasible, or the transitions proposed are disruptively inconsistent with regional economic and social norms.

As an option, hydrogen is generally considered compelling for three main reasons:

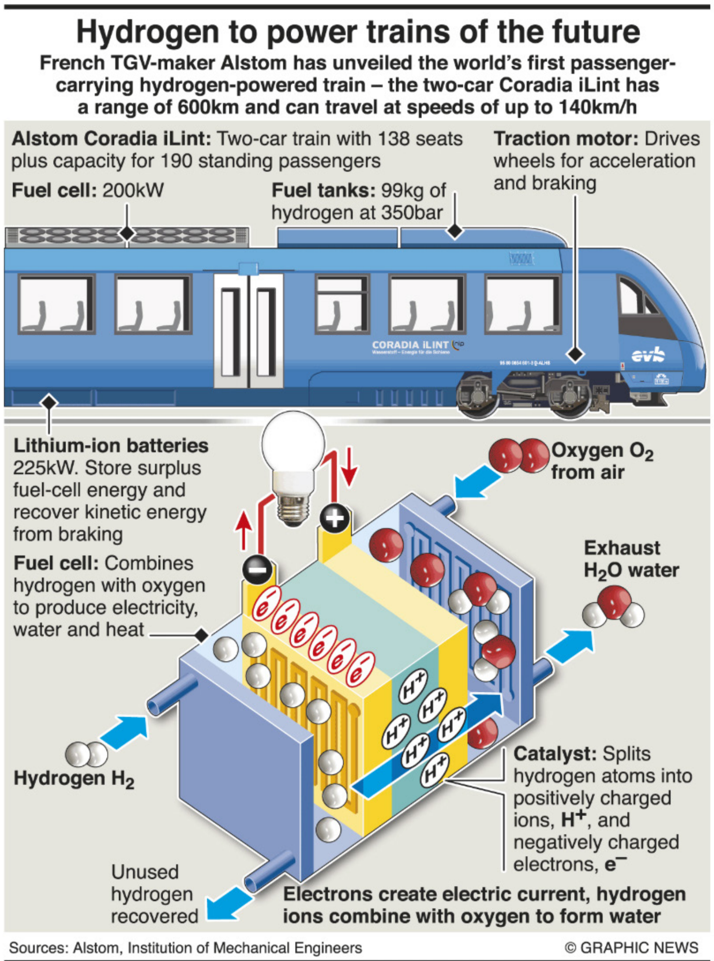
1. **Hydrogen has potential to serve as a versatile, non-carbon energy commodity, capable of meeting society's demands for power, heat and mobility (to some significant degree).**

   Converting the potential energy stored in molecular hydrogen (H_2) into work results in no emissions of carbon dioxide. This is true whether the hydrogen is used in a fuel cell to generate electrical power, or to generate heat through simple combustion. The electrochemical reaction in a fuel cell generates only pure water or water vapour. Similarly, burning hydrogen generates only water (plus low levels of nitrogen oxides when drawing oxygen from the air, which is four-fifths nitrogen).

   Hydrogen is thus a carbon-free carrier of energy.

   Furthermore, hydrogen has roughly three times the energy content of gasoline, diesel and natural gas, by mass. Accordingly, it has been shown to effectively power vehicles of all types. It can be used as a fuel for internal combustion engines; it can also serve as the source of energy for electric propulsion, stored onboard. It can efficiently deliver heat at high temperature in industrial process applications, or at lower temperatures suitable for buildings and district thermal systems.

   So, through the application of different technologies, the energy in hydrogen can be converted into heat or electricity. As well, the efficiency with which heat or electricity is produced from hydrogen is at least as high as that with other, more common technology, and often much more so. This is how hydrogen is considered capable of satisfying the demands of primary energy end-uses in industry, in buildings and in transportation.

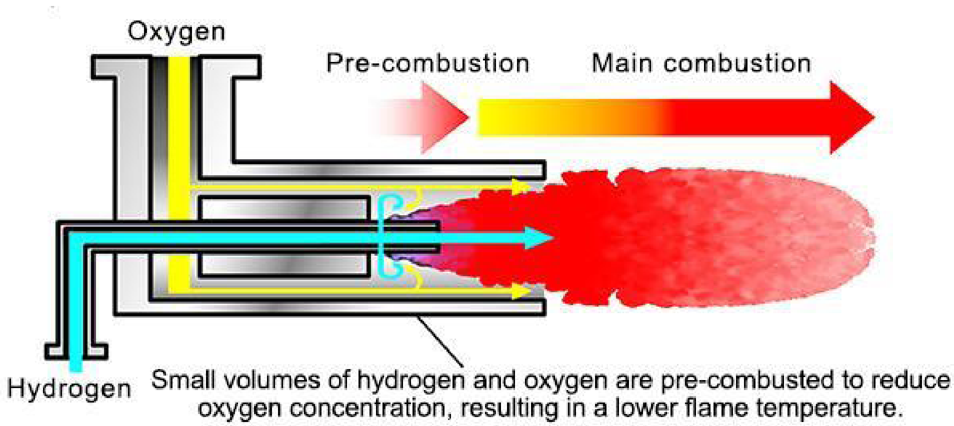


HYDROGEN FOR ELECTRIC MOBILITY

The inset image describes how hydrogen fuel cells are used to generate enough electrical power to propel a train. The fuel cells are supplied with hydrogen from pressurized tanks onboard, as well as with oxygen drawn from the surrounding air. In an electrochemical reaction, the hydrogen (H^2) and oxygen (O^2) bond to form water (H^2O), releasing energy in the form of electrical current. Some of the current from the fuel cell is used to power the electric motors that propel the train along the track, and some is used to maintain charge on a set of batteries. These batteries also help meet the demand for propulsion power, and for other systems onboard. The energy stored in the hydrogen is substantial – enough for the train to travel much father than would be possible on batteries alone.

The train shown is a model using fuel cells built by Hydrogenics, headquartered in Mississauga, Ontario.

Credit: Graphic News, sourcing Alstom, Institution of Mechanical Engineers. https://www.graphicnews.com/en/pages/38485/TRANSPORT-Hydrogen-powered-trains



HYDROGEN FOR INDUSTRIAL HEAT

The inset image describes the operation of a general-purpose burner, fueled by pure hydrogen. Recently developed by Toyota, and intended for industrial use, the burner uses the high-temperature properties of hydrogen combustion. For many industrial applications, this provides an option for zero-carbon process heat.

