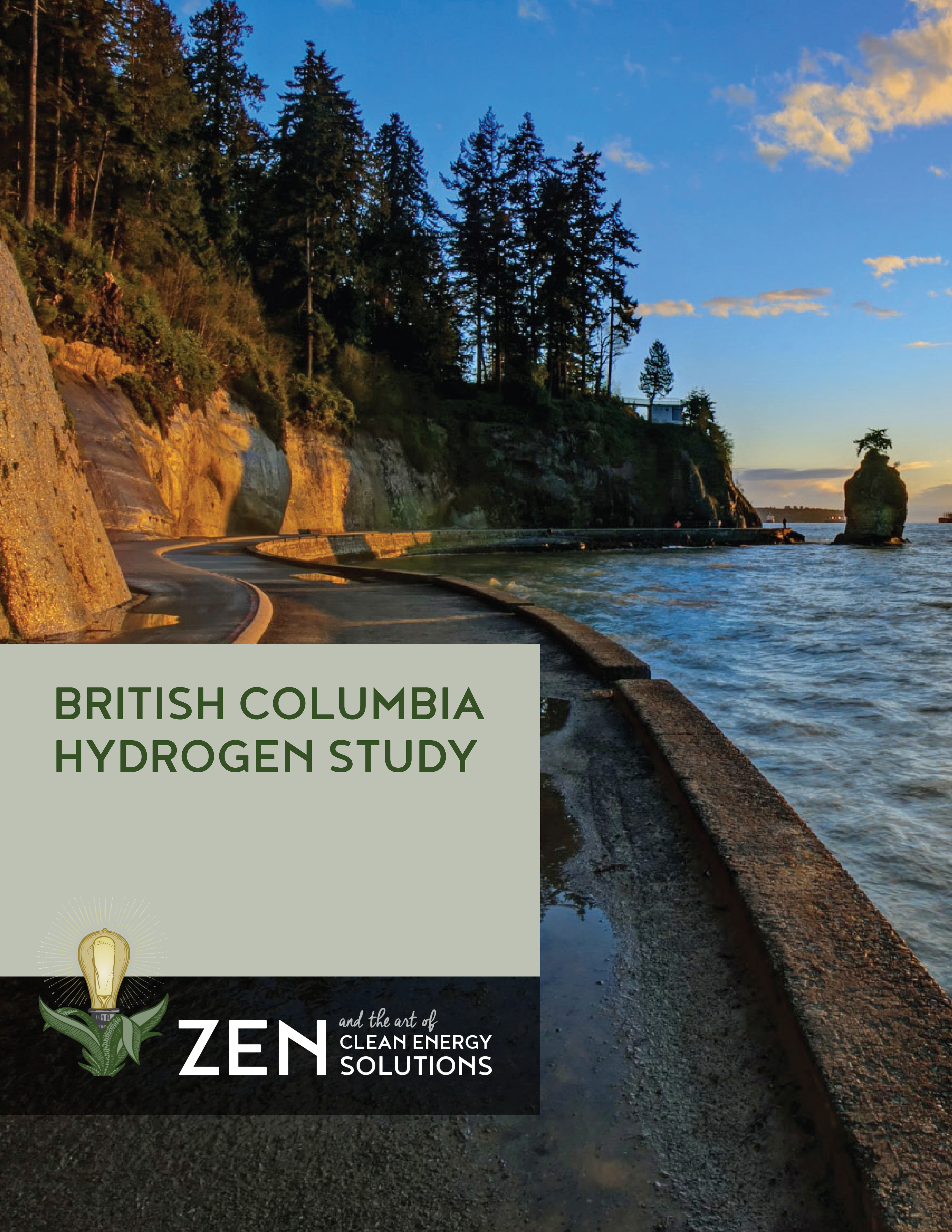
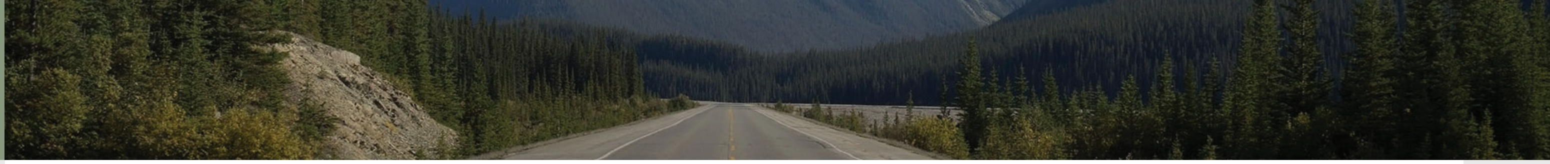


BRITISH COLUMBIA HYDROGEN STUDY

ZEN and the art of CLEAN ENERGY SOLUTIONS



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The project team would like to thank the many individuals and organizations that provided input to the study through participation in workshops, surveys, and individual interviews. The team would also like to thank the BC Ministry of Energy, Mines and Petroleum Resources, BC Bioenergy Network, and FortisBC for support and guidance throughout the study.

Project Team

IBET

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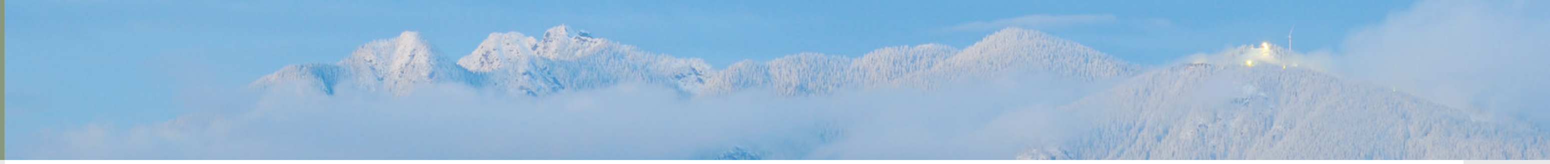


EXECUTIVE SUMMARY

Why Hydrogen in BC?

Deployment of hydrogen in British Columbia (BC) will be required for the Province to meet 2030 and 2050 decarbonization goals and emissions reduction commitments. End use energy demand in BC was 1,165 petajoules (PJ) in 2016, with 68% of demand met through refined petroleum products and natural gas. Direct electrification and increased supply of renewable natural gas will not be able to displace all this energy to transition the Province to lower carbon and ultimately renewable energy sources. Hydrogen will play a critical role, particularly in energy intensive applications that are most reliant on fossil fuels today such as long-range transportation and heating.

Hydrogen is a versatile energy carrier that can be made from a range of feedstocks that are abundant in our Province, and it has the advantage of being carbon free at the point of use. BC has a distinct comparative advantage because of its clean electricity and low-cost natural gas resources, both of which can be leveraged to produce hydrogen. Hydrogen can be:

- *Blended with BC's rich natural gas reserves to create a cleaner burning fuel and increase the renewable content of the gas delivered through our extensive natural gas infrastructure;*
- *Used directly in fuel cells to produce zero emission electricity in electric vehicles, stationary power systems, and off-road industrial vehicles; and*
- *Utilized as a feedstock in industrial applications, including to produce renewable synthetic liquid fuels that allow existing combustion engines to be used in a cleaner and more sustainable way.*

Use of hydrogen in BC is in the nascent stages, while the pace of worldwide deployment is clearly accelerating. For BC to realize 2030 emissions reductions goals as set out in the CleanBC plan, it is important for government to work with industry now to establish supply and infrastructure necessary to stimulate adoption in the Province. Export opportunities can help to bring international investment to the development of our hydrogen energy systems and provide strong revenue generation potential.

Building of a vibrant and robust hydrogen economy in the Province will result in:

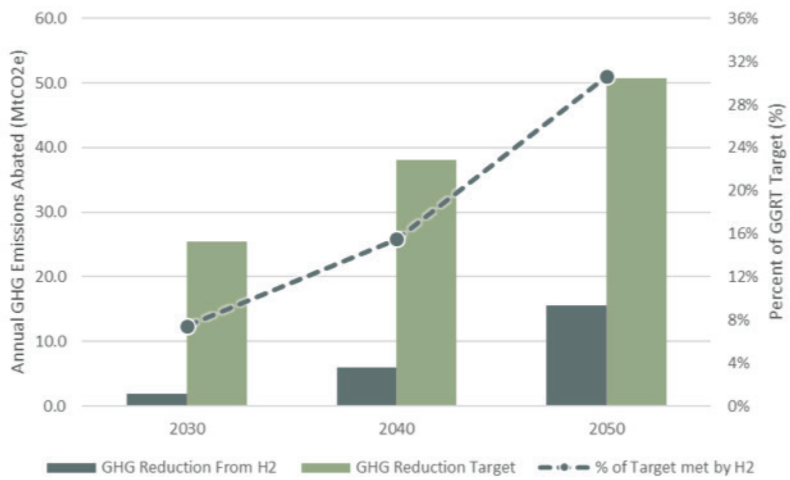
- *Decarbonization of hard-to-abate sectors of the economy such as heating and cooling, long-range transportation applications, and energy intensive industries;*
- *Economic growth and job creation through the development of BC's hydrogen supply chain and infrastructure, and supply to emerging export markets; and*
- *Leveraging BC's natural gas reserves and infrastructure to meet emissions reductions goals in the mid-term while transitioning to renewable energy sources in the long-term.*

Large-scale deployment of hydrogen in BC can close the gap in current plans to balance both emissions reduction and optimal utilization of BC's natural resources and infrastructure assets. It will also benefit the Province's world-class hydrogen and fuel cell sector which is increasingly facing pressures to develop new intellectual property (IP) abroad, in regions where governments support both deployment and development of hydrogen and fuel cell technologies.

Decarbonization of Economic Sectors

CleanBC is the Government of British Columbia's plan for achieving its greenhouse gas (GHG) emissions reductions commitments from the May 2018 Climate Change Accountability Act, formerly titled Greenhouse Gas Reduction Targets (GGRT) Act.

To meet its commitments, provincial emissions will have to fall 40% from the 2007 baseline by 2030 and 80% by 2050. Hydrogen is needed to meet those decarbonization objectives, with study findings demonstrating that hydrogen can contribute up to 31% of the 2050 carbon reduction target, at 15.6 Mt CO_2e/year reductions. The benefits of hydrogen will be strongest in the 2030 – 2050 timeframe, after other high-yield opportunities outlined in the CleanBC plan have been implemented and exhausted. In this period, hydrogen can reduce emissions by 13.7 Mt CO_2e, which represents 54% of the Province's goal during that timeframe.

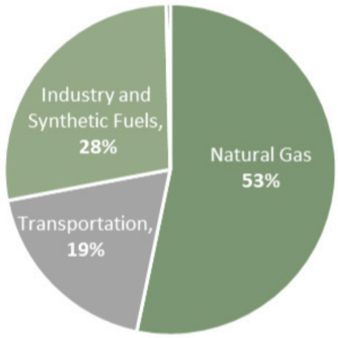


The opportunities where the greatest decarbonization impacts can be realized are: 1) through injection of low carbon hydrogen into the natural gas grid, which will have benefits in the built environment, transportation, and industry economic sectors in the Province; 2) through using low carbon hydrogen directly as a transportation fuel; and 3) through the production of low carbon synthetic fuels that can be used as drop in replacement for current combustion engines and are an important enabler in meeting the Renewable and Low Carbon Fuel Requirements Regulation in BC.

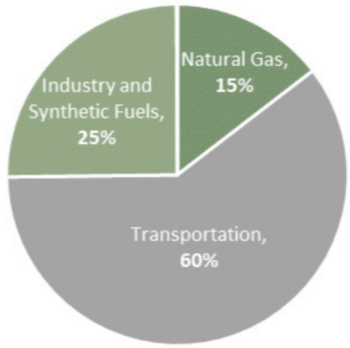
The relative benefits in these applications will shift over time. In the near-term, the easiest and lowest cost way to use hydrogen which will have the highest emission reduction potential in the Province is to inject it into the natural gas grid, and directly reduce emissions by utilizing the lower carbon hydrogen/natural gas blend. Ultimately directly using hydrogen as a transportation fuel will dominate in emissions reduction potential.

The deployment of both battery electric and fuel cell electric vehicles (FCEVs) is critical to reducing emissions in BC. The higher range and faster refueling times of FCEVs will lead to meaningful market share in the Province, particularly in larger passenger vehicles and in medium and heavy-duty vans, buses, and trucks. Utilizing hydrogen directly as a transportation fuel offers the greatest advantages for emissions reduction, as electrochemical conversion of hydrogen in fuel cells is twice as efficient as combustion. Regulation and financial support for infrastructure build out will be critical to achieving the adoption potential of FCEVs. As the transition to FCEVs is evolving, hydrogen can offer emissions reduction benefits in transportation applications through enabling higher use of renewable natural gas (RNG), in co-combustion retrofit engines, and as a low carbon feedstock for synthetic fuels.

2030 GHG Reduction Opportunities
1.9 Mt CO_2e/year



2050 GHG Reduction Opportunities
15.6 Mt CO_2e/year



In these graphs, 'Natural Gas' includes all end use applications that would benefit from the lower carbon H_2/NG blend, including heating in the built environment and industry, and transportation applications running on compressed natural gas (CNG). 'Transportation' refers to applications where pure hydrogen is used as a transportation fuel, either in fuel cell electric vehicles or hydrogen/diesel co-combustion engines.

Economic Growth and Job Creation

Since Geoffrey Ballard first set up shop in North Vancouver in 1979, Canada's hydrogen and fuel cell sector has been recognized as a global leader, with BC hosting Canada's largest industry cluster. BC has pioneered new technologies and industry expertise in areas such as hydrogen production and processing, fuel cell stack and system development, components and systems testing and test infrastructure development, technology research and development (R&D) and commercialization, and standards development. BC is also home to world class academic institutions with specialized programs and R&D supporting the clean tech sector. Local deployment of hydrogen technology will help to maintain a healthy economic cluster in the Province, and will help to develop technical expertise, job opportunities and IP, and will also contribute to continued growth of the sector by ensuring BC maintains a strong competitive advantage.

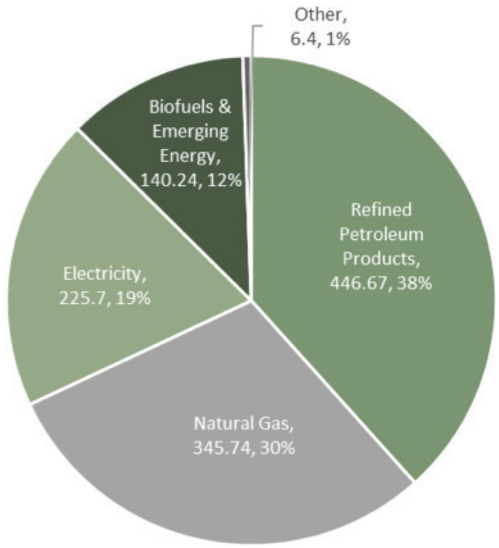
BC's economy is heavily dependent on the extraction, consumption, and export of natural resources, and hydrogen fits as a value-added future export resource that can support both local and international decarbonization efforts. Hydrogen is expected to become increasingly important in the world's energy systems as countries around the world develop roadmaps to achieve decarbonization goals and to improve local air quality. BC's coastal access and relative proximity to leading markets such as California, Japan, China and South Korea position BC to become an exporter of clean hydrogen. By 2050, demand in those target regions is projected to reach 100 million tonnes/year under moderate forecast assumptions, with significant upside potential. If BC were to capture 5% market share in those regions, the export market could be $15 billion annually. International investment for large-scale hydrogen production would benefit local markets while generating significant revenue and should be considered as a significant opportunity for the Province.

The Intergovernmental Panel on Climate Change (IPCC) estimates that USD $2.4 trillion will need to be invested through 2035 in clean technology deployments.[1] A portion of that investment will be made in the hydrogen sector, and BC can benefit from that through its leadership in the development and deployment of hydrogen technologies. BC is well positioned to reinvigorate its leadership position in innovation and venture creation. Build-out in the Province will benefit professional, trades, and manufacturing employment.

1 IPCC. (2018). Special Report: Global Warming of 1.5°C. Retrieved from https://www.ipcc.ch/sr15/

Low Carbon Use of Natural Gas Reserves and Infrastructure

BC is fortunate to have an abundance of clean, renewable hydroelectric power. In 2016 electricity supplied 19% of the Province's end use energy requirements. Electrification is a major theme in CleanBC to meet the Province's emissions reductions goals. While electrification will play an important role, it has limitations in generation capacity and transmission and distribution. Some applications are better served by gas as an energy carrier, such as high-grade heat production and long-range transportation. BC has abundant low-cost natural gas reserves that will play a role in meeting energy needs of the Province far out into the future. The National Energy Board (NEB) forecast shows increasing demand for both natural gas and refined petroleum products in BC out to 2040. This is at odds with the Province's emissions reduction goals unless we can find ways to decarbonize those energy sources. Hydrogen can play a key role in this through the decarbonization of natural gas at the source of extraction, and as a renewable feedstock for refined petroleum products and lower carbon intensity synthetic fuels to replace conventional refined petroleum products.



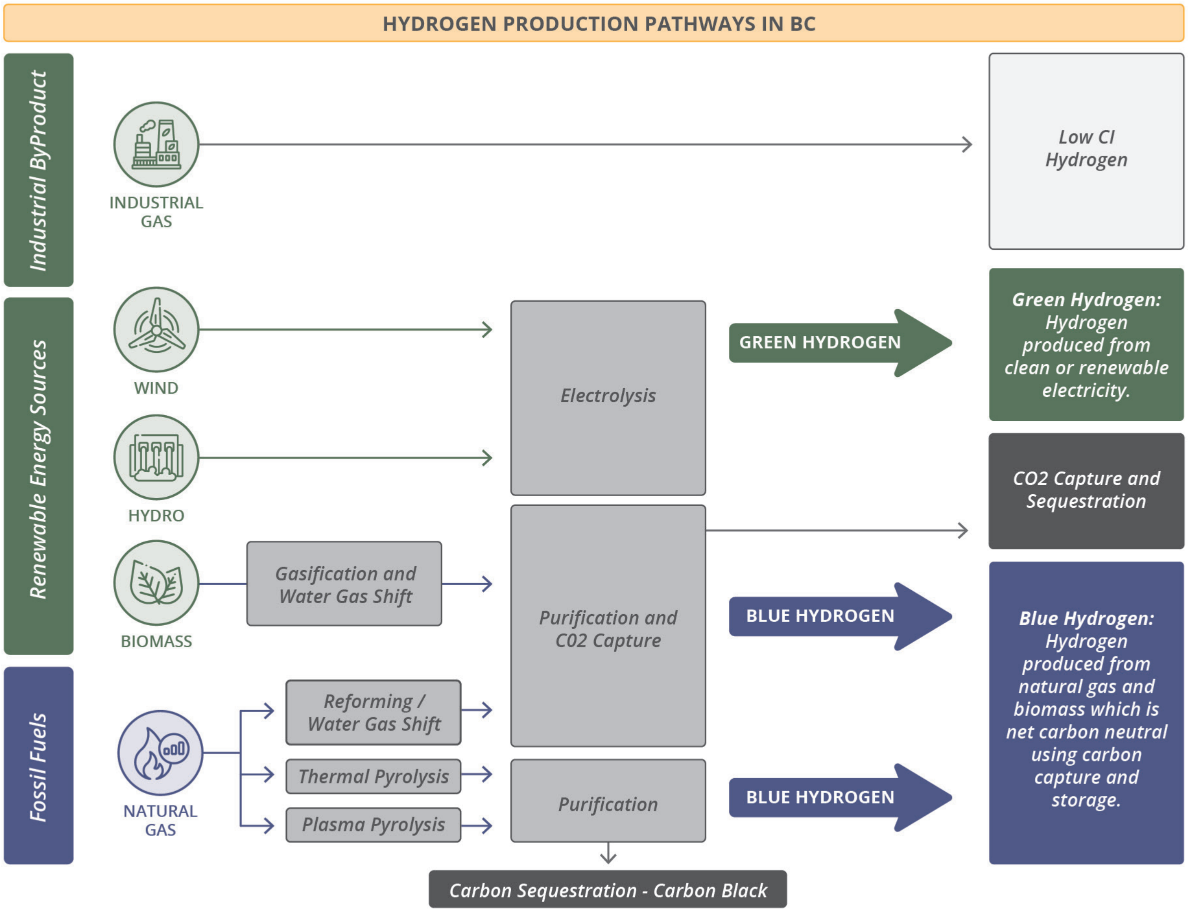
2016 BC End Use Energy Demand[2]

The natural gas infrastructure is a strategic asset for BC. Repurposing that asset for both the transportation and storage of hydrogen presents a cost-effective pathway for the large-scale deployment of hydrogen in the Province. The existing natural gas infrastructure can act as storage for low carbon hydrogen, initially as a hydrogen/natural gas blend and transitioning to 100% hydrogen in some regions of the Province over the longer-term. Hydrogen produced via electrolysis can also foster greater integration of our electricity and gas energy system, optimizing the Province's overall energy systems to achieve optimal efficiency and economic return on critical infrastructure assets.

Hydrogen Production Pathways in BC

Hydrogen can be produced via different pathways using a range of feedstocks. Hydrogen can be made via renewable and fossil fuel resources and is a by-product of some industrial processes. In this study, only 'Green Hydrogen' produced from clean and renewable electricity, 'Blue Hydrogen' produced from natural gas or biomass coupled with carbon capture and storage (CCS), and low carbon intensity (CI) industrial by-product hydrogen are considered.

2 *Canada National Energy Board (2017). Canada's Energy Future 2018: Energy Supply and Demand Projections to 2040. Retrieved from https://apps.neb-one.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA*

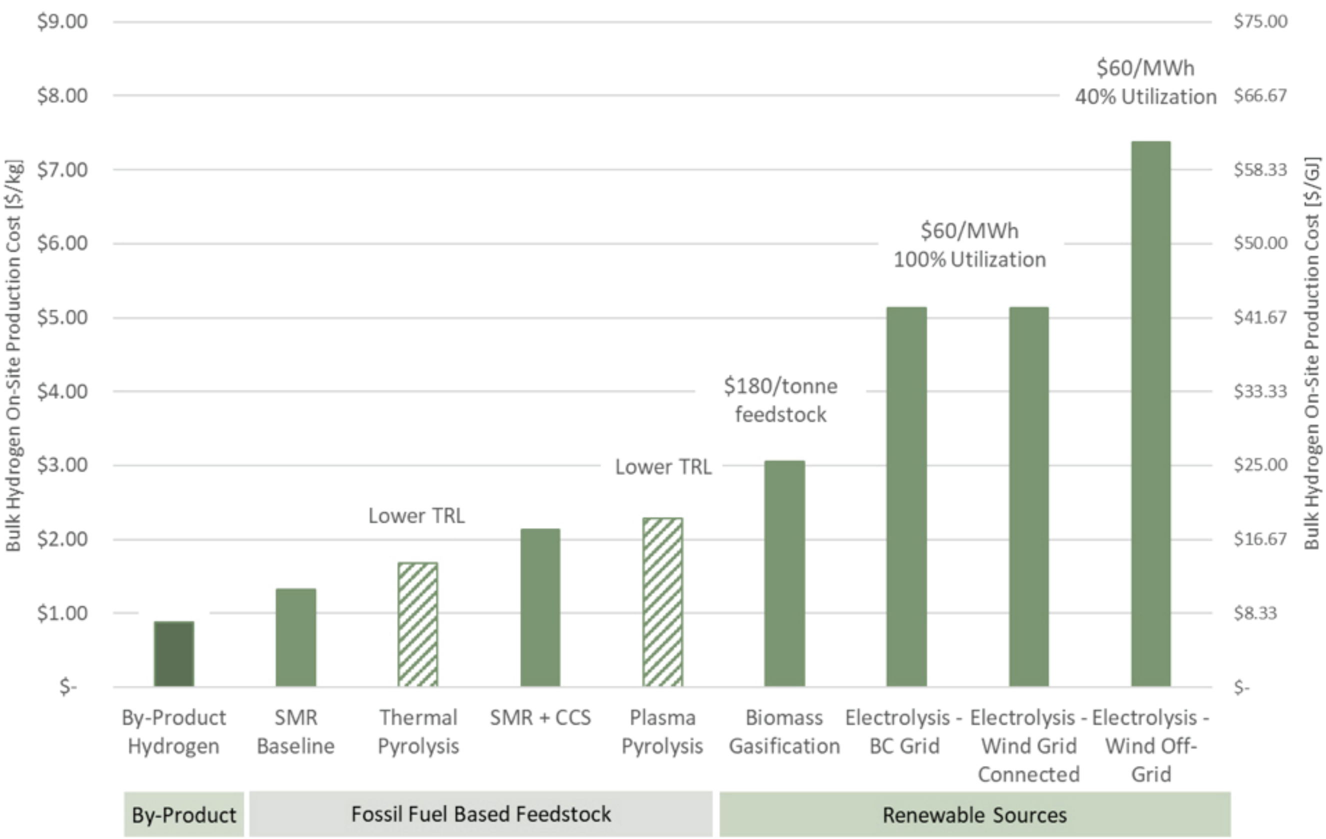


Hydrogen produced at scale from natural gas offers the lowest cost source of low carbon intensity hydrogen when coupled with carbon capture and storage technology. BC has substantial natural gas reserves in the Northeast of the Province, estimated at 525 trillion cubic feet and sufficient to meet 315 years of BC natural gas demand at current levels. The Province also has depleted gas reservoirs and saline aquifers that enable large volumes of CO_2 sequestration. Steam methane reforming (SMR) coupled with carbon capture and storage at the point of extraction is a mature commercial process, whereas pyrolysis with carbon black as a byproduct shows strong potential but is at lower technology readiness level (TRL).

Renewable sources of hydrogen in the Province are currently more expensive than fossil pathways. Production of hydrogen via electrolysis enables a distributed model of hydrogen production that is inherently scalable. While offering many advantages, the electrolysis pathway is currently the most expensive for at-scale hydrogen production in the Province. Flexible, low-cost electricity rates are essential to promoting the growth and adoption of Green Hydrogen.

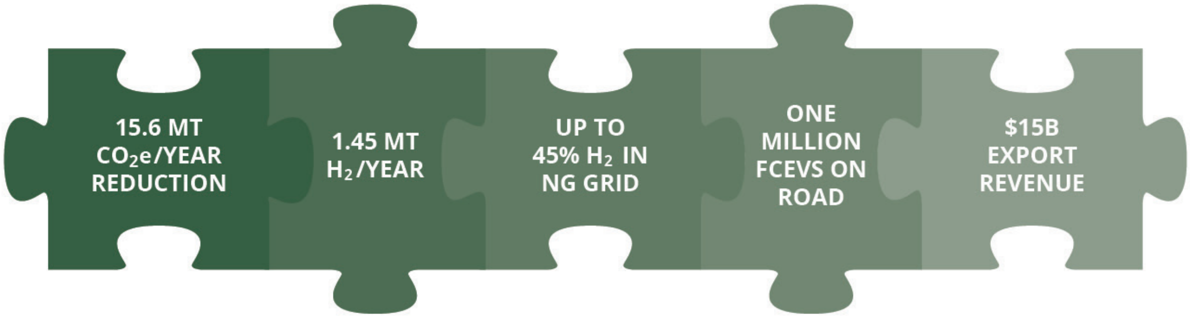
There is an immediate urgency to decarbonize BC's energy supply across all industry sectors, and low carbon intensity hydrogen from fossil fuels is seen as a key enabler to cost effective deployment of hydrogen in the intermediate period. The Province needs policy to drive adoption of multiple energy pathways to ensure both decarbonization and sustainability goals are met. Our policies should set BC as the global leader in hydrogen production with a clear understanding of how their inherent cost structure will drive market adoption of the lower cost natural gas sourced hydrogen to the more expensive fully renewable hydrogen as the finite hydrocarbon sources are depleted over time.

A key pillar to the successful introduction of hydrogen in BC is government support for infrastructure development for the production, distribution, and dispensing of hydrogen. Establishment of low-cost supply channels must lead large-scale adoption in the Province. Development of a robust hydrogen supply chain is also expected to attract new industry to the Province that relies on hydrogen as a feedstock.



Vision for 2050

BC 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 investment, hydrogen can play a major role in the Province by 2050.



Recommendations

The report outlines a comprehensive list of 38 instrument and policy recommendations to support development of a vibrant hydrogen economy in BC.

