



Ministry of Foreign Affairs

Market Scan of the Canadian Hydrogen Sector

Commissioned by the Netherlands Enterprise Agency

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International.

Market Scan of the Canadian Hydrogen Sector

Consulate General of The Netherlands, Vancouver



Netherlands Enterprise Agency

Supported by The Netherlands Enterprise Agency

December, 2020



ZEN and the art of
CLEAN ENERGY
SOLUTIONS



Table of Contents

SECTIONS

STRATEGIES

Highlights of Canada's National and Key Province Strategies

KEY PLAYERS

Key Hydrogen Companies, Associations & Research Projects in Canada

COLLABORATIONS

Current International Collaboration and Niches for Expansion

POTENTIAL CHALLENGES

Potential Regional Challenges to Doing Business for Dutch Companies

FUTURE PATHWAYS

Full Potential Trajectory and Outcomes of Dutch and Canadian Collaboration

RECOMMENDATIONS

Recommendations and Next Steps for Collaborations

Sources & Appendices



Executive Summary

Strong push to develop strategies

- ◆ Hydrogen is rapidly gaining momentum across Canada with regional strategies completed or in development in **9 of 13 provinces**
- ◆ Canada is positioned to become a **world-leading supplier of hydrogen** and **related technologies** producing more than **20 Mt** of hydrogen by 2050 worth **C\$50 billion** in revenues and creating **350,000 jobs**
- ◆ The Canadian government and provincial governments are **committed to developing hydrogen** in Canada; however, specific policy and funding mechanisms have yet to be announced

Large & Active H₂ Sector

- ◆ Canada has a **large and active hydrogen technology sector** and is already one of the **top 3 global producers** of hydrogen
- ◆ Hubs for hydrogen **fuel cell development**, **electrolyzers**, and **SMR+CCUS technology** are forming around **Vancouver**, **Toronto**, **Edmonton**, and **Calgary**; these hubs are supported by strong academic research universities and national labs across Canada
- ◆ Canadian firms are **collaborating around the world** on hydrogen and fuel cell projects with a strong focus in **Northern Europe** and **China**

Many Potential Niches for Collaboration

- ◆ There are many potential niches for future collaboration between Canadian and Dutch companies, researchers and governments, most critically in the areas of **hydrogen pipelines**, **ports and marine**, **transport and logistics**, and **codes and standards**
- ◆ There are several key areas of overlap in the **development of ports as hydrogen hubs** in both countries and this should be a high priority for immediate collaboration and shared development

Pathways & Scenarios

- ◆ The ideal pathway for Canadian and Dutch companies, researchers and governments to come together is by **forming working groups and consortia** around specific **technical, regulatory or project demonstrations**
- ◆ Canadian and Dutch companies can leverage one another's strengths to accelerate the development of the hydrogen sector

Recommendations & Next Steps

- ◆ Following from this study, several **high level introductory meetings** should be set up in **early 2021** between Canadian and Dutch officials and company representatives to discuss shared strategic priorities, commitments, and plans for collaboration
- ◆ Working groups should then be formed around key issues and a statement of shared commitment between the countries should be announced

Canada and several regions have released H₂ strategies

STRATEGIES

OVERVIEW

Canada released its national-level "Hydrogen Strategy for Canada" in December 2020

Legend

- Strategy or major study released
- Strategy in development
- Strategy to be determined

Yukon

- Potential for strategy development in early 2021

B.C.

- Hydrogen study released in 2019
- Roadmap to follow in 2021

Alberta

- Alberta government developing Hydrogen Roadmap

Saskatchewan & Manitoba

- Initial H₂ working groups formed
- SK. will likely collaborate closely with Alberta on their strategy

Québec

- Initial strategy document released in Dec 2019
- Full strategy pending

Newfoundland/Labrador

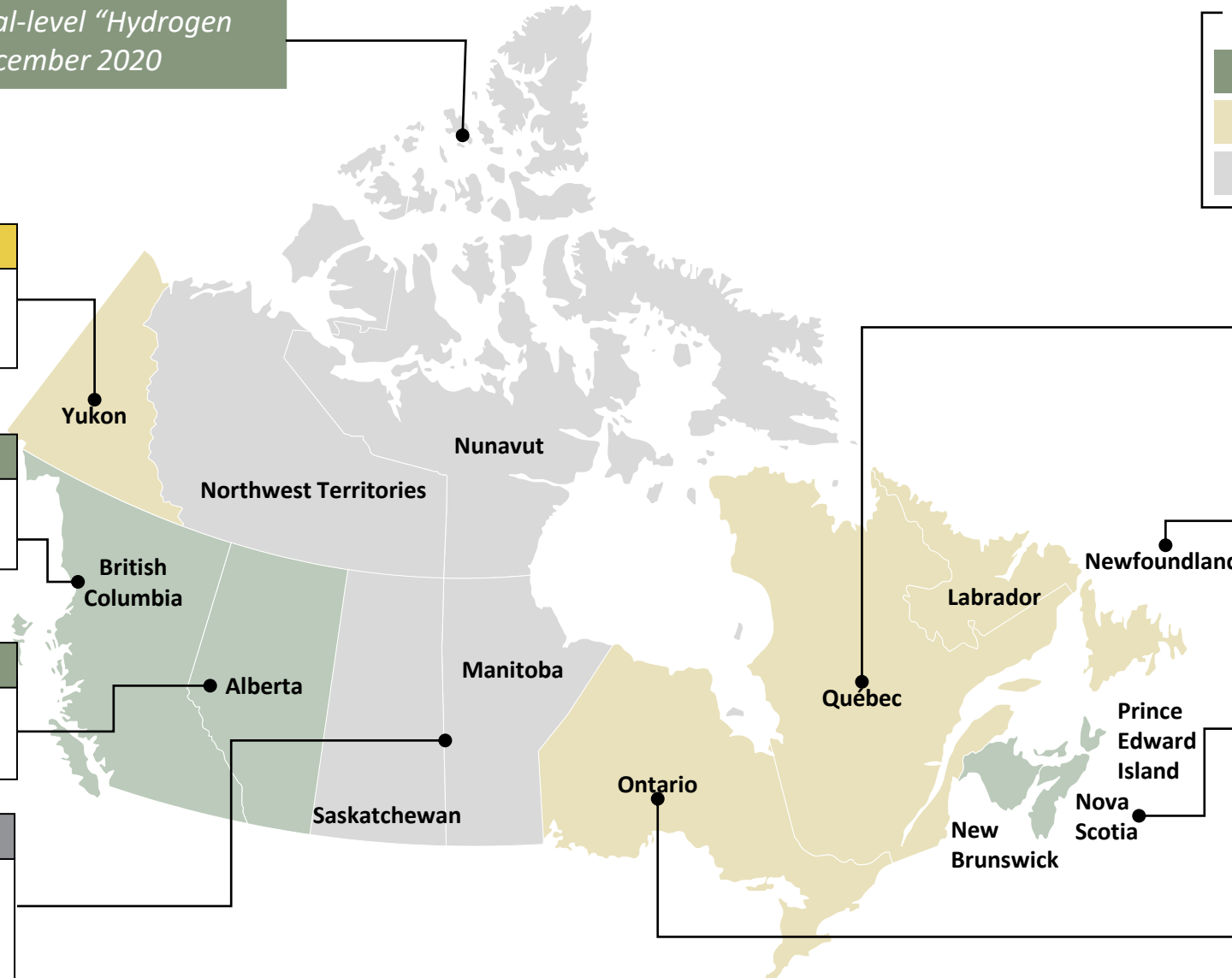
- Study building off Maritimes strategy to begin in 2021

Maritimes

- Opportunity study released in October 2020

Ontario

- Potential for strategy development in early 2021



Hydrogen Strategy for Canada (1 of 2)

STRATEGIES

CANADA





Summary: The Hydrogen Strategy for Canada is the national-level strategy developed by the Federal government. The Strategy covers Canada's advantages and existing momentum in the hydrogen sector globally and sets the course of the country's policies and plans up to 2050.

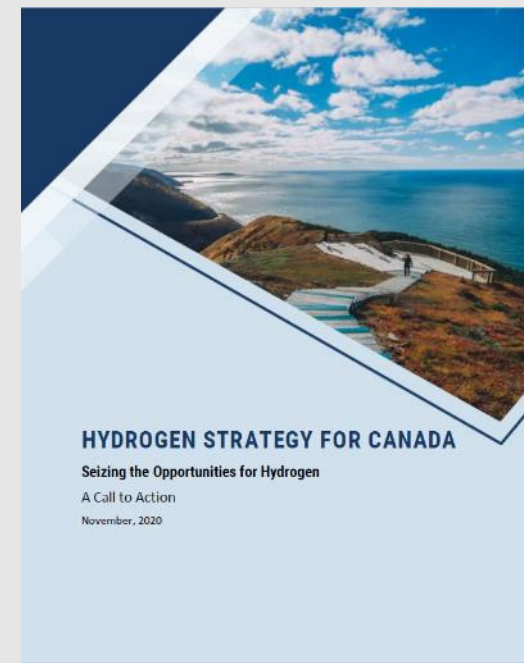
Report Highlights

- ◆ Canada is positioned to become a world-leading supplier of hydrogen and related technologies
- ◆ The hydrogen sector could produce more than 20 Mt of hydrogen by 2050 worth C\$50 billion in revenues and creating 350,000 jobs
- ◆ Hydrogen could represent 6% of delivered energy and 45Mt-CO₂e of GHG savings by 2030, and 30% of delivered energy and 190Mt-CO₂e GHG savings by 2050.
- ◆ Hydrogen production will come from a mix of low carbon intensity pathways including SMR of Natural Gas (combined with carbon storage), electrolytic hydrogen from renewables, and other pathways.
- ◆ Transportation and decarbonization of natural

gas distribution networks will be the largest sources of demand in addition to use as industrial feedstocks and process heat.

