THE CANADIAN ENERGY AND CLIMATE NEXUS

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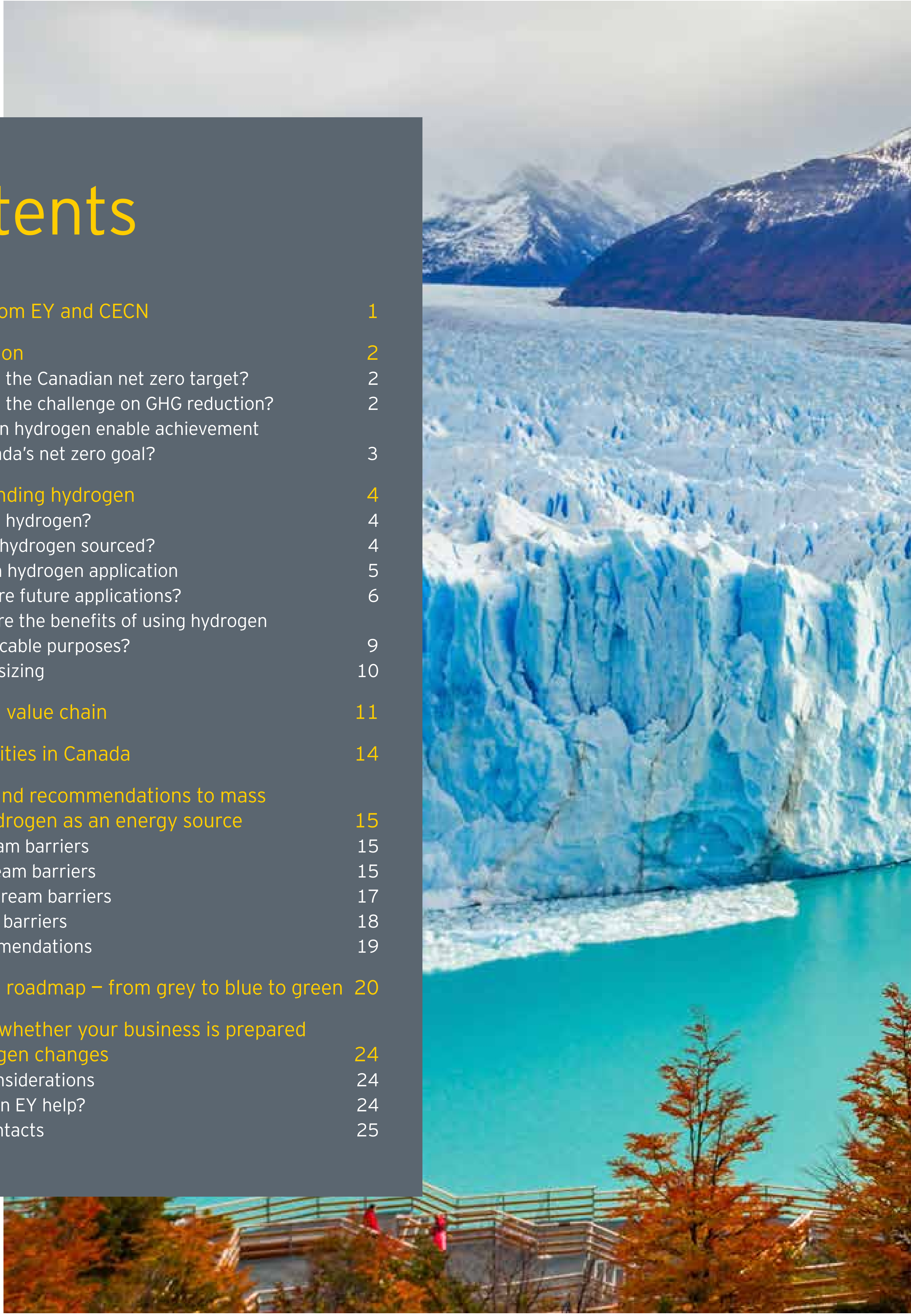
EY

Building a better working world

Canada's hydrogen future – risks and rewards



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Letter from EY

Why has the conversation around hydrogen meaningfully progressed over the past few years? The answer lies with the climate change action urgency and hydrogen's potential role in reducing greenhouse gas (GHG) emissions.

For organizations across the globe, the question of reducing GHG emissions to mitigate rising temperatures has become paramount. As a signatory in The Paris Agreement, Canada committed to a 30% emissions reduction below 2005 levels and set out on a path to achieve a net-zero economy by 2050. The scale of this reduction requires a multifaceted approach to establish a clean-fuel energy mix that can continue to meet the country's growing energy demands.

Canada has an opportunity to integrate existing energy infrastructure into the evolving hydrogen value chain to become a global leader in hydrogen production, distribution and market use. Leaders across the public and private sectors must assess the size of the opportunity and how their respective organizations can help enable the hydrogen future.

The time to support the development of the hydrogen ecosystem is now. EY has prepared the following report to provide an overview of hydrogen and identify some of the many ways Canadian organizations can participate across the value chain.

Lance Mortlock
Energy Managing Partner, EY Canada

Letter from CECN

The opportunities for Canada to be a Champion in hydrogen development are endless. Its unparalleled expertise in diverse energy production plays would allow it to further transform existing energy infrastructure to align with hydrogen production, all while pushing Canada closer to the commitment it made during COP 21 in Paris with regards to GHG emission reduction and climate change mitigation.

Demand for hydrogen is growing and Canada has one of the strongest potentials to adapt and expand hydrogen production and use in diesel and gasoline markets, natural gas distribution, power generation, and ammonia production to name a few.

There are clear signs that international investment markets are keen to invest in such plays as well, particularly given that hydrogen balances energy development with environmental and social drivers in Environmental, Social and governance standards (ESG). Expanding portfolios into hydrogen plays will not only attract capital, but also the talent and jobs that come with it.

Both at the federal and provincial governmental levels, multiple studies have been undertaken to identify where and how hydrogen has an opportunity to be developed, culminating in various geographically focused "Hydrogen Strategies". Now it is industry's turn to look at these jurisdictional strategies and turn them into active energy plays.

David L. Milia
President & Chief Executive Officer, Canadian Energy and Climate Nexus

2 Introduction

What is the Canadian-net-zero target?

In late 2015, the United Nations held the 21st session of the Conference of the Parties (COP) in Paris, France. This conference resulted in the adoption of what is now known as the Paris Agreement,[1] an international commitment between 72 nations to collectively address and take action on climate change.

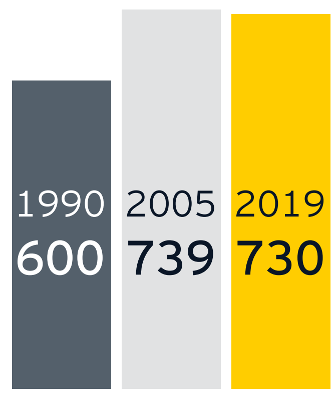
As a signatory, Canada committed to striving towards a net-zero economy by 2050 and reducing emissions to 511 million tonnes of carbon dioxide equivalent (Mt CO_2 eq) by 2030,[2] 30% below 2005 levels. These ambitious targets will require collaboration across all levels of government, the private sector and institutions, and significant amounts of energy-related innovation.