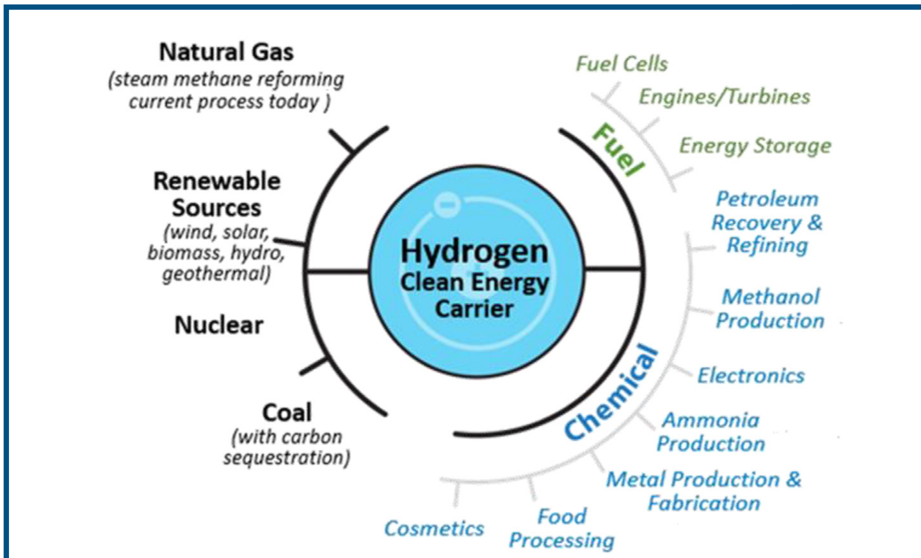
Credit: Gasworld. Toyota develops world's first general-purpose hydrogen burner for industrial use. https://www.gasworld.com/toyota-develops-worlds-first-hydrogen-burner/2015852.article

2. **Hydrogen can be produced from currently developed sources, the supply chains for which can be progressively decarbonized.**

Hydrogen is the most abundant element on earth, present in both organic and inorganic compounds. Through various processes, hydrogen can be drawn out of these compounds. Common means of hydrogen production include electrolysis of water (H_2O), where the application of electricity separates the hydrogen from the oxygen, and reforming of fossil fuels – mostly natural gas (CH_4) – where the application of heat separates the hydrogen from the carbon (which is usually released to the atmosphere as by-product carbon dioxide). Hence, a source of energy and a material are needed to generate hydrogen. As with electricity, hydrogen is a *carrier* of energy – not a primary source of energy.

The carbon-intensity of the hydrogen supply chain is, therefore, a function of its inputs. If, for example, hydrogen is produced using electricity generated from hydropower, nuclear power or wind power, then its carbon-intensity is virtually zero (or nearly so). If the hydrogen is extracted from natural gas, with the by-product carbon dioxide captured and sequestered, then the hydrogen can be considered to have net-zero carbon-intensity.

So, hydrogen can be used as an energy commodity, but that is only part of the story. In chemicals processing and in manufacturing processes, hydrogen often serves as a material input to production. It is also a by-product of many industrial processes. Where the appropriate facilities for storage and distribution exist, substantial volumes of hydrogen are currently generated, exchanged and used within industrial clusters. Where by-product hydrogen cannot be economically captured and put to practical use, it is usually vented to the atmosphere. Hydrogen is non-toxic and, as the lightest element, it rapidly disperses into the air. Biogenic industrial processes, such as the treatment of municipal solid waste and wastewater, represent further opportunities to build up the supply of hydrogen in Canada.



HYDROGEN CONNECTS AND INTEGRATES

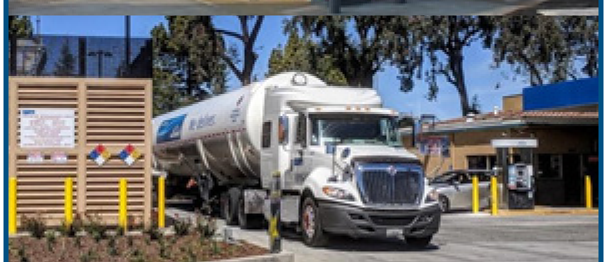
The U.S. Department of Energy's H2@ Scale program views hydrogen as an integrating medium connecting multiple sources and uses. "Hydrogen is an energy carrier: used as fuel or feedstock; produced from diverse domestic resources and used in many applications."

Credit: U.S. Department of Energy. http://www.metrolinx.com/en/news/announcements/hydrail-resources/Sunita%20Satyapal_DOE%20Keynote%20Metrolinx%20Canada%2011%2016%202017%20rev.pdf

3. Hydrogen has the potential to integrate with established energy infrastructure and modes of distribution.

To a significant degree, existing energy distribution infrastructure can be used to move hydrogen to market. Indeed, the integration of hydrogen and hydrogen technologies into energy systems can add value by enhancing the productivity and flexibility of deployed assets.

Existing retail forecourts for refueling vehicles already serve as host sites for many hydrogen dispensers, alongside gasoline, diesel and natural gas pumps. Like these fuels, hydrogen is trucked in via over-the-road transport and stored on-site. In some cases, hydrogen is generated at the forecourt by an electrolyzer or a reformer.



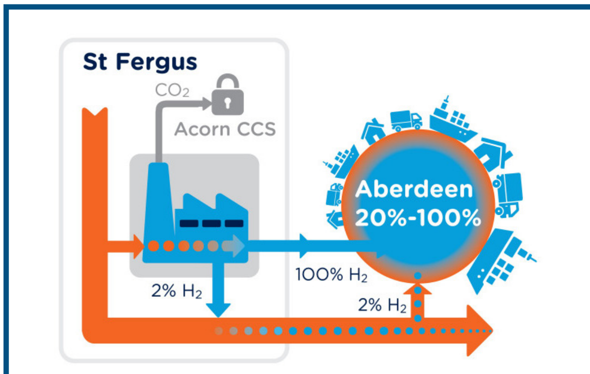
BUSINESS AS USUAL - HYDROGEN USING CURRENT DISTRIBUTION SYSTEM

- Newport Beach refueling forecourt with hydrogen dispenser – the 35th retail station to open in California, 2018. Credit: The California Fuel Cell Partnership.
- Hydrogen refueling station in Mountain View, California, with liquid-hydrogen delivery truck, and a Toyota Mirai fueling up. Credit Wikimedia Commons.

Credit: https://commons.wikimedia.org/wiki/File:Linde_hydrogen_station_Mountain_View.jpg

In either case, parts of the existing network of retail stations could service hydrogen-powered vehicles, the refueling patterns of which are like conventional vehicles.[1]

As well, hydrogen can blend with natural gas. In various hydrogen-methane mixtures, existing natural gas pipeline networks and equipment can be used – in some cases with little or no modification. Such blending of hydrogen produced from low-carbon sources effectively reduces the carbon-intensity of the gas delivered to customers.