- ◆ Canada is exploring opportunities to become a global exporter of hydrogen and hydrogen technologies taking advantage of its deep-water ports, existing LNG infrastructure and proximity to key markets in the US, Europe and Asia.

 H2 Opportunity		
	2030	2050
 % of Delivered Energy	6%	30%
 Hydrogen Demand	4 Mt-H2	20 Mt-H2
 GHG Emissions Abated	45 Mt-CO ₂ e 21% of 2030 Goal	190 Mt-CO ₂ e 26% of 2050 Goal



Report Facts

Report Title:	Hydrogen Strategy for Canada
Subtitles:	Seizing the Opportunities for Hydrogen: A Call to Action
Authors:	Zen Clean Energy Solutions
Subject Matter:	H ₂ production, End use, R&D, Economics, etc.
Published by:	Natural Resources Canada
Report Type:	National Strategy
Publish Date:	December 16, 2020

https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

Hydrogen Strategy for Canada (2 of 2)

STRATEGIES

CANADA

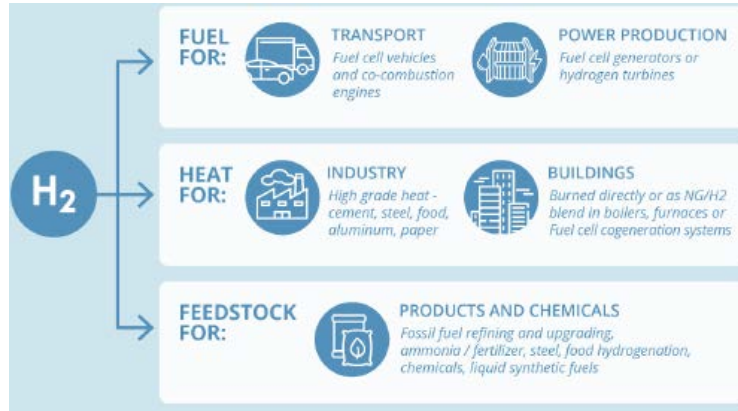
Production Pathways & Potential

- ◆ Canada is already one of the top ten global producers of hydrogen, producing an estimated 3 million tonnes (Mt) annually
- ◆ It is expected that bulk of Canada's hydrogen production will come from low-cost, low carbon intensity SMR+CCUS and electrolytic hydrogen from hydroelectricity, renewables and nuclear energy

Supply Chain and End-use Demand

- ◆ Large-scale, centralized production methods will dominate the supply, with concentrations in energy/feedstock rich provinces such as British Columbia, Alberta, and Québec
- ◆ This bulk hydrogen will be transported to market or storage and distribution points with a mixture of dedicated hydrogen pipelines and liquid hydrogen tank trucks
- ◆ Chemical carriers such as ammonium may also be used as a means to transfer hydrogen to overseas markets
- ◆ For end-uses across Canada, the largest demand for hydrogen will be as a transportation fuel and as Renewable Gas to

displace Natural Gas (methane) in the gas distribution system.

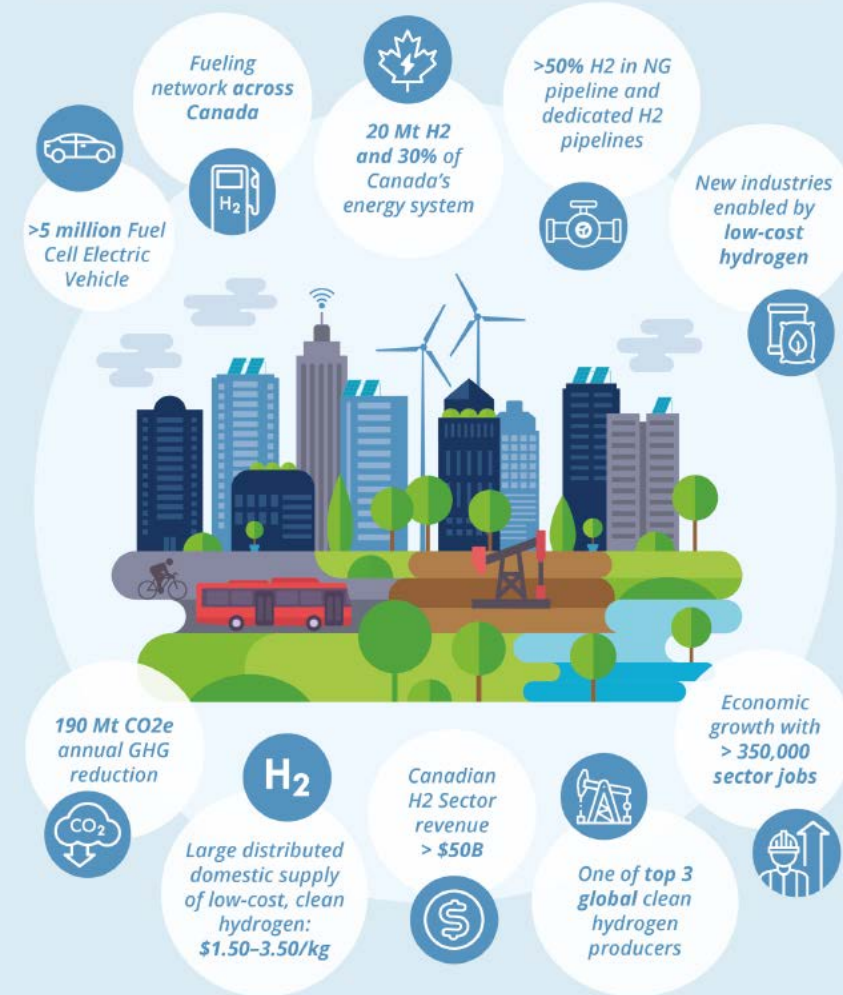


International Collaborations

- ◆ Canada has the potential to produce large amounts of low-cost, low CI hydrogen in excess of its domestic demand.
- ◆ Canadian governments, industry and academia have a long history of international collaboration to advance hydrogen production and use, including fundamental research, commercialization, deployment, and policy development.
- ◆ Canada is well positioned to continue as a global leader in both technology innovation and commercial developments.

Canada's Hydrogen Vision for 2050

VISION FOR HYDROGEN IN CANADA IN 2050



B.C. Hydrogen Study

STRATEGIES

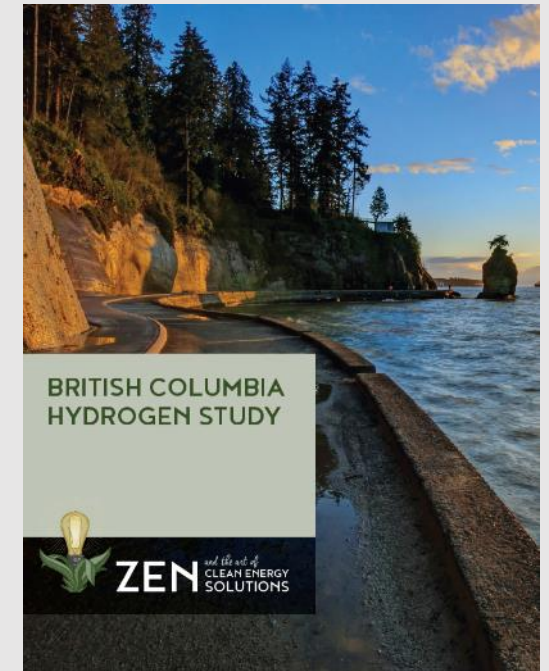
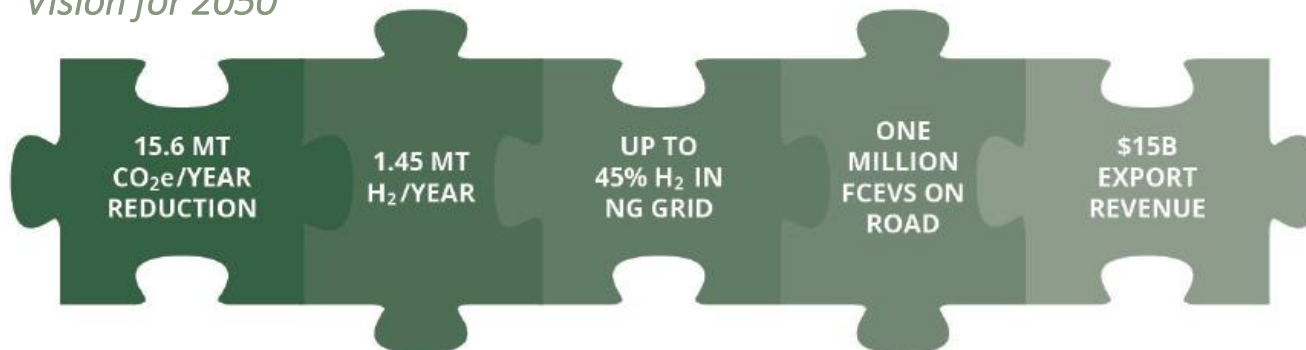
B.C.