What is the challenge on GHG reduction?

Achieving the GHG targets Canada has adopted is a multifaceted challenge that has several substantial barriers and will require meeting increased demand for affordable energy. Transitioning from the status-quo of fossil fuels to less carbon-intensive and more cost-competitive options will require investment, innovation, government subsidies and incentives.

Additionally, a major challenge with some forms of renewable energies is that they do not have the reliability of fossil fuels and often provide intermittent power. The future energy system will require replacing carbon-based fuels with several integrated sources to ensure energy demands can be met both cost effectively and reliably.

Canadian GHG emissions in Mt CO_2 eq



Change: 129 Mt CO_2 eq or 21.4% increase, mostly attributed to oil and gas extraction and transportation activities[3]

2% share

Canada's contribution to total global GHG emissions

How can hydrogen enable achievement of Canada's net-zero goal?

Currently, an estimated 3 million tonnes (Mt) of hydrogen (H_2) are produced in Canada, which makes the country a top 10 producer globally.[4] The production is expected to increase significantly as hydrogen expands its applicability across various industries and markets.

Today, hydrogen makes up <1% of Canadian energy demand but is projected to reach up to 27% by 2050.[5] Hydrogen has tremendous potential in decarbonizing the economy, particularly through upstream and downstream transformation. If estimates are achieved, hydrogen can reduce Canadian GHG emissions equivalent by 190 Mt CO_2 per year by 2050, or by 26%[6], a significant portion of Canada's targets.

Canada's federal government, along with several provincial governments, have recognized that hydrogen is a viable pathway in meeting climate change goals. As such, they have published hydrogen strategies specific to their jurisdictions.

Apart from the federal government's strategy,[7] hydrogen is listed as a key area of development most notably by the Governments of Québec,[8, 9] British Columbia,[10, 11, 12] Ontario[13] and Alberta[14]. All these strategies demonstrate how hydrogen will play a key role given it is a zero-emission fuel that is internationally recognized as a fuel of choice for net-zero energy systems of the future.[15]

Canada is well positioned to be a leader in hydrogen-related fields, benefiting a wide range of stakeholders and creating the potential for a nationwide opportunity in the space. Regions across the country have access to the foundational elements required for hydrogen production and can use the knowledge and expertise of Western Canada to meet and accelerate the advancement of net zero goals.

Key Canadian statistics

2020 H_2 production
3 million tonnes

2050 projected H_2 production
20 million tonnes

2050 projected GHG reduction
190 million tonnes or 26% per year

Key Canadian Statistics provided from the Canada 2020 Hydrogen Strategy by Natural Resources Canada

3 Understanding hydrogen

What is hydrogen?

Hydrogen is mostly known as a clean fuel that, when consumed in a fuel cell, produces only water as a by-product. Like fossil fuels, hydrogen can be used to store, move, and deliver energy obtained from other sources.[16]

On earth, hydrogen only occurs naturally in combination with other elements such as liquids, gases or solids, the most recognizable being H_2O,[17] Because hydrogen is readily found in a multitude of hydrocarbons – including natural gas, coal and petroleum – existing energy development/extraction has readily available access to unlock hydrogen as an energy source.

Additionally, hydrogen is a gaseous and highly combustible substance that can deliver or store a tremendous amount of energy, but it must be extracted from other resources and does not exist in its pure form.[18]

How is hydrogen sourced?

There are four primary processes for producing hydrogen, thermal and electrolytic will be discussed in this report:[19]

Thermal processes

In this process, steam reacts with a hydrocarbon fuel to produce hydrogen. Many hydrocarbon fuels can be reformed to produce hydrogen, including natural gas, diesel, renewable liquid fuels, gasified coal and gasified biomass. Today, about 95% of all hydrogen is produced from steam reforming of natural gas.

Electrolytic processes

Water can be separated into oxygen and hydrogen through a process called electrolysis. An electrolyzer, which functions much like a fuel cell in reverse, creates hydrogen from water molecules.

Solar driven processes

Numerous processes that use light as the agent for hydrogen production, including photobiological (bacteria and green algae), photoelectrochemical (semiconductors to separate water into hydrogen and oxygen), and solar thermochemical (concentrated solar power to drive water splitting reactions).

Biological processes

Use microbes (e.g., bacteria and microalgae) to produce hydrogen through biological reaction

Other production methods gaining momentum for commercial hydrogen production include methane and ammonia reformation.

Currently in Canada, most hydrogen is produced through fossil fuels, specifically natural gas.[20]

There are three primary ways industry designates hydrogen production types:

- **Grey H_2** is the most common form of hydrogen, produced through thermal processes, most commonly natural gas.[21] In conventional processes, natural gas is split into H_2 and CO_2 through steam methane reforming (SMR), or auto thermal reforming, and is the most carbon-intensive form.
- **Blue H_2** is an extension of grey H_2, with carbon capture utilization and storage (CCUS) integrated into the SMR process to sequester the majority of CO_2, producing hydrogen with very low emissions.
- **Green H_2** is produced through electrolytic processes and is emission free.

Modern hydrogen application

Today, hydrogen is predominantly used as an industrial feedstock for refining petroleum and processing foods, fertilizer, fuel, materials and chemicals.[22] It's also used in the production of ammonia and vehicle fuel cells. While these use cases will continue to be applicable in the future, expanding the market application of hydrogen will be critical to realizing Canada's GHG emission reductions goals and the 2050 net-zero target.