The top ten recommendation themes for the 2020 – 2025 timeframe are to:

1. *Identify and communicate hydrogen as priority sector for the Province.*
2. *Prioritize development of large-scale, low carbon intensity hydrogen supply infrastructure and strategic hydrogen liquefaction and distribution assets in the Province.*
3. *Adopt policy that specifies the carbon intensity of hydrogen, rather than limiting to renewable only. This includes updating the definition of renewable natural gas in BC's Greenhouse Gas Reduction Regulation to include low carbon intensity hydrogen.*
4. *Set longer-term objectives for transition to renewable hydrogen supplies through establishing tiered thresholds of required renewable content over time.*
5. *Develop flexible, lower cost electricity rate schedule to encourage production of Green Hydrogen.*
6. *Support lighthouse projects that will demonstrate the potential of hydrogen in critical end use applications.*
7. *Adopt recommended policies and regulatory framework for light and heavy-duty FCEVs and support the build out of hydrogen refueling infrastructure.*
8. *Support research, development and deployment in the Province to ensure the local hydrogen cluster maintains competitive global advantages and remains an important economic sector within the Province.*
9. *Support initiatives related to developing an export market for hydrogen, particularly those that can leverage international investment to develop local supply of hydrogen.*
10. *Prioritize a strategic investment fund to support the above recommendations.*

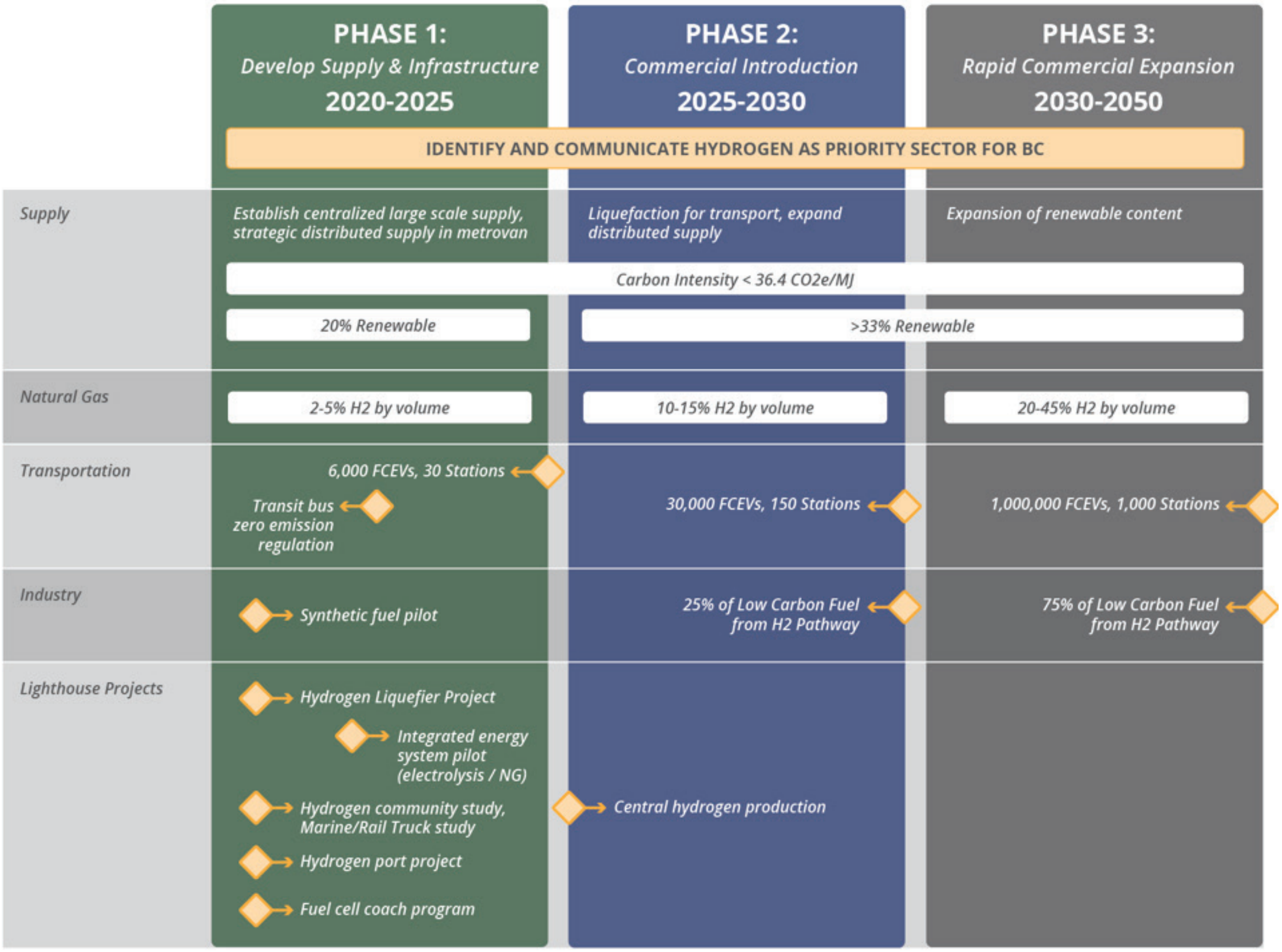
Recommended Investment, 2020-2025

Government investment is needed to establish a robust hydrogen economy in BC. That investment will provide the necessary infrastructure and sector support to allow industry to establish a foundation from which to grow commercial deployments. Government investment will yield necessary decarbonization benefits for the Province, economic growth potential, and long-term diversity and security of our energy systems.

Our analysis recommends a total spend from the Province in the order of $176,000,000 over the next five years, which is approximately $35,200,000 per year. This funding would be focused primarily on supporting lighthouse projects and studies, funding critical infrastructure development, providing subsidies for the rollout of light-duty FCEVs, and supporting the sector through establishing dedicated R&D funding. It is anticipated that this Provincial funding would be leveraged with Federal and Industry match funding, thereby amplifying the benefits of this investment in the Province.

Hydrogen in BC – A Phased Approach

For hydrogen to play a critical role in BC's energy systems in the mid and long-term, it is important to set goals and start developing supporting infrastructure and policies now. Over the next 5 years, the focus needs to be on establishing supply and distribution infrastructure for hydrogen, with lighthouse projects supported to initiate the rollout of end use applications in the Province. The following schematic summarizes the phases of hydrogen rollout and opportunities in the various applications over time.



GLOSSARY

TERM	DEFINITION
AANDC	*Aboriginal Affairs and Northern Development Canada.*
AZETEC	*Alberta Zero-Emissions Truck Electrification Collaboration.*
BC	*British Columbia.*
Ballard	*Ballard Power Systems.*
Bbl/d	*Barrels per day. Measure of production capacity for fuel.*
BCBN	*BC Bioenergy Network.*
Bcf	*Billion cubic feet. A measure of the energy content of one billion cubic feet of natural gas.*
Bcfd	*Billion cubic feet per day. A measure of natural gas production.*
BEB	*Battery Electric Bus.*
BECCS	*Bioenergy with Carbon Capture and Storage.*
BEV	*Battery Electric Vehicle.*
Blue hydrogen	*Hydrogen produced from natural gas or biomass which is net carbon neutral through carbon capture and storage.*
C	*Carbon.*
CAPEX	*Capital Expenditure.*
CCS	*Carbon Capture and Sequestration (or Storage). A process by which carbon dioxide is separated from a gas stream ("captured") and buried underground ("sequestered").* *Though industry prefers the term Carbon Capture and Utilization or Storage (CCU/S) this is less commonly used in a hydrogen context, so the convention of CCS will be maintained.*
CEV	*Clean Energy Vehicles. BC's incentive program designed to make clean energy vehicles more affordable for British Columbians.*
CHP	*Combined Heat and Power. Also called cogeneration (or cogen); it is the simultaneous production of electricity with the recovery and utilisation heat.*
CH_4	*Methane.*

TERM	DEFINITION
CI	*Carbon intensity.*
CNG	*Compressed Natural Gas.*
CO	*Carbon monoxide.*
CO_2	*Carbon dioxide.*
CO_2e	*Carbon dioxide equivalent. A measure of greenhouse gas warming potential expressed in terms of the equivalent amount of carbon dioxide.*
DAC	*Direct Air Capture.*
DCFC	*DC Fast Charger.*
DNV GL	*DNV GL is an international accredited registrar and classification society headquartered in Høvik, Norway. It provides services for several industries including maritime, renewable energy, oil & gas, electrification, food & beverage and healthcare.*
EER	*Energy efficiency ratio.*
EJ	*ExaJoule; a unit of energy equivalent to 10^{18} Joules.*
FCEB	*Fuel Cell Electric Bus.*
FCEV	*Fuel Cell Electric Vehicle.*
FCH JU	*Fuel Cells and Hydrogen Joint Undertaking. A public private partnership supporting research, technological development and demonstration activities in fuel cell and hydrogen energy technologies in Europe.*
FF	*Fossil Fuel.*
FF Gen	*Fossil Fuel Generation.*
g CO_2e	*Grams of CO_2 equivalent. A measure of GHG emissions intensity.*
Green hydrogen	*Hydrogen produced from clean or renewable electricity.*
GGRT	*Greenhouse Gas Reductions Target.*
GHG	*Greenhouse gas.*
GJ	*GigaJoule. One billion joules of energy.*
GWh	*Gigawatt-hour. One billion watt-hours, or one million kilowatt-hours.*
H_2	*Hydrogen.*
HARP	*Hydrogen Assisted Renewable Power.*

TERM	DEFINITION
HCl	*Hydrochloric acid.*
HDV	*Heavy-duty Vehicle, encompassing commercial trucks and buses.*
HOV	*High-Occupancy Vehicle.*
Hydrail	*Hydrogen fuel cell powered train.*
ICE	*Internal Combustion Engine.*
ICT	*Innovative Clean Transit.*
IEA	*International Energy Agency.*
IESO	*Independent Electricity System Operator*
IP	*Intellectual Property.*
IPCC	*Intergovernmental Panel on Climate Change.*
IPP	*Independent Power Producers.*
IRAP	*Industrial Research Assistance Program.*
IWHUP	*Integrated Waste Hydrogen Utilization Project.*
JIVE	*Joint Initiative for hydrogen Vehicles across Europe.*
JIVE 2	*Joint Initiative for hydrogen Vehicles across Europe (second project).*
JV	*Joint Venture.*
kWh	*Kilowatt-hour. One thousand watt-hours. A watt-hour is the amount of energy generated if one watt of power is sustained for one hour.*
LCFR	*Low Carbon Fuel Regulation.*
LCFS	*Low Carbon Fuel Standard, a market-based regulation designed to reduce the carbon intensity of the fuel mix.*
LDV	*Light-Duty Vehicle, encompassing the category known colloquially as passenger vehicles, from sedans to pickup trucks.*
LH_2	*Liquid hydrogen.*
LNG	*Liquefied Natural Gas.*
LPG	*Liquefied Petroleum Gas or Liquid Petroleum Gas.*
MCH	*Methylcyclohexane.*

TERM	DEFINITION
MDV	*Medium-duty Vehicle.*
METI	*Ministry of Economy, Trade and Industry from Japanese Government.*
MJ	*MegaJoule. One million joules of energy.*
Mt	*Megatonne; one million metric tonnes.*
MVRD	*Metro Vancouver Regional District.*
MW	*Megawatt.*
MWh	*Megawatt-hour. One million watt-hours, or one thousand kilowatt-hours. A price of $60/MWh is equivalent to a price of $0.06/kWh.*
NEB	*National Energy Board.*
NG	*Natural Gas.*
NGO	*Non-Governmental Organization.*
NGTL	*Nova Gas Transmission Limited.*
NRCan	*Natural Resources Canada.*
OCH	*Organic Chemical Hydride.*
OEM	*Original Equipment Manufacturer. An abbreviation generally used in reference to auto manufacturers.*
OGC	*Oil and Gas Commission.*
OPEX	*Operational Expenditure.*
P2G	*Power to Gas. Process of converting surplus renewable electricity into hydrogen gas through electrolysis.*
PE	*Polyethylene.*
PEM	*Proton Exchange Membrane.*
pH	*A figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acid and higher values more alkaline.*
PJ	*PetaJoule; a unit of energy equivalent to 10^{15} Joules.*
PNG	*Pacific Natural Gas.*
PSA	*Pressure swing absorption.*
PUD	*Public Utility District.*

TERM	DEFINITION
PVC	*Polyvinylchloride.*
R&D	*Research & Development.*
RFP	*Request for Proposal.*
RG	*Renewable Gas*
RNG	*Renewable Natural Gas.*
SME	*Small to Medium-sized Enterprise. Industry Canada defines SMEs as enterprises with fewer than 500 employees.*
SMR	*Steam Methane Reforming. A process by which natural gas (chemical formula CH_4) is reacted at high temperature with water vapour (H_2O) resulting in the production of hydrogen (H_2) and carbon dioxide (CO_2).*
SNG	*Synthetic Natural Gas.*
SWOT	*Strengths, Weaknesses, Opportunities and Threats. A SWOT analysis is a strategic planning technique used to help a person or organization identify strengths, weaknesses, opportunities, and threats related to business competition or project planning.*
Syngas	*Syngas, or synthesis gas, is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide.*
tcf	*Trillion cubic feet of gas. A measure of the energy content of one trillion cubic feet of natural gas.*
TPD	*Tonnes per day.*
TRL	*Technology Readiness Level.*
TWh	*Terawatt-hour. One-thousand Gigawatt-hours. 10^{12} watt-hours.*
VRE	*Variable Renewable Electricity.*
WCBS	*Western Canadian Sedimentary Basin.*
ZEV	*Zero Emission Vehicle.*

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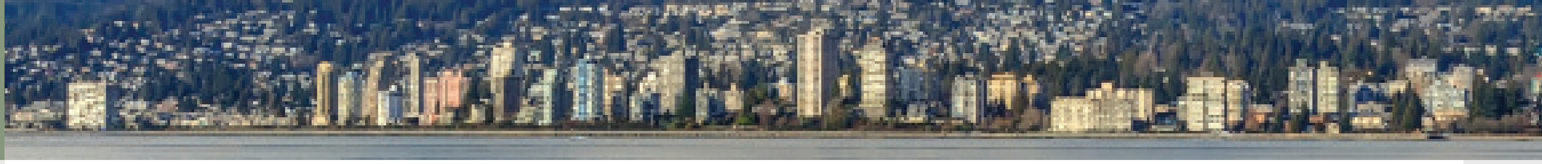

FIGURES

TABLES

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1.0 : INTRODUCTION

1.1 : Objectives and Scope

The British Columbia Hydrogen Study was commissioned by the British Columbia Ministry of Energy, Mines and Petroleum Resources, the BC Bioenergy Network, and FortisBC with the aim of building a vibrant and robust hydrogen economy in the province.

At a high level the goals of the Hydrogen Study are to identify roles hydrogen can play in BC in the mid-term (2030) and long-term (2050) and to provide recommendations for instruments and policies to enable hydrogen to play an important role in the decarbonization of BC's economy.

Specific questions to be answered in the study are:

Q1	What role(s) should hydrogen play in decarbonizing the energy system and sectors of the economy in BC? Including, but not limited to, explicit consideration of the following: natural gas (NG), transportation, industry, the built environment, feedstock for low carbon energy and fuel production, and remote and off-grid communities.
Q2	What is the anticipated global demand and market potential for hydrogen and what is the export opportunity for BC to meet a portion of that demand?
Q3	What are BC's existing and potential competitive advantages in the hydrogen and fuel cell sector? How can BC maintain and improve its advantages?
Q4	What are BC's competitive disadvantages in the hydrogen and fuel cell sector? How can BC address them?
Q5	What are the instruments and policies necessary to develop hydrogen supply chains in BC?
Q6	What are the existing and potential competitive advantages and disadvantages specific to using hydrogen in the BC natural gas grid as a drop-in fuel, or as a replacement for natural gas?
Q7	What are the opportunities, challenges and costs specific to incorporating hydrogen as storage for intermittent renewable energy in BC?

The specific desired outputs of the study are:

R1	A mid-term (to 2030) and long-term (to 2050) cost curve of potential hydrogen supply in BC by quantifying the amount available at progressively higher price points.
R2	A jurisdictional scan of international commitments, financial incentives and regulatory instruments for green and blue hydrogen development/deployment.
R3	Recommendations for policies, regulations and legislation to facilitate the development of the hydrogen sector in BC.

The scope specifically excluded:

- *Technology Readiness Level (TRL) and Commercial Readiness Index analysis for hydrogen and fuel cell technologies;*
- *Hydrogen pathways that would result in increased greenhouse gas (GHG) emissions.*

1.2 : Project Methodology

The project team used a collaborative, integrative approach in conducting this study.

Data underpinning the study were collected through a combination of stakeholder engagement, online surveys, market and technology reports, internet research, and through leveraging the project team's expertise in the field.

A broad base of stakeholders was consulted throughout the project to ensure a balanced view of the hydrogen sector and to develop aggressive but achievable recommendations supporting the goals of the Province's CleanBC plan. Participants in stakeholder engagement spanned the private sector, non-governmental organizations (NGOs), public utilities, academia and government. Follow-up interviews were also conducted with selected participants.

The project team conducted three workshops, with the following themes:

- *Large Centralized Production of Hydrogen in BC for Decarbonization of BC's NG Industry, Synthetic & Low Carbon Fuel Production, and Export (Workshop 1, March 14, 2019, hosted by FortisBC);*
- *Opportunities for Hydrogen in Transportation Applications in BC (Workshop 2, April 5, 2019, hosted by LGM Financial Services); and*
- *BC's Competitive Advantages in Hydrogen and Fuel Cells (Workshop 3, April 11, 2018, hosted by Ballard Power Systems).*

In advance of each workshop, an online survey was developed and sent to workshop invitees. The project sponsors provided input to the survey questions. Survey responses were used to help guide discussion at the workshop, and to provide input to the study.

A complete list of stakeholders that provided input to the study, along with a summary of select survey responses, and notes from the workshops are included in APPENDIX A: Summary of Stakeholder Engagements.

To assess where hydrogen could decarbonize BC's economic sectors, the team first developed a baseline of provincial energy use and emissions. Baseline data were drawn from reputable public references such as Canada's National Inventory Report and the National Energy Board (NEB). Industry sectors were broken down as: Natural Gas, Transportation, Industry, Built Environment, and Remote Communities. For natural gas, opportunities for injecting hydrogen into natural gas infrastructure and its use to reduce the carbon intensity of the Liquefied Natural Gas (LNG) export market were both evaluated. Hydrogen injection into the natural gas grid impacts both the industry and built environment sectors.

Opportunities for hydrogen to reduce GHG emissions in each sector were identified through an analysis of activities in leading jurisdictions, input from stakeholders, a review of technology options and technology readiness levels, and modeling to understand specific opportunities and constraints related to British Columbia.

For each economic sector, two scenarios were modeled:

- *A conservative scenario incorporating the lowest cost, lowest risk opportunities for hydrogen deployment, generally aligned with existing policy goals and/or regulation;*
- *An aggressive scenario incorporating ambitious targets to realize greater emissions reductions through hydrogen, reliant on increased investment for the development of supply and distribution infrastructure, new policies, and in some cases more ambitious assumptions for technology development.*

The team also met with representatives from the local hydrogen and fuel cell sector to understand BC's competitive advantages and disadvantages, to understand how the Province can benefit from cost-effectively supporting and growing the sector, and to provide reference cases to help support the development of provincial exports.

The global market for hydrogen was assessed by referencing previously published studies forecasting hydrogen demand. Where available, goals for hydrogen use by region announced by local governments were also assessed and rolled into the overall global forecast for hydrogen out to 2050. The BC target markets and opportunity size for export of hydrogen were projected based on market penetration rates in order to size the potential opportunity for export of hydrogen.

Notable initiatives in other jurisdictions are highlighted in the report in sidebars. The team has also identified several "Big Bold Goals" with which to take a leadership position in hydrogen deployment, over and above the aggressive scenarios. These goals are the construction of a hydrogen "backbone" pipeline, decarbonizing of LNG Canada, and the planning of a hydrogen community. If these seem ambitious, or even unreasonable, the climate commitments and climate action of recent years have demonstrated that the ambitious is attainable.

The study findings were synthesized to create hydrogen demand curves based on the opportunities in the examined economic sectors. Policy recommendations were also made to support the development of a vibrant, profitable, emissions reducing hydrogen economy in the Province in the coming decades.

1.3 : Alignment with CleanBC goals

CleanBC is the Government of British Columbia's plan for achieving the GHG emissions reductions commitments from the May 2018 Climate Change Accountability Act of:

- *40% GHG emissions reductions by 2030 (from 2007 levels);*
- *60% reductions by 2040;*
- *80% reductions by 2050.*

For British Columbia to meet its 2030 commitment, provincial emissions will have to fall 40% from 63.6 million tonnes of CO_2 equivalent (Mt CO_2e) in the baseline year of 2007, to 38.2 Mt CO_2e in 2030. Consequently, the province is targeting GHG reductions of 25.4 Mt CO_2e from the 2007 baseline provincial emissions profile, by 2030.

The province's gross GHG emissions in 2016, the most recent year for which data are available, were 62.3 Mt CO_2e, but economic development is expected to increase provincial emissions in the interim.

The CleanBC plan identifies 18.9 Mt CO_2e of emissions reductions; additional opportunities are being evaluated to meet the Climate Change Accountability Act commitments.

Hydrogen's versatility allows it to contribute to CleanBC's GHG emissions reductions goals in several capacities:

1. *For **cleaner transportation**, hydrogen is expected to play a supporting role in helping BC achieve its light-duty vehicle Zero Emission Vehicle (ZEV) mandate targets, and a stronger role reducing emissions from larger vehicles, through fuel cell and co-combustion technologies. Renewable or low carbon hydrogen will also be required for fuel suppliers to meet the low carbon fuel standard. Hydrogen can also enable larger quantities of renewable natural gas to be available to fuel Compressed Natural Gas (CNG) vehicles.*
2. *To **improve where British Columbians live and work**, hydrogen can help achieve the goal of renewable gas comprising 15% of the Province's natural gas consumption. Hydrogen technologies can also help BC's many remote communities reduce their dependence on diesel.*
3. *For **cleaner industry**, renewable and low carbon hydrogen can serve as emissions-free alternatives to natural gas for heat.*
4. *To **reduce waste**, the production of hydrogen-rich synthetic gas (syngas) could up-cycle wood and crop residues and agricultural wastes. Such efforts would also align with the BC Bioenergy Strategy.*

Hydrogen can also play an important role connecting BC's electric and natural gas energy systems together via power-to-gas systems where hydrogen can be used for bulk energy storage. Hydrogen's versatility enables it to provide benefits greater than the sum of each discrete opportunity.

This report evaluates how hydrogen can be harnessed, as a clean energy fuel and feedstock, to grow British Columbia's economy while reducing its GHG emissions, in line with the CleanBC plan.

1.4 : Energy Consumption and GHG Emissions in BC

1.4.1 : Energy Consumption in BC

To understand how hydrogen can reduce the Province's GHG emissions and build its energy economy, an understanding of BC's energy sources and consumption is necessary. Figure 1 shows the NEB's assessment of the Province's primary energy demand by end use in 2016 and 2040.[3]

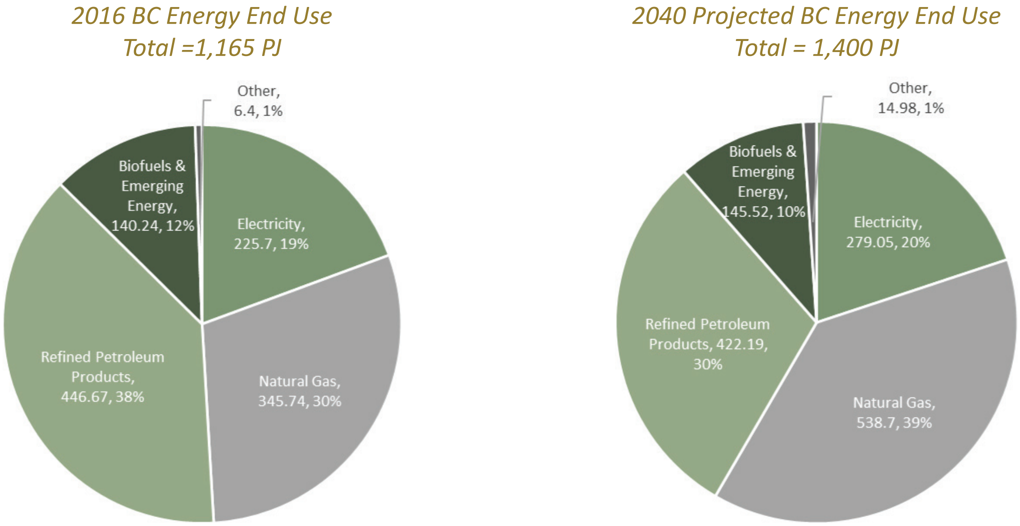


Figure 1. BC Historical and Projected Energy End Use by Energy Currency (2016 and 2040) [3]

The majority of primary energy consumption in the Province derives from fossil fuels: 68% in 2016 and a projected 69% in 2040.

Each energy source has a different GHG intensity, and the Province has provided guidance for quantifying GHG emissions from different energy sources.[4]

Electrification can improve energy efficiency and reduce primary energy demand – for example through the replacement of furnaces and boilers with heat pumps – but can only meet some of the Province's energy needs. A complementary strategy of using hydrogen to replace fossil fuels in other applications will be necessary for the Province to meet its longer-term climate goals. This includes contributing to increased use of renewable gas, which accounts for 75% of the GHG reductions attributed to the built environment in the CleanBC plan. Hydrogen blending in the NG pipeline will be required to meet the 15% renewable gas goal by 2030, which is needed to achieve the associated GHG reductions outlined in CleanBC.

3 *Canada National Energy Board (2017). Canada's Energy Future 2018: Energy Supply and Demand Projections to 2040. Retrieved from* https://apps.neb-one.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA

4 *(S&T) Squared Consultants Inc. (2018). GHGenius 5.0d. Calculations conducted by BC Ministry of Energy, Mines and Petroleum Resources Low Carbon Fuels Branch. Retrieved from* https://ghgenius.ca/index.php/downloads

1.4.2 : GHG Emissions in BC

BC's Climate Change Accountability Act sets GHG emission reduction targets of 40% by 2030, 60% by 2040, and 80% by 2050 compared to a 2007 baseline.[5] Figure 2 shows BC's GHG emissions from 1990 to 2016 and a linear path from 2007 GHG emissions levels to the 2030, 2040, and 2050 targets.