Summary: The B.C. Hydrogen Study was developed in partnership with the province, the B.C. Bioenergy Network, FortisBC, and other project partners. The study focuses on hydrogen's role in helping the province achieve its CleanBC GHG emission reduction target.

Report Highlights

- ◆ B.C. has a distinct comparative advantage from its electrical grid and low-cost natural gas resources
 - ◆ B.C. has substantial clean electricity and natural gas reserves in the Northeast of the Province. The Province also has depleted gas reservoirs and saline aquifers that enable large volumes of CO₂ sequestration.
 - ◆ The Province has a world-leading hydrogen and fuel cell sector with several high-profile
- ◆ companies with headquarters located in the province. It is a strategic priority for the Province to maintain this position and continue to develop new intellectual property and technologies.
 - ◆ B.C.'s economy is heavily dependent on the extraction, consumption, and export of natural resources, and hydrogen fits as a value-added future export resource that can support both local and international decarbonization efforts.
 - ◆ B.C. can be a global leader by adopting policies that promote and support all sides of an emerging hydrogen economy including demand, supply, and technology development. Through a combination of policy and industry, hydrogen can play a major role in the Province by 2050.

Vision for 2050



Report Facts

Report Title:	British Columbia Hydrogen Study
Subtitles:	Final Report
Authors:	Zen Clean Energy Solutions, IBET, G&S Budd Consulting
Subject Matter:	H ₂ production, storage, and use; Decarbonization, Power to Gas, Global Demand and Market
Published by:	B.C. Bioenergy Network
Report Type:	Provincial Study
Publish Date:	September 2019

https://www2.gov.bc.ca/assets/gov/government/ministries-organizations/zen-bcbrn-hydrogen-study-final-v6_executivesummary.pdf

Alberta Industrial Heartland H₂ Study

STRATEGIES

ALBERTA

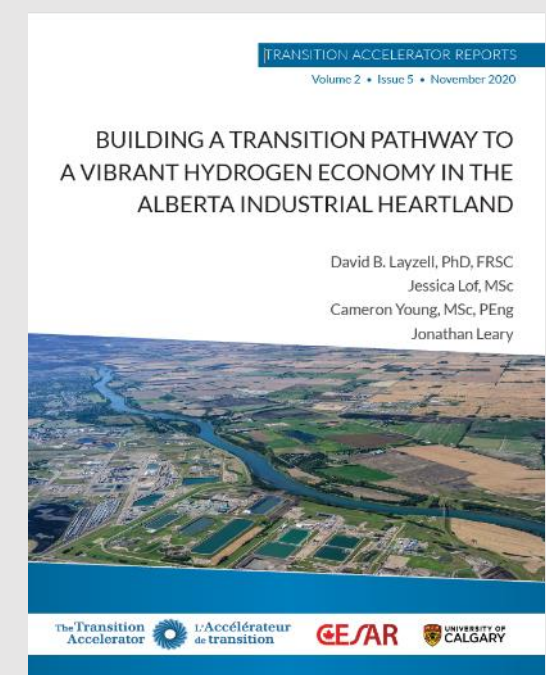
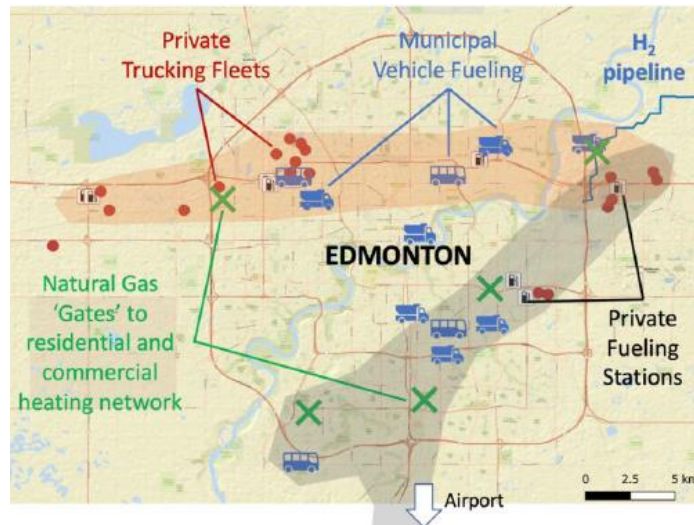
Summary: This report assesses the market potential for hydrogen in Alberta and then focuses on one region of Alberta, the Industrial Heartland near Edmonton¹, to explore how a vibrant hydrogen economy could be built there.

Report Highlights

- ◆ Alberta and Alberta's Industrial Heartland (AIH) are ideally positioned to produce, use and export hydrogen gas
- ◆ Sub regional 'Hydrogen Nodes' are the preferred model to ensure that risks and opportunities are understood to ensure both the private and public sectors are positioned to make informed decisions.
- ◆ The larger the scale of hydrogen production and distribution, the more economical the hydrogen system.
- ◆ Governments should incent and invest in hydrogen infrastructure that results in a low/no carbon heating fuel at \$1.50- \$2.00-/kg H₂, or as a transportation fuel at \$3-\$5/ kg H₂
- ◆ Canada should recognize early that a global race is well underway to produce low/no

carbon hydrogen for export.

- ◆ Other countries and political jurisdictions have stronger top-down policy signals that will make it easier on their companies to be early movers.
- ◆ Clear synergies exist between producing and transporting hydrogen for export and producing and distributing hydrogen for domestic use.
- ◆ Incentives and investment along the hydrogen value chain should understand this synergy early and be incorporated into hydrogen energy system planning.



Report Facts

Report Title:	Building a Transition Pathway to a Vibrant Hydrogen Economy in the Alberta Industrial Heartland
Authors:	David B. Layzell, PhD, FRSC; Jessica Lof, MSc; Cameron Young, MSc, PEng; Jonathan Leary
Subject Matter:	H ₂ production, End use, R&D, HD transport, buildings
Published by:	The Transition Accelerator, Canadian Energy System Analysis Research (CESAR), U of Calgary
Report Type:	Provincial Study
Publish Date:	October 2020

<https://transitionaccelerator.ca/wp-content/uploads/2020/11/Building-a-Transition-Pathway-to-a-Vibrant-Hydrogen-Economy-in-the-Alberta-Industrial-Heartland-November-2020-5.pdf>

¹The Alberta Industrial Heartland (AIH) includes Edmonton, Strathcona, Fort Saskatchewan, Sturgeon, and Lamont counties.

The Hydrogen Option for Québec

STRATEGIES

QUÉBEC

Summary: This document looks at the use of hydrogen as an energy vector, with emphasis on its different applications in the transportation sector as well as in industry. It shows the advantages related to hydrogen and its role in fighting climate change, the most recent advancements in hydrogen technologies, and how Québec can build out its hydrogen sector.

Report Highlights

- ◆ Québec has a distinct advantage due to its low carbon intensity electricity grid and potential for green hydrogen production through the electrolysis pathway.
- ◆ The province has access to surplus renewable energy, which is currently being lost due to system inefficiencies. This stream made up 54% of overall electrical production in 2016 and can be recaptured through integrating hydrogen production and storage systems
- ◆ The province is currently a renewable electricity exporter to states such as Vermont, New York, and Maine. Part of this export may be redirected to the production of hydrogen for export both within North America and internationally.

- ◆ In 2019, Air Liquide expanded its operations in Bécancour, Québec with a 20 MW Proton Exchange Membrane (PEM) electrolyzer capable of producing 8000 kg/day of green hydrogen. The system was supplied by Hydrogenics, a Canadian company based in Mississauga, Ontario, which was acquired by Cummins in September 2019

Availability of primary energy sources in Quebec, 2016

	Source	PJ	Percentage of total (%)	Equivalence
Import = 51 %	Oil	826	36	137 million barrels
	Natural gas	325	14	8.4 billion m ³
	Coal	13	1	0.6 million tons
Local = 49 %	Hydro	818	36	227 TWh
	Biomass	170	7.5	
	Wind	126	6	35 TWh
	Total	2,278	100	

Source: Whitmore and Pineau, 2018.

The hydrogen option for energy: a strategic advantage for Quebec

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Mario Demers, Ph.D.
Research Assistant, CHER
Université Sherbrooke



Report Facts

Report Title:	Hydrogen Option for Energy: A Strategic Advantage for Québec
Authors:	Jacques Roy, Ph.D, Marie Demers, Ph.D.
Subject Matter:	Emission reduction and Hydrogen deployment strategy, infrastructure deployment, innovative companies
Published by:	Hydrogène Québec
Report Type:	Provincial Study
Publish Date:	December 2019

https://www.researchgate.net/publication/340949199_The_hydrogen_option_for_energy_a_strategic_advantage_for_Quebec