Industrial feedstock

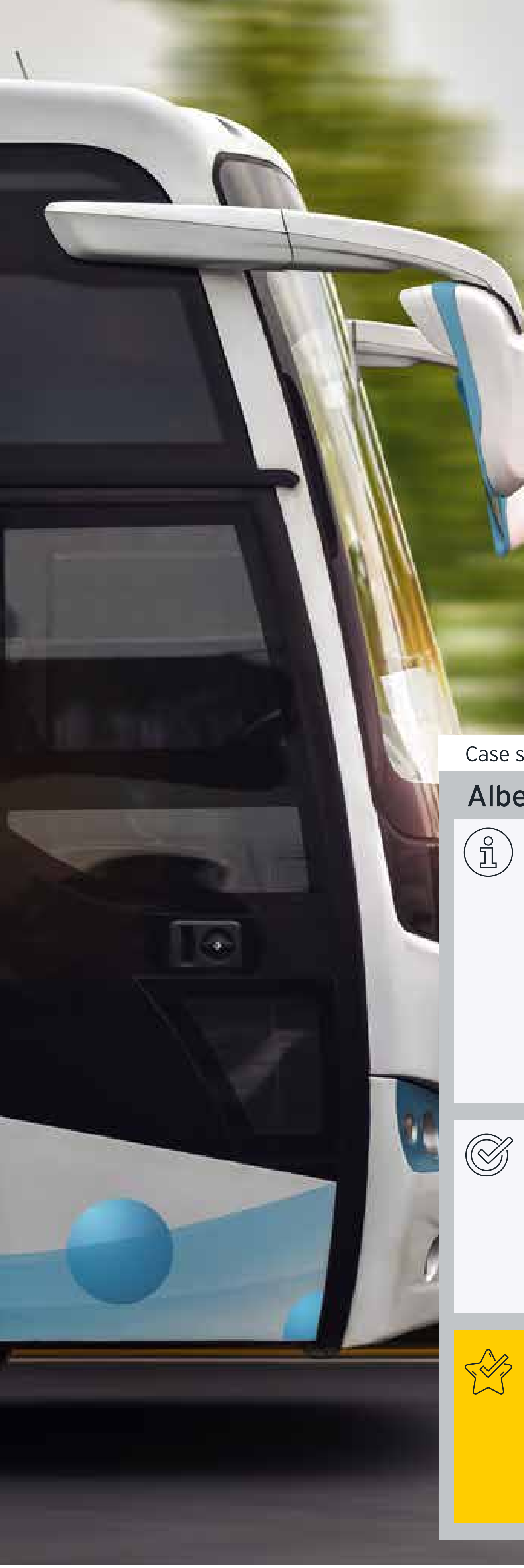
For decades, hydrogen has been used primarily by chemical and refining industries to create petroleum products. Oil refineries apply hydrogen to lower the sulphur content of diesel fuels and remove other contaminants.[23]

Ammonia production

Material manufacturers use hydrogen to make ammonia for agricultural fertilizers, also known as azane, while packaged food manufacturers use hydrogen to separate food oils and make margarine.[24]

Vehicle fuel cells

Car manufacturers in markets with access to hydrogen fuelling stations, including Honda, Hyundai and Toyota,[25] have begun production of hydrogen vehicles, while others, such as BMW, have stated goals to bring hydrogen lineups of vehicles to markets by 2030.



What are future applications?

Diesel fuel replacement – Hydrogen is a potential substitute for diesel fuel for use in the transportation and mining sectors. Currently, the majority of diesel is used in the freight sector, with lesser amounts being used for rail and passenger transportation.

The heavy-duty freight sector is a target market for hydrogen because of its operating conditions, which include long distance trips, heavy payloads, and cold weather.[26] These conditions make plug-in electric battery options difficult given their storage capacity constraints, recharge times and infrastructure requirements.[27]

The mining industry is heavily reliant on diesel and presents an opportunity for hydrogen in its haul trucks, mineral processing, and power plants. The mining sector is similar to heavy-duty freight in that location and usage are predictable."

Case study

Alberta Zero Emissions Truck Electrification

The what

Alberta Motor Transport Association (AMTA) is leading the Alberta Zero Emissions Truck Electrification Collaboration (AZETEC) project that is working with industry leaders Freightliner, Ballard, Nordresa and Praxair to design and build two heavy-duty (63.5 tonne) hydrogen fuel cell electric hybrid trucks and put them on the road in Alberta.[28]

The why

The project intends to demonstrate a 700 km+ range zero-emission truck to demonstrate a reduction in GHG emissions and a pathway to great emissions reductions in the future.

The result

The project has received funding from the federal government, Emissions Reduction Alberta and the private sector, and is currently still in planning phases.

Case study

NFI Group's Xcelsior

The what

NFI Group Inc. (TSE: NFI) is a leading independent bus and motor coach manufacturer. NFI has developed the Xcelsior Charge H_2, a 40- and 60-foot fuel cell-electric bus to obtain extended-range operation similar to existing transit vehicles.

The why

NFI is aiming to engineer progressive mobility solutions to support smarter communities and cities. The fuel cell-electric option qualifies for federal funding and is a fully zero-emission solution.

The result

In 2018, NFI delivered its 10,000th Xcelsior, which includes EV, FCEV, hybrid, compressed natural gas and clean diesel models.

Gasoline fuel replacement – Hydrogen is a potential solution in some gasoline-powered vehicles, specifically intensively driven fleet vehicles, such as municipal fleets and taxis, given their range and short refuelling requirements.[29] Additionally, these vehicles are more likely to be stored in centralized, industrial areas of a city where refuelling stations can be strategically located to maximize efficiency.

To power these vehicles, there are H_2-diesel dual-fuel internal combustion engines (ICEs) and fuel cell electric vehicles (FCEVs). Dual-fuel ICEs would use fuel blending technology at a rate of 40% hydrogen and 60% diesel but could operate with or without an assured hydrogen supply.[30] FCEVs convert hydrogen into electrical energy, leaving only water as the output.

Both of these use cases will help demonstrate viability and serve as bridge technologies to generate demand and support development of hydrogen infrastructure (e.g., fuelling stations and on-board hydrogen tanks)[31]. FCEVs can use H_2 as a fuel and offer twice the emissions efficiency of combustion engines.[32] These vehicles are commercially available today and will play a critical part of reaching Canada's goal of reaching 30% zero-emission vehicles by 2030 and 100% by 2040.[33]

Case study

Ballard Power Systems integrated fuel cell power systems

The what

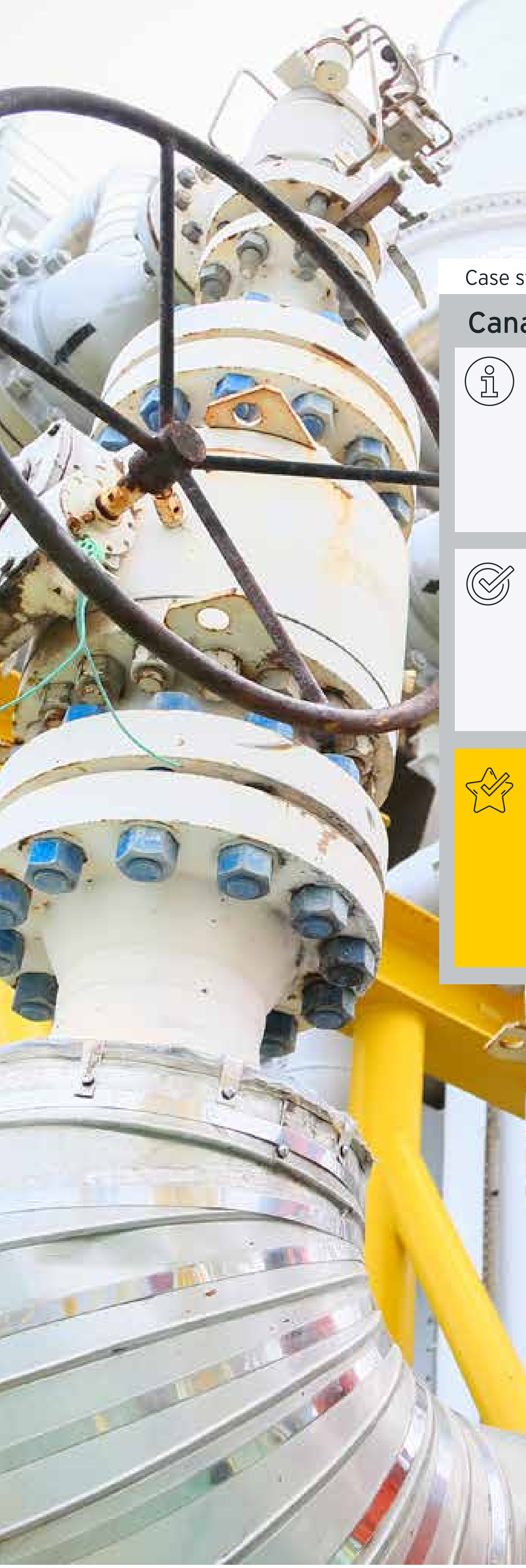
Ballard Power Systems Inc. (TSE:BLDP) is a world leader in the development, manufacturing, sales and servicing of hydrogen fuel cell power systems. The company services several transportation markets worldwide, including China, Germany, the US the UK and Spain.