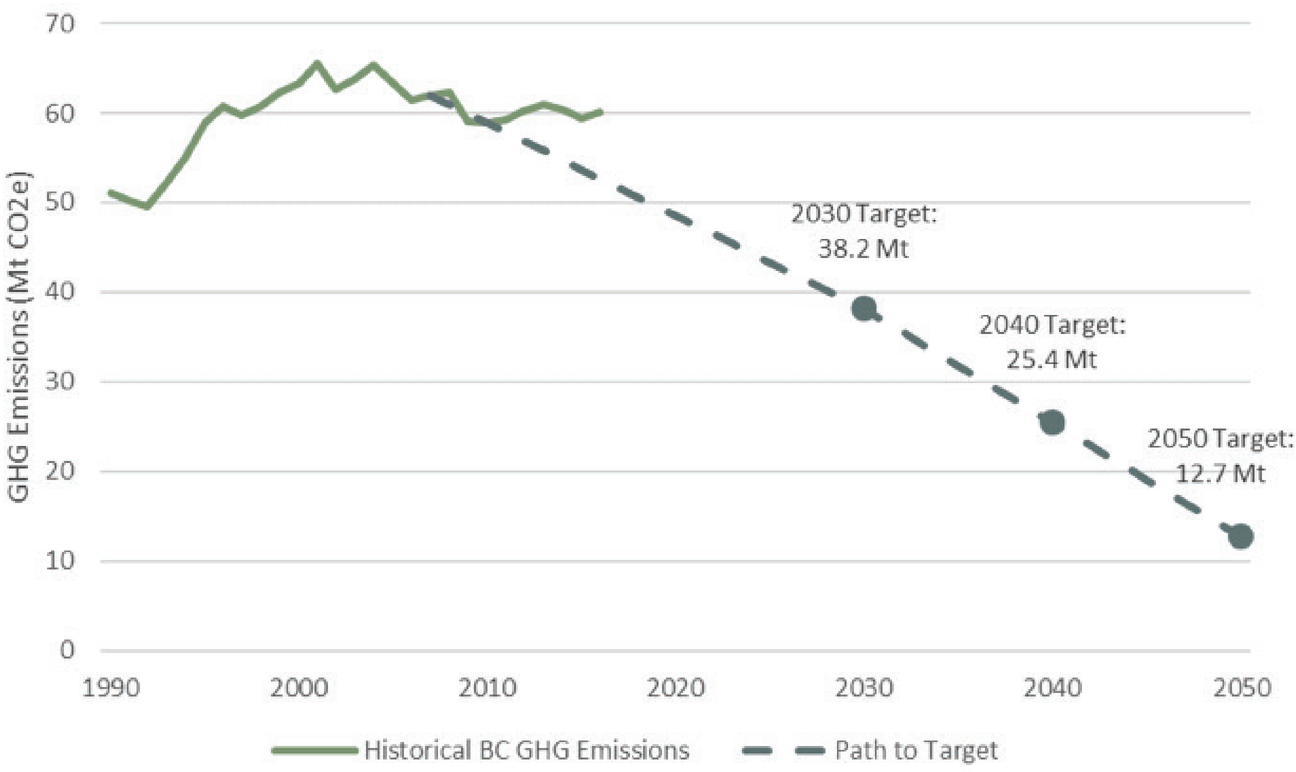


Figure 2. BC's Historical GHG Emissions and Path to Targets[5, 6]

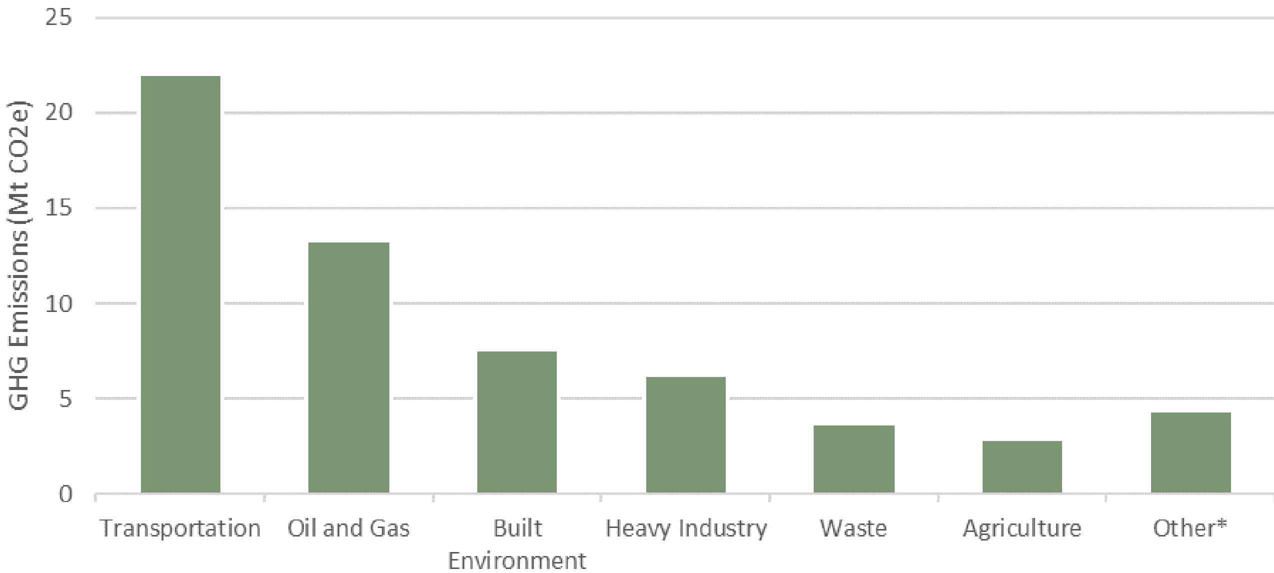
From 2007 to 2016, the Province experienced a moderate reduction in emissions of 3%.[6] To meet its GHG emissions targets, the Province needs to rapidly accelerate its decarbonization efforts. Over the same period, the GDP rose by 19%, demonstrating that economic growth can be decoupled from emissions growth.[7]

Figure 3 shows BC's 2016 GHG emissions by economic sector. Transportation made up the greatest share of total GHG emissions, followed by the oil and gas sector and the built environment.[6]

5 *BC Provincial Government. (2019). Climate Change Accountability Act. [SBC 2007] Chapter 42. Retrieved from http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/00_07042_01*

6 *Environment and Climate Change Canada. (2018). National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada, Annex 10. Retrieved from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b*

7 *British Columbia Provincial Government. (2018). Climate Action in BC: 2018 Progress to Targets. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/progress-to-targets/2018-progress-to-targets.pdf*



**Other includes light manufacturing, construction, forest resources, coal production, and electricity.*

Figure 3. BC GHG Emissions by Economic Sector (2016)[6]

Inexpensive, energy-dense fossil fuels lend themselves well to transportation and the built environment, which is a reason for these two sectors' large share of the Province's GHG emissions profile. Hydrogen is well-suited to decarbonize these hard-to-abate sectors.

1.5 : Current Uses and Applications of Hydrogen in BC

BC has a strong history of developing hydrogen and fuel cell technologies and is known as the "cradle" of the modern fuel cell industry. Paradoxically, there are relatively few ongoing hydrogen or fuel cell deployments in the Province, forcing the sector to export technology with limited home-province or home-country reference cases. The sector is instead supported by exports to regions such as China, Europe and California, where governments recognize the benefits of hydrogen and fuel cell technologies for their GHG emissions reduction, air quality improvement and energy security objectives.

Without local deployments of hydrogen and fuel cell technology, these regions stand to become the true "centre of gravity" for the sector, eclipsing the Province's early leadership in deploying hydrogen technology. Some notable projects in BC related to hydrogen, starting with the most recent, include:

- *Shell opening Canada's first retail hydrogen filling station in 2018 in Vancouver.*
- *Demonstration of a hydrogen-diesel co-combustion class 8 truck by Hydra Energy in 2017.*
- *BC being selected as Hyundai's first market for its Fuel Cell Electric Vehicles (FCEVs) in Canada in 2015, leasing 10 Tucson FCEVs.*
- *The deployment of 20 fuel cell electric buses (FCEBs) with Ballard Power Systems fuel cells in Whistler from 2009 to 2014. The FCEBs made up almost the entire Whistler bus fleet, which comprised 23 buses (26 buses during peak season).*
- *The Integrated Waste Hydrogen Utilization Project (IWHUP), a six-year project led by Hydrogen Technology & Energy Corporation (HTEC) that included the processing of by-product hydrogen from a sodium chlorate plant, distribution to end users, hydrogen station development, and transportation and stationary fuel cell power system deployment. The Project ran from 2006-2011.*

- *The world's first deployment of fuel cells in a material handling application by Cellex Power at London Drugs in Richmond in 2003.*
- *The world's first 700 bar (10,000 psi) hydrogen refueling station at Powertech Labs in Surrey in 2002.*

There are currently a small number of light-duty FCEVs on-the-road in BC, with growing numbers expected in 2019. No hydrogen powered heavy-duty vehicles, marine vessels, railway locomotives, or aircraft are currently deployed in the Province.

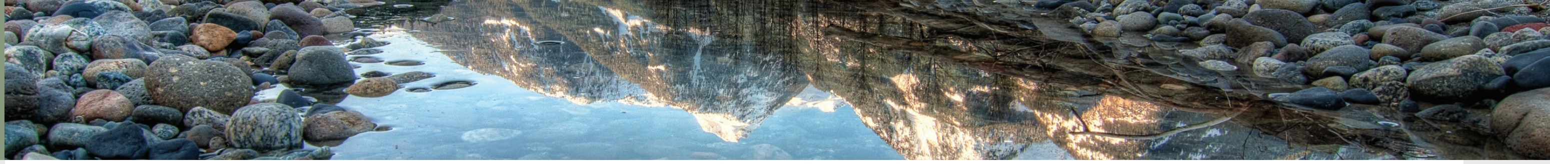
To support the rollout of vehicles, the Provincial and Federal governments have supported early development of hydrogen infrastructure. In addition to the first retail hydrogen fueling station that opened in Vancouver in June 2018, five more stations are in development as of May 2019.

BC industries using hydrogen include the hydrocarbon fuel refining, sodium chlorate, and chlor-alkali industries. The two refineries in BC, located in Burnaby (Parkland) and Prince George (Husky), use hydrogen as part of the refining process. Both produce hydrogen on site through naphtha as an internal part of the refining process and steam methane reformation respectively. There are also sodium chlorate plants in North Vancouver and Prince George and a chlor-alkali plant in North Vancouver. These plants produce hydrogen as a by-product. Some is currently captured for use in refineries, some is used to produce hydrochloric acid (HCl), some is used for process heat, and some is vented to the atmosphere. Vented hydrogen presents a potential hydrogen supply opportunity in the Province, discussed further in Section 3.0.

BC's Renewable and Low Carbon Fuel Requirements Regulation (LCFR), a form of Low Carbon Fuel Standard (LCFS), is driving demand for hydrogen in BC. The LCFR is made up of two components - the renewable content requirement for diesel and gasoline, and the decreasing carbon intensity of fossil fuels. Both of these are driving renewed interest in hydrogen.

Finally, there is strong hydrogen demand emerging from the Province and FortisBC as a means of meeting the CleanBC requirement that 15% of natural gas consumed in the Province comes from a renewable source, but at time of writing no Provincial regulation exists to enable the injection of hydrogen into the natural gas system and account for it as a feedstock for renewable gas.

Deployment of hydrogen within the Province has strong potential in the coming years, and early projects have helped to demonstrate the viability and benefits in various applications. The goal of this report is to recommend opportunities that will significantly assist the Province's decarbonization objectives, will support the goals for economic development in the province, and show the most promise for commercial and technical viability to ensure they can be sustained over the long-term.



2.0 : HYDROGEN PRODUCTION, STORAGE AND USE

2.1 : Hydrogen Production Technologies

Worldwide annual hydrogen production is approximately 55 million tonnes (Mt) or 6.6 ExaJoules (EJ) of energy.[8] The Hydrogen Council proposes that production could increase tenfold through 2050. The Council is a global initiative of leading energy, transportation and industry companies with a shared vision for hydrogen's role in the energy transition; at time of writing it comprised a 33-member Steering Group and 20 Supporting Members.[9]

Hydrogen can be produced via a number of different pathways using a range of feedstocks. Hydrogen can be made via renewable and fossil fuel resources and is a by-product of some industrial processes. Most hydrogen is made today from fossil fuels without carbon capture and sequestration. The majority is used in industrial processes and is produced at the site where it is used.

BC is focused on low carbon intensity hydrogen pathways, sometimes classified as "Green Hydrogen" or "Blue Hydrogen". Definitions for the two terms vary internationally. In this study Green Hydrogen is defined as hydrogen produced from clean or renewable electricity, and Blue Hydrogen as hydrogen produced from natural gas and biomass which is net carbon neutral using carbon capture and storage. The pathways that relate to BC are described in Section 3.1.

2.2 : Hydrogen Storage and Transport

There are several methods for storing and transporting hydrogen, illustrated in Figure 4 below. These include physical-based storage such as compressing or cryogenically liquefying the hydrogen. Hydrogen can also be stored in a range of material-based solid and liquid compounds. Storage methods are typically chosen based on end use requirements such as weight and volume available for energy storage. The natural gas pipeline can also be used to store and transport hydrogen using existing infrastructure. When the NG pipeline is used, a blend of H_2/NG is the result. In most cases this blend will be used directly, although it is possible to separate the H_2 and NG at the point of use once concentrations of hydrogen are high enough to cost effectively separate the gases.

8 *The Hydrogen Council. (2017). Hydrogen Scaling Up: A Sustainable Pathway for the Global Energy Transition. Retrieved from http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf*

9 *The Hydrogen Council. (2019). Frequently Asked Questions. Retrieved from http://hydrogencouncil.com/faq/*

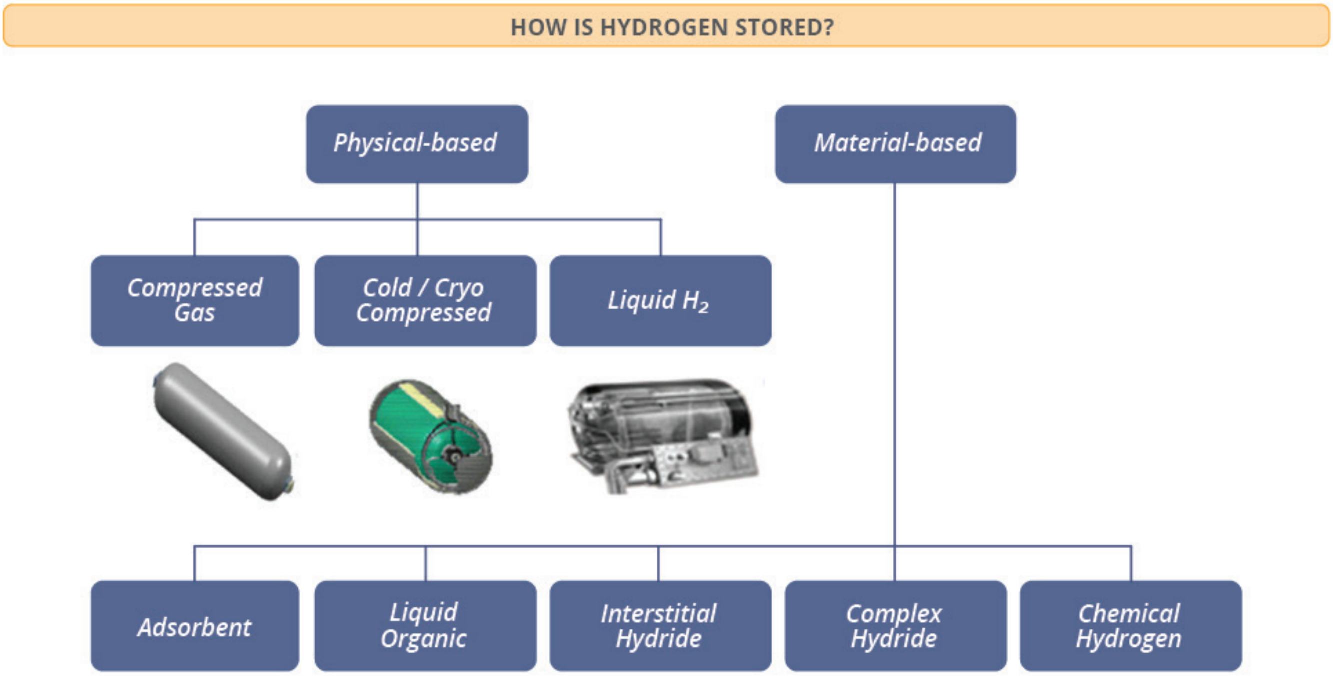


Figure 4. Methods of Hydrogen Storage. Source: US Department of Energy.[10]

2.2.1 : Compression

As a gas under atmospheric conditions, hydrogen must often be compressed, liquefied, or stored in an otherwise dense manner prior to use.

Hydrogen tanks for forklift and public transit applications often use hydrogen compressed to a pressure of 350 bar (5,000 psi) or 345 times as dense as it would be under atmospheric conditions. (Standard atmospheric pressure is 1.01 bar.)

This is somewhat higher than the 250 bar (3,600 psi) pressure in compressed natural gas, or CNG cylinders. The energy loss from having to compress the hydrogen to 350 bar was estimated by UC Davis to be on the order of 8.5 percent.[11] The results are consistent with a recent International Energy Agency (IEA) report.[12]

10 United States Department of Energy, Fuel Cell Technologies Office. Hydrogen Storage. Retrieved from https://www.energy.gov/eere/fuelcells/hydrogen-storage

11 Burke, A., and Gardiner, M., Hydrogen Storage Options: Technologies and Comparisons for Light-Duty Vehicle Applications, UC Davis Institute for Transport Studies, Jan 2005. Document reference UCD-ITS-RR-05-01. Retrieved from https://escholarship.org/uc/item/7425173j

12 Gielen, D. and Simbolotti, G., IEA Energy Technology Analysis: Prospects for Hydrogen & Fuel Cells, International Energy Agency, 2005. Retrieved from https://web.archive.org/web/20080307082839/http://www.iea.org/textbase/nppdf/free/2005/hydrogen2005.pdf

2.2.2 : Liquefaction

Where hydrogen must be made denser – such as for rail, marine, power plant or space applications -- it is likely to be liquefied, providing an 800-fold increase in density. Hydrogen liquefaction is performed in a series of compression and cooling steps, much as is done when producing liquefied natural gas. Liquid hydrogen (LH_2) is considerably more energy intensive to produce; natural gas liquefies at -160°C while hydrogen liquefies at -253°C. As a result, while the energy loss to liquefy natural gas is on the order of 10 percent, the energy loss to liquefy hydrogen is generally estimated to be on the order of 20 to 30 percent, though an energy loss of as little as 13 percent may be possible. [13, 14]

Organizations evaluating hydrogen export options such as Japan's Kawasaki Heavy Industries and Norway SINTEF favour liquid hydrogen for long-distance transport.

2.2.3 : Chemical Storage

Another means of storing hydrogen is in the form of compounds called chemical carriers. Liquid chemical carriers are relatively easily handled and can contain large quantities of hydrogen by volume: there is more hydrogen in a litre of gasoline (116 g H_2) than in a litre of liquid hydrogen (71 g H_2).

The two chemical carriers currently receiving the most development are methylcyclohexane (MCH) and ammonia. MCH is a liquid at atmospheric pressure with the chemical formula C_7H1_4 and can be handled by oceanic chemical tankers. Three hydrogen molecules (H_2) can be liberated from the MCH, transforming it into toluene, also a liquid. When hydrogen is added to toluene, it is transformed back into MCH. The business model consists of bonding hydrogen into toluene, forming MCH at the point of hydrogen supply, and then releasing the hydrogen from the MCH, forming toluene, at the point of hydrogen demand.

An illustrative diagram from Chiyoda Corporation is shown in Figure 5. A consortium is currently evaluating the export of hydrogen from the coast of British Columbia to Japan in the form of MCH.[15]

13 *Hydrogen Strategy Group. (2018). Hydrogen for Australia's Future: A Briefing Paper for the COAG Council. Retrieved from https://www.chiefscientist.gov.au/wp-content/uploads/HydrogenCOAGWhitePaper_WEB.pdf*

14 *Sadaghiani, M.S. and Mehrpooya, M., Introducing and energy analysis of a novel cryogenic hydrogen liquefaction process configuration, International Journal of Hydrogen Energy, Volume 42 (9), pp 6033-6050. Retrieved from https://doi.org/10.1016/j.ijhydene.2017.01.136*

15 *ITM Power. (2018). British Columbia Renewable Hydrogen Study. Retrieved from https://www.itm-power.com/news-item/british-columbia-renewable-hydrogen-study*

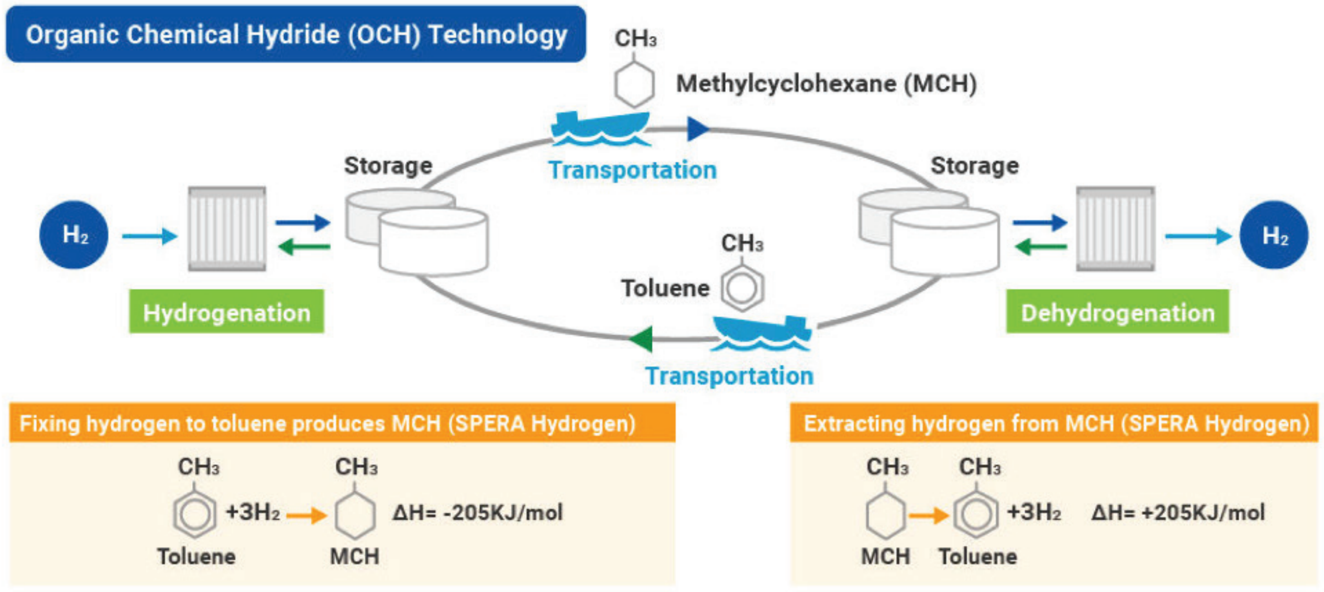


Figure 5. Methylcyclohexane as Hydrogen Carrier. Source: Chiyoda Corporation.[15]

Ammonia (NH_3) is also being evaluated as a chemical carrier for hydrogen, particularly for jurisdictions wishing to export electrolyzed hydrogen in the form of ammonia for fertilizer production. Ammonia is a common industrial chemical already produced and transported on a global scale; it is also the largest global consumer of steam methane reformed hydrogen. Once transported to the point of demand, the ammonia can be dehydrogenated, yielding 0.176 tonnes of hydrogen per tonne of ammonia.

2.2.4 : Adsorbent Storage

Hydrogen can also be stored by adsorbing the gas on powders. One advantage of this method is that the amounts of energy required to adsorb (bind) the hydrogen to the powder should be less than required to form chemical bonds, as per the chemical storage methods above. Adsorbent storage may make it possible to store relatively high densities of hydrogen – comparable to compressed gases – at lower pressures. BC's Hydrogen In Motion is developing a hydrogen storage technology by engineering a powder for this purpose.

2.2.5 : Transport

In gaseous form, hydrogen can be transported in existing natural gas pipeline networks. Small percentages of hydrogen could be blended into existing natural gas streams without requiring infrastructure retrofits. The blending of larger quantities, or of 100% hydrogen, could necessitate retrofits to pipeline equipment, though the pipe segments themselves are not expected to require replacement. This concept is discussed further in Section 4.1.

Smaller volumes of compressed hydrogen are also transported by truck in tube trailers, in much the manner done for other industrial gases.

Hydrogen can also be transported by truck in liquefied form, again in the manner of industrial gases. Kawasaki Heavy Industries, which built Japan's first LNG carrier vessel, plans to build the world's first liquid hydrogen (LH_2) carrier as part of its Hydrogen Energy Supply Chain project in Australia.

When stored in the form of a chemical carrier, hydrogen transportation would follow chemical industry practice for transporting the carrier.

2.3 : Hydrogen Applications

Demonstrating hydrogen's versatility, the Hydrogen Council enumerated seven separate supportive roles it could play in global decarbonization efforts, as shown in Figure 6 below.[16]

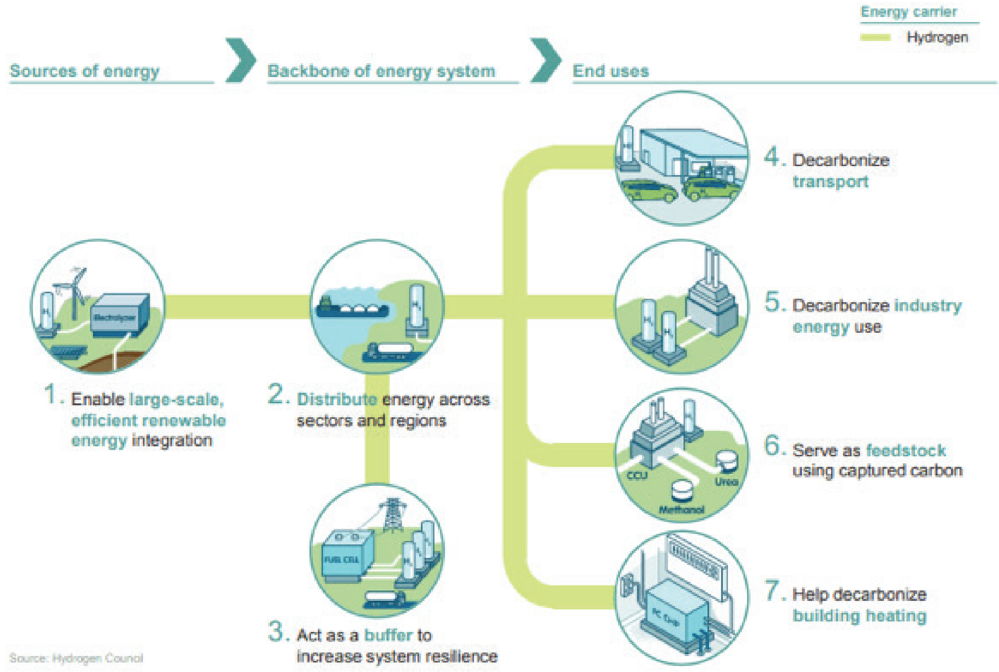


Figure 6. Roles for Hydrogen in Decarbonization. Source: Hydrogen Council.[16]

This report focuses how hydrogen can be deployed in support of the Province's CleanBC plan and broader climate targets. Consideration is given to hydrogen's potential in BC related to:

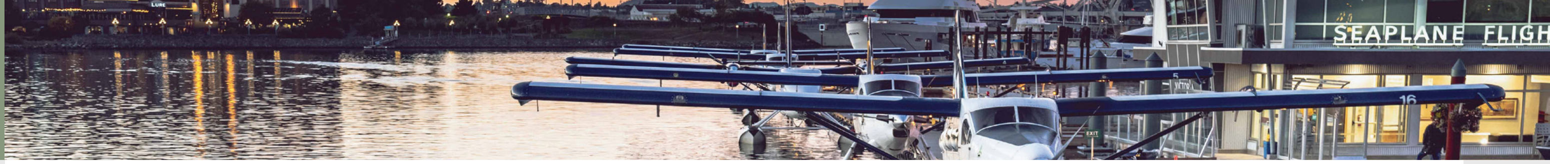
- *BC's Natural Gas sector (section 4.1)*
- *BC's Transportation sector (section 4.2)*
- *BC's Industrial sector (section 4.3)*
- *BC's Built Environment (section 4.4)*
- *BC's Remote and Off-Grid Communities (section 4.5)*
- *Energy Storage through Power to Gas opportunities (section 5.2)*

Hydrogen can be combusted as a cleaner burning substitute for fossil fuels such as natural gas or oil. This is one use case for end users of natural gas in the industrial and built environment sectors. Hydrogen combustion equipment and technology are also being pursued in jurisdictions where natural gas is combusted for power generation. In the transportation sector, BC company Hydra Energy has developed technology allowing for hydrogen-diesel co-combustion.

16 *The Hydrogen Council. (2017). How Hydrogen Empowers the Energy Transition. Retrieved from http://hydrogencouncil.com/wp-content/uploads/2017/06/Hydrogen-Council-Vision-Document.pdf*

Hydrogen can also be reacted electrochemically -- without combustion – in fuel cells, generating an electric current. Fuel cell technology is being developed across the transportation sector, from light-duty and heavy-duty vehicles up to rail and marine vessels. Fuel cells are increasingly being deployed for utility-scale power generation (South Korea) and to provide guaranteed on-site power, and sometimes hot water, at commercial facilities (California) or in residential homes (Japan, Europe). Proton Exchange Membrane (PEM) stationary fuel cell systems can run on both natural gas (with a reformer) or on pure hydrogen fuel.

During times of overproduction of renewable electricity, hydrogen can also be generated via electrolysis and used for long-term energy storage, a highly valuable characteristic for BC's remote and off-grid communities.



3.0 : HYDROGEN PRODUCTION IN BRITISH COLUMBIA

3.1 : BC Production Pathways

Hydrogen molecules do not generally exist on their own in a free state in nature but are found in many abundant compounds. Hydrogen must be produced from feedstocks using energy inputs. When investigating viable local hydrogen pathways, the availability of both feedstocks and energy sources must be considered. For energy sources, point source emissions and upstream emissions must both be considered; a fuller treatment is provided in APPENDIX B: Upstream GHG emissions In BC.

Feedstocks are the chemical sources of the hydrogen. BC is fortunate to have an abundance of three hydrogen feedstocks: water, biomass (predominantly carbon, hydrogen and oxygen) and natural gas (primarily methane). Crude oil and coal could also be used as hydrogen feedstocks, but they have a lower ratio of hydrogen to carbon, making them less attractive than natural gas. BC is a minor producer of crude oil and produces significant quantities of coal. The vast majority (80-90%) of this coal however is low hydrogen-content metallurgical grade coal used for high-value steel manufacture.

This report considers the three most likely energy inputs for large-scale hydrogen production in British Columbia: electricity, biomass, and natural gas. In the case of electricity, electricity generated from hydroelectricity and wind are considered, since these are the most abundant sources of electricity in the Province.

BC generates by-product hydrogen from two sodium chlorate plants operating in the Province, located in North Vancouver and Prince George, and one chlor-alkali plant in North Vancouver. Chemtrade operates the chlor-alkali plant in North Vancouver and the sodium chlorate plant in Prince George. While some of the by-product hydrogen is currently used as feedstock in chemical production, approximately 18,500 kg/day of hydrogen is vented. This represents an important near-term hydrogen source for the Province.