Industry Associations and Networking Organizations

KEY PLAYERS ASSOCIATIONS

Government & Industry Associations

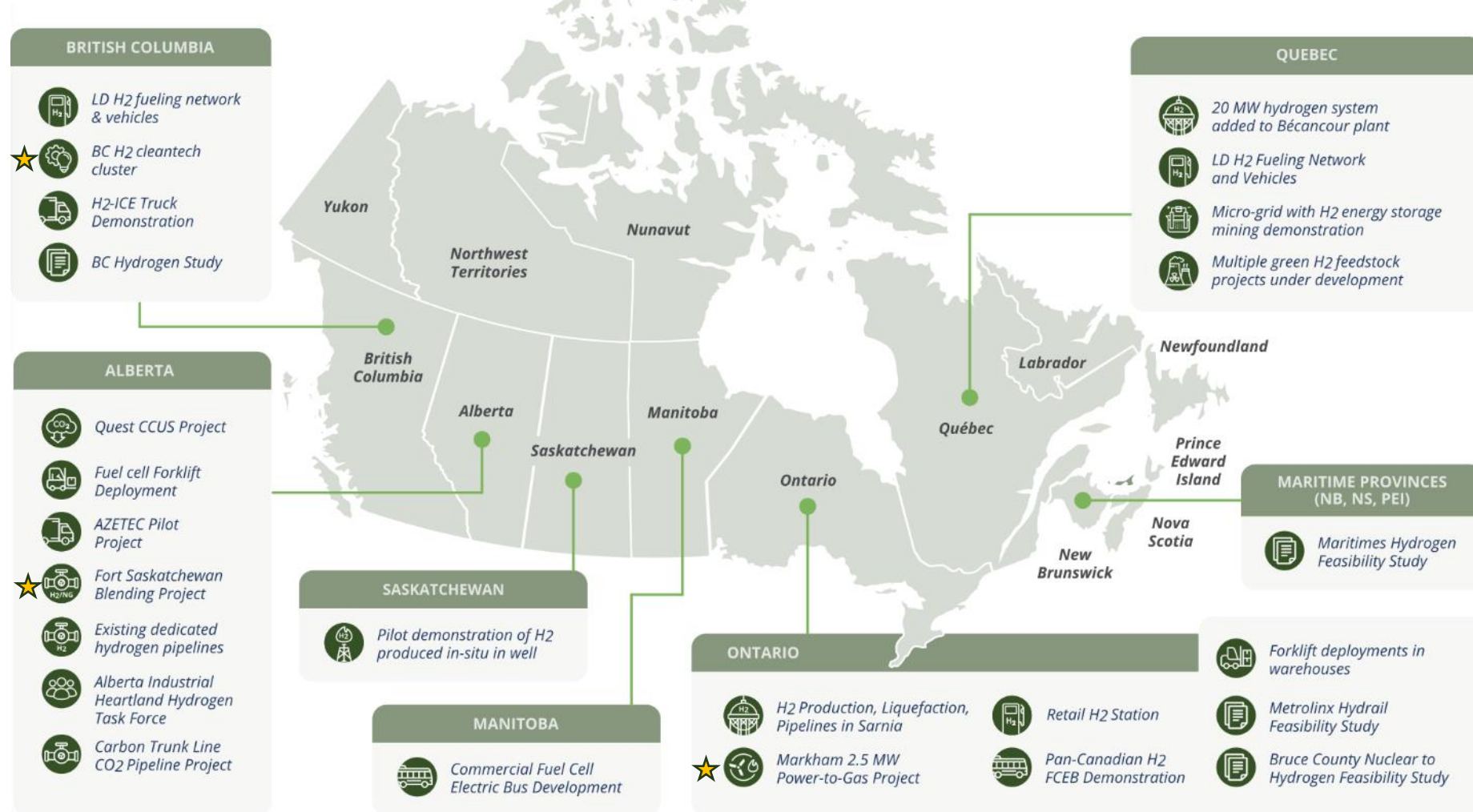


Canadian Sustainable Aviation Flight-Demonstrator & Ecosystems (CSAFE)



Hydrogen/Fuel Cell Research Projects and Initiatives

KEY PLAYERS RESEARCHERS



★ Projects detailed on following slides

Case Study: AZETEC Pilot Project

KEY PLAYERS CASE STUDY

Objectives:

- ◆ Development and operation of two heavy-duty hydrogen fuel cell electric Class 8 trucks
- ◆ Designed to meet unique demands of Alberta such as double-trailer operation, heavier gross vehicle weights (65,000 kg GVW), long distance hauling, and cold weather
- ◆ Development and operation of a HD vehicle refuelling station using Alberta hydrogen (via SMR without CCUS in Phase 1 and shifting to SMR+CCUS in the next phases)

Details:

- ◆ C\$17 million pilot project from 2020 - 2023
- ◆ Trucks will be powered by Ballard Power Systems next generation PEM fuel cell system and will have a range of 700km in all Alberta weather conditions
- ◆ Fueling infrastructure developed by HTEC in partnership with Suncor Inc.



AZETEC
ALBERTA ZERO-EMISSION TRUCK ELECTRIFICATION COLLABORATION

Project Partners



Case Study: Markham Power to Gas Project

KEY PLAYERS CASE STUDY

Objectives:

- ◆ Blend renewable hydrogen gas to decarbonize Enbridge Gas natural gas network in Markham, Ontario
- ◆ Demonstrate electrolyzers as sources of dispatchable demand and grid stability services to electrical power utility

Details:

- ◆ C\$5.2 million project beginning operation in 2021
- ◆ Leverages green hydrogen produced from 2.5 MW electrolyzer deployed in 2018 at Markham Energy Storage Facility to convert excess energy
- ◆ First project of its kind in North America
- ◆ Initial phase projected to provide blended gas distribution to 3,600 customers, abating 117 tons of CO₂



Project Partners



Government
of Canada

Gouvernement
du Canada

Case Study: HTEC Hydrogen Fueling Network

KEY PLAYERS CASE STUDY

Objectives:

- ◆ Construct hydrogen fueling station network across British Columbia to support the rollout of FCEVs in the Province (3 of 6 current in operation)
- ◆ Construct hydrogen fueling station network across Québec (1 of 6 current in operation)

Details:

- ◆ Stations in Vancouver and Burnaby were developed in partnership with Shell, and North Vancouver station in partnership with 7-Eleven Canada
- ◆ Developing 2,000 kg/day central hydrogen production facility in B.C. to supply network with renewable hydrogen from electrolysis
- ◆ HTEC builds, operates, and manages hydrogen distribution services for the fueling stations



HTEC's BC Hydrogen Fueling Station Network

Project Partners



TOYOTA

HYUNDAI






Current International Collaborations

COLLABORATIONS




GLOBAL STATUS






Canada-Global Collaborations

-  **IPHE:** Int. Partnership for Hydrogen in the Economy
-  **MI:** Mission Innovation
-  **CEM:** Clean Energy Ministerial
-  **Hydrogen Ministerial**
-  **IEA:** International Energy Association




USA

-  **Cummins-Hydrogenics:** Cummins acquired Hydrogenics in 2019
-  **Ballard-Rev Group:** Fuel cell transit buses, Port yard trucks
-  **Can-USA Gas Associations:** Collaboration on North American hydrogen codes & standards

Germany

-  **Ballard-Siemens:** Hyrail train demonstration
-  **2-G:** Hydrogen in CHP diesel engine research
-  **Hy2Gen Canada:** Large-scale green hydrogen from hydroelectricity project

France

-  **Various Universities:** High temperature steam electrolysis from nuclear energy
-  **Alstom-Ballard:** Coradia iLint fuel cell trains
-  **ABB-Sogestran-Ballard:** Hydrogen river boats

Legend



Government-to-Government
Collaboration





Business-to-Business
Collaboration




Knowledge-to-Knowledge
Collaboration




Norway/Denmark

-  **Ballard-Norled:** Partnership to develop fuel cell modules for ferries
-  **Ballard EU:** Marine centre of excellence HQ in Hobro Denmark



Rest of Europe

-  **Ballard:** Fuel cell buses deployments



Japan/Korea

-  **CHFCA/KEEI:** Research on Canada's H₂ supply chain for export
-  **Hyundai:** Vancouver chosen as first Canadian market for Nexo
-  **Ballard:** Automotive and stationary fuel cells


China

-  **Ballard:** Automotive fuel cells
-  **Ballard:** Joint Venture with Weichai

Australia

-  **ATCO Aus-Can:** Collaboration on hydrogen pipeline, storage, & generation technologies
-  **CHFCA & Australian Hydrogen Council:** MOU on H₂ in mining

South Africa

-  **Anglo-American-Ballard:** Fuel cell mining truck demonstration project



Case Study: Ballard Marine Center of Excellence

COLLABORATIONS CASE STUDY

Marine Center of Excellence

- ◆ Ballard established its **Marine Center of Excellence (CoE)** in Hobro, Denmark in 2019
- ◆ The CoE is dedicated to engineering, manufacturing and servicing fuel cell marine applications
- ◆ In Europe, regulations have been introduced to **reduce carbon dioxide emissions** from maritime transport by **at least 40%** of 2005 levels by 2050
- ◆ The **Norwegian parliament** has decreed that the country's UNESCO-protected fjords shall be **free from cruise and ferry emissions** no later than **2026**



Ballard-Norled Collaboration

- ◆ In April 2019, Ballard sign an agreement to supply **two 200kW fuel cell modules** to **Norled**, Norway's largest ferry and express boat operator.
- ◆ The modules will power Norled's new hybrid ferry planned to begin operating in 2021
- ◆ The ferries will have capacity for **299 passengers** and **80 vehicles** and will be the **first** liquid-hydrogen fuel-cell powered vessels in commercial operation globally
- ◆ Norled believes a hybrid **fuel cell-battery** solution will ultimately provide **safe** and **efficient zero-emission operations** for all Norwegian car ferry routes
- ◆ The project also involves **Linde** in Germany for liquid onboard storage, **Gexcon** for safety and risk analysis, and **Westcon Power & Automation** located at Karmøy, Norway for integration and building.