The why

Ballard aims to build fuel cell expertise and deliver fuel cell power to support a sustainable planet.

The result

FCEVs powered by Ballard have now driven over 50 million kilometers and the company holds over 1,400 patents and patent applications.[34]



Blue ammonia production – Hydrogen has the potential to be used in the production of low-carbon ammonia, also referred to as blue-ammonia.[35] Predominantly Asian markets, mostly Japan, are looking to blue ammonia as a marine fuel and as an alternative feedstock for thermal power generation plants.[36]

Case study

Canada and Japan, International Ammonia partnership

The what

PETRONAS Canada and Itochu Japan are teaming up to investigate the feasibility of building a US$1.3b facility on the outskirts of Edmonton that would produce low-carbon ammonia.

The why

The Japanese Government is looking to secure 30 million tonnes of ammonia by 2050 as part of its efforts to achieve net-zero emissions.

The result

The project partners have publicly stated their partnership and a feasibility study is underway. A target date of 2023 for construction of the facility has been set should the feasibility study show a financially viable possibility.

Natural gas replacement – Another potential market application of hydrogen is using it as a natural gas replacement for residential and industrial heating and for gas turbines. Currently, heating accounts for 80% of energy use in homes, and hydrogen can be blended with natural gas as a replacement to decrease emissions.[37] For industrial heating, more than 50% of space heating market demand is currently served by natural gas. Heat pumps are also a promising alternative in many areas of Canada, but regions with colder climates, such as the Prairies, are less suitable and hydrogen provides a suitable alternative.[38]

A final major potential application is using hydrogen as a fuel for power production through hydrogen combustion in turbines or electrochemical conversion in stationary fuel cell power plants. The use of hydrogen provides load management, long-term energy storage and a path to market that enables the growing use of intermittent renewables.[39] Existing gas turbines have limited abilities to be fuelled with hydrogen, but new turbines have been designed to use 100% natural gas, 100% hydrogen or anything in between.[40]

Expansion of each of these markets is dependent on innovation, research, development and funding, as this will allow producers and midstream organizations to benefit from economies of scale, ultimately decreasing the retail price of hydrogen.[41]

What are the different application benefits of using hydrogren?"

Growing the hydrogen ecosystem can reduce carbon emissions by up to 26% annually by 2050. Grey H_2 produces 9 kg of CO_2/kg of H_2, and another 1.72 CO_2eq./kg H_2 during the upstream recovery of natural gas.[42] Transitioning to blue H_2 made from natural gas with 90% CCUS ranges from 2-3 kg CO_2eq. /kg H_2.[43] However, it should be noted that there are opposing views in the emissions reduction potential of blue H_2, with some research suggesting CO_2 reductions are only in the 9% to 12% range and do not account for methane emissions.[44]

One of the major constraints with intermittent renewables — such as wind and solar — is the inability to store and deploy excess generated power. Building the capability to produce green H_2 has the potential to connect the two ecosystems by diverting excess supply to green H_2 production and storage.[45]

Emissions reduction opportunity[46]

% of delivered energy to Canadians

2030	2050
6%	30%

GHG emissions abated

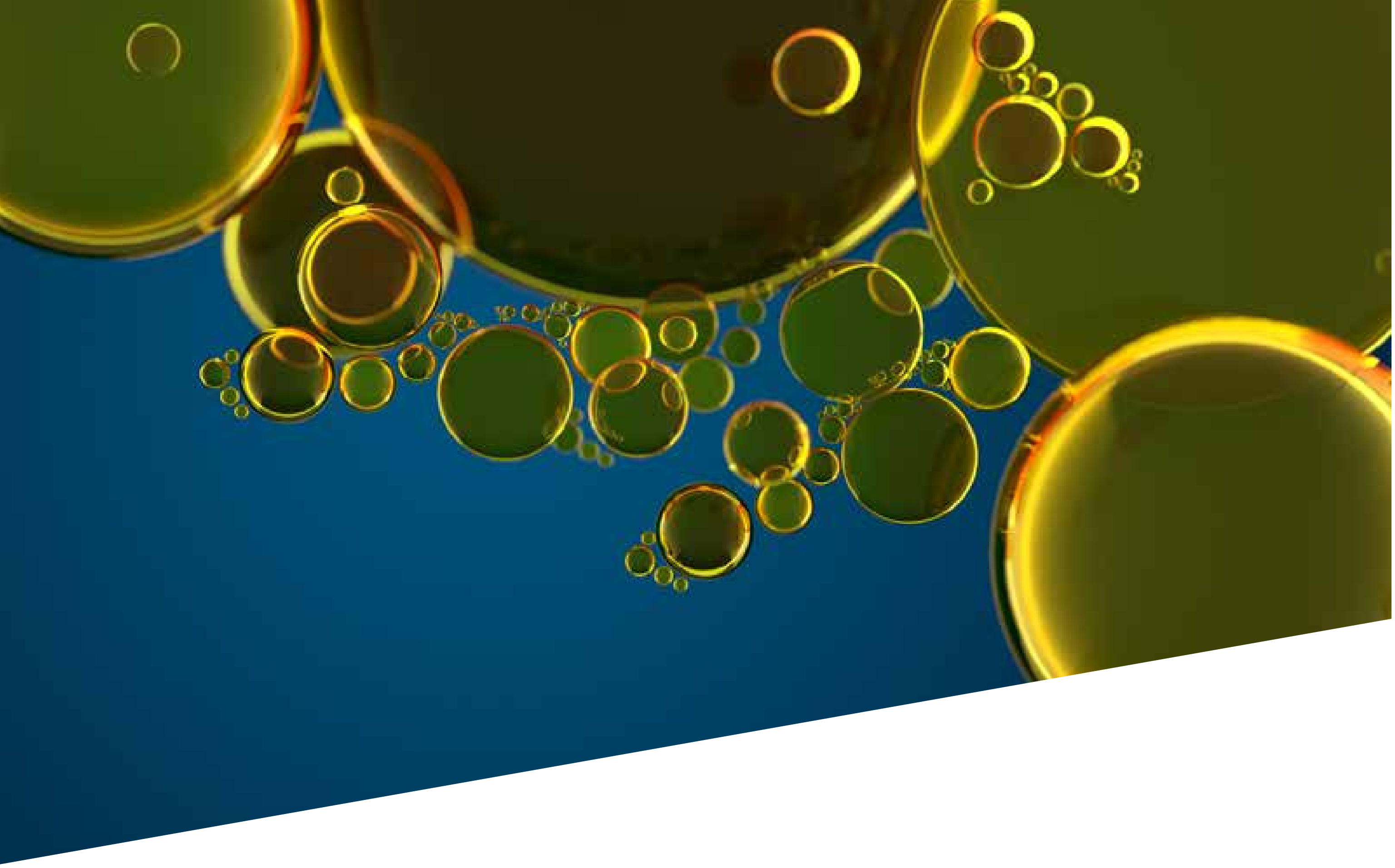
2030	2050
45 Mt CO_2eq.	190 Mt CO_2eq.