Considering feedstock and energy sources in tandem, the following pathways have been identified as primary options for producing large quantities of hydrogen in the Province:

- *Industrial by-product hydrogen;*
- *Electrolysis via hydroelectric or wind (grid connected or non-grid connected);*
- *Biomass gasification with water gas shift and reforming;*
- *Steam methane reforming with carbon capture and storage; and*
- *Methane pyrolysis (thermal and plasma) with carbon capture and storage.*

With hydroelectricity representing 86% of the electricity generated in BC the assumption has been made that grid connected electrolysis is primarily powered by hydroelectricity. Hydroelectricity, wind and biomass together account for approximately 95% of the province's electricity production.[17]

17 *National Energy Board. (2018). Canada's Renewable Power Landscape 2016 – Energy Market Analysis. Retrieved from* https://www.neb-one.gc.ca/nrg/sttstc/lctrct/rprt/2016cndrnwblpwr/prvnc/bc-eng.html

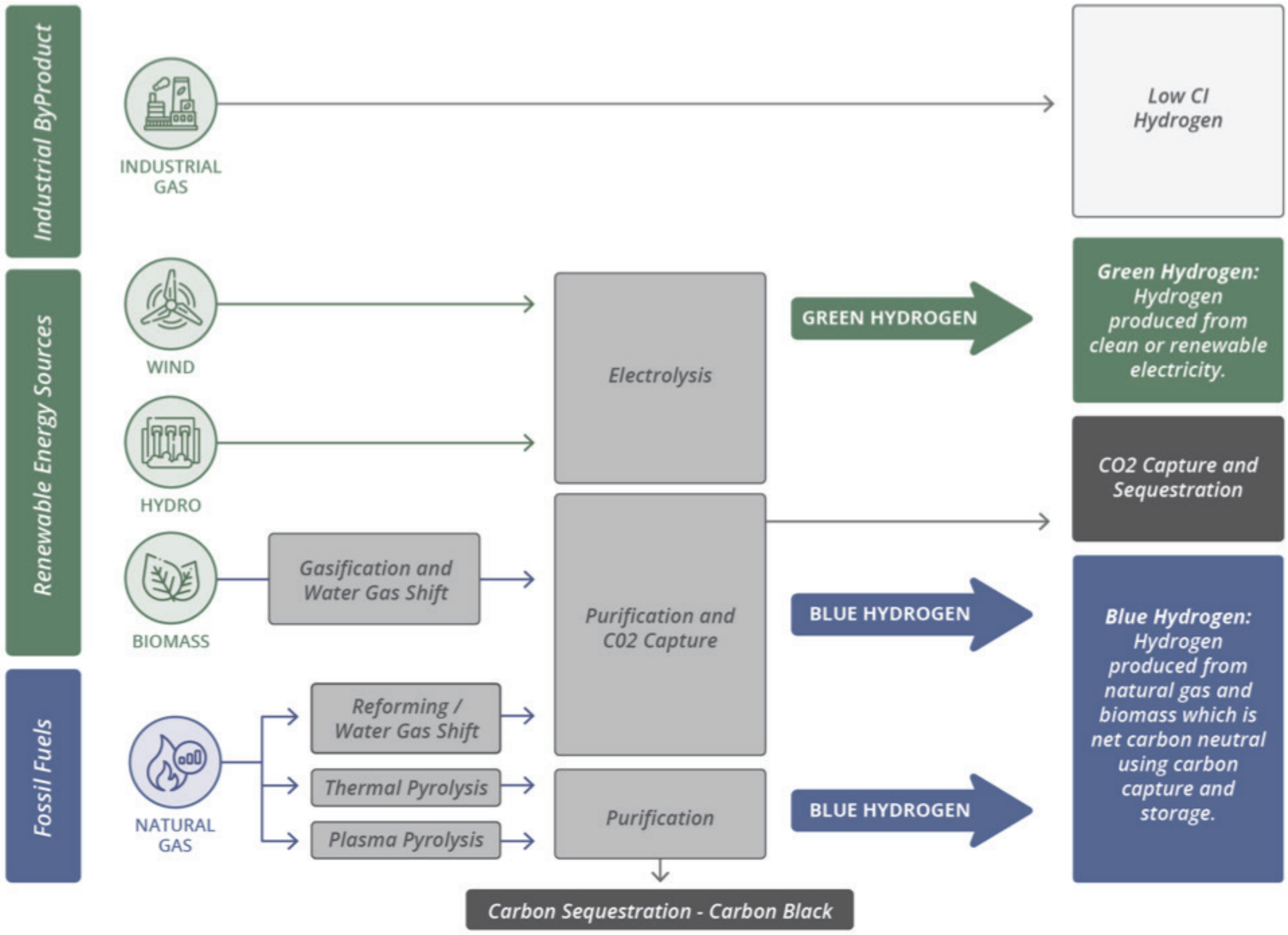


Figure 7. Hydrogen Production Pathways in BC

BC is focused on low carbon intensity hydrogen pathways, or Green and Blue Hydrogen as it is commonly called. The report focuses on low carbon intensity hydrogen, without the use of Green and Blue terminology. It is recommended that all pathways shown in Figure 7 above be evaluated based on production cost, carbon intensity, and availability in the Province.

Given the Province's interest in transitioning to sustainable energy in the longer-term, it is recommended that hydrogen produced from renewable resources including hydroelectric, wind, and biomass resources be given special consideration as identified in the policy recommendations of this report. By-product hydrogen currently produced in BC can also be considered renewable, as the primary energy source used in the brine electrolysis in the sodium chlorate and chlor-alkali plants comes from the electric grid.

The technology fundamentals for each production pathway is described in the following sections. A large production scale of 100 tonnes of hydrogen per day is assumed given that some technologies, such as steam methane reforming (SMR) followed by carbon capture and sequestration (CCS) are only expected to be feasible at large scale. Cost sensitivities have also been provided, where estimates could be made. Cost figures refer to bulk centralized production and do not include transportation costs, which can vary significantly by location. Costs also do not include any profit.

GHG intensities are also presented for each pathway. The analysis looks at both upstream and direct emissions, projected for 2030 which account for potential changes in upstream emissions per year. The assumptions and analysis for calculating carbon intensity are described in Appendix B.

3.1.1 : Industrial By-product Hydrogen

Approximately 18.5 tonnes of relatively pure hydrogen is currently vented to atmosphere every day in the Province. The by-product hydrogen requires minimal cleanup to remove traces of chlorine gas, and represents a low-cost, low carbon intensity hydrogen supply. It would have to be pressurized prior to purification and transportation to distributors (in the case of fuel stations) or end users. The cost of recovering this industrial by-product hydrogen is based on hydrogen's heating value, as it is often burned for process heat, and the amortized capital costs. These costs are estimated to be $0.88/kg as shown in Figure 8.

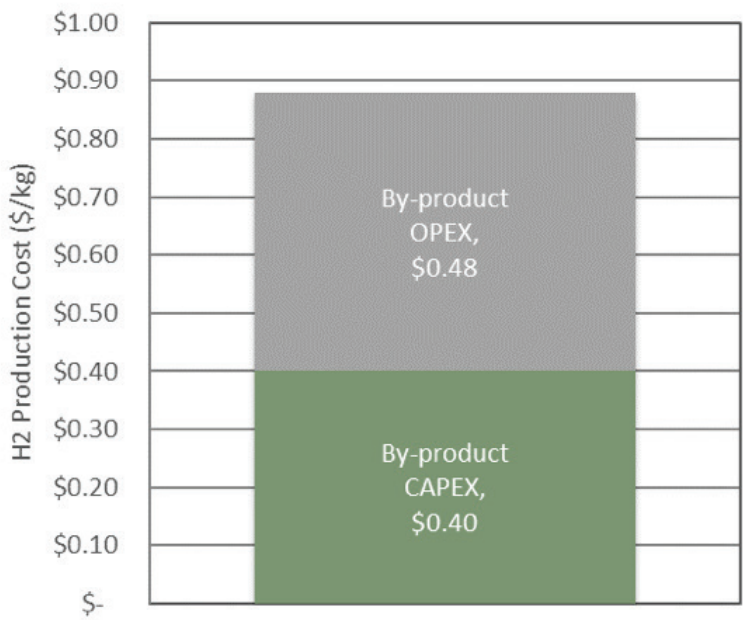


Figure 8. Cost breakdown for by-product hydrogen

Hydra Energy is looking to secure by-product hydrogen supply in the Province to operate trucks retrofitted with their hydrogen co-combustion technology. They have recently evaluated the carbon intensity from this pathway and have determined it to be 1.43 g CO_2e/MJ at the point of dispensing. This has been used in the pathway comparison in this report.

3.1.2 : Electrolysis

Water electrolysis is a hydrogen production pathway attractive in BC given the relatively low cost of electricity from the Province's low carbon intensity electric grid. In addition to existing hydroelectric dams, the Province also possesses significant wind energy resources.

Electrolysis is the process by which electricity is used to split water into hydrogen and oxygen. The chemical transformations are described in reaction (1).

(1) H_2O + electricity → H_2 + ½O_2

The ideal or minimum amount of electricity required to produce 1 kg of hydrogen is 39 kWh.

The equipment in which this reaction takes place is called an electrolyzer. Electrolyzers are modular, and their sizes vary widely depending on the chosen technology and required production capacity. They can range from appliance-sized equipment for small-scale hydrogen production to large-scale, central production facilities. Their modular nature makes electrolyzers attractive when relatively small quantities of hydrogen are required; higher per-kg production costs may be offset by reduced transportation costs.

Electrolyzers consist of an anode and a cathode separated by an electrolyte, as in Figure 9. The two major types of electrolyzers in current use are Proton Exchange Membrane (PEM) electrolyzers, and Alkaline electrolyzers.

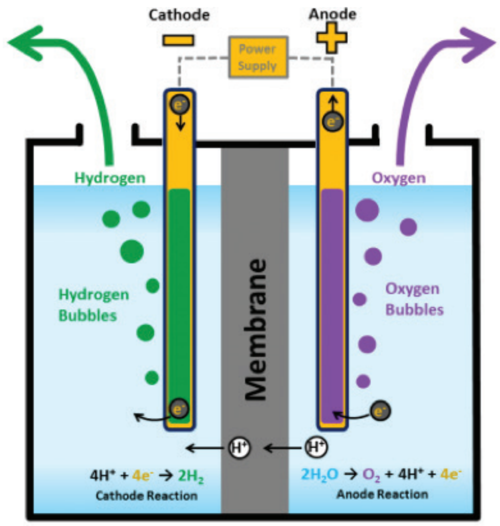


Figure 9. Electrolysis in a PEM Electrolyzer. Source: US Department of Energy.[18]

3.1.2.1 : PEM Electrolyzers

In a PEM electrolyzer, the electrolyte is a solid polymer, or plastic. At the anode, water is split into oxygen, positively charged hydrogen ions (protons) and negatively charged electrons. The protons migrate across the proton exchange membrane while the electrons flow through an external circuit. The protons and electrons recombine on the cathode to form hydrogen gas.

PEM electrolyzers have received heightened attention in recent years. This is due in part to breakthroughs allowing for significantly higher hydrogen production density. It is also due to PEM electrolyzers' flexibility; they can operate when the incoming current fluctuates, producing variable rates of hydrogen from second to second, depending on the power supplied. This "load-following" capability makes them a highly complementary technology to variable solar photovoltaic and intermittent wind energy. Curtailment of renewable electricity currently occurs during periods of excess production; more curtailment is expected to occur as renewable electricity is added to electrical grids. PEM electrolyzers provide a responsive electrical load, which can reduce the amount of curtailment while producing valuable hydrogen. Some PEM electrolyzer deployments have also generated additional revenue by providing grid services, being compensated for helping to buffer and stabilize the grid when solar or wind power suddenly ramps up or down.

3.1.2.2 : Alkaline and Solid Oxide Electrolyzers

While PEM electrolyzers transport protons (H^+) through a membrane, Alkaline electrolyzers transport hydroxide ions (OH-) through their electrolyte, which is generally sodium or potassium hydroxide. Both compounds are alkaline – in chemical terms they have a high pH – hence the term Alkaline electrolyzer.

A third electrolyzer technology, the Solid Oxide electrolyzer, is under development but has not yet been commercially deployed. These electrolyzers operate at high temperatures and hold the promise of being more efficient than PEM or Alkaline electrolyzers.

18 *U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. Hydrogen Production: Electrolysis. Retrieved from https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis*

3.1.2.3 : Hydrogen Production Cost

The price of electricity is the dominant factor determining the cost of hydrogen produced via electrolysis. Whereas ideal specific efficiencies for water electrolysis is 39 kWh/kg H_2, actual demonstrated specific efficiencies are between 50-60 kWh/kg H_2. Where an electrolyzer is run 24/7, operating costs account for approximately 80% of the cost of hydrogen, and the bulk of operating costs consist of the sourced electricity.

As shown in Figure 10 below, hydrogen production in BC via electrolysis is expected to be \$5-7/kg H_2 based on an industrial electricity rate of \$60/MWh (Megawatt-hour), representative of current industrial rate tariffs.[19]

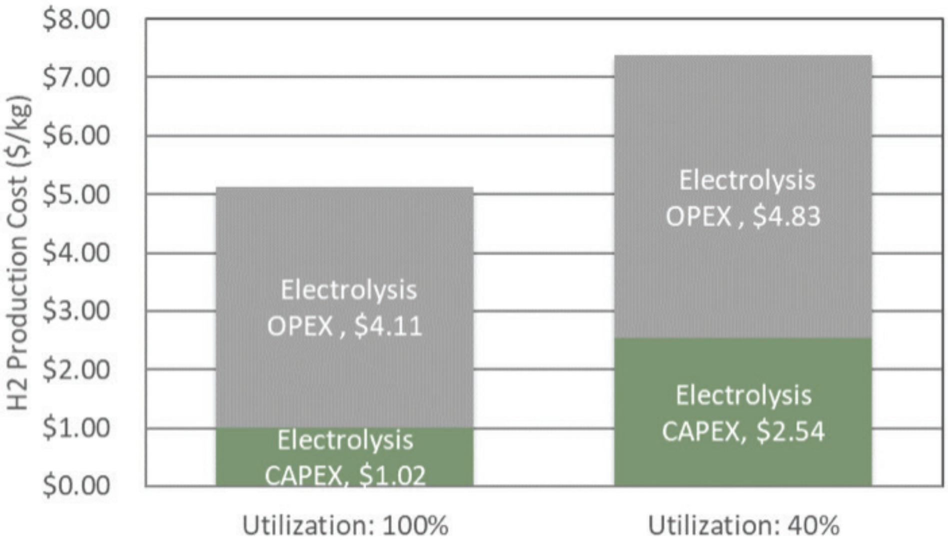


Figure 10. Cost breakdown for hydrogen produced via Electrolyzer

Figure 11 shows a sensitivity analysis of hydrogen production costs based on the cost of electricity and the size of the electrolyzer. As would be expected, larger electrolyzers drive economies of scale in capital equipment and installation cost.

For hydrogen to be produced at scale in BC using electrolysis, it is estimated that the cost of electricity must be <\$40/MWh. If the cost of electricity is higher, other hydrogen production processes will have a cost advantage. This report provides recommendations by which to decrease the cost of this production pathway, which has potential to be strategic for the Province.

19 *\$0.0606/kWh equates to \$60.60/MWh. Source: BC Hydro. (2019). General Service Business Rates. Retrieved from https://app.bchydro.com/accounts-billing/rates-energy-use/electricity-rates/business-rates.html*

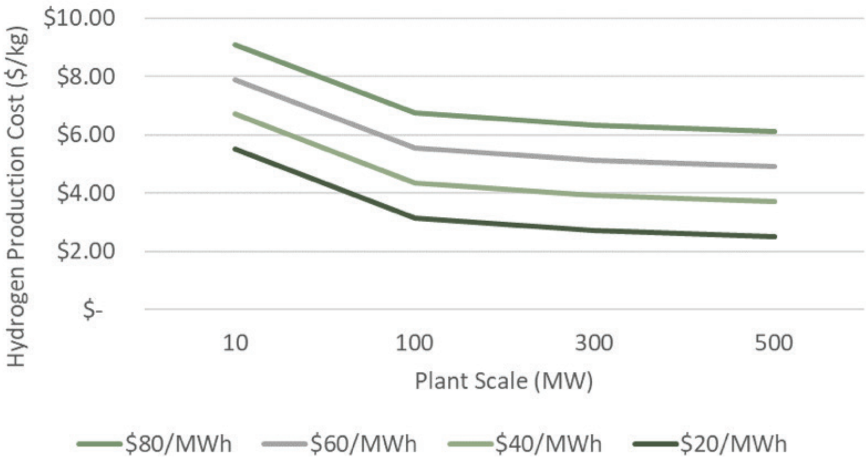


Figure 11. Impact of Scale and Electricity Feedstock Price for Electrolysis Pathway

In addition to rich hydroelectric resources in the Province, BC has significant wind reserves that can be leveraged to produce hydrogen. It is estimated that there are >5.4 GW of high-quality wind reserves with high utilization potential (40-70%) in areas that can be readily developed.

3.1.3 : Biomass Gasification and Purification

Biomass is a renewable organic resource predominantly comprised of carbon, hydrogen and oxygen, encompassing crop and forest residues, specialty crops, and even waste streams. Biomass gasification is a mature technology that uses the controlled application of heat (generally >700°C), steam, and oxygen (from air) to convert biomass to hydrogen and other products without combustion. Biomass gasification is generally undertaken in two stages, with an initial gasification stage (reaction 1) followed by a water-gas shift reaction (reaction 2) in which carbon monoxide (CO) is converted to carbon dioxide (CO_2), generating additional H_2.

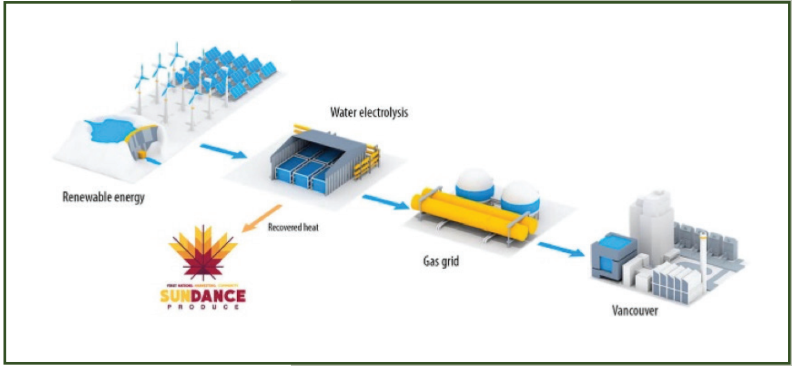
(1) $C_6H_{12}O_6 + O_2 + H_2O + \text{heat} \rightarrow CO + CO_2 + H_2$ + other species

(2) $CO + H_2O \rightarrow CO_2 + H_2 + \text{heat}$

The products of gasification are H_2 and CO_2, along with other species; pressure swing absorption is then used to purify the hydrogen. Though carbon dioxide is produced, biomass is considered a GHG-neutral fuel because biomass sequesters carbon dioxide during its life. Some biomass facilities may sequester the resulting CO_2, effectively making this pathway carbon negative. Such technology pathways are sometimes referred to in climate science literature as Bioenergy with Carbon Capture and Storage (BECCS).

The cost of hydrogen from biomass gasification

BC's Renewable Hydrogen Canada (RH_2C) is developing large-scale projects to produce hydrogen from renewable power, primarily wind augmented by hydroelectric power. They are in the stages of developing a project in Northeastern BC in the heart of the Montney gas formation. In the first phase of the project, a 120 MW electrolyzer farm will produce pure hydrogen and inject in into the natural gas grid. Longer-term, additional projects will be developed to use the hydrogen to produce methanol (Canadian Methanol) and low carbon gasoline (Blue Fuel Energy).



for this study was modeled without CCS. Feedstock costs of $80/dry tonne of biomass were assumed, with $100/tonne of processing costs. For a facility producing 100 tonnes of hydrogen per day the cost of hydrogen is modelled to be approximately $3/kg H_2 as shown in Figure 12.

A facility producing 100 tonnes of hydrogen per day would be very large, requiring 1,350 dry tonnes of biomass feedstock per day, and thus may or may not be feasible based on constraints for regional supplies. Smaller facilities would be more feasible from a feedstock availability perspective but would drive up the capex portion of the cost.

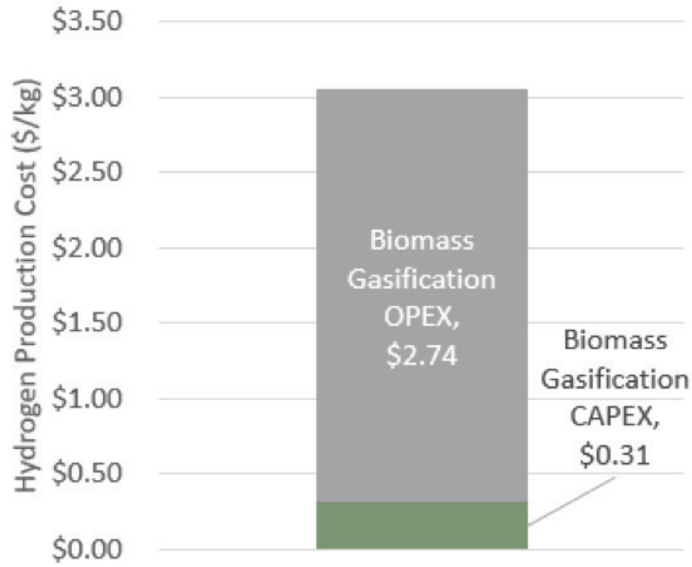


Figure 12. Cost breakdown for hydrogen produced via biomass gasification

3.1.4 : Steam Methane Reforming with CCS

Steam methane reforming (SMR) is the most common bulk hydrogen production pathway; fossil fuel reforming accounted for approximately 95% of worldwide hydrogen production in the year 2000 timeframe with natural gas representing about one-half the total.[20]

SMR involves reacting natural gas (primarily methane, CH_4) with steam (H_2O) to produce H_2 and CO_2. The efficiency of SMR is greater than 80% as measured by the higher heating value of the energy content of the hydrogen produced, compared to that of the natural gas consumed.[21] Higher heating value is a measure of the energy liberated from a compound if, after being combusted, all the combustion products are brought back to pre-reaction temperatures.

The overall chemical reaction for steam methane reforming process is shown in reaction (1) below. Reaction (2) describes the water gas shift reaction, which is used in SMR as well as in biomass gasification.

(1) $CH_4 + H_2O + heat \rightarrow CO + 3H_2$

(2) $CO + H_2O \rightarrow CO_2 + H_2 + heat$

20 Ogden, J. M. (1999). Prospects for building a hydrogen energy infrastructure. Annual Review of Energy and the Environment. 24: 227–279. Retrieved from https://www.annualreviews.org/doi/10.1146/annurev.energy.24.1.227

21 Peng, X. D. (2012). Analysis of the Thermal Efficiency Limit of the Steam Methane Reforming Process. Ind. Eng. Chem. Res., 51 (50), pp 16385–16392. Retrieved from http://www.airproducts.com/~/media/Files/PDF/industries/en-analysis-of-thermal-efficiency-limit-of-steam-methane-reforming-process.pdf

A process diagram for steam methane reforming is provided in Figure 13 below.

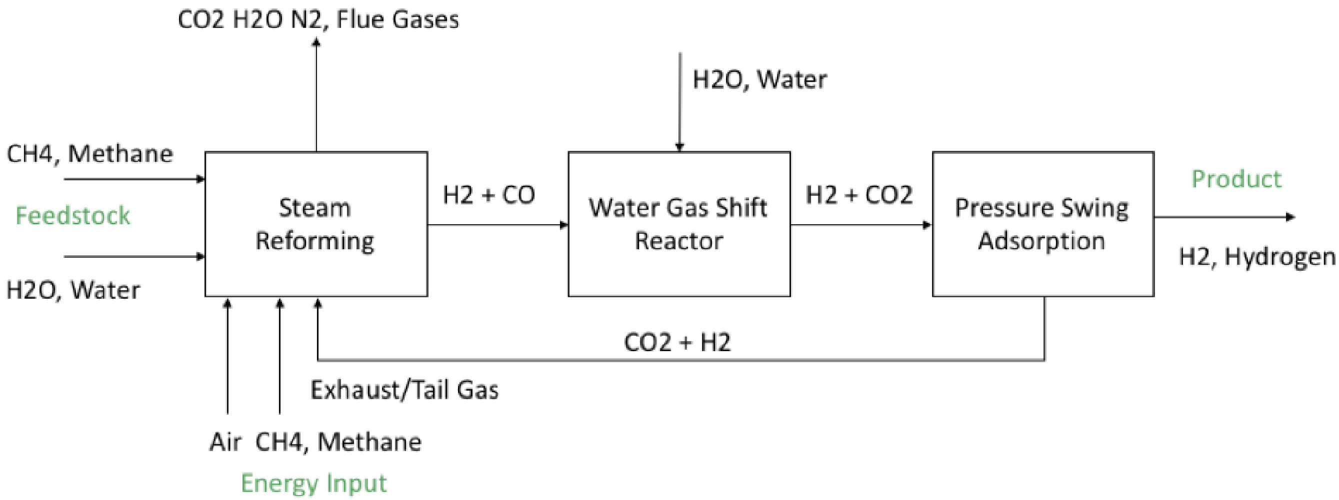


Figure 13. Steam Methane Reforming Process

Using a conservative 75% efficiency, applying SMR to 1 GigaJoule (GJ) of natural gas would result in 0.75 GJ of hydrogen, or approximately 5.3 kg.[22] SMR plants can produce hydrogen at very large scale; a recent plant announcement exceeded 300 tonnes H_2/day.[23]

SMR generates approximately 8-10 kg CO_2e per kg of H_2 produced (CO_2e/kg H_2). The report will use 10 kg CO_2e/kg H_2. Existing technology such as amine scrubbers and vacuum swing adsorption can be deployed within the SMR process to capture up to 56-90% of the generated CO_2 resulting in net emissions of 2 kg CO_2e/kg H_2.[24]

Factoring in upstream natural gas GHG emissions, total GHG emissions from SMR with CO_2 capture and storage comprise 2.7 t CO_2e/t H_2.[25, 26]

In SMR processes, hydrogen production costs are driven by feedstock costs and amount to 2 to 3 times the cost of natural gas on a $/GJ basis. For example, for a natural gas price of $4/GJ (approximately $4.20/MMBTU) hydrogen production costs can be expected to range from $8-12/GJ H_2. Our analysis of SMR production costs yielded a per-kilogram cost of $1.32/kg H_2.

CCS is estimated to add approximately $0.82/kg H_2 to base SMR costs. The hydrogen production cost of SMR + CCS is then estimated to be approximately $2.14/kg H_2. The cost breakdown is shown in Figure 14, with the sensitivity to natural gas feedstock price shown in Figure 15.

22 *Based on higher heating value of hydrogen at 0.142 GJ/kg*

23 *Bailey, M.P. (2018). Air Products Inaugurates Steam-Methane Reformer at Covestro's Baytown Site. Chemical Engineering. Retrieved from https://www.chemengonline.com/air-products-inaugurates-steam-methane-reformer-at-covestros-baytown-site/*

24 *ieaghg. (2017). SMR Based H_2 Plant with CCS. Retrieved from https://ieaghg.org/terms-of-use/49-publications/technical-reports/784-2017-02-smr-based-h2-plant-with-ccs*

25 *Upstream emissions = 3.3 kg CO_2/GJ NG ÷ 5.3 kg H_2/GJ NG = 0.62 kg CO_2e/kg H_2*

26 *This analysis assumes the 2030 upstream natural gas business as usual emissions in 2030 are equal to 2016/2017 emissions. This is supported by the figure on page 10 of the CleanBC plan. Retrieved from https://blog.gov.bc.ca/app/uploads/sites/436/2019/02/CleanBC_Full_Report_Updated_Mar2019.pdf See APPENDIX B: Upstream GHG emissions In BC for full details.*

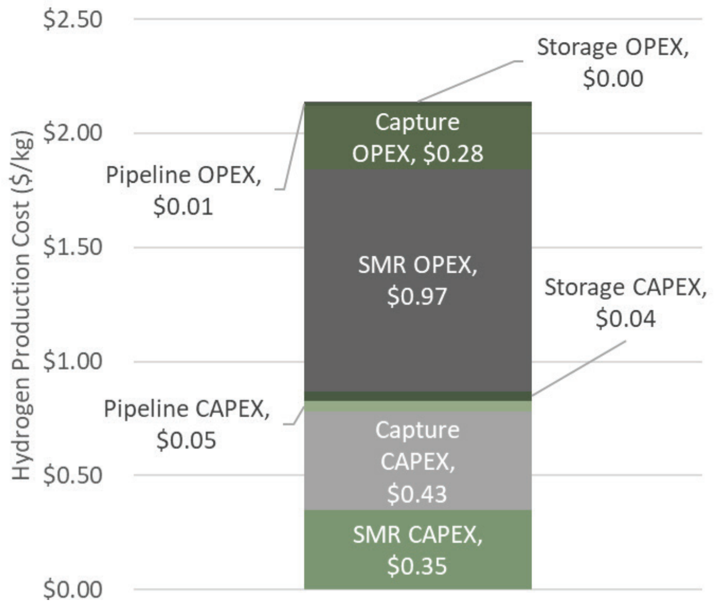


Figure 14. Cost breakdown for hydrogen produced via SMR + CCS

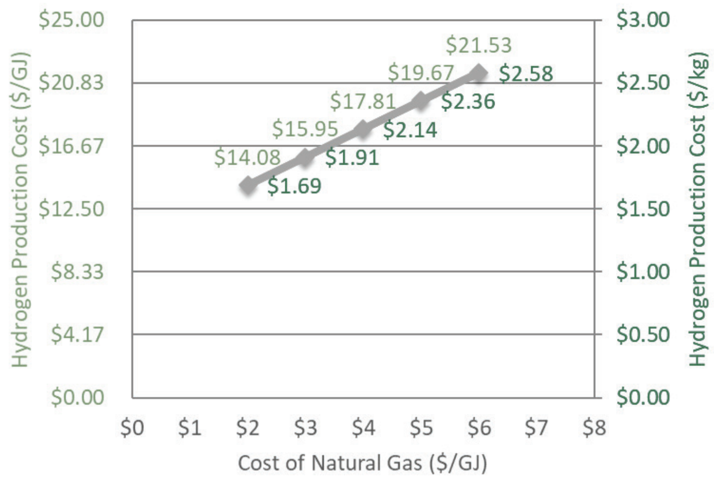


Figure 15. Impact of natural gas feedstock cost on hydrogen cost from SMR + CCS

Assuming that CCS processes cost approximately $0.82/kg H_2 and remove 8 kg of the 10 kg CO_2e produced per kg H_2 in the SMR process, the equivalent cost of carbon capture and storage can be calculated as $0.82/8 kg CO_2e, or $0.102/kg CO_2e. This is equivalent to $102/tonne CO_2e.