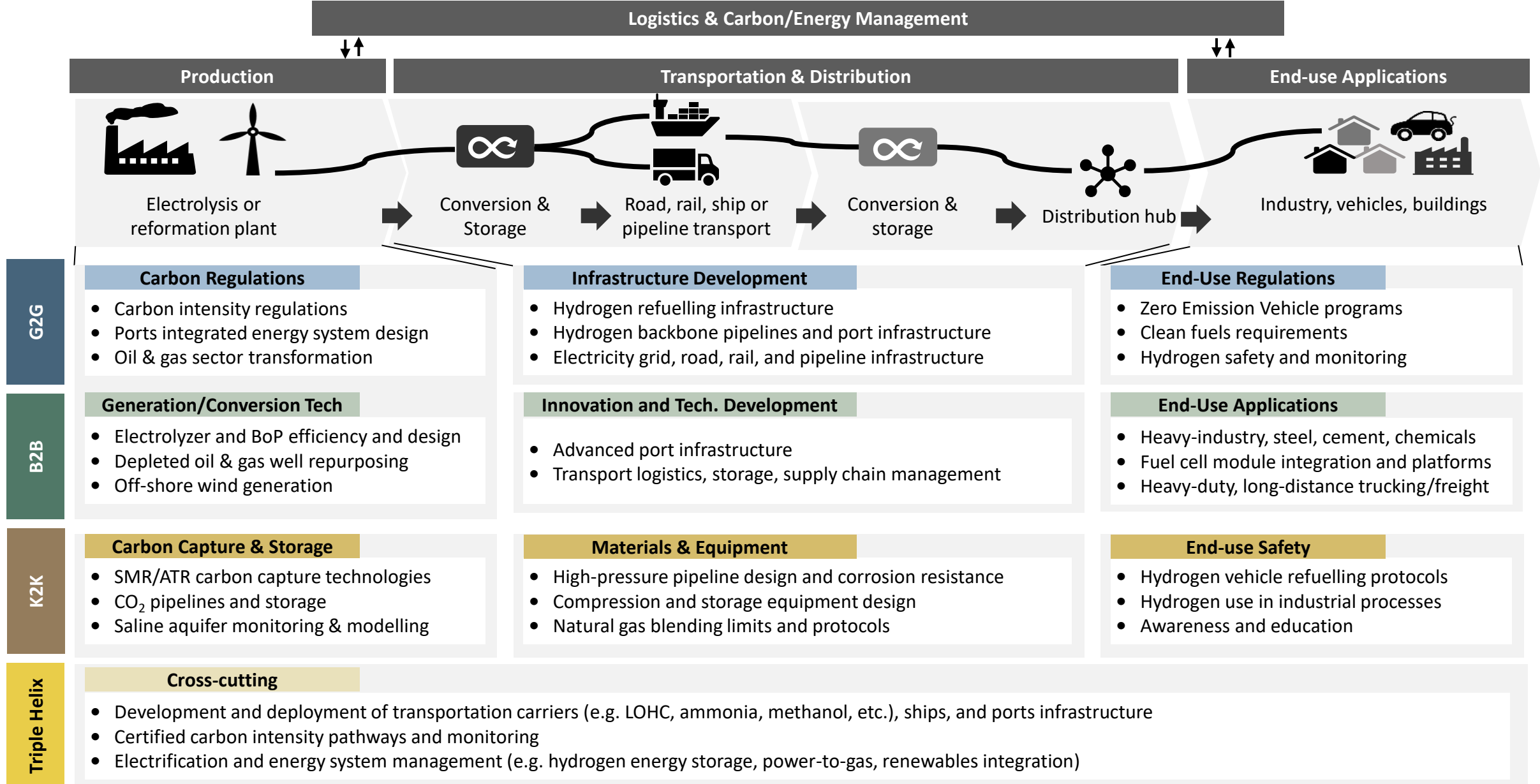
Other Ballard Collaborations in the Marine Sector in Europe

- ◆ Ballard is actively involved in a number of marine projects in Europe, including:
 - **Megawatt-scale marine power** solutions with ABB in Switzerland
 - The development of **HySeas III**, the world's first sea-going renewables-powered car and passenger ferry in collaboration with Ferguson Marine Eng., Kongsberg Maritime, and the Orkney Islands Council
 - Participation in Europe's **H2PORTS project** to implement hydrogen and fuel cell projects at ports, in collaboration with CNH2 - Centro Nacional del Hidrógeno, Enagas, Hyster-Yale Nederland BV and others
 - The **Flagships Project** to demonstrate fuel cell powered ferries and barges, in partnership with a consortium of European marine technology organizations



Niches for Future International Collaborations

COLLABORATIONS NICHE AREAS



Regional Challenges for Dutch Companies in B.C., AB, QC

POTENTIAL CHALLENGES

British Columbia



- ◆ CleanBC Climate Plan Carbon Tax must be paid by local and foreign companies operating in B.C.
- ◆ Low Carbon Fuel Regulation Credits can be created, bought and sold by both local and foreign companies, but cannot be traded outside of B.C.
- ◆ Some project funding is limited to B.C.-based companies and/or B.C.-made products
- ◆ Partnering with a B.C.-based company can help secure access to government funding

Québec



- ◆ Bill 101 states that French is the official language of Québec
 - ▶ Government and business interactions may be conducted in French
 - ▶ Companies operating in Québec must have a firm name in French
 - ▶ Companies must advertise and label products in French
- ◆ Funding focus is on job creation/economic development, transport, and renewable energy technologies

Alberta



- ◆ Focus of government is economic development and provincial job creation (Made in Alberta Initiative)
- ◆ Funding focus is on low carbon fuels, CCUS, and other related oil and gas technologies

Canada-wide

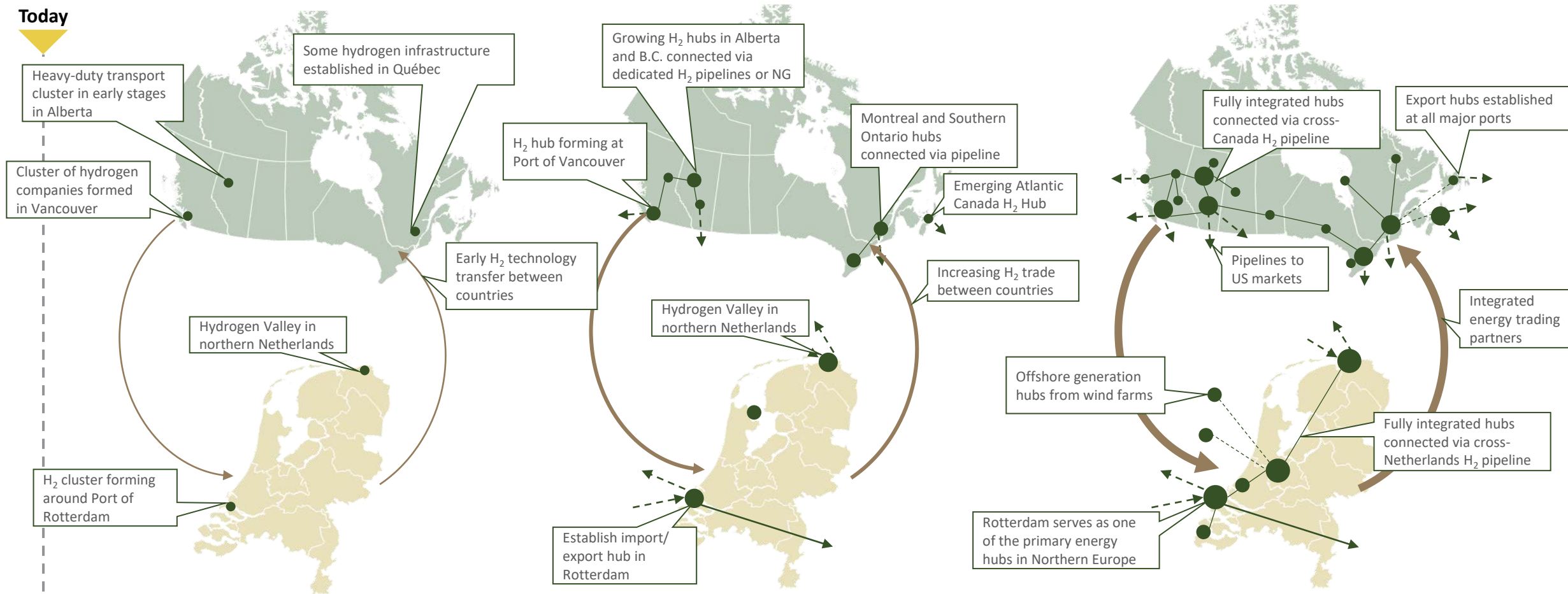


- ◆ Lack of specific hydrogen regulation
- ◆ Different equipment certification codes and standards from Europe (CSA vs. CE)
- ◆ Lack of export standards for hydrogen purity and carbon intensity
- ◆ Undeveloped international collaboration and export strategy
- ◆ Difficult to piece together projects
- ◆ Hydrogen funding in Canada is complex, including sources from different levels of government and private funding

Dutch & Canadian collaboration to reach common goals

FUTURE PATHWAYS

Today



- Canada-Netherlands joint commitment to hydrogen sector development
- Early stage collaborations around ports infrastructure, storage, mobility, pipelines and related H₂ technologies

- Co-developed hydrogen demonstration projects at ports in Canada and the Netherlands
- Compatible standards and regulations around carbon intensities, hydrogen/NG blending, safety, etc.