The abatement of **190 MtCO_2eq** is equivalent to removing over **41 million passenger cars driven for one year**.[47]

Nearly three quarters (73%) of global GHG emissions were generated by **transportation, industry and electricity** in 2020.[48]

73%

While intermittent renewables can support the abatement of these emissions, a broader energy ecosystem will be required to achieve a net-zero economy by 2050.



Market sizing

Hydrogen opportunity – market sizing 2050 snapshot

Total Canadian annual market potential

$100 billion

including export markets

350,000

Sector jobs created in Canada

$2.5 trillion

Total global annual market potential

$47 billion

Total domestic annual market potential

Current hydrogen production is estimated to be about **8,200 tons of H_2/day**, with projections of **>20 Mt/year by 2050**.

This is equivalent to **72% of Canada's current natural gas production** and would make up **27% of Canada's primary energy demand.**[49] To reach these expectations, the carbon capture and storage requirements (CCUS) would be about 203 $MtCO_2e$/yr.

4 Hydrogen value chain

A value chain is a model that describes a full range of activities needed to create a product or service output. The hydrogen value chain consists of three primary stages: upstream, midstream and downstream. Each segment is broken down into further functions and activities, which have their own unique opportunities and challenges in the Canadian landscape. Energy sector stakeholders must have a clear understanding of the value chain to capitalize on the potential hydrogen benefits and identify areas for cooperation.

As highlighted in the value chain, Canada has access to necessary resources, storage capabilities and an expansive distribution network, all of which can be integrated to enable the hydrogen ecosystem. Evolving the ecosystem to achieve a future state that successfully abates carbon emissions involves significant complexities that we explore further in this report.

Value chain

Stages	Upstream	
	1. Resource feedstock	**2.** Hydrogen production
Key components	**Power generation** The process of mass producing hydrogen and converting it from natural resources to its pure form requires tremendous amounts of energy. Existing energy infrastructure from renewables, nuclear, coal, natural gas, and conventional storage can be used to power the production. **Natural gas** Hydrogen does not exist in its pure form, so it needs to be extracted from other chemical elements, most commonly natural gas. Existing supplies of natural gas can be utilized in the production of hydrogen. **Water** Renewables used to power the grid today, particularly H_2O, can be used to extract hydrogen.	**Thermal processes** Steam reformation in which steam reacts with a hydrocarbon fuel to produce grey H_2, a carbon intensive pathway to generating hydrogen. Using the same method, but using carbon capturing utilization and storage (CCUS), produces blue H_2 with very low emissions. **Electrolytic processes** Water can be separated into oxygen and hydrogen through electrolysis to create green H_2.
Canada's opportunities	The West has established infrastructure to produce natural gas and renewable energy. The abundance of resources presents a cost-effective opportunity for feedstock supply.	There is significant capacity for CCUS, with existing infrastructure, government support, and regulation.
Current barriers	Canada is still heavily reliant on carbon based fuels, and must rapidly scale renewable production to fully benefit from Hydrogen GHG reductions.	Significant amounts of innovation to scale CCUS and green hydrogen technologies will be required to reduce retail pricing.
Notable case studies	**The What** – The BC Hydrogen Strategy proposes leveraging renewable generation for H_2 electrolysis, Nearly 95% of BC electricity is generated from renewables[77].	**The What** – Enbridge launched green H_2 production facilities in Ontario with the $5.2m project (5MW plant)[78] and in Quebec with the $90m (20MW plant)[79].

Midstream

3. Hydrogen storage

Geological storage
Hydrogen can be stored underground in either porous media, such as depleted oil/gas reservoirs and aquifers, or cavern storage, e.g., excavated or solution mined rocks.

Compressed hydrogen
The most space saving storage option is to compress hydrogen in a gaseous state. Such as advanced pressure vessels made of fibre reinforced composites.

Materials-based storage
Hydrogen can also be stored on the surfaces of solids (by adsorption) or within solids (by absorption).

The West has underground caverns suitable for hydrogen storage.

There is limited accessible storage near established infrastructure.

The What – ATCO announced a partnership with Suncor in July 2021 to build a blue hydrogen facility, whereby ATCO will construct and operate hydrogen storage and a pipeline.[80]

4. Hydrogen distribution

Gas pipelines
Utilisation of existing gas pipelines to deliver mass hydrogen quantities.

Shipping and rail transportation
Ships can export hydrogen by sea and trains can be used as a connector for bulk land supply. Denser hydrogen carriers (e.g., methane and ammonia) can also transport more easily.

Road tanker transportation
Conventional trucks could resupply smaller storage.

On-site production
As technologies improve, smaller scale on-site operations can take place.

Retail stations
Consumer facing locations, such as hydrogen fuel stations.

The existing fossil fuel industry has established an expansive pipeline network that can be repurposed for the distribution of hydrogen or a blended hydrogen.

There are limited options to distribute produced hydrogen to the market and international markets.

The What – A major pension fund announced a consortium with Brookfield to acquire a 50% stake in Scotia Gas Networks Ltd. The company is a pioneer in repurposing gas networks for H_2 systems.[81]

Downstream

5. Market application

Industrial chemicals
Various applications in oil refining.

Agriculture
Used in fertilizer production.

Aviation, marine, ground transportation
Potential for hydrogen fuel cells.

Power storage
More efficient electricity storage.

Iron and steel
Can potentially replace coke fuel.

Heat networks
Apply as a zero emissions gas.

Other use cases
Pharmaceuticals and manufacturing.

The ability to deploy each stage of the value chain using existing infrastructure, decreasing downstream retail pricing.