3.1.5 : Methane Pyrolysis

Methane pyrolysis is the decomposition of natural gas without oxygen into its two main elements; gaseous H_2 and solid carbon (C). CO_2 is not produced, as the reaction takes place in the absence of oxygen. Thermal pyrolysis of natural gas has been commercially operated at scale by Cancarb of Alberta since the early 1900s.

The pyrolysis process is described in reaction (1) and a process diagram is shown in Figure 16 below.

(1) $CH4 + energy \rightarrow C + 2H_2$

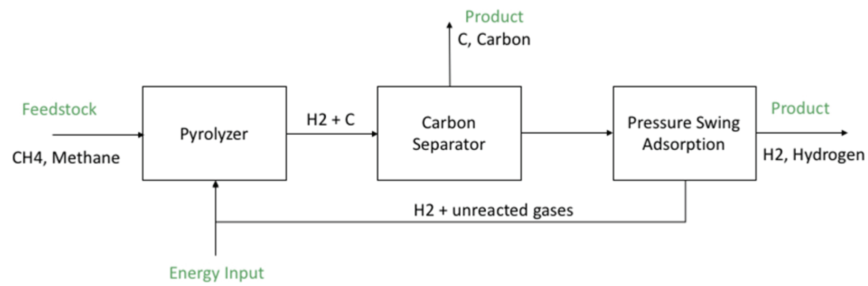


Figure 16. Methane Pyrolysis Process

Thermal pyrolysis and plasma pyrolysis are two technologies under development.

Carbon powder, sometimes called carbon black, commands a price of $50 to $500/tonne in a market of approximately 12 million tonnes per year.[28] Methane pyrolysis will generate approximately 3.75 kg of carbon black per kg of hydrogen, so large-scale pyrolysis could saturate BC carbon black markets and reduce the powder's market price.

3.1.5.1 : Thermal Pyrolysis

In thermal pyrolysis, complete conversion of methane to hydrogen and carbon is difficult to achieve; hydrogen leaving the reactor will contain unreacted methane. Pressure swing absorption is likely to be used to separate the hydrogen from the methane, with the latter recirculated and combusted to provide the heat for the reaction. A novel type of thermal pyrolysis, using a liquid or molten metal to separate the gases, may circumvent this requirement.

Energy inputs were estimated assuming a 90% conversion of methane to hydrogen and carbon and an 80% yield in the pressure swing absorption process, resulting in an estimated 0.32 GJ/kg H_2 of which 0.028 GJ/kg H_2 is required to provide heat for the reaction.

Based on natural gas feedstock costs of $4/GJ, no value being assigned to the carbon black, and building on a recent analysis[29] for a liquid metal thermal pyrolysis technology, the study calculated the hydrogen production costs at $1.68/kg H_2 comprising approximately $1.26/kg for operating costs and $0.43/kg for capital cost amortization. This is shown in Figure 17.

BC's Ekona Power proposes to use unsteady gas dynamics and multiple reactors to create a continuous output of decarbonized hydrogen at a cost similar to SMR. The startup has attracted funding from Evok Innovations[27] and BC's ICE Fund, has completed modelling of the process and is designing a proof-of-concept reactor to test the process

27 *Evok Innovations. (2019). Fueling Industrial Innovation. Retrieved from http://www.evokinnovations.com*

28 *Jung CG, Bouysset JP. (2015). Recovered Carbon Black from Tyre Pyrolysis. Université Libre de Bruxelles. Retrieved from https://docplayer.net/60487355-Recovered-carbon-black-from-tyre-pyrolysis.html*

29 *Parkinson, B., Matthews, J. W., McConnaughy, T. B., Upham, D. C., and McFarland, E. W., (2017). Techno-Economic Analysis of Methane Pyrolysis in Molten Metals: Decarbonizing Natural Gas, Chem. Eng. Technol. 40, pp 1022–1030. Retrieved from https://doi.org/10.1002/ceat.201600414*

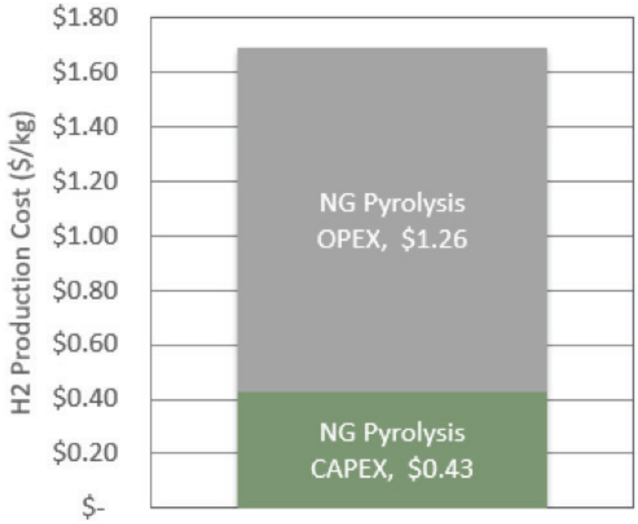


Figure 17. Cost breakdown for hydrogen produced via Liquid Metal Thermal Pyrolysis

The sensitivity of hydrogen costs to natural gas feedstock costs is provided in Figure 18 below:

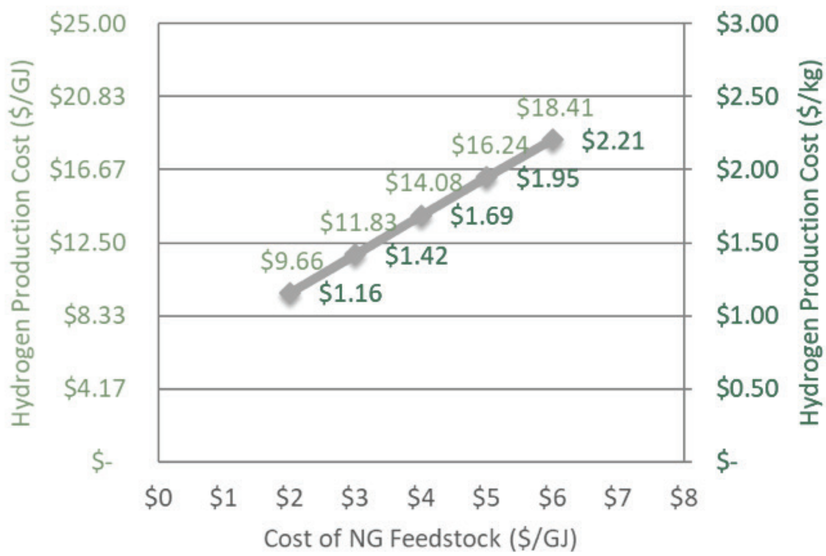


Figure 18. Impact of natural gas feedstock cost on hydrogen cost from liquid metal thermal pyrolysis

The Province estimates emissions associated with natural gas combustion as 57.94 kg CO_2e/GJ.[30] Combined with the above information this provides an emissions intensity of 0.66 kg CO_2e/kg H_2 for the hydrogen produced from thermal pyrolysis, owing to the combustion of natural gas in the process for heat. Factoring in upstream emissions, the GHG emission intensity from thermal methane pyrolysis would be 1.77 kg CO_2e/kg H_2 or 14.7 g CO_2e/MJ.[31]

30 *(S&T) Squared Consultants Inc. (2018). GHGenius 5.0d. Calculations conducted by BC Ministry of Energy, Mines and Petroleum Resources Low Carbon Fuels Branch. Retrieved from https://ghgenius.ca/index.php/downloads*

31 *This analysis assumes the 2030 upstream natural gas business as usual emissions in 2030 are equal to 2016/2017 emissions. This is supported by the figure on page 10 of the CleanBC plan. (https://blog.gov.bc.ca/app/uploads/sites/436/2019/02/CleanBC_Full_Report_Updated_Mar2019.pdf) See APPENDIX B: Upstream GHG emissions In BC for full details.*

The cost of carbon capture and storage was calculated (on a $/tonne CO_2e basis) in section 3.1.4, and an equivalent calculation can be made for pyrolysis processes. Pyrolysis is more expensive than steam methane reforming but produces significantly less GHG emissions, so the cost of the avoided CO_2 emissions can be calculated.

- *The cost of hydrogen from thermal pyrolysis has been calculated as $1.68/kg H_2, higher than the $1.32/kg H_2 to produce hydrogen through SMR; a cost premium of $0.36/kg H_2.*
- *The CO_2e emissions from thermal pyrolysis have been estimated at 1.77 kg CO_2e/kg H_2, significantly less than the 10.7 kg CO_2e/kg H_2 for SMR; a reduction of 8.9 kg CO_2e/kg H_2.*
- *For each kg of H_2 produced, it costs $0.36 to avoid 8.9 kg CO_2e emissions, for a mitigation cost of $0.041/kg CO_2e or $41/tonne CO_2e emissions.*

Put differently, using thermal pyrolysis in place of SMR reduces CO_2e emissions from hydrogen production at an equivalent cost of $40/tonne CO_2e.

The Cancarb plant in Medicine Hat, AB produces approximately 45,000 tonnes/year of carbon black through thermal pyrolysis; it is currently the only plant in North America producing carbon black from natural gas. Pre-heated natural gas feedstock is decomposed at approximately 1400°C in the absence of air or flame to produce carbon black and hydrogen.

3.1.5.2 : Plasma Pyrolysis

In plasma pyrolysis, electricity is used to generate a plasma arc in a reactor chamber, which decomposes methane into hydrogen and carbon. Process costs relate to the amount of electricity required per kg H_2. Thermal processes use high temperatures to decompose methane, with process costs largely driven by the amount of fuel used to bring reactors to high temperature.

Plasma pyrolysis requires electricity inputs of 10-12 kWh/kg H_2 [32], approximately one-fifth of the amount currently required for PEM electrolysis.[33]

Based on 10 kWh/kg H_2 and $0.06/kWh industrial electricity costs, electricity inputs for plasma pyrolysis amount to $0.60/kg H_2. Assuming the cost structure is otherwise similar to that of thermal pyrolysis the total hydrogen production cost for plasma methane pyrolysis is estimated to be $2.28/kg H_2. This is depicted in Figure 19.

32 Personal communication, Pete Johnson, Monolith Materials

33 Stakeholder input.

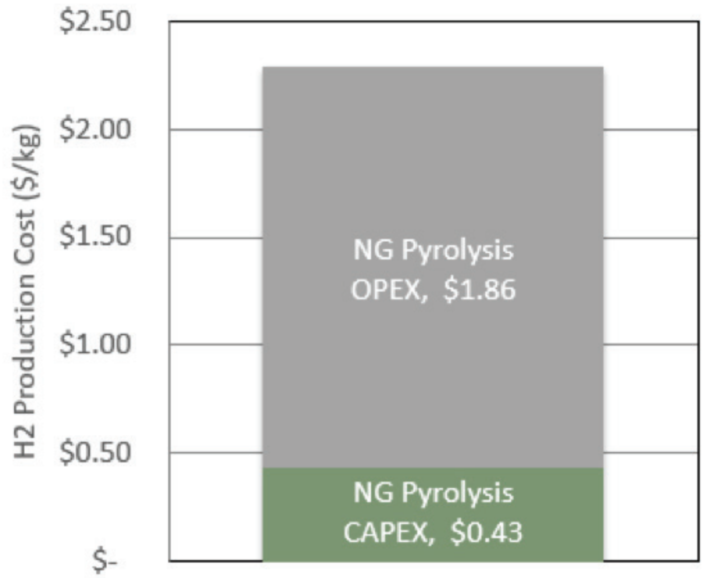


Figure 19. Cost breakdown for hydrogen produced via Plasma Pyrolysis

The sensitivity of plasma pyrolysis to natural gas feedstock costs is shown in Figure 20.

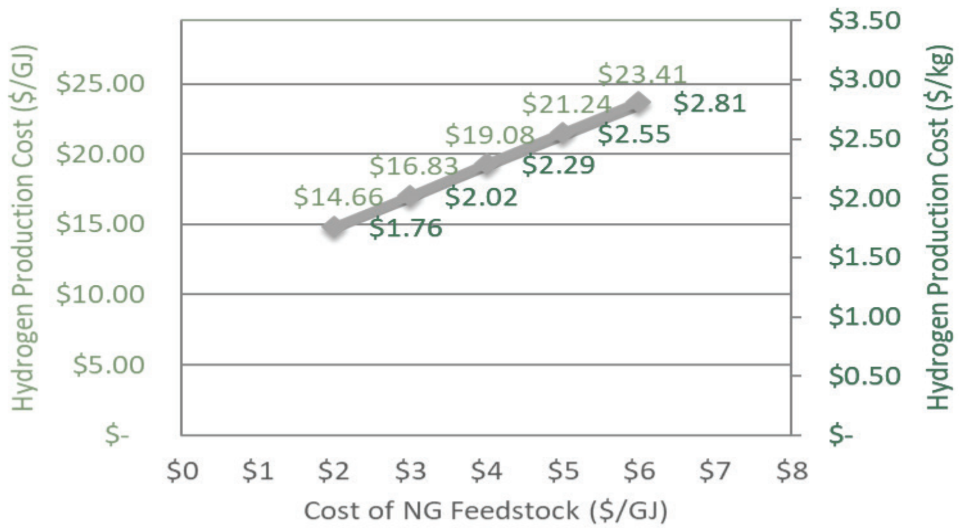


Figure 20. Impact of natural gas feedstock cost on hydrogen cost from plasma pyrolysis

Given the GHG emissions intensity of electricity from BC Hydro (54.72 g CO_2e/kWh)[34] the emissions intensity of hydrogen production from plasma pyrolysis would be on the order of 150 g CO_2e/kg H_2, or 0.150 kg CO_2e/kg H_2.

34 *(S&T) Squared Consultants Inc. (2018). GHGenius 5.0d. Calculations conducted by BC Ministry of Energy, Mines and Petroleum Resources Low Carbon Fuels Branch. Retrieved from https://ghgenius.ca/index.php/downloads*

Knowing these figures, the equivalent cost of mitigating GHG emissions using plasma pyrolysis in place of SMR can also be calculated.

- *The cost of hydrogen from plasma pyrolysis has been calculated as \$2.28/kg H_2, higher than the \$1.32/kg H_2 to produce hydrogen through SMR; a cost premium of \$0.96/kg H_2.*
- *The CO_2e emissions from thermal pyrolysis have been estimated at 0.150 kg CO_2e/kg H_2, significantly less than the 10.69 kg CO_2e/kg H_2 for SMR; a reduction of 9.18 kg CO_2e/kg H_2.*
- *For each kg of H_2 produced, it costs \$0.96 to avoid 9.18 kg CO_2e emissions, for a mitigation cost of \$0.105/kg CO_2e or \$105/tonne CO_2e emissions.*

Put differently, using plasma pyrolysis in place of SMR reduces CO_2e emissions from hydrogen production at an equivalent cost of \$105/tonne CO_2e.

3.1.6 : CO_2 sequestration

Effective CCS will be necessary for BC to capitalize on its abundant supply of natural gas to produce hydrogen without sacrificing GHG emissions goals. This section describes the state of CCS technology and storage capacity in BC.

3.1.6.1 : Overview

The Intergovernmental Panel on Climate Change (IPCC) defines carbon dioxide capture and storage as:

> "…a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere."[35]

Subterranean geological formations are currently used for CO_2 storage, and are expected to continue being so in the future. The technologies in use are similar to long-established processes in the oil & gas sector. An overview of the storage options is given in Figure 21.

35 *Metz B, et al. (2005). IPCC Special Report on Carbon Dioxide Capture and Storage. IPCC. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_wholereport-1.pdf*

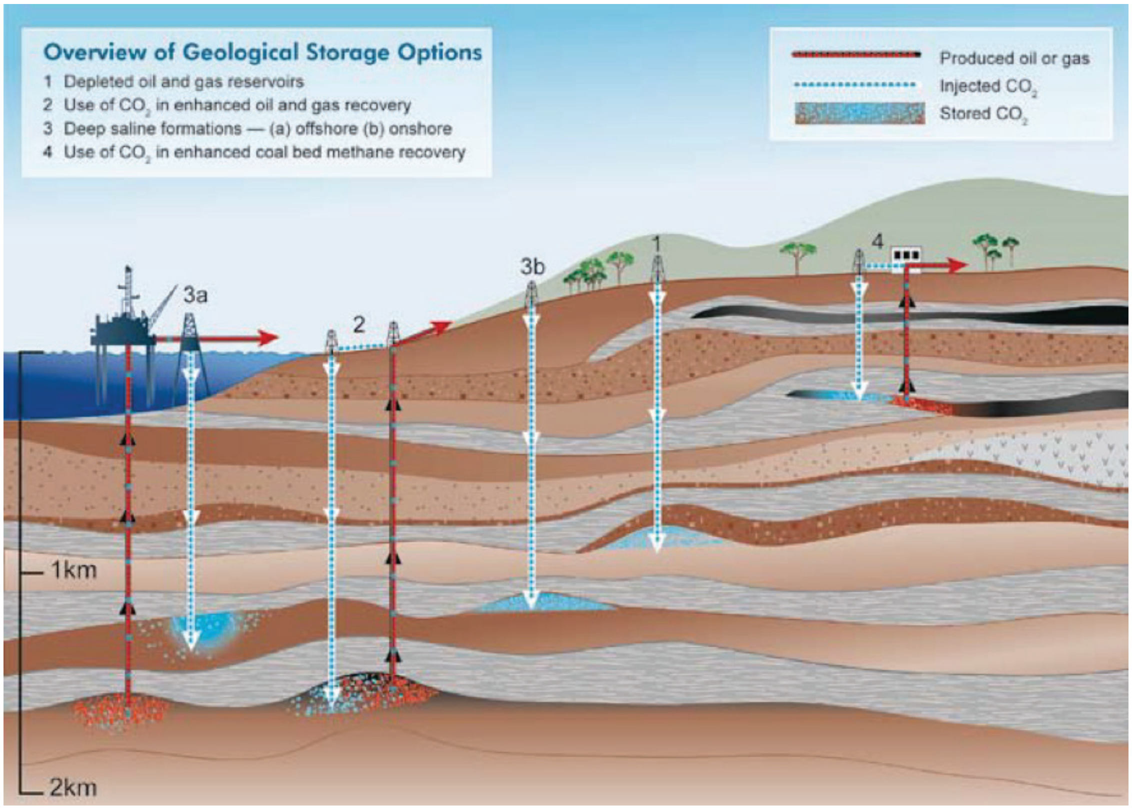


Figure 21. CO_2 Storage Options. Source: IPCC.[35]

A common feature in CO_2 storage options is the presence of a caprock which prevents the CO_2 from migrating back to the surface. Reservoir depths are recommended to be at least 800 m below ground, so the CO_2 can be stored as a supercritical fluid. This is desirable, as CO_2 is about 200x denser as a supercritical fluid than a gas, allowing considerably more CO_2 to be stored in each reservoir.

Shallower coalbeds can also be used for storage, as the CO_2 adsorbs onto the coal.

Over 200 million tonnes of CO_2 have been stored underground to date.[36] The Sleipner Gas Field off the coast of Norway is one the largest CO_2 storage sites; it has been used to sequester approximately 1 million tonnes of CO_2 per year since 1996.[37]

The IPCC conservatively estimates worldwide CO_2 storage capacity in depleted oil and gas reservoirs and saline aquifers to be approximately 3 trillion tonnes[35] representing sufficient capacity to store 80 years' worth of CO_2 from fossil fuel combustion at 2018 consumption rates.[38]

Promising sequestration sites can be found around the globe, including in Canada's Western Canadian Sedimentary Basin (WCSB), which extends from Alberta into BC.[39]

36 *Global CCS Institute. (2018). The Global Status of CCS: 2017. Retrieved from https://www.globalccsinstitute.com/wp-content/uploads/2018/12/2017-Global-Status-Report.pdf*

37 *Wikipedia. (2019). Sleipner gas field. Retrieved from https://en.wikipedia.org/wiki/Sleipner_gas_field*

38 *2018 CO_2 emissions from fossil fuel energy sources – 37 Gt.*

39 *Wikipedia. (2019). Sleipner gas field. Retrieved from https://en.wikipedia.org/wiki/Sleipner_gas_field*

3.1.6.2 : CO_2 storage in BC

CO_2 storage options in BC include depleted gas reservoirs and saline aquifers. Gas reservoirs exist in the Northeast of the Province, in the Western Canadian Sedimentary Basin. Storage potential in these gas reservoirs – shown in Figure 22 – is estimated at approximately 2,000 Mt CO_2 per year.

Carbon dioxide can also be stored in saline aquifers, which exist throughout the province, as shown in Figure 23. The aquifers' potential for CO_2 storage has only been assessed in the Northeast of the province, so there remains considerable uncertainty about the aquifers' storage capacity. Estimates vary from 880 to 3580 Mt CO_2 per year.[40]

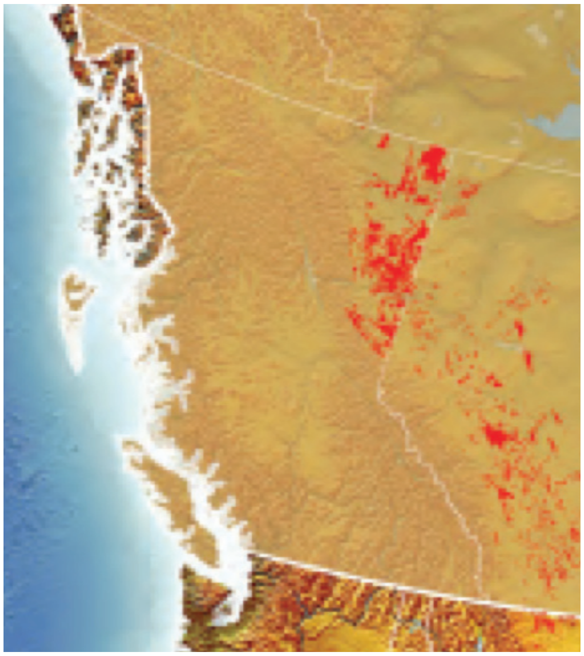


Figure 22. Natural Gas Fields in BC[41]

Figure 23. Location of Saline Aquifers in BC (light blue=non-assessed, dark blue=assessed)[40]

Drawing these together, Table 1 compiles the estimated CO_2 storage capacities for geological formations in the Province.

40 U.S. Department of Energy. (2015). Carbon Storage Atlas, Fifth Edition. National Energy Technology Laboratory. Retrieved from https://edx.netl.doe.gov/dataset/netl-carbon-storage-atlas-fifth-edition

41 Bachu, S. (2006a): The potential for geological storage of carbon dioxide in Northeast British Columbia; Report to the BC Ministry of Energy, Mines and Petroleum Resources, 71 pages.

CO_2 STORAGE OPTION	ESTIMATED CAPACITY (MT CO_2e)
Gas Reservoir	2,000
Saline Aquifer	1,000
Total	3,000

Table 1. CO_2 storage capacity in BC

In our hydrogen supply analysis, the study determined the annual capacity based on the assumption the CO_2 storage capacity would last 160 years. Further assuming that half of the storage capacity would be allocated to hydrogen, the maximum production through SMR+CCS processes would be 1.1 million tonnes hydrogen per year.

3.2 : Cost of Hydrogen Production in Province

The levelized cost of production for each pathway was calculated based on a 100 tonne per day (TPD) hydrogen plant, to evaluate the viability of large-scale centralized hydrogen production in the province. Figure 24 compares the hydrogen production cost of the various pathways relevant to BC's strategic resources. The cost to produce hydrogen via steam methane reformation is shown in the graph as a comparative baseline. It is recommended that the province focus only on low carbon hydrogen pathways, as described in 3.1.

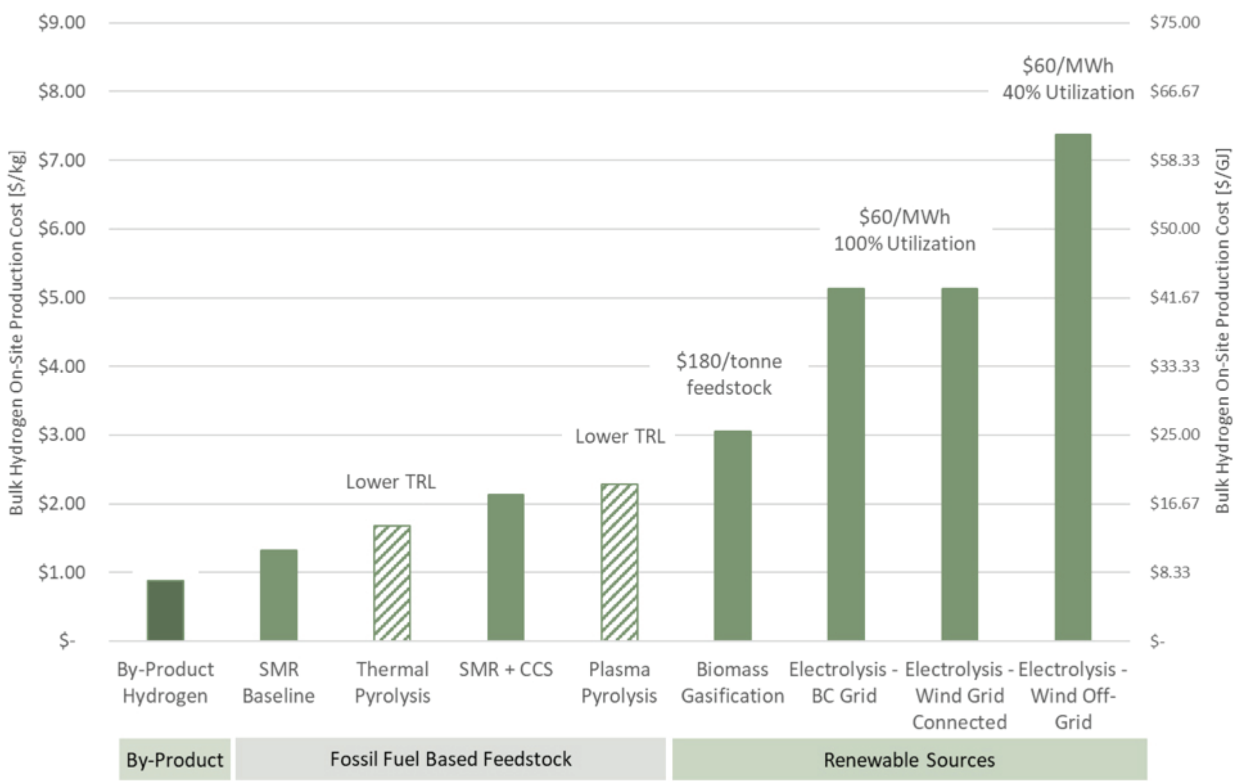


Figure 24. Cost of Bulk On-site Hydrogen Production by Pathway in BC (2030). Production costs are normalized to production scale of 100 TPD

Additional costs will be incurred during transportation, for which three pathways are likely:

1. *Injection into the natural gas grid, leveraging BC's natural gas pipeline infrastructure to store and deliver the hydrogen. In the near-term, hydrogen would be blended at low enough levels into the natural gas that the mixture could be consumed by existing end users without necessitating changes to their equipment. In the longer-term, hydrogen could be blended into natural gas at higher levels and then separated out for hydrogen-specific end users.*
2. *Delivery as a compressed gas, generally done through tube trailer trucks common to the chemical industry.*
3. *Delivery as a cryogenic liquid, also by delivery truck.*

The cost of delivering hydrogen as a compressed gas or a cryogenic liquid are a function of distance; estimated costs are shown in Figure 25.