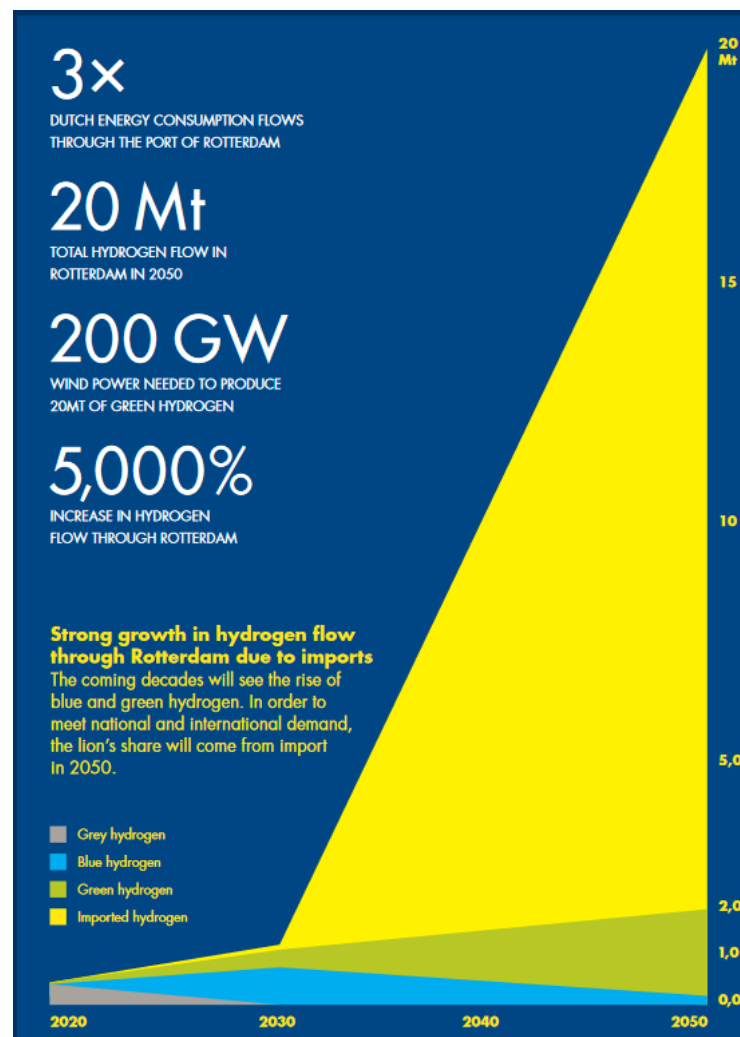
- Closely integrated hydrogen supply chains and joint companies leading the world in hydrogen management and logistics
- Trade in bulk hydrogen via LH₂ or chemical carriers serving EU markets

Case Study: H₂ Hubs at Dutch & Canadian Ports

FUTURE PATHWAYS

CASE STUDY

- ◆ The Port Authority at the Port of Rotterdam is working with various partners to introduce a large-scale hydrogen network across the port complex
- ◆ The goal is to make Rotterdam an international hub for hydrogen production, import, application and transport to other countries in Northwest Europe
- ◆ The Port of Vancouver, is developing pilot projects around vehicles and material handling with the potential to eventually develop a fully integrated hub focused on hydrogen exports
- ◆ Ports on the East Coast, including the Ports of St. John, Montreal and Halifax are also exploring the potential of hydrogen
- ◆ Ports in both countries could share information and develop projects to understand critical infrastructure, technologies, codes/standards, and project delivery approaches
- ◆ The best practises and lessons-learned from these two ports could be shared across Canada and the Netherlands to rapidly expand infrastructure and hydrogen trade flows

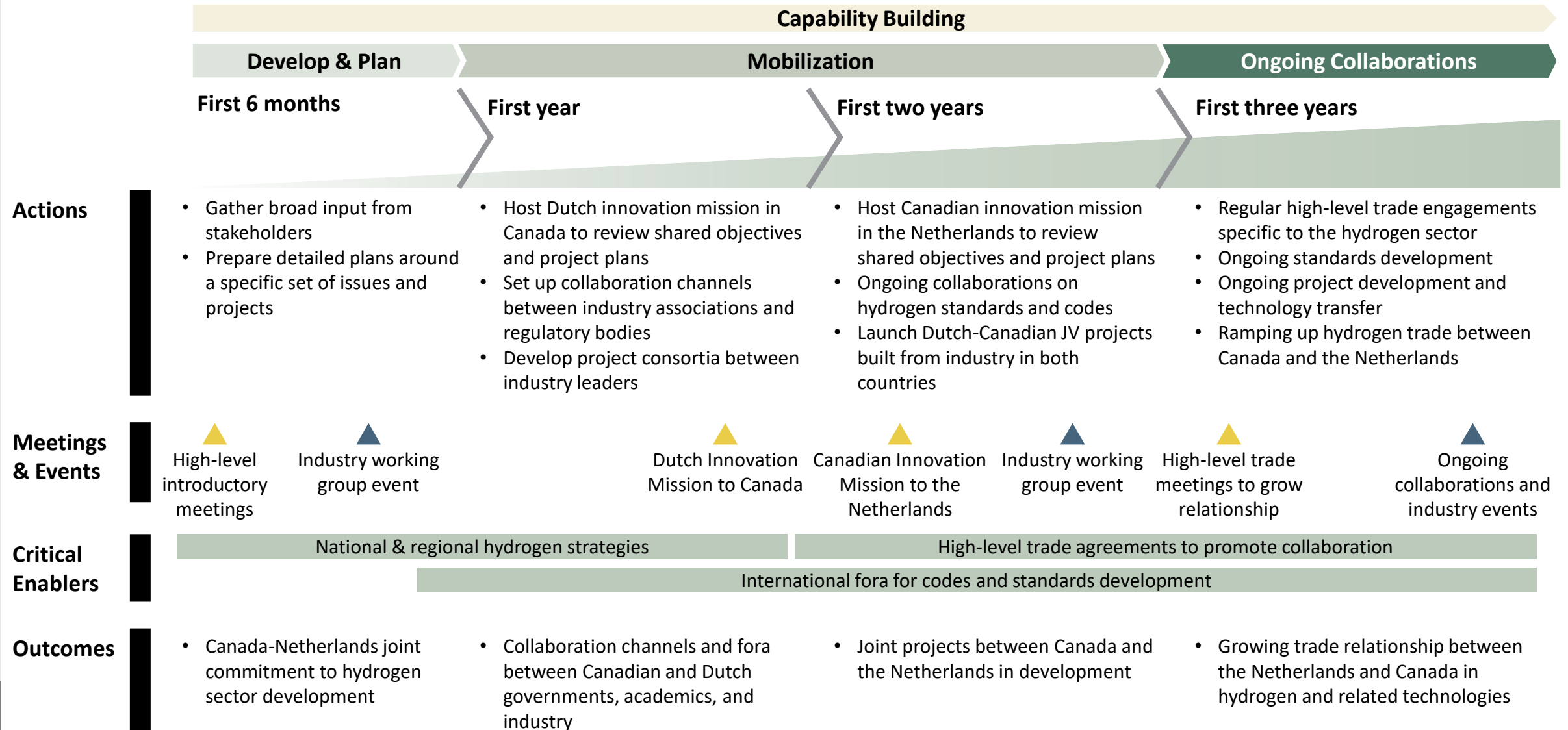


Why Hydrogen at Ports

- ◆ Multiple end uses to drive scale and develop full value chain
- ◆ High point emission sources of both GHG and local air pollutants (NO_x, SO_x, PM)
 - Decarbonization benefits
 - Local air quality benefits
- ◆ Heavily reliance on diesel, equipment runs demanding duty cycle - more suited to hydrogen fuel cell vs battery
 - Higher energy capacity w/ lower weight
 - Fast fill – less impact on productivity
- ◆ Many applications can share common fueling infrastructure
 - Return-to-base operation or geographically constrained
- ◆ Federal government influence