Developing additional downstream application to generate demand will require significant investment.

The What – In 2018, Shell and HTEC launched the first retail hydrogen vehicle refuelling station in Canada (Vancouver). More hydrogen investments are also expected.[82]

5 Opportunities in Canada

Canada has several regions, particularly in Western provinces, that possess characteristics to create a small regional ecosystem to deploy the entire hydrogen value chain at scale.

Feedstock

The region has ample hydropower, renewable potential and fossil fuels (especially natural gas) and the ability to produce at a low cost, providing it with the required feedstock to produce grey, blue and green H_2.

Storage

The Edmonton area in Alberta contains numerous salt deposits into which caverns could be used for large-scale storage of hydrogen.

Distribution

As a result of the existing natural resource sector, Canada has significant pipeline infrastructure of in-service and abandoned or decommissioned pipelines.

Labour

Canada's energy sector accounted for 832,500 direct and indirect jobs in 2019, the majority of which are located in Western Canada. The necessary skills required to transition the nation's energy use are abundant and available in the area.

Carbon capture

Currently, Canada is home to 20% of the world's large-scale CCUS projects in operation[50] and 139 Mt CO_2/year of physical capacity exists in Alberta alone, far exceeding the anticipated amount required in the region. Additionally, there are in-flight projects actively practicing the sequestration of CO_2 by-product, giving the region the knowledge and capabilities to adjust and scale.

Partnerships

Canada has begun establishing international connections and collaborations, including the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)[51] and the IEA Hydrogen and Advanced Fuel Cell Initiatives, which evolved into the Technology Collaboration Program to coordinate private and public researchers to accelerate R&D.

Substantial nearby markets

Canada has proximity to international ports, giving it access to hydrogen import markets, including Japan, South Korea, California and all of Europe. In the domestic market, the region holds potential for many of the future market applications discussed throughout this report, including a diesel and gasoline fuel replacement for the heavy-duty freight sector and intensively driven fleet vehicles, and a significant natural gas market.

Engaged stakeholders

Natural Resources Canada has released its Canada 2020 Hydrogen Strategy, the British Columbia[52] and Alberta[53] Governments have released respective visions and strategies as they relate to hydrogen, and numerous major corporations headquartered in the region have released emission reduction goals, including Suncor[54], Canadian Natural Resources Limited (CNRL)[55] and Enbridge.[56]

Existing capabilities

Currently, there are over 2,100 employees and 100 hydrogen focused companies in Canada.[57] Further, Canada has established supply chains, primarily in Alberta, for fuel upgrading, refining and nitrogen fertilizer production. These can be used to build out the hydrogen ecosystem[58] and make Canada one of the top 10 hydrogen producers in the world today.

The cost-intensive, critical characteristics highlighted above (e.g;. distribution, CCUS, feedstock) are located in close proximities, positioning the region to bring hydrogen to market at a price that is more competitive with existing carbon-based alternatives.

Note: icons represent the value chain stages.

6 Barriers and recommendations to mass use of hydrogen as an energy source

As highlighted in the value chain, there are several substantial barriers in each stage and sub-stage that must be addressed to evolve the hydrogen ecosystem. Retail pricing and policy and regulation are additional overarching and macro challenges that should be tackled to achieve the long-term success of the hydrogen market in Canada.

Upstream barriers

The ability to decarbonize added production cost effectively will be critical to market adoption.

To achieve its market potential, increasing production capacity at market-competitive rates is the most prominent barrier to overcome. From a capacity perspective, achieving the 2050 target of 20 Mt H_2/year will require added production from natural gas and low-carbon electricity. Decarbonizing natural gas adds significant costs, which will either require consumers accepting a higher cost for fuels or innovation to decrease the cost of production.[59]

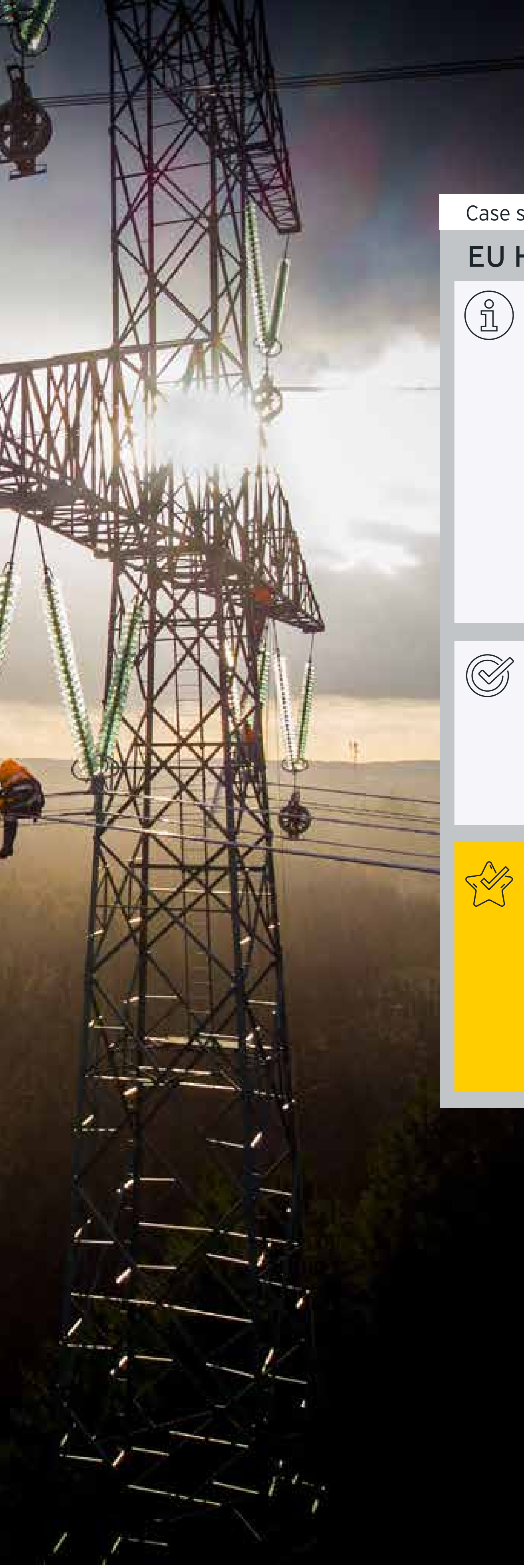
There will be a requirement to increase the CCUS capacity to be approximately 203 Mt CO_2/year. Canada's current operational projects (Shell Quest project, Alberta Carbon Trunk Line) capture and store about 4 Mt CO_2/year.[60] CCUS comes at an additional cost, but it is expected to produce income by generating CO_2 credits from government programs.[61]

Midstream barriers

A lack of suitable infrastructure exists to store and transport hydrogen to end-market uses, creating yet an additional cost barrier.