HYDROGEN INTEGRATING WITH NATURAL GAS INFRASTRUCTURE

SGN, which manages the natural gas network for much of Scotland and the south of England, has initiated an investigation into the viability of converting the existing natural gas pipeline network for the purpose of distributing pure hydrogen. The study will inform the U.K. Government's strategy for decarbonizing heat for buildings and industrial processes, which is key to it achieving greenhouse gas emissions reductions goals in 2050. Various hydrogen delivery options are being examined, including:

- using Aberdeen's regional gas system to deliver up to 100% hydrogen to power up to 300 homes;
- blending hydrogen with natural gas in concentrations of up to 2% in the older national network serving the wider U.K.; and
- constructing a dedicated hydrogen pipeline that would serve Aberdeen's transportation hubs.

Work on the study officially started in late 2018 and is expected to be completed by the summer of 2019.

Credit: Pale Blue Dot. 2018. https://pale-blu.com/2018/10/10/sgn-and-pale-blue-dot-collaborate-on-aberdeen-hydrogen-vision

1 A typical fill-up for fuel cell-electric vehicles currently sold in parts of Canada by Hyundai and Toyota can take only three minutes.

Hydrogen production can also add energy storage and buffering capacity to existing electricity networks. Grid-scale electrolysis plants are currently being used in Europe to add load to the grid to minimize curtailment of supply, especially in areas served by non-dispatchable generating assets, such as nuclear power plants and wind farms. The fleet of electrolyzers produce hydrogen, representing stored energy from the grid. This hydrogen, which is zero-carbon, is often injected directly into the natural gas grid, helping to decarbonize gas supplied to customers. It can also be used as a fuel for hydrogen-powered vehicles. Because it is feasible to store hydrogen as a gas indefinitely, the prospects for *seasonal* energy storage are also being explored.

In these ways and more, hydrogen and hydrogen technologies can expand and extend the utility of existing infrastructure and the services it supports, while also improving energy system efficiencies and asset utilization.

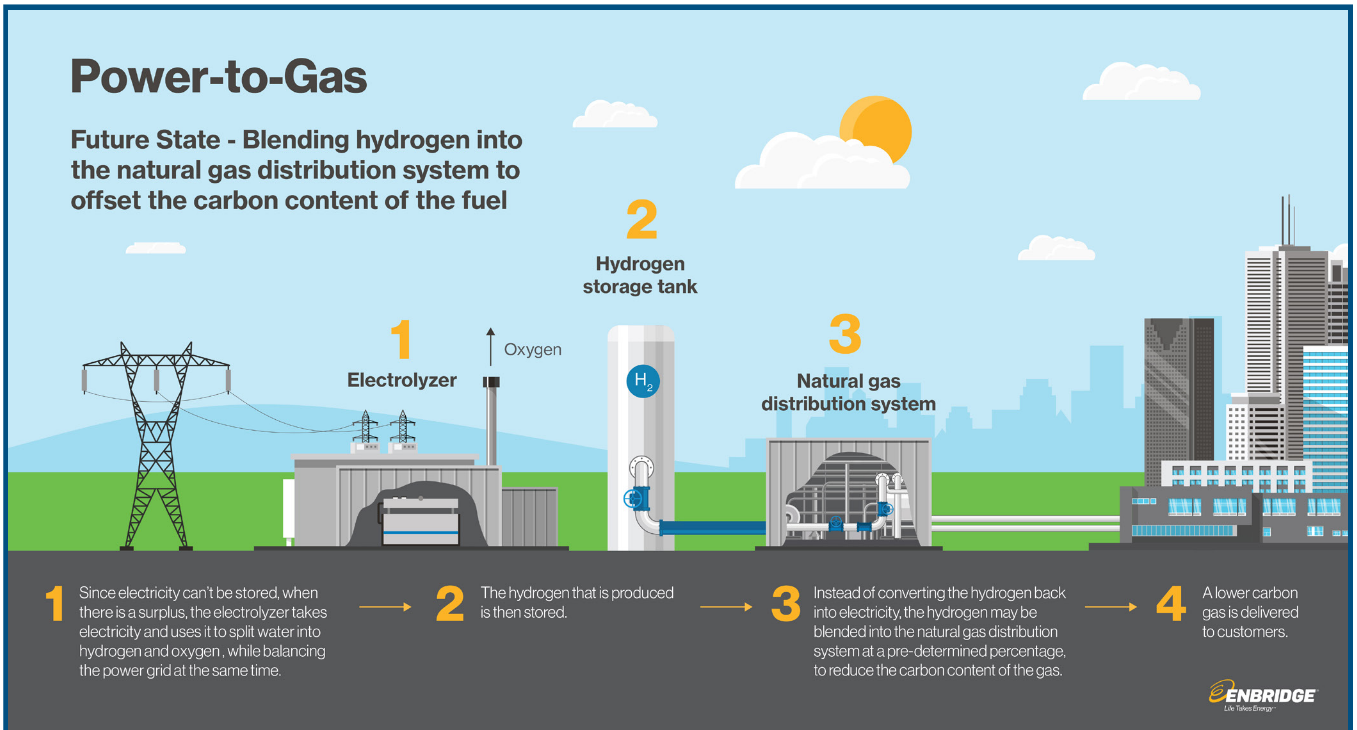
The above-described attributes of hydrogen – (i) its capacity to meet the demand for heat, power and mobility, (ii) the range of developed sources that can contribute to its supply, and (iii) its integration with existing infrastructure and distribution channels – make it a compelling option for decarbonization of energy systems.

While these attributes are driving investments in hydrogen systems *globally*, Canada has the potential to realize benefits that are particularly relevant to its national and regional circumstances.

First, hydrogen offers a pathway to decarbonization that is highly *inclusive*. Crucial roles must be played by established companies in resource extraction, power generation and manufacturing, among others, as well as by technology innovators and entrepreneurs.

Second, existing infrastructure and industrial assets need not be stranded, since hydrogen integrates with current systems. Hydrogen technologies build *onto* these systems, using them in ways that create new value as opposed to marginalizing their role or advancing their displacement.

Third, as a consequence of the previous two benefits, the hydrogen pathway is an option that can preserve current employment <u>and</u> create new jobs.



HYDROGEN INTEGRATING WITH ELECTRICITY INFRASTRUCTURE

Electrolyzers can also improve grid power quality and stability. Electrolyzer facilities can be developed as a fast-response, dispatchable, multi-megawatt load, from which a grid system operator draws valued services, including frequency regulation, flexibility ramping and spinning reserve. Hydrogen is the by-product of such grid services, which can be stored or distributed to other applications. A 2.5 MW Power-to-Gas plant was co-developed by Hydrogenics and Enbridge in Markham, Ontario, is currently being operated by that province's Independent Electricity System Operator.