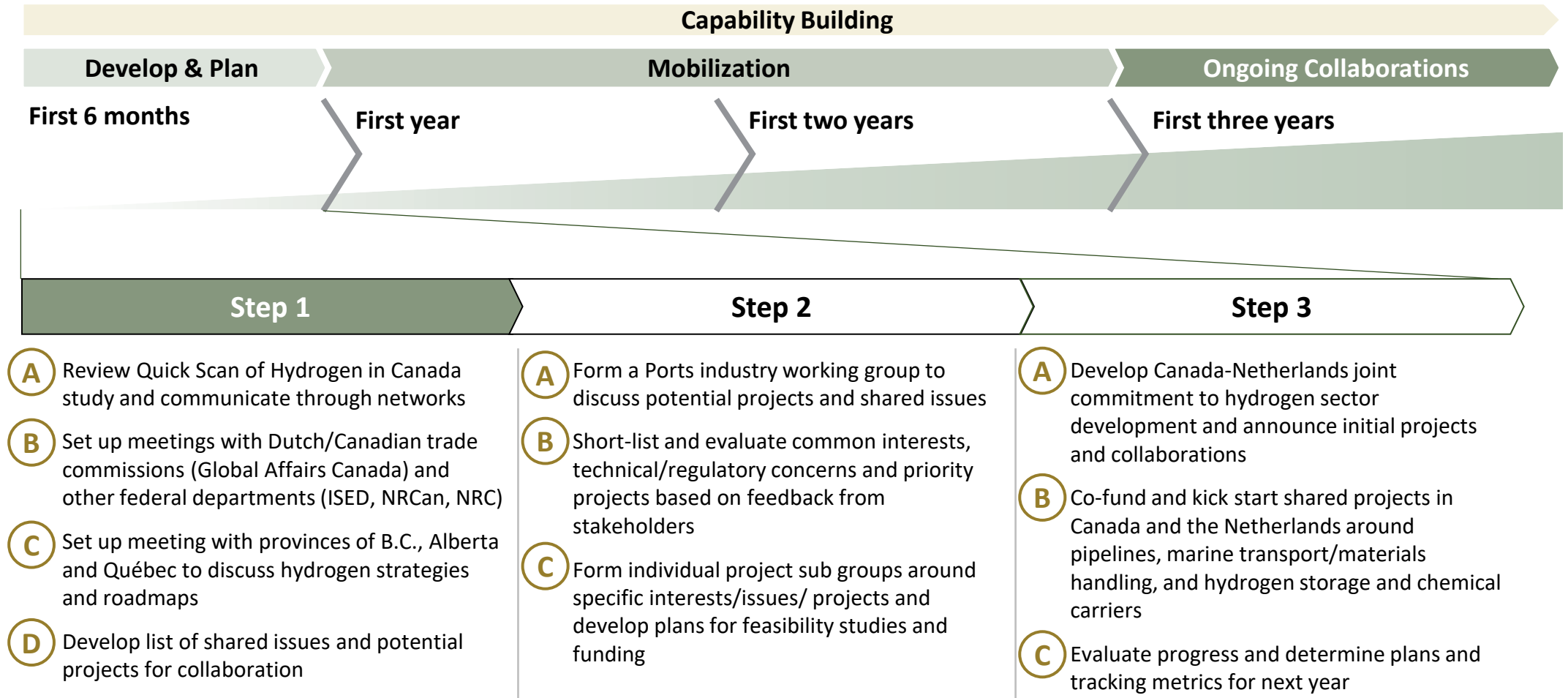
Ideal/Full Potential Pathway for Collaborations

FUTURE PATHWAYS



First Steps for Dutch Hydrogen Sector in Canada

RECOMMENDATIONS



Sources and Acknowledgements

SOURCES

Sources

- ◆ The following reports and sources were used to develop this study:
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 - Zen Clean Energy Solutions , Dunskey Energy Consulting, Redrock Power Systems.(2020). A Feasibility Study of Hydrogen Production, Storage, Distribution, and Use in the Maritimes. Retrieved from <https://oera.ca/sites/default/files/2020-11/A%20Feasibility%20Study%20of%20Hydrogen%20Production%20Storage%20Distribution%20and%20Use%20in%20the%20Maritimes.pdf>
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Stakeholders Interviews

- ◆ The following organizations and individuals were consulted as part of this study:
 - Nicolas Pocard, Director of Marketing, Ballard Power Systems
 - Aaron Hoskins, Senior Manager-Intergovernmental Initiatives, NRCan
 - Eric Barker, Manager, IESD
 - François Girard, National Research Council
 - Nicolas Chartrand & Taylor Sterzuk, Global Affairs Canada
 - Guy Gensey, Director , Energy and Industry Collaborations, B.C. Ministry of Energy, Mines and Petroleum Resources
 - Barb Korol, Manager, Alberta Government
 - Mark Kirby, President and CEO, Canadian Hydrogen & Fuel Cell Association
 - David Layzell, Director, Transition Accelerator
 - Lester Dyck, Business Development, BC Hydro

Acknowledgements

- ◆ Zen would like to thank all those who contributed their knowledge and insights into this project
- ◆ Note: All input from stakeholders are not directly attributable to individuals and any errors or omissions in interpretation are the responsibility of Zen Clean Energy Solutions

Appendices

Abbreviations

◆ ATR	Autothermal Reforming
◆ BoP	Balance of Plant
◆ CI	Carbon Intensity
◆ CCUS	Carbon Capture, Utilization, and Storage
◆ CHP	Combined Heat and Power
◆ ICE	Internal Combustion Engine
◆ LH ₂	Liquid Hydrogen
◆ LNG	Liquified Natural Gas
◆ LOHC	Liquid Organic Hydrogen Carriers
◆ NG	Natural Gas
◆ FCEB	Fuel Cell Electric Bus
◆ FCET	Fuel Cell Electric Truck
◆ FCEV	Fuel Cell Electric Vehicle
◆ PSA	Pressure Swing Adsorption
◆ RNG	Renewable Natural Gas
◆ SMR	Steam Methane Reforming

Ballard Power Systems



Company Strengths

- ◆ Over 40 years of fuel cell development and manufacturing experience
- ◆ World class automated testing capability from electrochemical and material characterizations, single cell to full motive systems
- ◆ Large scale manufacturing facilities in Canada and China
- ◆ Established quality and automotive development processes

Strategic Shareholders



Past Projects

- ◆ 2016 – First 22 of 300 FCEBs planned for deployment in Foshan and Yunfu in China began operation
- ◆ 2009 – 20 FCEBs deployed in Whistler, B.C. in conjunction with 2010 Winter Olympics
- ◆ 2003 – Deployment of 30 FCEBs in revenue service in 10 European cities

Background



History

Founded in 1979 in Burnaby, British Columbia



Key Markets

Canada, USA, Europe, China



Sectors

Automotive, backup power generation, trains, forklifts



Employees

900+

Hydrogenics



Company Strengths

- ◆ World class industrial PEM Electrolyzer systems deployed across North America and Europe
- ◆ First mover in MW scale Power-to-X applications:
 - ▶ Power-to-Methanol: MefCO₂, Germany 2019
 - ▶ Power-to-Gas: Markham, Ontario, 2018
 - ▶ Power-to-Power: Uniper, Falkenhagen, 2014
- ◆ Manufactures and deploys fuel cell power systems, and hydrogen fueling stations

Joint Venture Acquisition (2019)



80%



Air Liquide

20%

Past Projects

- ◆ 2021 - Planned 5 MW PEM system in Wenatchee, USA
- ◆ 2020 - 20 MW PEM system in construction in Bécancour, Québec
- ◆ 2018 -2.5 MW PEM installation in Markham, Ontario
- ◆ 2015 – Hydrogenics GmbH signed 10-year exclusive agreement to supply fuel cell engines for Alstom regional trains

Background



History

Founded in 1995 in Mississauga, Ontario.
Acquired by Cummins in 2019



Key Markets

Canada, USA, Europe



Sectors

Hydrogen Production, Power-to-gas, backup power, FCEBs



Employees

190+

Powertech Labs



Company Strengths

- ◆ Technical leader in design, construction, and operation of compressed hydrogen fueling infrastructure solutions (15+ stations deployed across North America)
- ◆ World class testing and certification facility for high pressure hydrogen storage components and systems
- ◆ Specialized testing and investigation services to support utilities' capital assets, including generation, transmission and distribution

Subsidiary Of



Past Projects

- ◆ 2020 - Launched new commercial hydrogen dispenser model with integrated POS system and T 40 700 bar and 350 bar fueling capability
- ◆ 2019 - Deployed Québec's first public hydrogen fueling station
- ◆ 2015 – Constructed first 70 MPa fast-fill hydrogen fueling station in Canada

Background



History

Founded in 1979 in Vancouver, B.C.



Key Markets

Asia, Canada, USA, Europe



Sectors

Utilities, Renewable Energy, Transportation, Electrical OEMs



Employees

200+

Loop Energy



Company Strengths

- ▶ Patented eflow plate design removes 30% of CapEx of traditional fuel cell systems by optimizing air flow and increasing efficiency
- ▶ Electric hydrogen fuel cell range extender system for medium and heavy-duty transportation applications

Strategic Shareholders



Past Projects

- ◆ 2020 - C\$15 million procurement announced to utilize Loop's technology in 7000 buses in Nanjing, China
- ◆ 2018 – Deployment of fuel cell range extender system in two hybrid-electric Class 8 drayage trucks in California, USA
- ◆ 2017 – Deployment of fuel cell range extender in yard truck with partner China National Heavy-Duty Truck Company (CNHTC)

Background



Founded in 2001 in Vancouver, British Columbia



Canada, USA, China



Medium and heavy duty trucks and buses



30+

Employees

Quadrogen Power Systems



Company Strengths

- ◆ Design, construction, and operation of high-performance gas clean up and upgrading systems
- ◆ Proprietary C³P process purifies biogas contaminants from sources such as waste-water treatment plants and landfills to parts-per-billion (ppb) levels
- ◆ Purified product can be utilized as a feedstock for renewable hydrogen production

Past Projects

- ◆ 2020 – \$7.5 million “quad-generation” project in Delta, British Columbia purifies landfill gas to:
 - Generate up to 250 kW of renewable electricity and 12 GJ/day of heat
 - 5 tonnes/day of ultra clean CO₂ for greenhouse use
 - 125 kg/day of high purity hydrogen
- ◆ 2014 – \$1 million project to deploy C³P technology at Dry Creek Water Reclamation Facility in Wyoming to purify biogas to power a fuel cell
- ◆ 2011 – Biogas clean-up system at Orange County Waste-water treatment plant

Background



History

Founded in 2007 in Vancouver, British Columbia



Key Markets

Canada, USA, China



Sectors

Biogas purification,
Oil and Gas, Power
Generation



Employees

15+



Company Strengths

- ◆ Deploys commercial-scale carbon capture systems for emission sources such as flue gas from cement, ammonia, and steel industries
- ◆ Svante's technology requires half the capital cost of existing CCUS technology of \$60-90 per tonne of CO₂
- ◆ Offers pre-engineered turnkey systems for large industrial emitters and provides a pathway to low-cost carbon sequestration