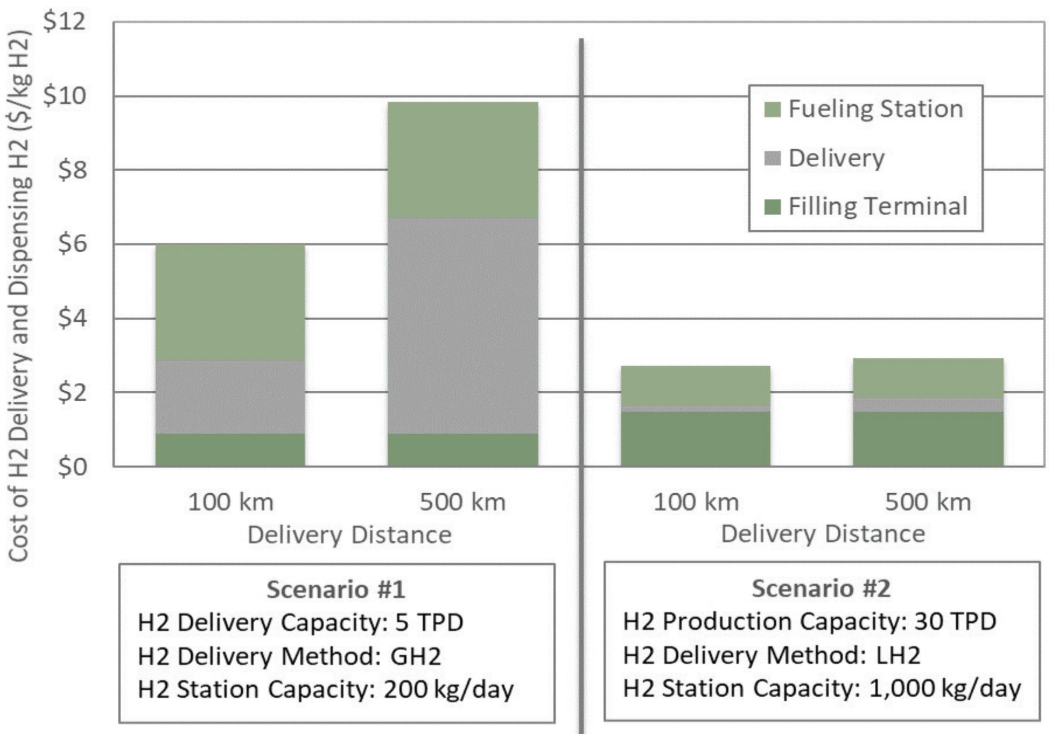


Figure 25. Truck-based delivery cost for hydrogen as a compressed gas and cryogenic liquid

On a per-kg basis, it is more economic to deliver hydrogen as a cryogenic liquid, but not all customers consume enough hydrogen to justify the higher capital expenditures liquid hydrogen deliveries require.

A hydrogen production plant might need to produce at least 10 tonnes H_2 per day to warrant investment in a liquefaction plant by the producer. Most end users are likely to use hydrogen in gas form, so would need to install a cryogenic tank on-site and vaporize it prior to use. Ballard Power Systems has such an installation at their Burnaby facility.

3.3 : Carbon Intensity of Hydrogen Production Pathways in BC

The GHG emissions intensity of the hydrogen pathways considered in this report is given in Figure 26 below. For context, it is noted that 1 kg H_2 contains 120 MegaJoules (MJ) of chemical energy. Thus, SMR baseline emissions of 89.1 g CO_2e/MJ is equivalent to 10.69 kg CO_2e/kg H_2.

All the pathways under consideration provide at least a 69% GHG emissions reduction relative to SMR. It is recommended that the Province set a threshold for hydrogen production carbon intensity of 36.4 g CO_2e/MJ going forward. This is consistent with the European CertiHy threshold.[42]

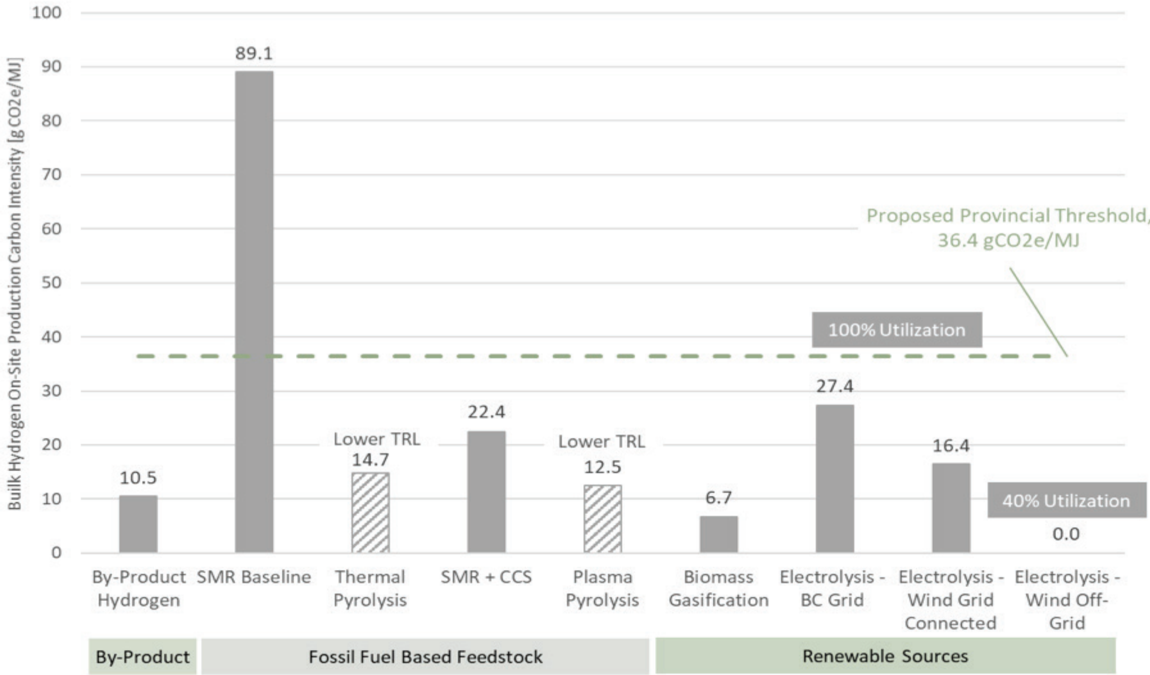


Figure 26. Carbon Intensity of BC's Hydrogen Production Pathways

An important metric for each pathway is the relative cost of carbon mitigation: the hydrogen production cost premium measured in terms of avoided CO_2e emissions. This metric measures the cost effectiveness of each hydrogen production pathway, relative to the emissions reductions it offers over SMR. Figure 27 shows this cost of carbon mitigation for each pathway.

42 *Fuel Cells and Hydrogen 2 Joint Undertaking (2019). Hydrogen Roadmap Europe: A Sustainable Pathway for the European Energy Transition. Retrieved from* https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

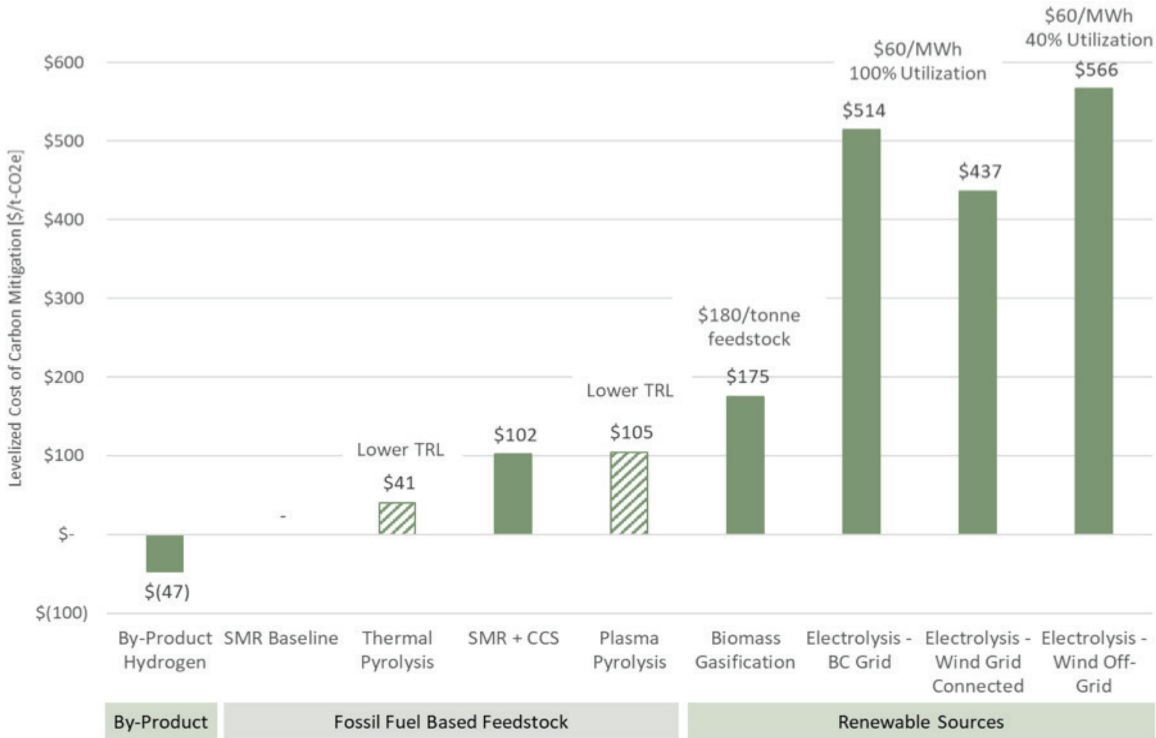


Figure 27. Cost of Carbon Mitigation by Hydrogen Production Pathway in BC (2030)

This chart shows by-product hydrogen to be the most cost-effective means of procuring hydrogen, relative to the avoided GHG emissions. Hydrogen supply from this pathway should be prioritized.

While Figure 24 showed that natural gas-based hydrogen pathways offer the lowest-cost hydrogen supply and Figure 26 showed that renewable hydrogen pathways offered the greatest emissions reductions potential, Figure 27 shows that the natural gas pathways have a lower cost of carbon mitigation.

The inference is that with prevailing price structures, natural gas-based hydrogen production pathways will be critical for cost-effective hydrogen production in the Province. If prevailing natural gas prices rise, perhaps through access to export markets, or if biomass or renewable electricity costs fall, perhaps through public policy measures, preferred rate tariffs or technology development, the cost comparisons would need to be revisited.

3.4 : Hydrogen Availability in BC

Each production pathway can supply different amounts of hydrogen based on the Province's natural resources. Figure 28 and Figure 29 show hydrogen supply curves against production cost; Figure 28 does so for all evaluated sources of hydrogen, while Figure 29 does so only for renewable pathways.

Industrial by-product hydrogen is the lowest-cost source of supply, and it can currently supply approximately 18.5 tonnes per day or 6, 800 tonnes per year.

BC's production capacity is estimated to be in excess of 2.2 million tonnes per year, positioning it to satisfy not just provincial demand but also proving excess capacity that could be exported.

Appendix C outlines the key assumptions underpinning the calculations for both hydrogen cost and availability above.

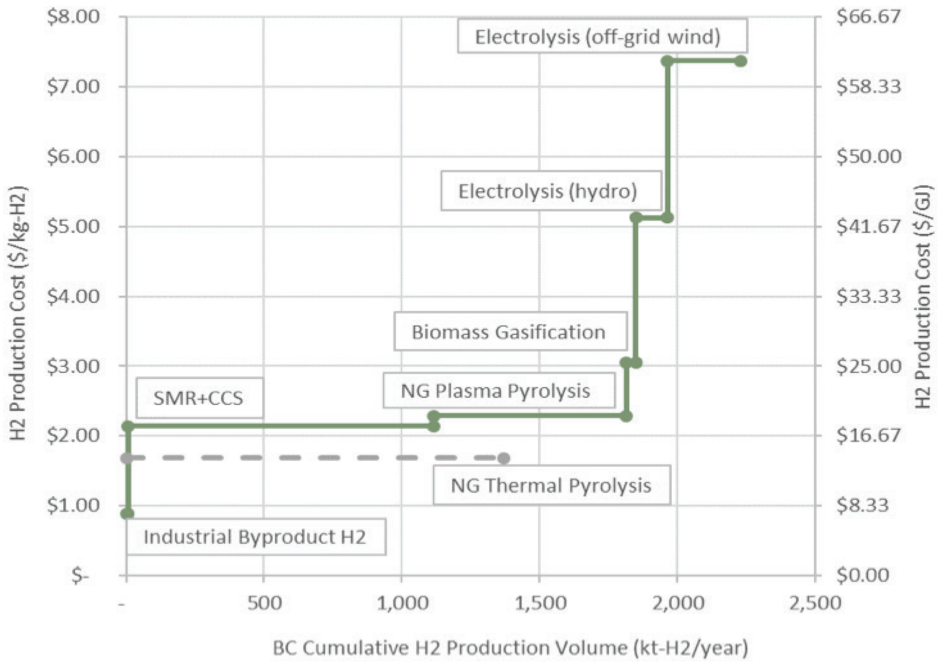


Figure 28. Estimated Hydrogen Production Price and Maximum Annual Volume by Pathway in BC (2030)

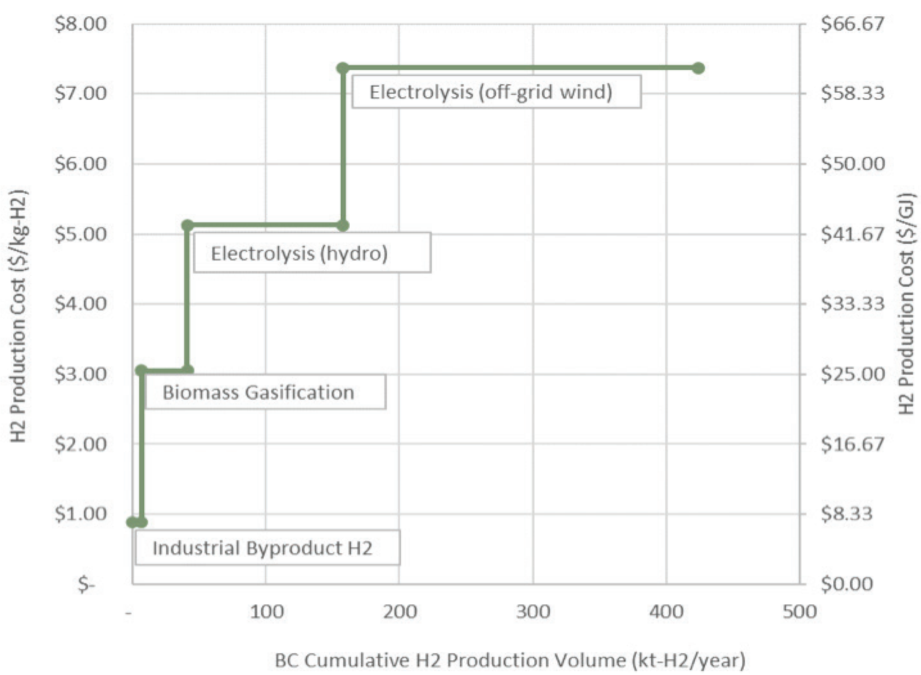


Figure 29. Estimated Hydrogen Production Price and Maximum Annual Volume by non-Fossil Fuel Pathway in BC (2030)

While there are uncertainties in potential production volume for each pathway, uncertainty in hydroelectric capacity warrants elaboration. The Province's CleanBC plan and the more recent City of Vancouver's Climate Change Emergency Response[43] focus on the electrification of transportation and the built environment will tend to increase hydroelectricity consumption; falling electric demand in BC's industrial sector[44] and the deployment of other renewable energy will tend to decrease it.

BC Hydro's peak capacity forecast does not show excess capacity after 2031[45], but the forecast load factor was not provided as input to the study. Both total electricity production and the shape of the load curve are important to accurately model the economics and capacity of electrolyzer development. BC Hydro has indicated that they build capacity to match demand. The values forecasted above for 2030 and 2050 for hydroelectric capacity were deemed to be reasonable by BC Hydro, provided adequate advance forecasting is given.

3.5 : Supply Development Approach

In the near-term, the lowest-cost, low-emissions sources of hydrogen will be necessary to maximize hydrogen's potential for decarbonizing BC's economy, complementing other efforts throughout the Province. Higher-cost hydrogen supplies will have greater challenges displacing GHG emissions in the public and private sector, and winning contracts for hydrogen exports.

In the longer-term it will be necessary for the Province to transition to renewable hydrogen sources rather than risk depleting fossil resources.

To that end, it is recommended that the Province support the development of a provincial industry for the production of clean hydrogen, while mandating that an increasing proportion of hydrogen be sourced from renewable feedstocks. This would allow the Province to capitalize on its natural gas resources in the mid-term while establishing a framework for a transition to renewable hydrogen.

Given the availability of low-cost, low-emissions by-product hydrogen from chemical facilities in Metro Vancouver and Prince George, it is recommended that one or more lighthouse projects be developed in the region to capitalize on the resource. When hydrogen demand exceeds by-product hydrogen supply, if large-scale hydrogen production has not begun, supplemental hydrogen could be generated from modular electrolyzers. These could be placed near end user facilities to minimize transportation costs.

Hydrogen liquefaction facilities will be necessary to move hydrogen economically around the Province. To that end, it is recommended that liquefaction facilities be seen as strategic assets to facilitate the decarbonization of the BC economy through hydrogen. Given the proposed lighthouse projects in Metro Vancouver, a nearby liquefaction facility will be critical to lower the delivered costs of hydrogen in the region.

The Peace Region, with ample natural gas, hydroelectric generation capacity, carbon sequestration and wind resources along with existing gas and electric transmission infrastructure could be suitable for large-scale clean hydrogen production, whether from natural gas or electrolysis or both. Hydrogen could be blended into existing natural gas pipelines in the near-term, as plans develop for larger hydrogen-specific deployments.

43 City of Vancouver, Climate Emergency Response. (2019). Retrieved from https://vancouver.ca/green-vancouver/climate-emergency-response.aspx

44 BC Hydro, Transmission Service Rate Design Workshop. (11 October 2018.)

45 BC Hydro, forecast data provided for study.

3.5.1 : Recommendations

Adopt policy that specifies the GHG intensity of hydrogen, rather than limiting to renewable only

- *Set longer-term objectives for transition to renewable hydrogen supplies through establishing tiered thresholds of required renewable content over time*

Prioritize development of large-scale, low carbon hydrogen supply infrastructure and strategic hydrogen liquefaction and distribution assets in the Province

- *Set a threshold for the GHG intensity of the hydrogen for all provincially funded projects and stipulate that there must be a transition plan for hydrogen to be produced within the province during the project*

Develop flexible, lower cost electricity rate schedule to encourage production of green hydrogen

- *In near term, small, distributed electrolyzers will require lower electric rates*

Lighthouse project: Support a study to look at the potential for centralized hydrogen production and transport from the Peace region, both through the NG pipeline and as liquid through liquefaction plant

BC HYDROGEN PIPELINE

The Peace Region of BC, with extensive gas reserves, CO_2 sequestration potential, hydroelectric generation capacity and wind resources, coupled with an abundant fresh water supply, could become a centralized large-scale producer of clean hydrogen supplying not only BC, but also the US Pacific Northwest and California.

There is potential to use the existing NG grid and inject large amounts of hydrogen and create a blended NG/ H_2 gas stream. Liquefaction coupled with rail or road transport would enable delivery of pure hydrogen. A 'big bold goal' would be to construct a dedicated hydrogen pipeline that runs from the Peace Region right down to California. This would be built with a view to future energy systems, rather than one retrofitted to the hydrocarbon energy systems of the past. There could also be potential to run the pipeline east into Alberta. This carbon-free energy pipeline could provide a means for both provinces to transmit carbon-free energy derived either from renewable resources or fossil resources where the carbon is sequestered directly at the source of extraction, thereby alleviating many of the environmental concerns connected to existing pipeline projects under development.

4.0 : Hydrogen's Role in Decarbonizing BC's Energy System and Economic Sectors

Given the Study goal of identifying roles hydrogen can play in BC's decarbonization efforts, an evaluation of economic sectors in the Province was made, with the following analysis for each sector:

- *Baseline for energy use and emissions;*
- *Opportunities for hydrogen based on technical and commercial factors;*
- *Sector-specific challenges or barriers, and policy recommendations to overcome these;*
- *Adoption scenarios based on factors such as technology maturity, cost, and pertinent and potential policies and regulations.*

4.1 : Natural Gas

4.1.1 : Baseline

As per Figure 30 below, natural gas represents 30% of BC energy consumption and 80% of the Province's energy production.[46] As such, it is an important energy source and a vector for economic development. The upstream oil and gas sector contributes approximately 10,000 jobs and almost $1 billion per year in provincial revenues.[47] Extracting hydrogen from oil and gas, and capturing and sequestering the carbon dioxide produced, could provide a path for BC's oil and gas sector to continue supplying energy in a carbon-constrained future.

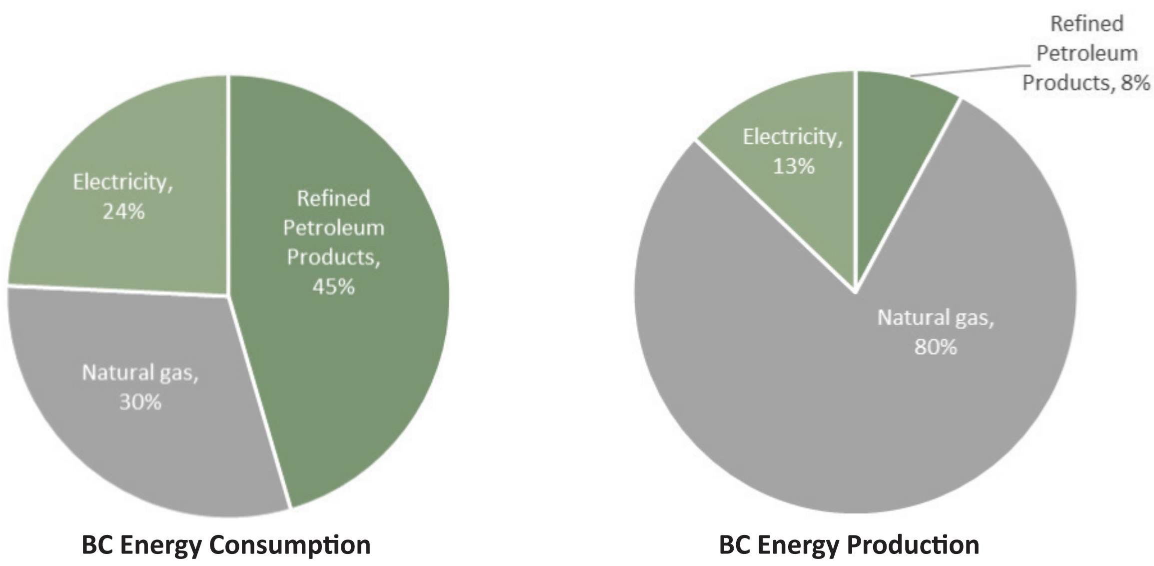


Figure 30. BC Energy Consumption and Production by Energy Type.[46]

46 *Canada's Oil and Natural Gas Producers. (2018). British Columbia's Oil and Natural Gas Industry. Retrieved from* https://www.capp.ca/publications-and-statistics/publications/335337

47 *Ibid 46*

The Province has extensive low-cost natural gas resources which technology innovations have made feasible for extraction. BC's natural gas fields are located in the Northeast of the Province, which overlaps the Western Canadian Sedimentary Basin; the largest are the Montney Formation, the Horn River Basin, the Cordova Embayment and the Liard Basin.

BC's natural gas reserves are estimated at more than 525 trillion cubic feet (tcf), sufficient to meet more than 100 years of natural gas demand at current levels. The Province's approximately 10,000 producing wells produce about 1.5 tcf of natural gas per year, representing about 28% of Canadian natural gas production, only 10% of which is consumed in-province.[48]

Natural gas is distributed around the Province and to neighbouring jurisdictions through networks of pipelines, shown in Figure 31 below. Pipeline operators include Enbridge, FortisBC and Pacific Northern Gas (PNG). BC's extensive natural gas pipeline network represents a significant capital investment and infrastructure for energy supply that presently serves all major population centres in the province.

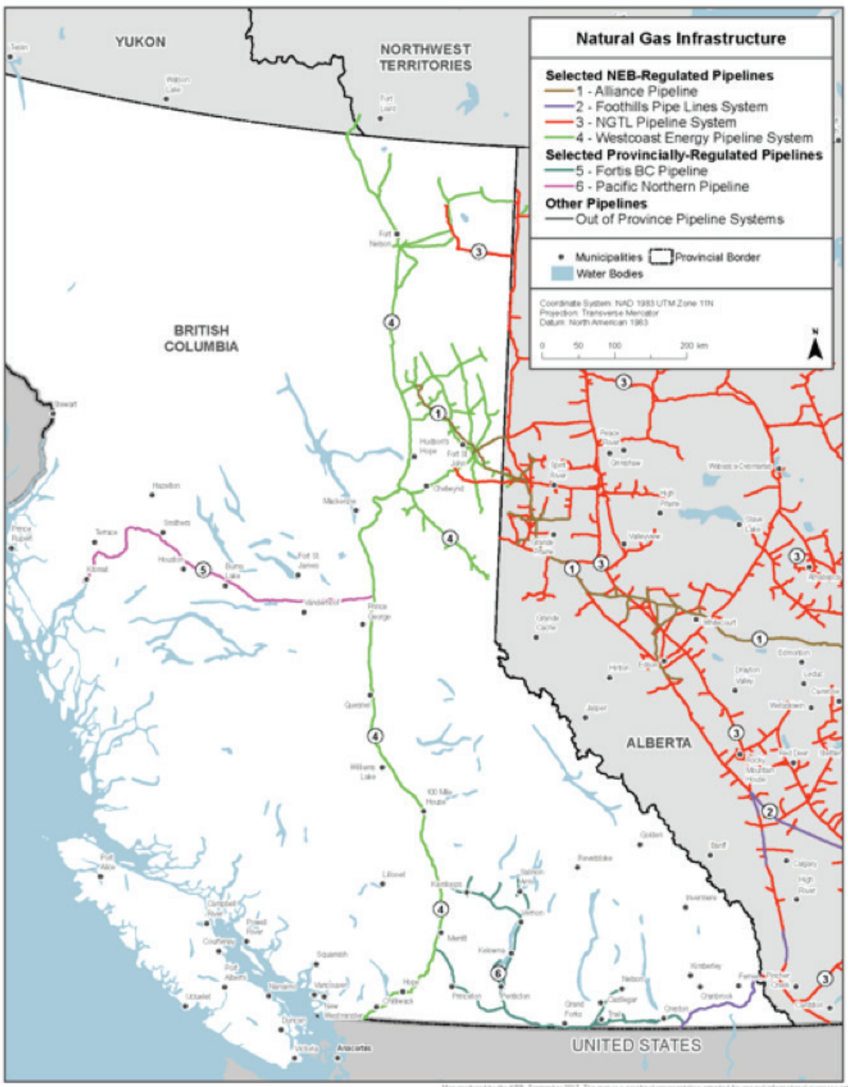


Figure 31. Map of BC Natural Gas Infrastructure [49]

48 Ibid 46.

49 National Energy Board. (2017). Electricity Capacity and Primary Fuel Sources. Retrieved from https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/nrgsstmprfls/mg/bc-fg03-lg-eng.png

The Westcoast Energy Pipeline, operated by Enbridge and sometimes called the Westcoast Transmission System or the BC Pipeline, was built in 1957. It is shown in green in the Figure above. The Enbridge-owned and operated pipeline delivers natural gas from the Western Canadian Sedimentary Basin to Metro Vancouver. It transports about 60% of the natural gas produced in BC and supplies about 50% of natural gas demand in Washington, Oregon and Idaho. The pipeline consists of two systems, Transmission North and Transmission South, both of which are being upgraded to increase capacity beyond the current 2.9 billion cubic feet (Bcf) per day. (This figure is equivalent to approximately 1.0 tcf/year of transmission capacity, as compared to the province's current 1.5 tcf/year of production.)

BC's eastbound natural gas flows through TransCanada's Nova Gas Transmission Limited (NGTL) system, which is also expanding to accommodate new supply from the Montney Formation. The Province's natural gas is also exported to the U.S. Pacific Northwest at the Huntingdon export point, via the Westcoast Pipeline (Enbridge), or exported to the U.S. Midwest via the Alliance Pipeline (Enbridge) and through the Alameda, Saskatchewan export point.

The BC Oil and Gas Commission (OGC) provides oversight for industrial activities, licensing, regulations, growth and associated economic development. Natural gas prices are regulated in the Province through the BC Utilities Commission. Rates vary between customer type – residential, commercial or industrial – and from region to region. Medium-sized commercial operations in BC pay a rate structure for NG supply broadly in line with that outlined in Table 2.