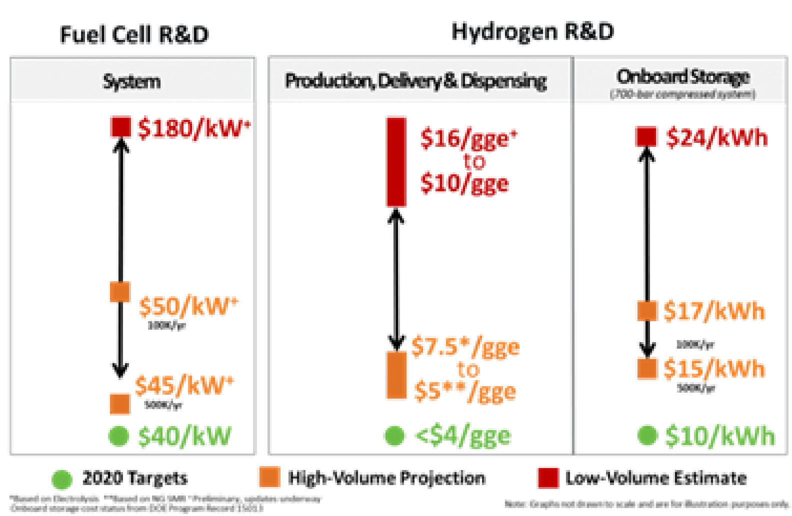
Credit: Enbridge. https://www.enbridgegas.com/Natural-Gas-and-the-Environment/Enbridge-A-Green-Future/Hydrogen-Storage

WHAT IS STOPPING US?

The challenge facing sustainable hydrogen deployment

Notwithstanding all the potential benefits of hydrogen systems, the deployment of technology and supporting infrastructure faces practical barriers, most of which are economic in nature. Using established modes of production and distribution, the effective price of hydrogen in the market is usually much more than that of conventional fossil fuels. Worse still, the lower the carbon-intensity of the hydrogen, the larger this cost disadvantage often becomes.

However, efforts to scale up hydrogen production and use are expected to moderate prices. Moreover, as demand for hydrogen increases, corresponding innovations in business models and supply solutions are being developed, with the aim of further minimizing cost. Similarly, the cost of hydrogen technologies (e.g., fuel cells, electrolyzers) shipped to market are also expected to drop due to scale-of-production effects and manufacturing improvements.



COST AND PRICE PROJECTIONS

Accomplishments and progress reported by the U.S. Department of Energy's Fuel Cell Technology Office show a 60% reduction on high volume automotive fuel cell costs from 2006 to 2016, during which time durability quadrupled. The cost of producing hydrogen from renewable power and dispensing hydrogen at high pressure have also reduced significantly

Credit: U.S. Department of Energy, Fuel Cell Technologies Office https://www.energy.gov/eere/fuelcells/fuel-cell-technologies-office-accomplishements-and-progress

In certain applications the business case for hydrogen systems is already strong. Examples include long-term energy storage and critical backup power supply, and where zero-emissions vehicle operation is an overriding constraint. Such cost-effective deployments could form the building blocks of a broader network of hydrogen systems, wherein multiple actors contribute to the supply and the take-up of hydrogen, each deriving value from the exchange.

BUSINESS CASE FOR HYDROGEN USE IN FORKLIFTS

More than 20,000 hydrogen fuel cell-powered forklifts are now in use across the U.S. (ref. U.S. Department of Energy. Industry Deployed Fuel Cell Powered Lift Trucks. 2018. https://www.hydrogen.energy.gov/pdfs/18002_industry_deployed_fc_powered_lift_trucks.pdf)

In materials handling applications where indoor, zero-emissions operation is required, the business case for hydrogen is strong, partly due to fast-refueling. Fuel cell-electric lift trucks tend to remain in productive use longer with fewer, briefer breaks to refill.

Credit: Conneticut Hydrogen-Fuel Cell Coalition; U.S. National REnewable Energy Lab

NREL Image Gallery Photo by Hydrogenics

To achieve the scaling-up of production and use that is required for hydrogen to become an effective decarbonization pathway in Canada, a plan is needed that coordinates the activities of many diverse organizations, private-sector and public-sector alike. Currently, there is no such plan, meaning that hydrogen systems are likely to deploy slowly and in a fragmented manner. This will inhibit participation in the hydrogen pathway for many organizations, keeping costs high and narrowing the scope of options for reducing greenhouse gas emissions.

THE WAY FORWARD

A diverse array of industry stakeholders is prepared to collaborate with government on the development of a strategic plan for hydrogen in Canada. The representatives from the organizations that participated in the H2GO Canada consultations support the Government of Canada using its capacity as a national convenor to form a multi-stakeholder team, which could work together to define a set of objectives and a suitable process. It is further advised that this process be industry-led, such that the needs of the market are duly addressed in any plan that emerges.

Principles and opportunities to consider

A hydrogen plan for Canada can be developed according to a set of principles, such that it capitalizes on existing advantages and opportunities. Stakeholders in the plan should collectively determine the key indicators of success, which help steer activities toward desired outcomes. The following recommendations offer guidance on the development of such a plan.

1. Prioritize a ***net gain in employment.***

   Hydrogen systems build on existing energy infrastructure and the production of hydrogen relies on currently developed resources. As well, the distribution of hydrogen can work within existing business models. Therefore, as the use of hydrogen for heat, power and mobility expands, it should be possible to preserve jobs in traditional sectors while growing the opportunities for new employment in the development, deployment and support of hydrogen technologies. Nurturing opportunities with potential for this outcome should be a focus area of a hydrogen plan.

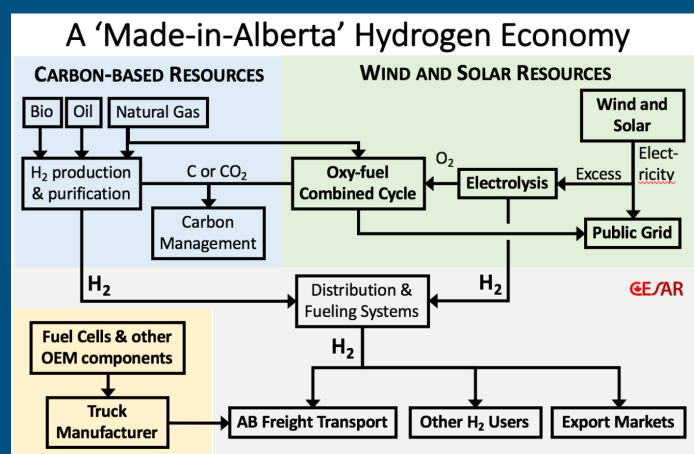
A VISION OF HYDROGEN-DRIVEN GROWTH IN ALBERTA

The Canadian Energy Systems Analysis and Research initiative (CESAR) at the University of Calgary has begun to quantify the potential for Alberta to benefit from a transition to hydrogen in North America. Noting that exports of Alberta's oil sands products are mainly refined into gasoline, diesel and jet fuel, the CESAR team asserts that the province is very much in the transportation fuel business. From this perspective, hydrogen used to power heavy-duty, fuel cell-electric vehicles is a growth opportunity.