Strategic Shareholders



Past Projects

- ◆ 2020 – Partnership with LafargeHolcim for feasibility study of carbon capture plant at Florence, Colorado cement plant to capture 725,000 tonnes CO₂ per year for underground sequestering
- ◆ 2019 – Pilot project at Lafarge's Richmond, British Columbia cement plant to capture CO₂ from flue gas and re-use in processes such as CO₂-injected concrete and fly ash
- ◆ 2017 - \$20 million plant constructed at Husky Energy's heavy oil plant in Lloydminster, Saskatchewan capable of capturing 30 tonnes per day of CO₂

Background



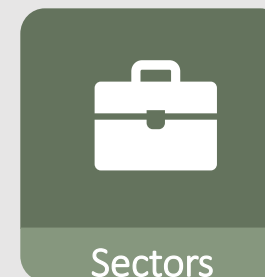
History

Founded in 2007 in Burnaby, British Columbia



Key Markets

Canada, USA, Europe



Sectors

Carbon capture, flue gas treatment



Employees

60+



Company Strengths

- ◆ Canadian leader in the construction of hydrogen fueling stations, starting with Canada's first retail station in 2018
- ◆ Design and construction of heavy-duty and public light-duty hydrogen refueling stations
- ◆ Customized hydrogen storage and distribution solutions, including hydrogen purification, mobile fueling systems, and logistics optimization

Strategic Shareholders



Past Projects

- ◆ 2020 - Chart Industries Inc, a leading manufacturer of cryogenic equipment, invests \$20 million
- ◆ 2019 - Partnership with 7-Eleven Canada to construct 2 hydrogen refueling stations in British Columbia
- ◆ 2018 – Partnership with Shell to construct Canada's first retail hydrogen refueling station in Vancouver, British Columbia with plans to develop 3 additional stations

Background



History

Founded in 2004 in Vancouver, British Columbia



Key Markets

Canada, USA



Sectors

Hydrogen storage technologies, hydrogen refueling stations



Employees

25+

Hydra Energy



Company Strengths

- ◆ Hydrogen Injection System (HIS) technology capable of retrofitting any conventional diesel engine without modifying engine block
- ◆ Converted engine capable of 40% hydrogen injection into fuel mix
- ◆ Unique “Hydrogen as a service” business model removes barriers for hydrogen adoption by retrofitting existing fleets and deploying hydrogen fueling infrastructure at no cost to fleet operator in exchange for hydrogen supply agreement

Past Projects

- ◆ 2020+ – Planned demonstration projects in B.C. and Alberta to scale technology
- ◆ 2017 – Successful demonstration of a hydrogen-diesel co-combustion class 8 truck

Background



History

Founded in 2012 in Delta, British Columbia



Key Markets

Canada, USA



Sectors

Hydrogen Infrastructure, Heavy duty vehicle conversion



Employees

15+

Ionomr Innovations



Company Strengths

- ◆ Develops ion-exchange membrane and polymer products for applications such as fuel cells, hydrogen production, and energy storage
- ◆ Pemion™ hydrocarbon proton exchange membrane (PEM) achieves higher performance and mitigates environmental concerns of traditional perfluorinated sulfonic acid (PFSA) membranes
- ◆ Pemion™ may be used for hydrogen production via electrolysis and in hydrogen fuel cells

Past Projects

- ◆ 2020 – Pemion™ awarded the “Products & Markets” award at the F-Cell conference
- ◆ 2019- Ionomr awarded joint development agreement with Nouryon

Background



Founded in 2012 in
Vancouver, British
Columbia



Canada, USA



Ion Exchange
membranes,
polymers



25+



Company Strengths

- ◆ H₂X systems upgrade hydrogen-containing reformat, petrochemical gas and refinery off-gas streams to pure and ultra-pure hydrogen product
- ◆ Compact PSA units 5-15x smaller footprint compared to conventional systems
- ◆ Deployment of small scale SMR and electrolyzer systems for hydrogen production

Past Projects

- ◆ 2020 – Xebec acquires HyGear, a Dutch-based leader in onsite hydrogen generation solutions, including small-scale SMR and electrolyzer systems
- ◆ 2020 – Partnership with Bühler Biogas Inc for a \$28 million facility in Québec to produce over 150,000 GJ of RNG and 7,500 tonnes of biofertilizer annually
- ◆ 2014 – Commissioned first European biogas to renewable hydrogen purification system at the Trifyl landfill site in Tarn, France

Background



Founded in 1967 in Québec

History



Canada, USA, Europe, Asia

Key Markets



Renewable Gas purification, SMR, Electrolysis

Sectors



100+

Employees

List of Contacts

- Below is a select list some of the stakeholders interviewed as part of this study. These individuals expressed an interest in being contacted for additional consultations and questions. Please reach out to Zen Clean Energy Solutions in order to coordinate and introduction.

Key Industry and Utilities Contacts

Contact	Company/Org	Role
Kevin Larmer	Canadian Gas Association (CGA)	Director, Innovation & Markets
Greg Caldwell	ATCO	Manager, Hydrogen
Tyler Bryant	FortisBC	Public Policy Manager
Lindsay MacKay	TC Energy	Director of Business Development
Lester Dyck	BC Hydro	Business Development Manager
Scott Dodd	Enbridge	Manager, Hydrogen
Juergen Puetter	RH ₂ Canada	CEO

Key Government Contacts

Contact	Company/Org	Role
Aaron Hoskins	NRCan – Federal Government	Senior Manager-Intergovernmental Initiatives
Eric Barker	ISED- Federal Government	Manager, Clean Technology
Guy Gensey	B.C. Ministry of Energy, Mines & Petroleum Resources	Director, Energy and Industry Collaboration
Barb Korol	Alberta Government	Senior Manager, Energy

Key Academic Contacts

Contact	University/Org	Role
David B. Layzell	University of Calgary	Professor, Department of Biological Sciences, Director, Canadian Energy Systems Analysis Research (CESAR) Initiative
Walter Mérida	University of British Columbia	Professor of Mechanical Engineering Associate Dean of Research and Industrial Partnerships
Michael Fowler	University of Waterloo	Professor, Chemical Engineering Canada Research Chair – Zero-Emissions and Hydrogen Energy Systems
Pierre Bénard	Université du Québec à Trois-Rivières (UQTR)	Director, Hydrogen Research Institute

Canadian & International Hydrogen Events, 2021

Event/Conference	Dates	Location	Public/ Private	Info Link	Category	Description
Connection Green Hydrogen APAC 2021	March 23-24, 2021	Pullman Melbourne Albert Park, Australia	Public	https://www.greenhydrogenevents.com/	Hydrogen and Fuel Cell	Region leading event concentrating on hydrogen development and supply chains from Australia to other APAC countries and a business networking platform between multiple hydrogen stakeholders. The two-day conference is estimated to attract 500+ industrial stakeholders, representing Australia federal and state governments, home and international investors, hydrogen producers, suppliers, utilizers, financiers, as well as technology and solution providers.
CGA - Operations, Engineering, Integrity, and Construction (OEIC) Conference	Feb 23, 2021 3:00-4:15 PM EST	Virtual	Private	https://na.eventscloud.com/ehome/466933/948516/	Industrial	Provide excellent learning opportunities combined with a forum for discussion & the exchange of ideas around the safety, efficiency, integrity, resilience & construction of natural gas delivery systems. The program will include a mix of roundtables, plenaries, interactive panel discussions and detailed breakout sessions. The target audience is Directors, Managers, Engineers, Field & General Supervisors & Suppliers & Manufacturers engaged in the design, construction, operation & maintenance of natural gas delivery infrastructure. The two and a half day program will also include industry manufacturers and suppliers presenting & exhibiting their innovative products and services.
WHTC 2021	June 20 - 24, 2021	Virtual	Private	https://www.whtc2021.org/	Hydrogen and Fuel Cell	local and international attendees have the opportunity to present their technical findings and advancements in hydrogen and fuel cells, as well as participate in f-cell+HFC The Hydrogen and Fuel Cell Event for marketing and networking.
Hydrogen Online	21-Oct-21	Virtual	Public	https://hydrogen-online-conference.com/	Hydrogen and Fuel Cell	Currently offering free tickets 24 hr online H2 conference about successful implementation of hydrogen technology
H2 View - Realising Hydrogen's future Role - at Speed and Scale	03-Mar-20	Virtual	Public	https://gasworldconferences.com/conference/virtual-hydrogen-event-2021/	Hydrogen and Fuel Cell	deliver the experts and insights to drive debate and provide key takeaways to help companies strategise their future role in the clean energy sector.
International Conference on Green and Renewable Energy	Oct 4 - 6, 2021	Vancouver	Public	https://10times.com/green-energy-conferences	Clean Energy	International Conference on Green and Renewable Energy is a platform that gathers global speakers and delegates to share their research and further provide them various profile upgradation programs. After successful commencement of Green Energy 2019 in Italy and having listed in one of the finest environmental engineering conferences in Europe and the USA, the committee is highly optimistic for an overwhelming response from all the potential and interested persona of the relevant subject in Green Energy.
2nd World Hydrogen Summit	March 9 - 11 2021	Virtual	Public	https://www.world-hydrogen-summit.com/	Hydrogen and Fuel Cell	the Summit will gather global Government, industry and research experts all in one place with each session designed to facilitate intensive analysis, planning, networking, consolidation and debate in order to harness Hydrogen's potential.



ZEN *and the art of*
CLEAN ENERGY
SOLUTIONS

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