COST ELEMENT	COST ($/GJ)
Cost of Natural Gas	$1.50
Delivery Charge	$3.00
Storage and Transport Charge	$1.20
Total	$5.70

Table 2. Typical Natural Gas Rate Structure, Medium-Sized Commercial Operation[50]

50 Fortis BC. (2019). Business Natural Gas Rates. Retrieved from https://www.fortisbc.com/accounts-billing/billing-rates/natural-gas-rates/business-rates

4.1.1.1 : BC Energy Demand and GHG Emissions

In 2016 BC end use energy demand was 1,165 petajoules (PJ) of which natural gas accounted for 346 PJ, supplying approximately 30% of total energy demand for the province.

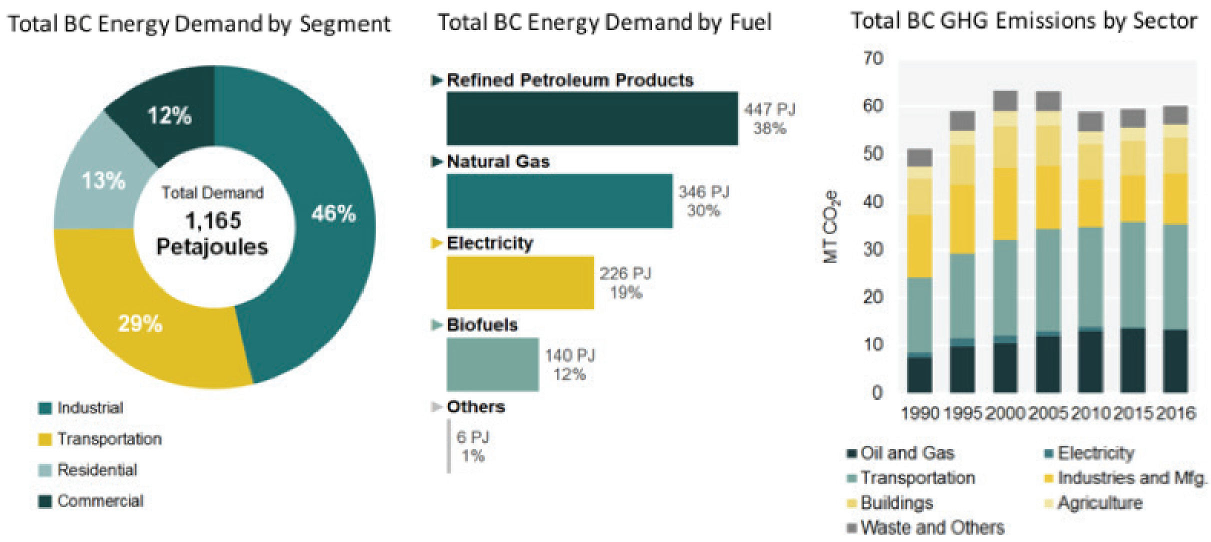


Figure 32. Energy Demand and GHG Emissions in BC[51]

BC's GHG emissions in 2016 were 62.3 Mt of CO_2e.[52] Natural gas plays a role in the largest emitting sectors of the Province's economy: transportation, oil and gas, and the built environment.

4.1.1.2 : Renewable Natural Gas

Biogas is a renewable form of methane gas, generally produced from biomass feedstocks. Renewable Natural Gas, or RNG, is biogas that is cleaned to pipeline-quality standards. It is typically blended with fossil natural gas. Sometimes called bio-methane, it is carbon-neutral and chemically similar to fossil natural gas.

RNG is produced from a variety of resources, including landfill gas (from anaerobic decomposition of organic matter), sewage, farm waste and food waste. Forestry residues and dedicated energy crops can also be cultivated for RNG production, although these have more often been considered for liquid fuels production. The major benefit of RNG production is that the methane that is already naturally produced from waste is captured and utilized before it can escape to the atmosphere.

Given its feedstocks, RNG is a carbon-neutral fuel that can displace fossil natural gas and the upstream GHG emissions associated with its production and supply. Recent studies have suggested that anywhere from 5% to 20% of current natural gas demand could be met with RNG.[53] That said, at present only 0.3% of natural gas consumption in the Province consists of RNG.[54]

51 *National Energy Board. (2019). Provincial and Territorial Energy Profiles – British Columbia. Retrieved from https://www.neb-one.gc.ca/nrg/ntgrtd/mrkt/nrgsstmprfls/bc-eng.html*

52 *British Columbia Provincial Government. (2018). Provincial Greenhouse Gas Emissions Inventory: 2016 Provincial Inventory. Retrieved from https://www2.gov.bc.ca/gov/content/environment/climate-change/data/provincial-inventory*

53 *Alberta Research Council - Potential Production of Methane from Canadian Wastes*

54 *Provided by FortisBC during Stakeholder workshop #1.*

One barrier for RNG is its cost of production, which ranges from $6 to $45/GJ depending on plant size, feedstock, and location, and in most cases is significantly higher than fossil-derived natural gas. Other barriers to RNG adoption include lack of standards, dispersed feedstock supply and geographical constraints for pipeline delivery. Nevertheless, the most attractive sources of renewable biogas, such as landfill gas, can yield energy supply in the form of RNG at half the cost of electricity in British Columbia, and these sources of renewable and carbon-neutral energy are being rightly exploited in BC and elsewhere.

4.1.2 : Opportunities for Hydrogen

4.1.2.1 : Hydrogen's Role in Decarbonizing the Natural Gas Grid

Hydrogen can be blended into the natural gas grid; if cleanly generated it can reduce the GHG emissions intensity of the delivered blend. Large-scale demonstration and lighthouse projects have been undertaken in the past decade. At relatively low concentrations of 5-15% hydrogen by volume, this approach does not appear to increase risks associated with utilization of the gas blend in end use devices such as household appliances, for overall public safety, or the durability and integrity of the existing natural gas pipeline network.[55]

The blending of hydrogen into natural gas pipelines has also been proposed as a means of delivering pure hydrogen to markets; separation and purification technologies could separate hydrogen downstream of the injection points and closer to end users. Blending can delay costs associated with building dedicated hydrogen pipelines or other costly infrastructure during early market development.

4.1.2.2 : Hydrogen's Role in the CleanBC 15% Renewable Gas Target

The CleanBC plan establishes a target of 15% renewable content for natural gas consumption in industrial, commercial and residential sectors in BC by 2030. The Province, FortisBC and PNG are evaluating the expanded use of RNG from wastewater treatment plants, landfills and the anaerobic digestion of agricultural waste. While these sources of renewable biogas supply are an excellent resource for scaling RNG production in the province, challenges remain in terms of meeting the 15% RNG target by 2030 at a cost structure that competes with incumbent fossil-based natural gas. This report recommends adopting low-cost, low carbon hydrogen production for natural gas grid injection as a means to complement more traditional RNG supply methods and meet the Province's renewable gas targets.

It is recommended that all sources of low carbon hydrogen qualify towards the CleanBC target given the primary objective of decarbonization. Defining the CleanBC target as "Renewable Gas" could restrict the Province's ability to cost-effectively decarbonize natural gas energy services.

55 *Melaina MW., et al. (2013). Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues. National Renewable Energy Labs Technical Report 5600-51995. Retrieved from* https://www.nrel.gov/docs/fy13osti/51995.pdf

THE ORKNEY ISLANDS HYDROGEN COMMUNITY

Orkney is a group of islands off the north coast of Scotland with abundant wind, tidal, and wave energy resources. Orkney aims to establish a sustainable hydrogen supply chain to replace fossil fuels with clean, locally-sourced energy. To minimize curtailment, excess electricity powers a 500 kW electrolyzer on Eday Island and a 1 MW electroyzer on Shapinsay Island to produce hydrogen. The compressed hydrogen is transported on a storage trailer via truck and ship to Kirkwall where it is either run through a 75 kW fuel cell to power the local electricity grid when there is not enough renewable electricity being generated or fuels FCEVs. Waste heat produced from the fuel cell is piped into nearby buildings. Eventually, the hydrogen will also be used to power passenger and vehicle ferries between the islands and the mainland.

Hydrogen can contribute to meeting the 15% Renewable Gas target through two principal pathways: (1) direct injection, or (2) methanation/biomethanation through the Sabatier reaction. Methanation combines CO_2 with hydrogen to produce synthetic methane and steam, according to the reaction below:

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O + \text{energy}$$

Synthetic methane production has the advantage of providing a gas supply that is chemically similar to fossil-based natural gas and can be added to the pipeline network with virtually no restriction. However, the methanation process adds cost, which makes it less favoured to direct grid injection of low carbon hydrogen.

- *Prevailing natural gas costs are on the order of \$4/GJ.*
- *Low carbon hydrogen pathways range from \$2 to \$5/kg H_2, equivalent to \$17 to \$42/GJ.*
- *Approximately 10 kg of H_2 are required to produce 1 GJ of synthetic methane, in addition to capital and operating expenditures for the Sabatier process, meaning synthetic methane would be the most expensive option.*

Therefore, strategies for injecting low carbon and/or renewable gas into the natural gas pipeline network will always favour direct hydrogen injection over synthetic methane production, provided hydrogen injection levels are acceptable to prevailing pipeline networks and end use technologies. As such, synthetic natural gas production is expected to play only a minor role in meeting the CleanBC 15% Renewable Gas target.

As hydrogen has a lower heating value than natural gas, its injection into natural gas networks will result in a mixture with a lower heating value on a volume basis. Delivering the same amounts of energy to end users would therefore necessitate increased volumetric flows. For example, injecting 10% H_2 by volume will require the total volumetric flow rate in the pipeline to increase by ~ 8% compared to pure natural gas. At 40% hydrogen, the total volumetric flow rate must increase by 40% indicating a slightly non-linear trend.

To accommodate higher flows, pipelines and distribution networks will need to increase system pressure and increase the density of the gas mixture flowing through the pipeline. Pipelines' pressure ratings may therefore constrain the amount of hydrogen injection into natural gas infrastructure, along with the compatibility of end users' appliances as hydrogen concentrations increase.

Hydrogen injection limit concerns could be circumvented by localizing portions of the natural gas infrastructure or end customers who can tolerate higher hydrogen concentrations. The 15% Renewable Gas target is a provincial annual average, and so could be met if selected pipelines and end users converted to renewable or low carbon hydrogen, even if the rest of the province remained on fossil-based natural gas. For example, if the PNG pipeline system terminating at Kitimat was converted to 100% hydrogen, it would fulfill 2.3% of the 15% Renewable Gas requirement.

DECARBONIZING THE LNG SECTOR

In October 2018, the Government of British Columbia approved the construction of LNG Canada's export terminal in Kitimat; an export license has been awarded for 40 years. The capacity of the project is 26 Mt per year of LNG exports, expected to be deployed in two stages, the first of which will build two LNG trains with a total capacity of 13 Mt/year.

At full capacity, total emissions for the LNG Canada project are expected to be 6.9 Mt CO_2e/year. Of these emissions, about one half are due to upstream and pipeline emissions – mostly caused by leaks, or "fugitive" methane -- and the balance relates to LNG Canada's liquefaction plant. Currently, power for the facility is expected to come from natural gas.

The cost of natural gas for the Kitimat terminal is estimated to be about \$3/GJ. This is equivalent to an electricity cost of \$11/MWh, much lower than BC Hydro's \$60/MWh industrial rate. If the terminal's power consumption were fully electrified with hydroelectricity, there would be a decrease of approximately 3.0 Mt CO_2e/year, representing about 42% of the project's overall emissions.

Clean hydrogen could be used in place of natural gas to power the LNG terminal and reduce its environmental footprint. The hydrogen could be run through the turbine to generate clean power and significantly reduce the emissions associated with producing LNG in the Province.

If electrolysis was used to generate renewable hydrogen for the 15% Renewable Gas requirement, it would represent a significant new electrical load for the Province. Meeting just a third of the CleanBC target in this manner would require approximately 100,000 tonnes per year of hydrogen, representing an average load of approximately 700 MW. As this exceeds BC Hydro's surplus capacity, and the Province has committed to self-sufficiency in electricity, it would be necessary for some renewable hydrogen to be derived from biomass or for new renewable electricity projects to come online.

4.1.3 : Challenges and Barriers

Blending hydrogen into natural gas networks can significantly reduce GHG emissions if low-emission hydrogen is used. Implementing hydrogen blends into the natural gas pipeline network however introduces considerations of composition, pressure, material compatibility and appliance operation, and in some cases hydrogen extraction, to ensure a robust gas delivery system is achieved.

Embrittlement

Some metal pipes can degrade when exposed to hydrogen over long periods, particularly for the higher hydrogen concentrations and pressures that may occur when it is injected into high-pressure natural gas transmission systems. Embrittlement effects depend on the type of steel and on operating conditions and must be assessed on a case-by-case basis.

Natural gas transmission pipelines are typically made of high-strength steels, with diameters of 4–48 inches, operate at high pressures of 600–2,000 psi_g (42–139 bar) and are usually wrapped/coated and cathodically protected against corrosion. Because of the high strength steels employed and the high pressure of operation, transmission pipelines can be susceptible to hydrogen embrittlement. Therefore hydrogen concentrations are more limited in transmission networks. Nevertheless, the high pressure and large throughput of gas in transmission networks can translate into significant hydrogen volumes, even if conservative grid injection levels of 5-10% by volume are employed.

Steel and polyethylene (PE) are the dominant materials for natural gas distribution systems. The metallic pipes used in the lower-pressure natural gas distribution systems are usually made of low-strength steels, and these materials are not generally susceptible to hydrogen-induced embrittlement under normal operation. Other metallic pipes including iron (ductile, cast and wrought) and copper that are sometimes used in natural gas distribution are also free from embrittlement concerns. Town gas, containing approximately 50% H_2, was in common use in Europe prior to the switch to natural gas, and continues to be used in some jurisdictions, including Hong Kong.[56]

There are no major concerns about hydrogen aging the polyethylene (PE), polyvinylchloride (PVC) or elastomeric materials more common in recent natural gas distribution networks.

While the allowable concentrations of hydrogen in natural gas pipeline networks remains an area of active research and evaluation, recent studies have concluded that transmission pipelines can accept hydrogen concentrations of 5% (by volume) with minimal risk.[57] Distribution networks have been judged able to accept hydrogen concentrations of up to 25% with minimal risk and as high as 50% with additional validation. The majority of stakeholders consulted in this study concluded that a hydrogen concentration target of 10% represents a conservative near-term target for hydrogen grid injection into the natural gas network.

56 *Towngas, Gas Production. The Hong Kong and China Gas Company. Retrieved from* *https://www.towngas.com/en/About-Us/Hong-Kong-Gas-Business/Gas-Production*

Pipeline Standards and Policy

The amount of hydrogen presently allowed in natural gas infrastructure is limited by country-specific standards and regulations. In certain countries, hydrogen injection limits have been established, ranging from less than 1% to as high as 12% H_2 by volume (see sidebar).

Hydrogen injection standards have yet to be established in British Columbia and elsewhere in North America. The Canadian Gas Association was interviewed for this study and anticipates the release of a report advising that hydrogen blending of up to 5% by volume is acceptable in the near-term.

Technical specifications and interface requirements for hydrogen blending will need to be established and standardized across affected regions. These steps should be considered for near-term policy development.

The amount of H_2 presently allowed in the NG grid is limited by country-specific standards and regulations

- *UK: 0.1% (vol.)*
- *Belgium: 0.1% (vol.)*
- *Sweden: 0.5% (vol.)*
- *Austria: 4% (vol.)*
- *Switzerland: 4% (vol.)*
- *France: 6% (vol.)*
- *Germany: 10% (vol.)*
- *Holland: 12% (vol.)*

Reference: Review of hydrogen tolerance of key Power-to-Gas (P2G) components and systems in Canada, NRC, July 2017

Pipeline Capacity

For hydrogen blending to occur, hydrogen production capacity must be matched to existing natural gas pipeline capacity. A detailed study of pipeline capacity and injection location must be conducted to optimize hydrogen injection efforts.

Appliances

Natural gas-consuming appliances must be able to operate without impediment on hydrogen-blended natural gas. While most appliances are compatible with hydrogen concentrations of up to 10% H_2 by volume and lower, this is unlikely to be the case for combustion turbines, compressors (which may contain natural gas but leak hydrogen) and CNG tanks.

For higher hydrogen concentrations – in the range of 30% and higher – performance issues may arise with engines, burners, boilers and stoves. Appliance testing and validation for all product models and makes would be necessary to move to these higher hydrogen levels.

Hydrogen Separation

A low-cost method for separating hydrogen from a natural gas stream would be an enabling technology for hydrogen blending, and reduce concerns relating to downstream appliance compatibility. Pressure swing absorption (PSA) technology is mature and could be used to remove hydrogen from a natural gas pipeline. Leveraging the pressure difference between (high-pressure) transmission and (low-pressure) distribution networks could facilitate a low-cost PSA solution for hydrogen separation, and it is recommended that research to this end be supported.

Hydrogen separation technology would be particularly important where downstream natural gas might be used by CNG vehicles, as some Type 3 CNG tanks can only tolerate hydrogen concentrations of less than 2%. An alternative would be to require the replacement of the affected tanks.

Gas Metering

Hydrogen blends can influence the accuracy of existing gas meters. Studies have shown that gas meters would not need to be tuned for low hydrogen blend levels (less than 50% volume).[58]

57 *Yoo Y., et al., (2017). Review of Hydrogen Tolerance of Key Power-to-Gas (P2G) Components and Systems in Canada. NRC-EME-55882. Retrieved from* https://nrc-publications.canada.ca/eng/view/fulltext/?id=94a036f4-0e60-4433-add5-9479350f74de

Contaminants

The potential impact of contaminants associated with hydrogen injection into the natural gas network deserves examination, though this would be less urgent for hydrogen production methods producing relatively pure hydrogen, such as electrolysis methods.

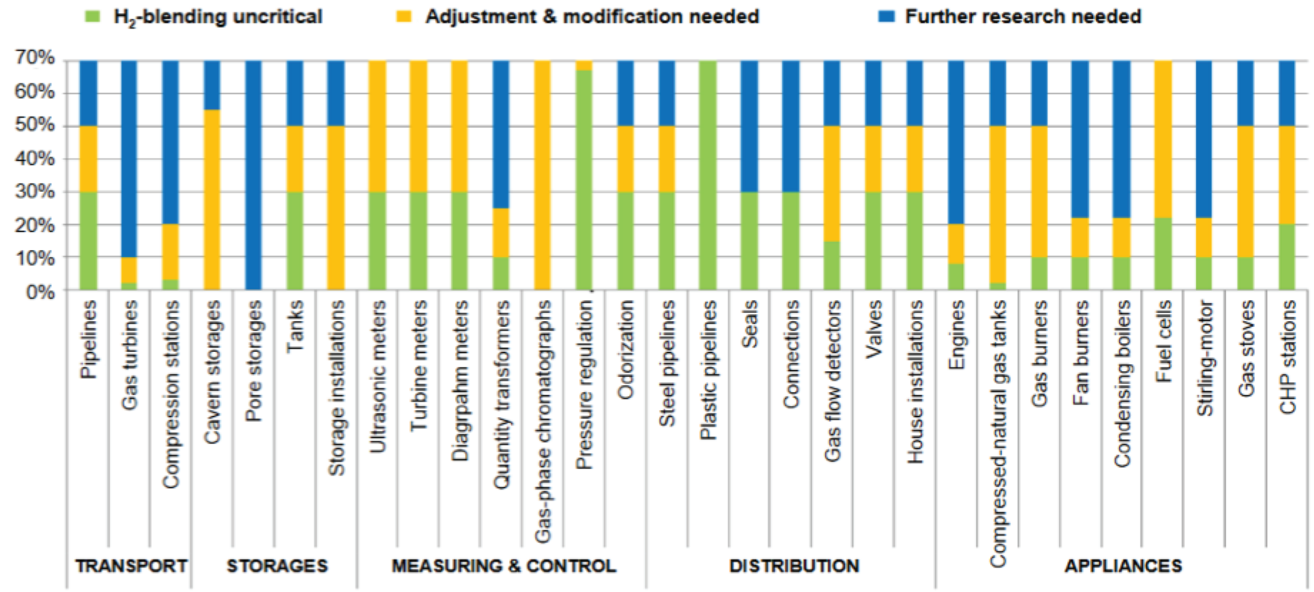


Figure 33. Limit of Hydrogen Blending along the Natural Gas Infrastructure[59]

4.1.4 : Adoption Scenarios

Adoption scenarios that project hydrogen demand through 2050 have been developed on conservative and aggressive cases. The amount of hydrogen introduced into the grid has been defined as a percentage of natural gas volume consumed by the Province's industrial, commercial and residential sectors. Natural gas demand in

58 *Melaina MW, Antonia O, Penev M. (2013). Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues. NREL Technical Report 5600-51995. Retrieved from https://www.nrel.gov/docs/fy13osti/51995.pdf*

59 *SBC Energy Institute. (2014). Hydrogen-Based Energy Conversion. Retrieved from http://www.4is-cnmi.com/feasability/doc-added-4-2014/SBC-Energy-Institute_Hydrogen-based-energy-conversion_Presentation.pdf*

BC was forecasted based on FortisBC's long-term planning report [60] and assuming FortisBC continues to provide 95% of natural gas delivered in the Province.[61] Beyond 2036, which is the last year forecasted in FortisBC's long term planning report, natural gas demand was assumed to remain constant through 2050.

YEAR	BC FORECASTED NATURAL GAS DEMAND (PJ)		
	Non-Transportation	Transportation	Total
2015	202	1	204
2020	203	8	211
2025	205	40	245
2030	208	58	266
2035	212	75	287
2040	212	78	291
2045	212	78	291
2050	212	78	291

Table 3. BC Natural Gas Demand Forecast 2020-2050

The conservative scenario assumes that hydrogen content reaches 10% by volume by 2030 and increases to 20% by volume 2050. The aggressive scenario assumes hydrogen represents 15% by volume by 2030 and increases to 45% by volume by 2050. The scenarios represent plausible pathways to help meet CleanBC renewable gas targets.

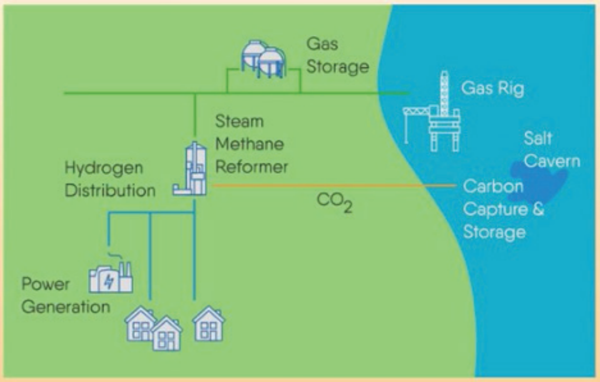
The resulting hydrogen demand curves for natural gas grid injection are given in Figure 34 below.

BC HYDROGEN COMMUNITY

Some regions are exploring the conversion of entire communities and regions to run on 100% hydrogen to decarbonize their energy system. The City of Leeds is one such example and the United Kingdom has developed long-term plans to convert Northern England to hydrogen. The H21 North of England is a detailed engineering solution for converting 3.7 million UK homes and businesses from natural gas to hydrogen, in order to reduce carbon emissions. H21 North of England finds that converting the UK gas grid to hydrogen has the ability to provide "deep decarbonisation" of heat, as well as transport and power generation, with minimal disruption to customers.

In that spirit, BC could adopt a "Big Bold Goal" to convert one of its communities to hydrogen. This could include local hydrogen production, distribution through a pipeline, zero carbon energy delivery to houses running fuel cell cogeneration systems, and a fully zero emission transportation system consisting of light duty FCEVs and transit buses. A smaller community such as Revelstoke, which has an isolated LPG grid, is one such option. A bolder option would be to convert Vancouver Island -- which is at the end of the BC's natural gas pipelines – to 100% hydrogen by 2050.

H21 Leeds City Gate – Amended Concept



60 FortisBC. (2017). FortisBC 2017 Long Term Gas Resources Plan. Retrieved from https://www.bcuc.com/Documents/Proceedings/2018/DOC_50742_B-1_FEI-2017-Long-Term-Gas-Resource-Plan.pdf

61 BC Provincial Government. (2018). Production and Distribution of Natural Gas in BC. Retrieved from https://www2.gov.bc.ca/gov/content/industry/natural-gas-oil/statistics

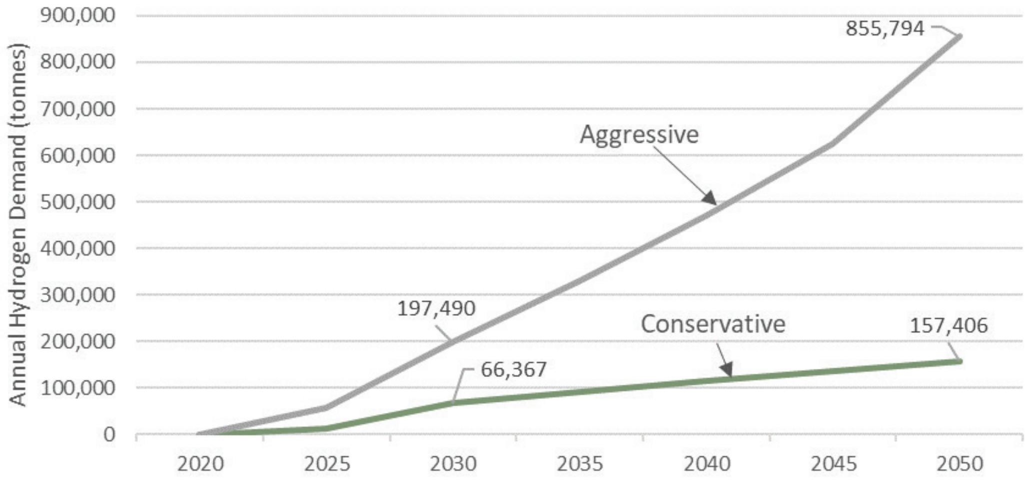


Figure 34. Hydrogen Demand for Natural Gas Grid Injection in BC

These adoption rates of hydrogen into the natural gas grid will result in significant GHG emissions reductions. In 2030, the projected emissions reduction ranges from 0.3 to 0.5 Mt CO_2e/year while in 2050 the projected emissions reductions would range from 0.8 to 2.3 Mt CO_2e/year. The GHG emissions were calculated assuming the hydrogen displaces natural gas based on lower heating values of natural gas of 38.9 MJ/m^3 and hydrogen of 10.8 MJ/m^3. The natural gas carbon intensity was assumed to be 57.9 g CO_2e/MJ[62] and the hydrogen carbon intensity was estimated to be 15.9 g CO_2e/MJ (1.91 kg CO_2e/kg H_2) based on the weighted average of carbon intensity for the different low carbon pathways studied in this report based on capacity in BC. It was assumed that all the hydrogen injected into the grid is burned. If the hydrogen was separated from the natural gas before consumption and run through a fuel cell to generate electricity and heat, the improved efficiency would increase the abated emissions by a factor of at least 2 depending on the energy efficiency ratio (EER) of the equipment.

4.1.5 : Recommendations

Allow all sources of clean hydrogen to qualify as "Renewable Gas"

- *Specify fraction of green hydrogen content to support transition to renewable pathway*

Develop provincial codes and standards for hydrogen blending into the natural gas grid

Change provincial codes to mandate all new gaseous pipelines are compatible with 100% hydrogen

Investigate integration of electricity grid and natural gas grid through low cost hydrogen production

Lighthouse Project: Hydrogen Community Feasibility Study

62 (S&T) Squared Consultants Inc. (2018). GHGenius 5.0d. Calculations conducted by BC Ministry of Energy, Mines and Petroleum Resources Low Carbon Fuels Branch. Retrieved from https://ghgenius.ca/index.php/downloads

4.2 : Transportation

4.2.1 : Baseline

Transportation makes up approximately 37% of total GHG emissions in BC.[63] This sector can be divided into the several broad categories shown in Table 4.

CATEGORY	DESCRIPTION
Light-Duty Vehicles	Light-duty vehicles registered in BC and licensed to operate on roads
Heavy-Duty Vehicles	Heavy-duty vehicles registered in BC and licensed to operate on roads
Off-Road Vehicles	Vehicles not licensed to operate on roads excluding oil & gas, heavy industry, agricultural, manufacturing, construction, and forest resource services.
Domestic Railway and Marine	Locomotives operating in BC and marine vessels registered and fueled in BC
Pipeline Transport	Transportation and distribution of crude oil, natural gas and other products
Domestic Aviation	Canadian registered aircrafts flying domestically within Canada and originating in BC, including commercial, private, and agricultural flights

Table 4. Definition of Transportation GHG Emissions Categories[63]

Figure 35 shows the GHG emissions of each category in BC from 1990 to 2016.