The CESAR team has considered three ways in which hydrogen can be economically produced in Alberta: (1) steam-methane reforming of natural gas, (2) gasification of bitumen or biomass, and (3) electrolysis of water using wind or solar power. These options reflect the province's vast oil and gas resources, its geology that facilitates CO2 sequestration, its plentiful wind and solar energy resources and its human resources (citing skills and expertise in Alberta, which is already a major producer of hydrogen used in hydrocarbon refining and fertilizer production).

The team concluded that the business of exporting hydrogen for use in heavy-duty vehicles, in the way industry in Alberta currently meets the demand for diesel throughout North America, could generate two-to-four times more economic activity. Importantly, the relatively low cost of natural gas coupled with prospects for carbon capture and storage in Alberta's sedimentary basin, led CESAR researchers to project ways for the province to become one of the lowest-cost sources of low-carbon, large volume hydrogen in North America.

According to the CESAR team, "This will not only mean jobs, but the earnings from the production, wholesale and retail sale of hydrogen will contribute to the province's gross domestic product, royalty and tax revenue."



Credit: Canadian Energy Systems Analysis Research. Zero-emission Transportation Fuels: Alberta's New Economic Opportunity. 2019. http://www.cesarnet.ca/blog/zero-emission-transportation-fuels-alberta-s-new-economic-opportunity

EMPLOYMENT POTENTIAL OF HYDROGEN

The Hydrogen Council – a global CEO-level advisory body providing long-term vision on the important role of hydrogen technologies towards an energy transition – estimates that hydrogen can deliver nearly one-quarter of the global reductions in greenhouse gases necessary to fulfill the Paris Agreement (ref: IEA, 2017; from 34 Gt in 2015 to 26 Gt in 2023 and 13 Gt in 2050), while creating 30 million jobs worldwide.

Credit: The Hydrogen Council vision for 2050, from Hydrogen scaling up – a sustainable pathway for the global energy transition. November 2017. http://hydrogencouncil.com/study-hydrogen-scaling-up/

2. Be guided by analytical rigour – deployments should be based on ***full life cycle analysis of sustainability criteria.***

   In the early stages of market development, installation costs often run high. The initial deployment of hydrogen systems and supporting infrastructure will likely be no different. For sustainable markets to evolve around the early, strategic deployments, careful analysis will be needed to ensure that the optimal, value-creating opportunities are prioritized. The analysis should be based on transparent, full life cycle assessments of the relative economic, social and environmental factors.

   It will be important that life cycle assessments are normalized to a set of common metrics or indices, facilitating a fair comparison with other low-carbon pathway options. It should not be expected that hydrogen will always be the best solution for every problem. A vehicle application, for example, must be considered from the perspective of the fuel supply, the vehicle type and its pattern of use. Each of these factors must be considered to establish the extent to which a business case favours hydrogen as a fuel, and these factors may further vary by geography and jurisdiction.

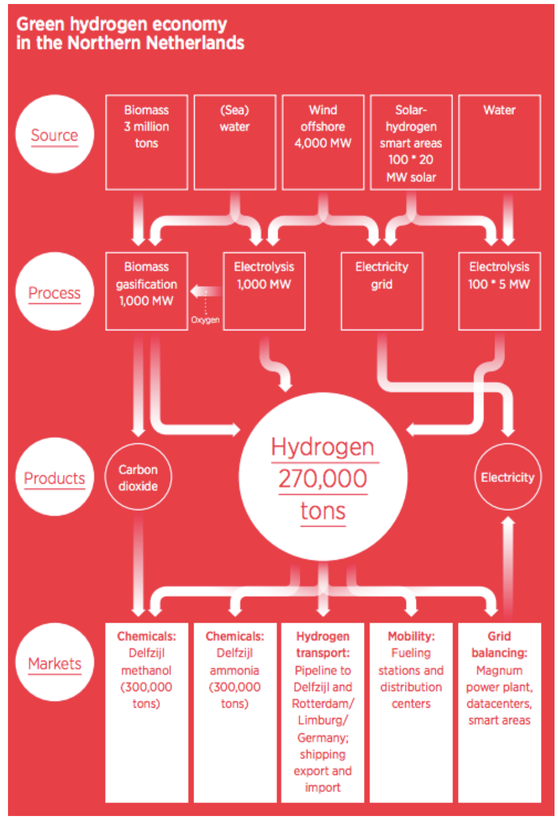
   A comprehensive, analytical approach will also help to characterize distinct roles for government policy and for free market forces in jointly advancing hydrogen systems deployment. Where the analysis shows that tangible value is created using hydrogen, but the required capital cannot be mobilized – perhaps through insufficient returns on private investment – there may be a role for government to help bridge the gap between sustainable development objectives and commercial tolerance for risk as part of a long-term pathway to decarbonization. Strategic procurement by government can also help to establish centres of hydrogen production and use in volumes enough to catalyze and support market-driven growth.

3. Focus on the ***development of markets*** to accelerate scale-up.

   Real value arises in exchange, and markets are where exchange happens. For hydrogen to scale-up efficiently, such that transactions in hydrogen as a fungible commodity can significantly contribute to decarbonization, commercially sustainable markets must be cultivated. Scaling-up is crucial to the success of hydrogen markets – the greater the number of transactions and the greater the volume of trade, the more opportunity for competition to drive hydrogen prices down. This enables more users to embrace hydrogen, thus creating greater value overall.

   The technologies involved in hydrogen production, storage, distribution and use are already in commercial use all around the world. So, limited or sporadic deployments that mainly serve to demonstrate technology are no longer needed.

   Instead, the simultaneous development of hydrogen supply and demand, with an eye towards the opportunities that are most promising for scalability, should be the objective. Once a stable exchange in hydrogen is achieved in a given area, it is easier and less costly to subsequently introduce additional sources of supply and demand on the margin. This will create the conditions for incremental scale-up of the market, ideally achieving commercially self-sustaining growth.



HYDROGEN PLAN FOCUSES ON SUPPLY CHAIN AND MARKET DEVELOPMENT

The Northern Netherlands Innovation Board has a vision and plan, called the Green Hydrogen Economy in the Northern Netherlands, to coordinate the development of "production projects, markets, infrastructure and societal issues."

Credit: November 2017. http://hydrogencouncil.com/study-hydrogen-scaling-up/

4. Build on international leadership to ***secure growth in exports*** of technology, services and expertise.

Canadian hydrogen technology developers and manufacturers are already considered leaders in the global market, with growing sales in Europe, Asia and the U.S. According to a member survey conducted by the Canadian Hydrogen and Fuel Cell Association, 2018 revenues of more than $150 million were generated through exports, mainly to China, the U.S. and Germany.[2] Product sales ranged from fuel cells and electrolyzers to hydrogen and refueling infrastructure. The revenues support direct employment of more than 2,000 Canadians.