There are numerous limitations to connecting hydrogen production to downstream applications. There is currently a lack of infrastructure that is suitable to transport and store hydrogen from production sites to end users, while trucking compressed gas as a cryogenic liquid is extremely expensive.[62] Furthermore, tube trucks can only hold up to 800 kg of H_2, making trucking a nearly impossible option to meet target prices.[63] However, it should be noted that distributing in ammonia and methanol and reforming downstream can alleviate pipeline transport limitations and pricing pressures.

To achieve production targets and fully amalgamate hydrogen into an integrated energy system, storing hydrogen and connecting storage to areas of market application will become an additional barrier. In some regions, there is potential to cost effectively store hydrogen in subsurface salt caverns and deliver it through new or retrofitted natural gas pipelines. This can provide an opportunity for hydrogen to complement renewable generation at times when peak generation does not coincide with timings for peak electricity demand.[64] Excess electricity can be diverted to the production of green H_2 and stored for later use.



Case study

EU Hydrogen Backbone

The what

Eleven European gas infrastructure companies from nine EU member states have unveiled a European Hydrogen Backbone (EHB) plan to repurpose existing gas infrastructure to transport hydrogen at an affordable cost.

The report outlines hydrogen infrastructure maps for 2030, 2035 and 2040 with largely repurposed existing gas infrastructure. By 2030, the EHB has the potential of an initial 6,800 km of pipeline network, growing to 23,000 km by 2040.[65]

The why

The report acknowledges the critical role of hydrogen in tackling climate change and identified relevant goals for a dedicated transport network across Europe.

The result

Designed to inform future action, the report estimates expected future investment, projected operational costs and addressed critical barriers. The EHB is an open initiative to other gas infrastructure companies from across Europe and adjacent geographies to contribute to future thinking.

To meet target retail pricing, fuelling stations must deliver 2-10 tons of H_2/day or more. It's estimated that in addition to large trucks and buses, ~100 hydrogen-using vehicles or more must be on the road to support each fuelling station.[66] Additionally, these fuelling stations must be strategically located to be able to serve both FCEVs and dual-fuel vehicles.

Several projects worldwide are demonstrating blending hydrogen with natural gas in concentrations as high as 20%. However, the impact of hydrogen on materials and equipment is still not well understood, making it difficult for utilities and industry to plan around blending at a large scale.[67] Beyond blending limits of ~20% by volume, dedicated hydrogen pipelines start to become an attractive alternative. Further consideration will have to be given to whether additional costs should be shared by ratepayers.

Case study

ATCO's Hydrogen Blend Pilot

The what

ATCO (TSE: ACO.X) is running a first-of-its-kind pilot project for Alberta in Fort Saskatchewan, attempting to blend hydrogen into a subsection of its natural gas distribution system with a concentration of 5% by volume.[68] Approximately 2,000 customers will be a part of the study.

The why

The project is intended to be used as a stepping stone into the Canadian hydrogen market, allowing ATCO to demonstrate its abilities in the sector while working through regulatory, commercial, technical and public engagement requirements

The result

The pilot was announced in July 2020 and is expected to commence in the fall of 2022.

Downstream barriers

Establishing and generating demand for new market applications and in international markets is the final step in encouraging upstream investment.

There are numerous potential market applications for hydrogen, and new market applications are essential for creating demand and encouraging investment in production and distribution. However, they also require significant investment and an increased risk of exposure by manufacturers.

Additionally, there are currently limited capabilities to access international markets with hydrogen. Limited export markets further reduce upstream and midstream investment, slowing the integration of hydrogen into Canada's energy mix.

Retail pricing barriers

The added steps to create a net-zero fuel make it difficult to be cost competitive with carbon-based alternatives. A multifaceted approach will be required to drive down costs.

In addition to the barriers in each stage of the value chain, bringing hydrogen to market at competitive prices is critical to encouraging market adoption and ensuring costs are not passed along to the consumer. With most hydrogen originating from natural gas, the additional steps to produce hydrogen will add costs and create a higher retail price. Bringing hydrogen to the market at a competitive price is critical to encouraging market adoption and will require overcoming the barriers in each stage of the value chain.

- **Transportation –** (diesel and gasoline) fuel replacement — A \$25-\$35/GJ_{hhv} (gigajoule of higher heat value energy) price for a hydrogen alternative would be required to be competitive with current carbon-based alternatives retailing at \$24-\$41/GJ_{hhv}.[69]
- **Natural gas –** Retail pricing currently ranges from \$5-\$20/GJ_{hhv}. If combined with energy efficiency and policy measures, hydrogen could retail at \$7-20/GJ_{hhv}.[70] To achieve the cost-competitive targets, it will be necessary to support policy and regulation. Alberta's Technology Innovation and Emission Reduction program has the potential to generate emission performance credits from the production of low carbon hydrogen.
- **Electricity -** Retail pricing for electricity is highly variable due to the balance between supply and demand, ranging between \$22-\$83/GJ_{hhv}. However, hydrogen can be made from electricity and converted into electricity, giving them the potential to complement each other in net-zero energy systems.[71] Achieving the bottom end of the \$25-\$35/GJ_{hhv} target for transportation fuels will be a challenge given the costs associated with transporting, compressing and delivering hydrogen to customers. However, it may be possible to meet the top end with strategic locations and policies. Additionally, it's anticipated that there will be substantial innovation and manufacturing improvements in renewable generation, leading to for a reduction in costs for generating green hydrogen by as much as 64% by 2040.[72]

Recommendations

Supporting policy and regulation In addition to integrating hydrogen into energy strategies at all levels of government, environmental regulations and fuel standards will be required to level the playing field. There is currently no long-term policy and regulatory framework that includes hydrogen. Whether it be FCEVs or dual-fuel engines, or other end-use applications that have high R&D and manufacturing cost barriers, effective policy and regulation will be required to encourage investment, research and innovation.

Global hydrogen projects are seen in regions with supporting policies and regulations; these could include regulations that encourage the use of hydrogen technologies, carbon pricing, vehicle emission regulations, zero-emission vehicle mandates, creation of emission-free zones and renewable gas mandates in natural gas networks.

The Clean Fuel Standard (CFS) can help make the retail target price of hydrogen more comparable to carbon-based alternatives. For example, CFS credits worth \$200/t CO_2e would reduce retail costs for the fuel by up to \$1kg/H_2. Using blue H_2 to displace diesel in a hydrogen-diesel vehicle or in a HFCE could generate credits of \$1.50 or \$2.40/kg H_2, respectively.[73]

Small regional ecosystems Using small regional ecosystems, where the entire value chain can be deployed at a scale where it is economical, can demonstrate the viability of hydrogen as an alternative fuel source without ongoing public investment and subsidies. Ecosystems that hold promise will have reliable supply, the ability to make low-cost hydrogen, substantial nearby markets, the ability to connect supply and demand, and engaged industry, government and academics.[74] These ecosystems would support the development of hydrogen expertise as the broader market evolves.