Furthermore, research and development expenditures were more than $90 million in 2017. Investments by Canadian firms and governments have helped to advance the state-of-the-art in hydrogen technologies, globally. This is particularly true of proton exchange membrane systems, which are the dominant fuel cell technology for mobility applications.

Any plan to deploy hydrogen systems within Canada should lever its existing export advantage and ensure that its world-leading innovators have a competitive incentive to remain headquartered in Canada. As the growth in hydrogen systems adoption accelerates in Asia and Europe, Canadian firms (and their intellectual property) will be under pressure to move central operations closer to their main markets in other jurisdictions.

Additionally, consideration should be given to how promoting the adoption of hydrogen systems internationally can help Canada – as an exporter of hydrogen technology and knowhow – to improve its trade balance.

2 ref: Canadian Hydrogen and Fuel Cell Sector Profile – November 2018. http://www.chfca.ca/media/CHFC%20Sector%20Profile%202018%20-%20Final%20Report.pdf

HYDROGEN TECHNOLOGY EXPORTS TO CHINA

Through licensing agreements and direct sales, Hydrogenics is supplying companies in China with thousands of fuel cell modules, valued at more than $50M, for its fast-growing fleet of fuel cell-electric buses.

Credit: https://www.hydrogenics.com/2017/06/08/hydrogenics-signs-purchase-and-license-agreement-valued-at-over-50m-usd-for-1000-fuel-cell-bus-power-modules/

https://www.hydrogenics.com/2018/01/18/hydrogenics-receives-7-8-million-fuel-cell-order-in-china/

HYDROGEN TECHNOLOGY EXPORTS TO U.S.

The Orange County Transportation Authority, which has ordered 10 of New Flyer's 40-foot *Xcelsior CHARGE*™ hydrogen fuel cell-electric buses, recently completed a test demonstration of the model in which a range of more than 560 km without refueling was achieved, exceeding the Authority's performance target by 17%. These buses use fuel cells built by Burnaby-based Ballard Power Systems.

Credit: https://www.greencarcongress.com/2019/04/20190426-nfi.html

5. Help mobilize Canada's ***resources for export.***

It has been noted that hydrogen can be synthesized from Canada's hydrocarbon resources (e.g., natural gas) and from its renewable resources (e.g., hydroelectric power, biomass). This hydrogen can be moved to international markets to meet the growing, global demand for low-cost, low-carbon hydrogen.

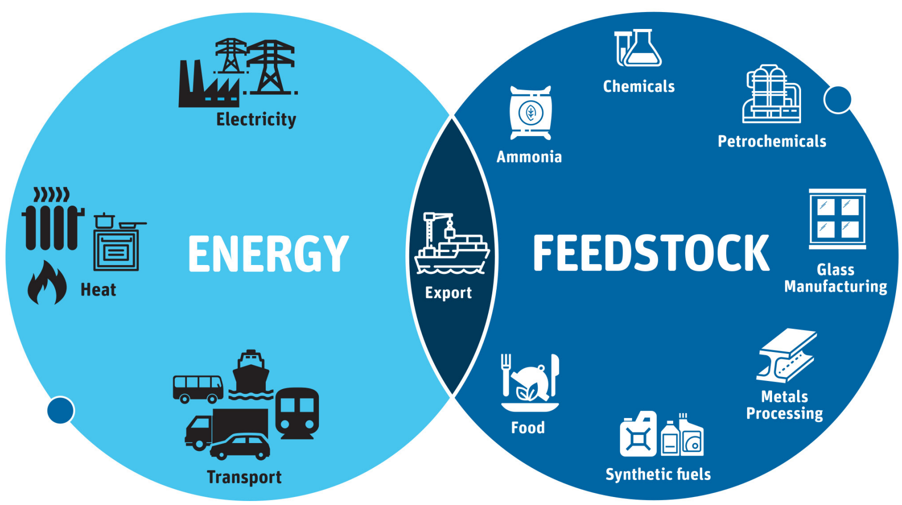
Export of hydrogen is thus a potential growth opportunity for Canada's resources and energy sectors, possibly using existing corridors and rights-of-way to reach border crossings and coastal ports.

HYDROGEN FOR EXPORT AND DOMESTIC USE

Air Liquide and Hydrogenics will build a 20 megawatt PEM electrolyzer – the largest water electrolysis plant of its kind in the world – in Bécancour, Québec, at Air Liquide's existing facility. The plant will be capable of producing 3,000 tonnes of hydrogen daily using low-carbon hydropower from Hydro-Québec. The proximity of the site to major industrial markets in Canada and the U.S. boosts the supply of low-carbon hydrogen in North America.

Credit: https://www.greencarcongress.com/2019/02/20190226-airliquide.html

APPLICATIONS FOR HYDROGEN



HYDROGEN EXPORTS STRATEGY FOR AUSTRALIA

Commonwealth Scientific and Industrial Research Organisation (CSIRO) – an independent Australian federal government agency – in its National Hydrogen Roadmap declared that the country's "extensive natural resources, namely solar, wind, fossil fuels and available land lend favourably to the establishment of hydrogen export supply chains." Indeed, the first trial shipment of hydrogen from Queensland to Japan happened in March 2019. The hydrogen was embedded in a liquid chemical compound, methyl cyclohexane, which can be safely and efficiently transported in conventional road tankers, pipelines and supertankers. The Australian Government's Chief Scientist describes hydrogen as the country's next multibillion-dollar export opportunity.

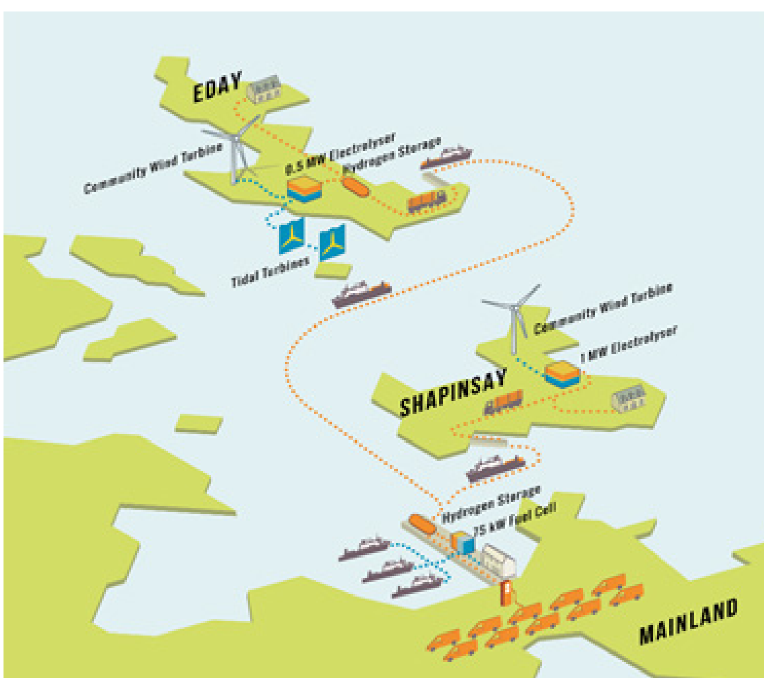
Credit: https://www.csiro.au/en/Do-business/Futures/Reports/Hydrogen-Roadmap
https://www.pv-magazine.com/2019/03/29/queensland-sends-first-green-hydrogen-shipment-to-japan/

6. Showcase/study application of hydrogen to ***integrated community energy system*** design.

Hydrogen could work well with integrated community energy systems. For example, in district thermal systems requiring low-temperature heat, hydrogen could be used as a fuel in combustion engines that power generators to meet local electricity needs. As well, hydrogen can be produced using electrolyzers powered by local sources of electricity. In an example of cascading energy use that makes integrated community systems so energy efficient, the waste heat from either engines or electrolyzers could help meet the load within a district thermal distribution system. This helps community energy systems lower greenhouse gases even further.

As well, hydrogen used as a fuel for vehicles (ranging from light-duty to heavy-duty) can help resolve the challenge of integrating transportation into community energy systems. As previously noted, this is because hydrogen can be used as a zero-carbon energy commodity that can be combusted or converted to electricity in a fuel cell, thus delivering heat, power and mobility within the community. The hydrogen used could also be produced within the community as by-product of industrial processes or waste treatment, and from local renewable energy sources.

In electrical grid modernization efforts, hydrogen systems provide remote communities with a means to improve service reliability through low-carbon back-up power facilities. In off-grid settings, hydrogen systems can reduce the community's reliance on imported diesel for power generation. In both cases, hydrogen facilitates the commercial development of local energy resources (i.e., power generation coupled to seasonal energy storage, process and building heat, and fuel cell-electric vehicle operation).



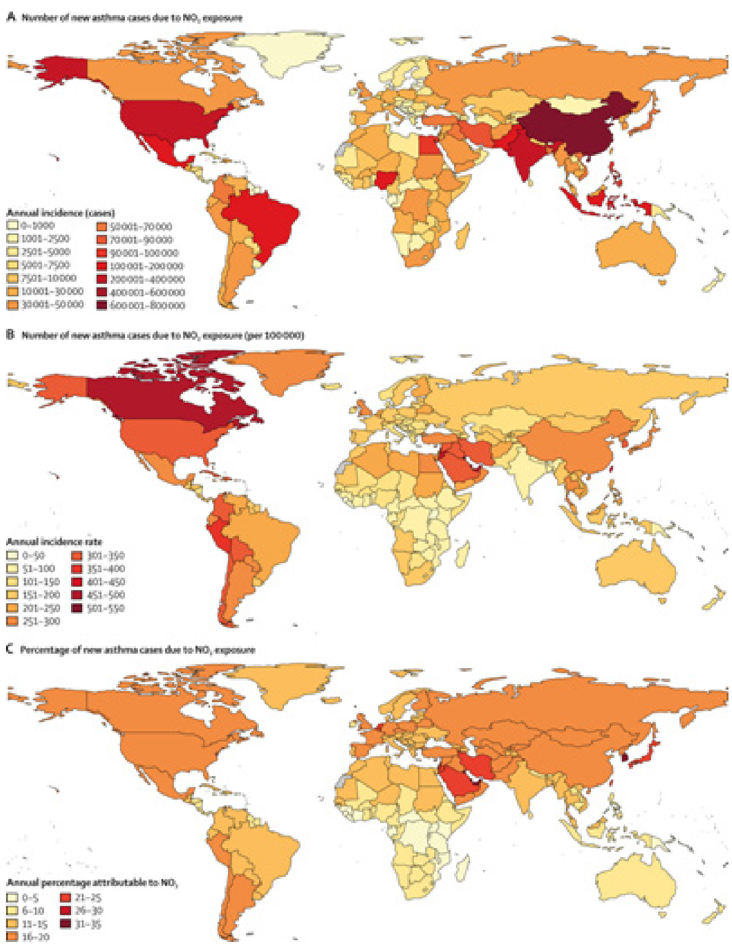
HYDROGEN IN REMOTE COMMUNITIES

The remote Orkney Islands in Scotland have the potential to generate more renewable power (e.g., tidal, wind) than the small island population can consume. To become an energy exporter and to fully decarbonize its local systems of transportation, industrial energy, building heat and power, and industrial feedstocks, the community is pursuing a transition to a hydrogen-based integrated energy system.

Credit: Orkney Surf'N'Turf. http://www.surfnturf.org.uk/

7. Deliver ***clean air*** benefits to the public.

   The social costs of air pollution are often overlooked, given the general improvements in air quality owing to industry efforts to reduce smog-forming emissions from vehicles and stationary sources. Yet local emissions sources are still a threat to human health and cited by the public as an ongoing environmental concern. Cultivating uses of hydrogen that can deliver immediate health benefits to the public, via cleaner air, can reduce health care costs. It also has the co-benefit of building public acceptance of hydrogen by putting risks in the context of real, tangible benefits.



AIR QUALITY A CONTINUING DRIVER OF CHANGE

About 4 million children worldwide develop asthma each year because of inhaling nitrogen dioxide air pollution, according to an open-access study published in The Lancet Planetary Health by researchers at the George Washington University Milken Institute School of Public Health (Milken Institute SPH). The study, based on data from 2010 to 2015, estimates that 64% of these new cases of asthma occur in urban areas.

"The study is the first to quantify the worldwide burden of new pediatric asthma cases linked to traffic-related nitrogen dioxide by using a method that takes into account high exposures to this pollutant that occur near busy roads." said Susan C. Anenberg, PhD, the senior author of the study and an associate professor of environmental and occupational health at Milken Institute SPH.

Credit: April 2019. https://www.eurekalert.org/pub_releases/2019-04/gwu-moc040919.php

BARRIERS TO CONFRONT

Notwithstanding the benefits that drive interest in hydrogen, there are many practical barriers to successful deployment. Organizations participating in the H2GO Canada consultations identified several that a strategy should address. These barriers are thematically organized as supply chain maturity, financing and policy, and knowledge and awareness.

- **Supply chain maturity**

  Stakeholders consulted generally viewed fuel cell technology as proven and market-ready. Installed systems have been operating for years, which has built confidence. Increased durability and reduced cost are expected as the scale of commercial adoption expands. Yet scaling up faces significant market inertia. Costs won't drop until volume grows, and volume won't grow until costs drop. Some impulse is needed to activate market development.

  Indeed, an organization's procurement officer is often obligated by policy to source materials and services competitively. For specific applications of hydrogen technology, there may only be a handful of suppliers, globally, from which to buy. Similarly strained is the supply of trained installers and maintenance personnel. Thus, many companies may be deterred from embracing hydrogen alternatives until robust supply chain conditions are achieved. Navigating this dilemma will require leadership.