Encouraging investments The ecosystem will be enabled by expanding hydrogen as a fuel source in current uses, such as industrial feedstock, and by building new large markets, such as transportation fuels and heating and power generation. Support for potential manufacturers with investment incentives, funding programs, subsidies and long-term policies can go a long way in encouraging the private sector to pursue development of the required market applications.

To contribute to these demand requirements, it's necessary to deploy hydrogen-powered vehicles to demonstrate their applicability. When sufficient evidence is demonstrated, there will be a need to support the deployment of hundreds of FCEV and dual-fuel vehicles in public and private sector.[75]

Access to international markets Canada has begun establishing international connections and collaborations, including the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)[76] and the IEA Hydrogen and Advanced Fuel Cell Initiatives, which evolved into the Technology Collaboration Program to coordinate private and public researchers to accelerate R&D.

Continued development of these partnerships can help grow the potential export market and encourage upstream investment.

7 Hydrogen roadmap from grey to blue to green

The hydrogen roadmap is designed to communicate the complexity and opportunities involved in the transition from grey to green hydrogen. Expanding the hydrogen market will require an ecosystem approach from numerous stakeholders and is expected to occur over the next three decades. In the near to medium term, existing energy infrastructure can be leveraged and integrated into the hydrogen ecosystem to accelerate its maturation. This will enable the longer-term future of green hydrogen made from electrolytic processes.

Transitioning into blue H_2 production is a necessary transition to allow for the ecosystem (production, storage, distribution, stakeholder involvement, regulatory regime, market demand) to evolve and prepare for green H_2 to be the dominant form. Each phase will require involvement and collaboration from multiple stakeholders to overcome the many barriers in place.

In the near term, public policy and regulatory support to market players across each stage of the value chain will be required to demonstrate the viability of hydrogen as an energy source and broaden awareness of the opportunity. This can take numerous forms, including emission performance credits, carbon taxes, investment incentives and continued advocacy for decreased emissions and advancement of clean technologies. These measures can help attract capital and encourage investment into additional production and CCUS technologies, the repurposing of pipelines, and development and manufacturing of market applications. Another form of public support can come from partnerships and think tanks between all levels of government, the private sector, institutions and professional service groups. These partnerships can foster expertise in all critical stakeholders and help identify and overcome critical hydrogen ecosystem barriers.

Roadmap

SUMMARY

CURRENT-STATE AND NEAR-TERM TARGETS
2020-2025

Grey H_2 Dominant production type

3 Mt
H_2 production a year

SMR
The primary process to produce H_2

10.72 kg CO_2e
During production of one kilogram of H_2

MID-TERM TARGETS
2025-2030

Blue H_2 Dominant production type

4 Mt
H_2 production a year

SMR 90% CCUS
The primary process to produce H_2

2-3 kg CO_2e
During production of one kilogram of H_2

WHAT'S REQUIRED

Upstream

Labour: Targeted awareness for the industry and career opportunities to pivot the skilled energy workforce.

Carbon Capture Utilization and Storage (CCUS): Increased operational CCUS projects, to bring CCUS capacity to 203 Mt CO_2/year.

Midstream

Infrastructure development: Retrofitted pipelines to support H_2 blends, or built net new for H_2.

Downstream and retail

Industrial feedstock: Expanded demand from its current market and market penetration into other sectors (e.g., steel making, glass production).

Transportation fuel: Replacement of gasoline and diesel for transportation and expansion of FCEVs, dual-fuel engines, heavy industry equipment.

Heating and power generation: Replacement of natural gas for heating and power generation.

Enablers

Regulatory: A regulatory regime that encourages production of low-carbon energy and discourages carbon-based fuels.

Public policy and incentives: Government incentives and subsidies to encourage upstream production of H_2 and investment into development of suitable low-carbon market applications.

Institutions: Research and skill development to transition and build an H_2 workforce with support for local governments.

Partnerships: Collaboration between federal, provincial and municipal governments, thought leadership groups, corporations and institutions.

Capital investment: Expanded awareness into the economic opportunity of H_2 to attract new capital.

LONG-TERM TARGETS
2030-2050

Green H_2 Dominant production type

20 Mt
H_2 production a year

Electrolysis
The primary process to produce H_2

0.8-3.4 kg CO_2e
During production of one kilogram of H_2

Labour: Continued development of the workforce to meet H_2 demand.

Capacity: Approximately 1054 TWh/year of added renewable generation capacity.

Infrastructure development: Continued development of infrastructure used to enable blue H_2.

Market expansion: Increased application of transportation, heating, and power generation fuels.

New industry application: Innovation into unknown market uses for produced H_2.

Regulatory: Continuation of the regime that supported the blue H_2 ecosystem.

Government incentives: Continuation of supporting policies to encourage upstream investment into low carbon production and development and use of H_2 technologies.

Technology and innovation: investment into innovation to develop additional end-use application for H_2 will be required.

8 Consider whether your business is prepared for hydrogen changes

Key considerations

Energy market players face several challenges and uncertainties over the hydrogen revolution. Consider the following questions to determine whether your organization is prepared to support the hydrogen future:

1. Should hydrogen become an organizational focus, and is our organization well positioned to compete?
2. What parts of our business operate in the hydrogen value chain?
3. Are our competitors positioning themselves to participate in the hydrogen future?
4. What operating, investment and infrastructure requirements does our organization need to fulfill to capitalize on hydrogen opportunities?
5. What subsidies and other government incentives exist with regard to hydrogen, and which of them apply to our organization?
6. Do we have a complete understanding of the hydrogen market, and have we considered different scenarios associated with development of the energy sector?
7. What other organizations can we partner with to bring complimentary capabilities together to drive value?

How can EY help?

Hydrogen is an important segment of the Canadian energy sector, and its critical role will only become more prominent. EY is fully aware of the market transition and trends, and we're dedicated to supporting the stakeholders along this journey. We help organizations in both the public and private sectors overcome some of the existing barriers and develop strategies to drive implementation.

We offer a wide range of services, including:

Transformation Strategy Services: Business model reinvention, market analysis, go-to-market strategy, scenario planning, innovation and integrated planning.

Climate Change and Sustainability Services: Energy optimization strategies, climate change risk and scenario planning, climate change and decarbonization strategy advisory, renewable energy or carbon abatement analysis, public and private sector policy, management systems for GHG emissions, and ESG strategy.

Supply Chain and Operations Services: Supply chain strategy and establishing end-to-end visibility, integrated digital planning, supply-side optimizations, manufacturing excellence and smart factory, and digital fulfillment.

Corporate Finance & Portfolio Management Services: Corporate finance strategy, capital allocation services, infrastructure advisory, investment strategy and portfolio analysis.

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The Canadian Energy and Climate Nexus is a Canadian non-profit that aims to guide Canadians towards an all-inclusive and progressive energy and climate future. At CECN, we believe that a climate friends energy system is possible and essential. We work to bring people from all stakeholder classes together to combine their knowledge to take action on the most complex issues affecting Canada in energy and Climate Change.

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