  Specific to hydrogen-powered vehicles, another major barrier is the availability of hydrogen refueling stations. Return-to-base commercial vehicle fleets that can refuel in a private, centralized depot are likely to be economically viable in the near-term. But for interurban goods movement, the ability to refuel at public roadside stations (ideally along highways) is necessary to achieve market-driven scale-up of technology adoption.

In terms of the price for hydrogen, the majority is currently produced for use as a material for industrial processes, not as an alternative energy commodity for generalized end-uses, such as heat, power and mobility. The market price for hydrogen today can range well upward of $16/kg, delivered by industrial gas suppliers or merchant gas suppliers. This is not competitive with the price of gasoline or diesel. However, the U.S. Department of Energy estimates that less than $4 per gallon of gasoline-equivalent is achievable, through technical improvements in production and distribution arising from further research and the development of economies-of-scale.[3]

A lack of pipeline infrastructure for moving hydrogen is also noted as a barrier to the use of industrial by-product hydrogen. A pipeline network linking local industrial producers and users of hydrogen could enhance economic productivity. It would enable low-cost, by-product hydrogen to be exchanged among manufacturers who otherwise have few supply options, and thus pay a premium for delivered hydrogen. The value arising in this exchange would serve to monetize by-product hydrogen within industrial clusters.

3 U.S. Department of Energy.

Presentation: *U.S. Department of Energy Hydrogen and Fuel Cell Technology Overview*. 2018. https://www.energy.gov/sites/prod/files/2018/03/f49/fcto_doe_h2_fc_overview_satyapal_fc_expo_2018_0.pdf

DOE Hydrogen and Fuel Cells Program Record. *Current Status of Hydrogen Delivery and Dispensing Costs and Pathways to Future Cost Reductions*. 2018. https://www.hydrogen.energy.gov/pdfs/18003_current_status_hydrogen_delivery_dispensing_costs.pdf

- **Financing and policy**

  There are trillions of dollars in investor appetite for energy and infrastructure developments, globally.[4] Scarcity of capital is not a barrier to hydrogen deployment. However, a consistent policy framework that mobilizes the requisite capital may be needed. Many investors are attracted to long-life assets, in which contracted cash flows can provide high visibility on achieving a return on invested capital threshold. This may facilitate the level of investment needed to rapidly scale hydrogen markets, but it would rely on the extent to which hydrogen technology and infrastructure (and the services provided) could be incorporated into the scope of a regulated or unregulated operation. Infrastructure investors typically avoid investing in unproven or first-of-a-kind assets. Infrastructure investments are typically highly levered, and debt investors like to see a long track record of performance. Hence, large-scale hydrogen system financing will likely require a degree of policy innovation to indemnify investors.

  Furthermore, a project that is large in scale may be necessary to attract the interests of large-scale investors (e.g., into the hundreds of millions). The larger the project, the more substantial the opportunity to build knowledge on hydrogen systems and normalize their use. As public infrastructure initiatives, large projects could be appropriately de-risked through government involvement, based on the fulfillment of a public good. In this context, cost-minimization may not be the only driver of the public good; indeed, innovation is also widely recognized as a function of government procurement.

A related challenge to scaling up hydrogen supply and reducing cost is a fundamental lack of demand for more hydrogen. There is no market *pull*, because the deployment of fuel cells in stationary and vehicle applications is minor in Canada. Partly, this is because consumers (individuals and businesses) have little incentive to pay a premium for zero-emission solutions. The climate change and clean air benefits are distributed across society, and globally. The benefits are highly valued but are *external* to a discrete project business case.

As said in the previous section, techno-economic analytics are foundational to the business case of hydrogen projects. For example, the current cost of hydrogen refueling station construction and operation is higher than typical plug-in vehicle recharging stations. However, the cost disparity narrows as the electricity infrastructure is sized to meet multiple, concurrent demand for fast, convenient electric vehicle recharging. Some of the stakeholders consulted estimate that hydrogen-electrified transportation *en masse* can be cost-competitive with other carbon-neutral alternatives, and that in some applications, there may be no other practical option. A full cost comparison would help put equipment and installation costs into context. Such analysis is needed to inform the public discourse.

4 Institutional investment in real assets could represent a $100 trillion market by 2030, according to a Brookfield Asset Management Investor Day presentation in New York on 26-Sep-2019. https://bam.brookfield.com/~/media/Files/B/BrookField-BAM-IR-V2/ir-day/2018/copy-of-investor-day-2018-bam-f-aum-update.pdf

- **Knowledge and understanding**

A general lack of experience with hydrogen systems is a practical barrier to deployment. This applies to professional teams as well as to the public. Installation crews and inspection personnel require familiarity with prevailing codes and standards. Otherwise, commissioning of new work may be inefficient and costly. Certainty and clarity from the permitting authority is likewise crucial.

At the same time, the public needs to have confidence in the safety and reliability of hydrogen systems that are put into general use. Unfamiliar with hydrogen in their day-to-day lives, people tend to focus on examples of downside risks. Absent an understanding of how hydrogen is safely used and the benefits it yields, fears can become amplified and erode the support of the community.

In the U.S., government and industry organizations work together to develop and disseminate knowledge on safe hydrogen management through various programs and initiatives, such as *Hydrogen Tools*, the *Hydrogen Risk Assessment Model* (HyRAM) *Toolkit* and the newly-established *Centre for Hydrogen Safety*. Likewise, there is the California Fuel Cell Partnership, a not-for-profit organization that works with the state government to educate the public and to mobilize stakeholders in the development of policy. By contrast, there is not an identifiable, organizing *presence* in Canada to build national capacity and to engage at the local level to cultivate support for hydrogen.

Lacking visibility, hydrogen is not well-represented in public policy dialogues in Canada. Often the efforts to promote hydrogen options are too technically-oriented and too focused on engineering discussions, marginalizing the participation of many stakeholders. Consequently, it becomes an afterthought when setting objectives and developing plans. There is a need for more sophisticated stakeholder outreach and engagement.

Concluding remarks

The findings of the consultations presented in this report lead H2GO Canada to believe that the time has come for hydrogen and hydrogen systems to be properly recognized as an important part of Canada's long-term plan for decarbonization. Work must begin now to scope near-term opportunities to deploy hydrogen systems that are in the public interest and can become commercially viable. Such deployments may be separately initiated, but part of the underlying justification is their connection to a broader vision. Thus, we need to approach the challenge of scaling up hydrogen at two levels, simultaneously: a regional level, in which the local sources of supply and demand are knitted together into a self-sustaining market; and a national level, in which the sum of the regional efforts contribute to the realization of a broadly-held vision.

This approach will require careful analysis, the development of partnerships, the mobilization of investors and the engagement of the public. H2GO Canada looks forward to doing its part to support the development of sustainable, scalable hydrogen markets in Canada.

H2GO CANADA