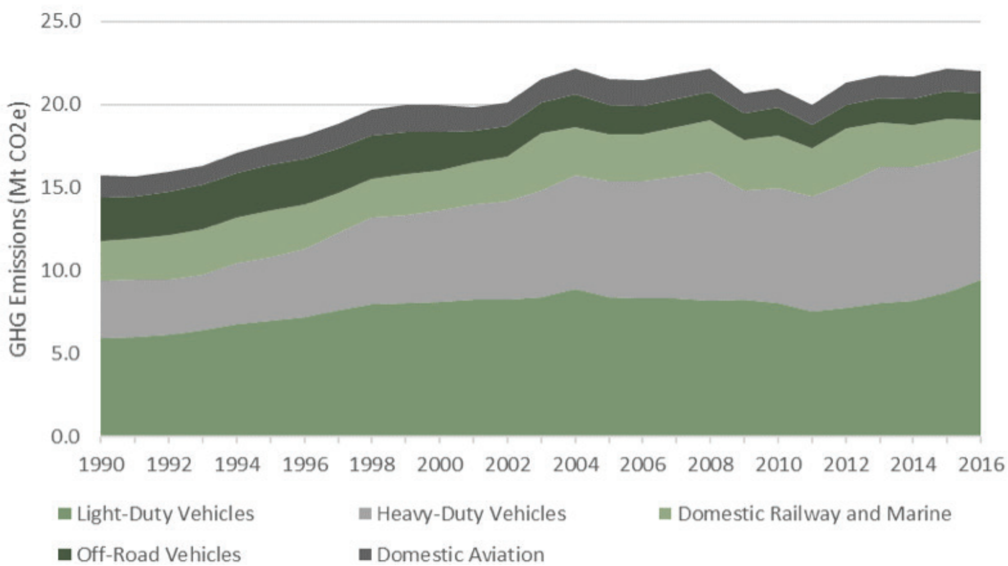


Figure 35. BC Transportation GHG Emissions by Category (1990-2016)[63]

63 *Environment and Climate Change Canada. (2018). National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada, Annex 10. Retrieved from https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b*

Total transportation GHG emissions peaked in 2004, but following a dip to 2011, have trended upward through 2016. Figure 36 shows the percent of total transportation GHG emissions attributable to each category in 2016.

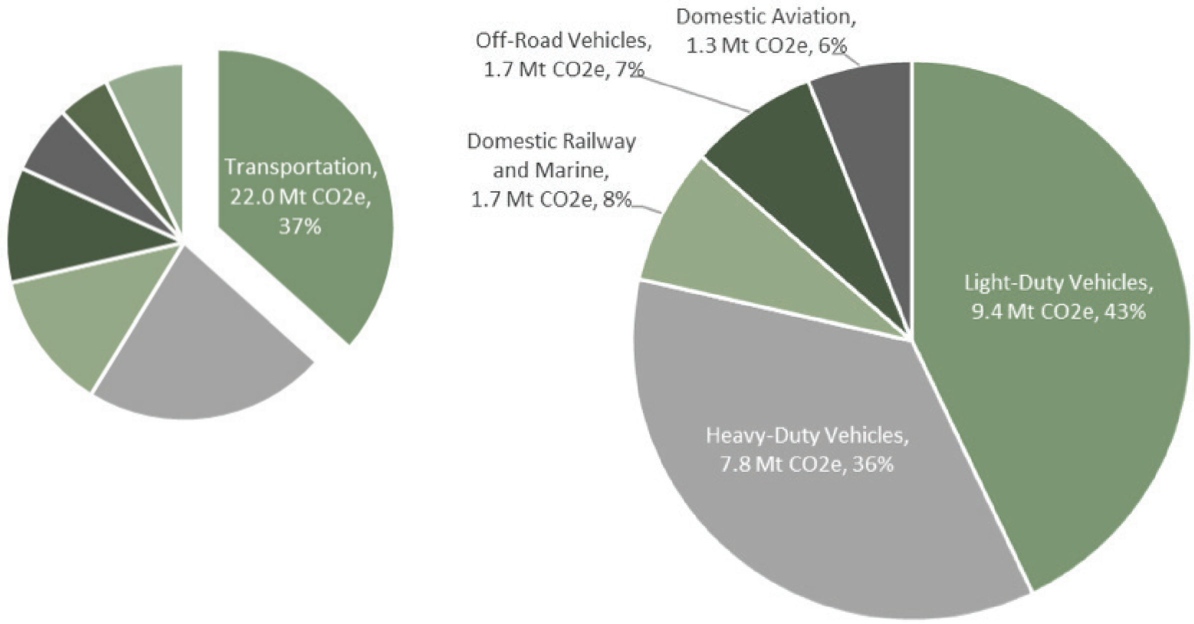


Figure 36. BC Transportation GHG Emissions by Category (2016)[63]

Combined, light and heavy-duty vehicles make up almost four-fifths of BC's total transportation GHG emissions (79%). Domestic railway, marine and aviation comprise 14% of GHG emissions and off-road vehicles make up the remaining 7%.

4.2.1.1 : Light- and Heavy-Duty Vehicle Baseline

Since light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs) are the primary sources of BC's GHG emissions, they are the predominant categories of interest in this study within the Transportation sector.

<table>
<tr><th>VEHICLE TYPE</th><th>NEW VEHICLE REGISTRATIONS (2018)[64]</th><th>REGISTERED VEHICLES (2017)[65]</th><th>PER-VEHICLE GHG/YEAR (2016) (TONNES CO_2E)[63, 65]</th><th>EST GHG/ YEAR (2016) (MT CO_2E)[63]</th></tr>
<tr><td>Light-Duty Vehicles</td><td>219,387</td><td>3,082,813</td><td>3.2</td><td>9.4</td></tr>
<tr><td>Heavy-Duty Vehicles (excluding buses)</td><td>5,788</td><td>165,675</td><td rowspan="2">47.4</td><td rowspan="2">7.8</td></tr>
<tr><td>Buses</td><td>364</td><td>10,211</td></tr>
</table>

Table 5. BC New Vehicle Registrations, Registered Vehicles, and Related GHG Emissions

Light-duty vehicles far outnumber heavy-duty vehicles, but because of the latter's greater size and annual driving distances, each heavy-duty vehicle generates almost fifteen times as many GHG emissions per year: an average of 47.4 tonnes CO_2e per HDVs compared to 3.2 tonnes per LDV.[63, 65]

Public transit accounts for approximately 30% of buses in BC.[65] Public transit fleets are operated by two large agencies: TransLink in Metro Vancouver, and BC Transit in the rest of the province. Table 6 shows the makeup of both agencies' fleets.

TRANSIT VEHICLE TYPE	TRANSLINK[66]	BC TRANSIT[67]
Electric Trolley Bus	262	0
Compressed Natural Gas (CNG) Bus	116	120
Diesel-Electric Hybrid Bus	226	6
Non-Hybrid Diesel Bus	697	683
Gasoline Community Shuttle Bus	147	0
Diesel Community Shuttle Bus	47	0
Marine Vessels	3	0
Conventional Diesel or Hybrid Bus (Unspecified)	48	0
HandyDART (Accessible Transit) Vehicle	307	347
TOTAL	**1,853**	**1,156**

Table 6. Transit Vehicle Fleet Inventory in BC

64 *Statistics Canada. Table 20-10-0002-01 New motor vehicle sales, by type of vehicle. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2010000201*

65 *Statistics Canada. Table 23-10-0067-01 Road motor vehicle registrations, by type of vehicle. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310006701*

66 *TransLink. (2016). Fleet and Technologies. Retrieved from https://www.translink.ca/About-Us/Corporate-Overview/Operating-Companies/CMBC/Fleet-and-Technologies.aspx*

67 *BC Transit. Our Fleet. Retrieved from https://www.bctransit.com/about/fleet*

Translink has been incorporating CNG vehicles into their fleet as a way to reduce emissions. Hydrogen can play a role in CNG vehicles by enabling a greater availability of renewable gas (RG) in the network for operators, like Translink, willing to pay a premium to further reduce emissions. Both Translink and FortisBC are working together to increase the use of RG in BC's transit system.

Although buses are a small percentage of vehicles on the road, they provide an early opportunity for hydrogen adoption as a direct transportation fuel with higher efficiencies because of the high commercial readiness of FCEBs. There are currently 30 FCEBs on roads in California and 22 more in development.[68] The 22 buses to be deployed in the near-term are all manufactured by Canada's New Flyer Industries and incorporate heavy-duty fuel cell modules designed and manufactured by BC's Ballard Power Systems.

Europe is projected to deploy 300 FCEBs by the early 2020's and Japan plans to operate 100 FCEBs for the 2020 Tokyo Olympics.[69]

Jurisdictions around the world are setting aggressive targets to reduce emissions from public transit vehicles, and in some cases are mandating a transition to zero emission fleets. For example, California's Innovative Clean Transit (ICT) ruling in December 2018 legislated that all public transit vehicles in California must be zero emission vehicles by 2040. This has driven transit agencies to consider the challenges of scale deployments of Battery Electric Buses and FCEBs. Several agencies including SunLine Transit, Orange County Transit and Alameda-Contra Costa Transit District are scaling their fleets of FCEBs. They cite FCEBs' longer range, flexibility for route deployment, faster fueling times and improved refueling logistics as advantages over Battery Electric Buses.

4.2.1.2 : Deployments to Date

EV-Volumes.com estimates that 550,000 plug-in electric heavy-duty vehicles (encompassing trucks and buses, plug-in hybrid and battery electric vehicles) had been deployed around the world through 2018. Virtually all these deployments came in China due to strong policy support. EV-Volumes.com tracked 5,800 plug-in electric heavy-duty vehicle deployments in the rest of the world, or one percent of the Chinese total.[70]

Significantly, China's industrial policy has shifted to favour fuel cell vehicles, with a focus on taxis, long- distance buses, urban logistics and long-haul trucks, the latter three being heavy-duty applications.[71] Chinese automotive conglomerate Weichai recently reaffirmed its plans to deploy a minimum of 2,000 commercial fuel cell vehicles containing stacks from BC's Ballard Power Systems.[72]

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68 *California Fuel Cell Partnership. (2019). By the Numbers: FCEV Sales, FCEB, & Hydrogen Station Data. Retrieved from https://cafcp.org/by_the_numbers*

69 *California Fuel Cell Partnership. (2018). Largest Bus Manufacturer Markets Fuel Cell Buses. Retrieved from https://cafcp.org/blog/largest-bus-manufacturer-markets-fuel-cell-buses*

70 *EV-Volumes.com, personal correspondence.*

71 *Bloomberg News. (2018). Senior China Official Urges Shift Towards Fuel-Cell Vehicles. Retrieved from https://www.bloomberg.com/news/articles/2018-12-17/senior-china-official-urges-shift-toward-fuel-cell-vehicles*

72 *Ballard Power Systems. (2019). Ballard Reaches Agreement for $44M Order With Weichai-Ballard JV to Support Initial Fuel Cell Vehicle Deployments in China. Retrieved from http://www.ballard.com/about-ballard/newsroom/news-releases/2019/05/01/ballard-reaches-agreement-for-$44m-order-with-weichai-ballard-jv-to-support-initial-fuel-cell-vehicle-deployments-in-china*

4.2.1.3 : Other Transportation Baseline

Rail

Railway operations in BC are dominated by two large freight operators: Canadian National Railway and Canadian Pacific Railway. Several other rail companies operate short line routes in BC, including BNSF Railway, which travels from the U.S. border to Vancouver, and the Southern Railway of British Columbia, which travels from Vancouver to Chilliwack.

Several passenger railway companies also operate in BC, including VIA Rail, Rocky Mountaineer, Amtrak *Cascades*. TransLink also provides a commuter rail service called the West Coast Express between Metro Vancouver and the Fraser Valley Regional District.

Transport Canada has a Memorandum of Understanding with the Railway Association of Canada to reduce GHG emissions from the rail industry. In 2017, Locomotive Emissions Regulations came into effect, which enforces mandatory emissions standards and reduced idling.

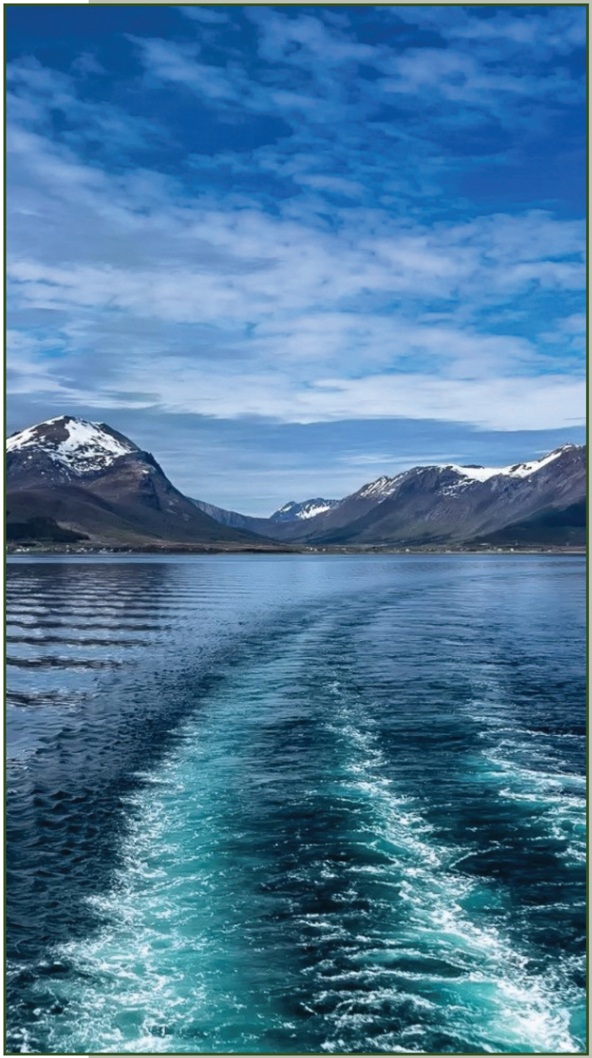
Marine

BC Ferries is one of the world's largest ferry operators, providing vehicle and passenger service on 25 routes between 47 terminals. Their fleet comprises 35 vessels powered by a mix of diesel and liquid natural gas (LNG). In fiscal 2018, the company consumed 118.2 million litres of diesel and 2.0 million diesel litres-equivalent at a cost of $102.5 million, representing its second-largest operating expense.[74]

BC Ferries is a leader in transitioning to lower carbon and more efficient fuel sources. They were the first passenger ferry system in North America to adopt LNG, and by 2020 project LNG will make up 22% of their fuel consumption.Their diesel vessels currently consume an average of 5% biodiesel, making them one of the largest biodiesel consumers in the Province. They have also been using ultra-low sulfur diesel in all diesel applications since 2007.[74]

HYDROGEN FERRIES

Norway plans to deploy the world's first hydrogen-electric ferry in 2021. Norled is leading the development of the ferry, which will carry 299 passengers and 80 vehicles. According to the development contract, at least 50% of the energy requirement must come from hydrogen.[73] Norway is aggressively focused on marine vessel emissions, as the marine fleet accounts for approximately 30% of the country's total NOx emissions.



73 *World Maritime News. (2019). Norled to Build World's 1st Hydrogen-Electric Ferry. Retrieved from https://worldmaritimenews.com/archives/268356/norled-to-build-worlds-1st-hydrogen-electric-ferry/*

74 *British Columbia Ferry Services Inc. (2018). Fuel Management Plan Outcomes in Performance Term Four. Retrieved from https://www.bcferries.com/files/AboutBCF/2018_09_28_PT4_fuel_management_outcomes_report.pdf*

Aviation

There are 5,198 aircraft registered in BC. The majority are airplanes (82%) and helicopters (16%); a small number of gliders, gyroplanes, and balloons are also registered. Nearly three quarters of aircraft are privately owned (74%) and almost the entire balance (26%) is used for commercial purposes. The exceptions are a small number of airplanes (5) and helicopters (11) owned by the Provincial government.[75]

In 2012, the Federal Government published Canada's Action Plan to Reduce GHG Emissions from Aviation, which sets target to improve fuel efficiency by 1.5%, measured in litres of fuel per 100 revenue tonne-kilometers, by 2020 compared to a 2008 baseline.[76] In 2019, BC airline Harbour Air announced plans to electrify its fleet of airplanes. While an excellent solution for the airline's typical flights, batteries are not expected to be practical for larger flights.

4.2.1.4 : Transportation Hydrogen Baseline

From 2009 to 2014, BC Transit deployed 20 fuel cell electric buses in Whistler. These comprised almost the entire Whistler bus fleet, which totaled 23 buses (26 during peak season). During this period, it was the largest single deployment of fuel cell electric buses in the world. The buses drove over 4 million kilometers and avoided more than 5,835 tonnes of CO_2e emissions.[77]

While this was an important flagship deployment for the Province timed with the 2010 Winter Olympics, the buses suffered reliability and operating cost challenges. Not being able to secure a local supply of hydrogen in BC, liquid hydrogen was trucked in from Quebec, adding to operating costs, and leading to negative public perception. As a result, BC Transit decided to retire the fleet in 2014.

In 2015, Hyundai selected BC as its first market for FCEVs in Canada, leasing up to 10 Tucson FCEVs.

At time of writing there are nine light-duty FCEVs on-the-road in BC: three Hyundai Tucsons, five Hyundai Nexo, and one Toyota Mirai. Since 2016, BC-based Hydra has run a pilot project demonstrating a heavy-duty hydrogen/diesel co-combustion engine on a semi-trailer, logging approximately 250,000 km of operation.

Hydrogen has yet to be deployed to power marine vessels, railway locomotives, off-road vehicles or aircraft in BC.

4.2.2 : Opportunities and Challenges

Hydrogen technologies can significantly reduce GHG emissions from the transportation sector.

Battery electric vehicles (BEVs) and FCEVs are complementary types of Zero Emission Vehicle; both will play roles in decarbonizing transportation in the Province.

Batteries provide greater "well-to-wheel" efficiency for transportation than fuel cells but offer lower energy storage density than compressed or liquid hydrogen tanks. That said, batteries remain very well-suited for many light-duty vehicle applications, and for heavy-duty vehicles with shorter routes.

Though battery fast charging speeds have increased with ever-more powerful DC Fast Chargers (DCFCs) hydrogen refueling remains faster, and the infrastructure has potential to be more scalable and economic at mass scale. This is because fuel cell vehicles can be expected to refuel at regular intervals. Because BEVs can be charged more slowly but more cheaply at home, at work, or at publicly available "Level 2" stations, drivers can be expected to use DCFCs sparingly – except on weekends and long weekends, when overcrowding is likely to occur. In short, regular fueling from FCEV owners provides a path to return-on-investment for owners of hydrogen stations.

75 *Transport Canada. (2018). Canadian Civil Aircraft Registrar. Retrieved from http://wwwapps.tc.gc.ca/Saf-Sec-Sur/2/CCARCS-RIACC/DDZip.aspx*

76 *Federal Government of Canada. (2018). Summary: 2017 Annual Report – Canada's Action Plan to Reduce Greenhouse Gas Emissions from Aviation. Retrieved from http://www.tc.gc.ca/eng/policy/2017-greenhouse-gas-emmissions-aviation-annual-report-summary.html*

77 *Eudy L., Post M. (2014). BC Transit Fuel Cell Bus Project Evaluation Results: Second Report. National Renewable Energy Laboratory. Retrieved from https://www.nrel.gov/docs/fy14osti/62317.pdf*

For these reasons and others, a variety of studies have concluded that hydrogen infrastructure can be less expensive, on balance, as vehicle penetration increases.[81]

Fuel-related GHG emissions per km were calculated using provincially-established carbon intensities for gasoline and electricity as a transportation fuel, as well as efficiency equivalent ratios. The carbon intensity used for gasoline was 3.2 kg CO_2e/L[82] with an efficiency of 10 L/100km. The carbon intensity for electricity used was 0.05 kg CO_2e/kWh[83] with an efficiency equivalent ratio (EER) of 3.4.[84] The carbon intensity for hydrogen was established to be 15.9 g CO_2e/MJ (1.91 kg CO_2e/kg H_2) based on the weighted average of carbon intensity for the different low carbon pathways studied in this report based on capacity in BC.

Figure 37 shows the calculated per kilometer GHG emissions from a gasoline, fuel cell electric, and battery electric vehicles.

IS ELECTRIFICATION THE ANSWER?

While the Province should do everything it can to leverage its renewable electricity infrastructure to reduce GHG emissions, electrification has limitations.

Consider the light-duty vehicle transportation sector. In 2017, there were 3 million light-duty vehicles registered in BC [78]. Assuming an average annual distance traveled of 15,000 km, fuel efficiency of 10 L/100-km, and an energy effectiveness ratio of 3.4, the resulting electricity demand would be 46 PJ per year if all of these vehicles were electric.

This would require an increase in annual electricity generation of 21% [79], equivalent to 2.5 Site C projects.[80] Electrification of the medium- and heavy-duty transportation sectors would roughly double this effect. Hydrogen powered vehicles will allow BC to leverage its abundant natural gas supplies while reducing emissions if the hydrogen is produced via SMR or Pyrolysis with carbon capture and sequestration.

78 *Statistics Canada. Table 23-10-0067-01 Road motor vehicle registrations, by type of vehicle. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310006701*

79 *Canada National Energy Board (2017). Canada's Energy Future 2018: Energy Supply and Demand Projections to 2040. Retrieved from https://apps.neb-one.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA*

80 *BC Hydro. (2019). Site C Clean Energy Project: Site C At a Glance. Retrieved from http://sitecproject.com/sites/default/files/fact-sheet-sitec-project-201905_0.pdf*

81 *Robinius M, et al., (2018). Comparative Analysis of Infrastructures: Hydrogen Fueling and Electric Charging of Vehicles. Forschungszentrum Jülich GmbH Zentralbibliothek. 1866-1793. Retrieved from https://www.researchgate.net/publication/322698780_Comparative_Analysis_of_Infrastructures_Hydrogen_Fueling_and_Electric_Charging_of_Vehicles*

82 *(S&T) Squared Consultants Inc. (2018). GHGenius 5.0d. Calculations conducted by BC Ministry of Energy, Mines and Petroleum Resources Low Carbon Fuels Branch. Retrieved from https://ghgenius.ca/index.php/downloads*

83 *Ibid.*

84 *British Columbia Provincial Government. (2017). Regulation 394/2008 O.C. 907.2008. Greenhouse Gas Reduction (Renewable and Low Carbon Fuel Requirements) Act. Retrieved from http://www.bclaws.ca/civix/document/id/lc/statreg/394_2008*

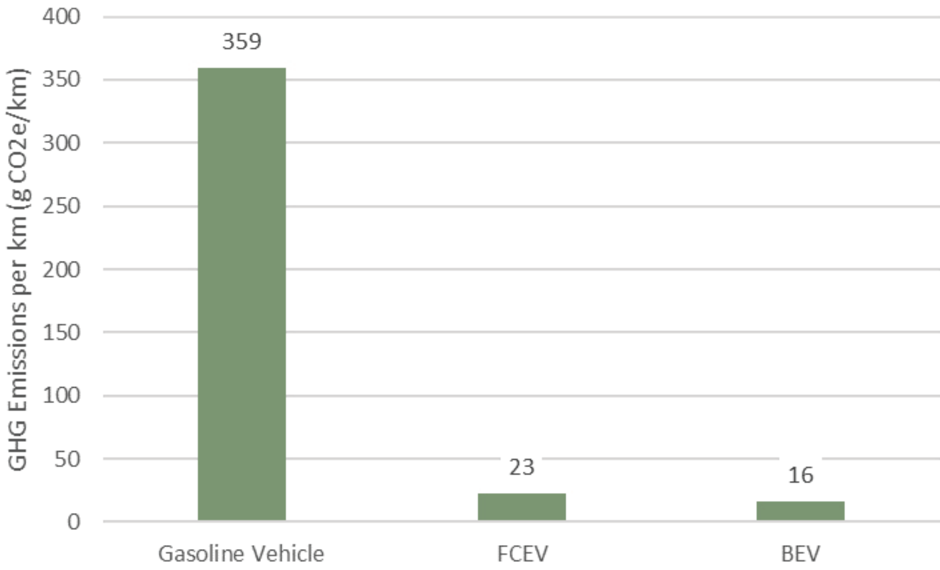


Figure 37. Calculated Light-duty Passenger Vehicle GHG Emissions per Kilometer

Figure 38 shows the European Fuel Cells and Hydrogen Joint Undertaking's enumeration of major segments in the transportation sector, and evaluation of the relative strengths of battery electric and fuel cell electric technology in each.

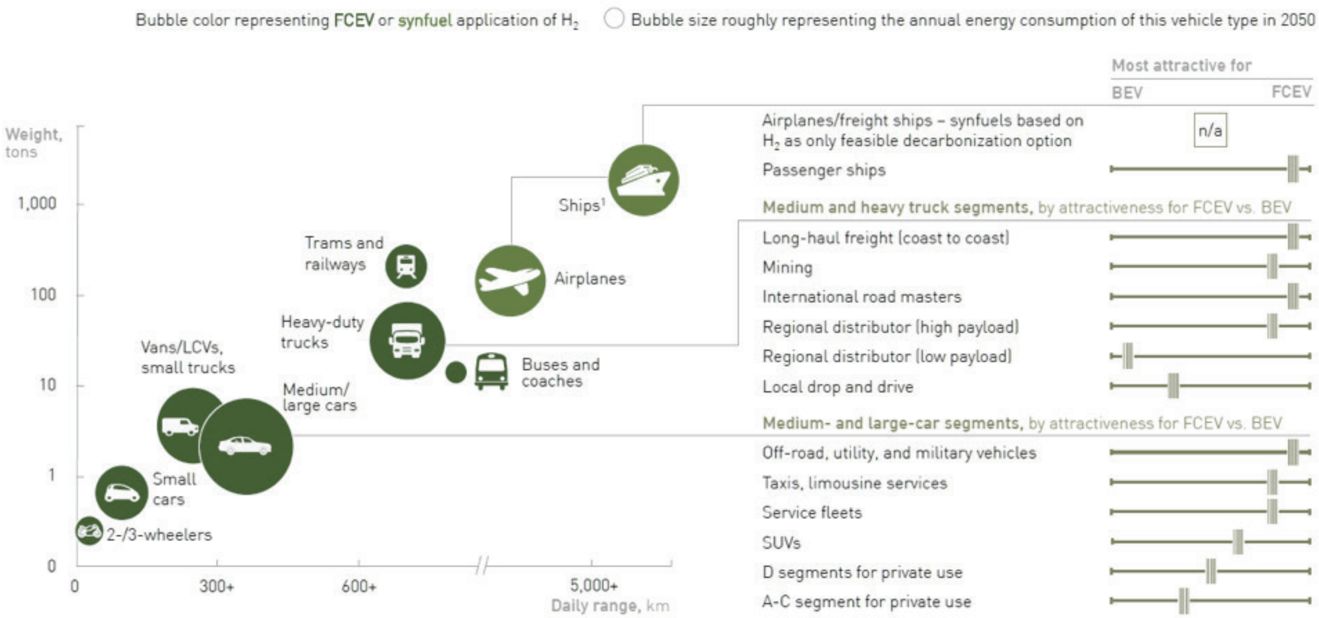


Figure 38. Comparison of Range, Payload, and Technology Preference[85]

85 *Fuel Cells and Hydrogen Joint Undertaking. (2019). Hydrogen Roadmap Europe. Retrieved from https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*

4.2.2.1 : Light-Duty Vehicles

The future light-duty vehicle market will comprise a mix of BEVs and FCEVs. Compared to BEVs, FCEVs offer greater range and faster refueling, which allows for a driver experience closer to a conventional internal combustion engine (ICE) vehicle. However, BEVs are expected to dominate the light-duty vehicle market, having already achieved widespread commercialization and benefiting from electricity's relative ubiquity. FCEV commercialization is lagging by approximately one decade, and hydrogen fueling infrastructure remains limited.

Fuel cell vehicles are likely to be more attractive for drivers in multi-unit residential buildings (condominiums, apartments, townhouses with shared garages, etc.) where cost and strata law barriers can make retrofits of home charging stations expensive and difficult: a comprehensive literature review from UC Davis found that the availability of a home charging station was the most important piece of infrastructure in convincing consumers to purchase a BEV, followed by workplace charging, and lastly public charging stations.[86]

This is particularly pertinent for the Province, where 33% percent of households live in multi-unit residential buildings.[87] Households who cannot recharge their vehicles from their parking stalls may opt for fuel cell electric vehicles – providing they feel well-served by hydrogen fueling infrastructure.

Three-shift (24/7) fleet vehicles such as taxis will find fast refueling times attractive, again providing hydrogen fueling infrastructure is adequate. The cost premium for hydrogen over electricity will have to be modest enough that fleet operators value increased uptime higher than the potential cost savings from battery electric vehicle options.

Although FCEVs are currently available on the market, they are still produced at a relatively small scale. The greatest impediment to deployment of light-duty fuel cell vehicles in the Province in the near-term is supply. The Province could incentivize auto manufacturers (generally referred to as original equipment manufacturers, or OEMs) to bring their vehicles to BC by recognizing the benefits of long range and fast fueling in the credit system adopted by the ZEV mandate.

Since FCEVs are currently produced in small volumes, they remain more expensive than comparable ICE or BEVs. Until production scale reduces costs, the Province is advised to incentivize the purchase of light-duty fuel cell vehicles. The $6,000 Provincial incentive available as of the initial issue of this study in June 2019[88] (comprising the $5,000 CEV for BC purchase rebate and $1,000 in fuel) can be applied to fuel cell vehicles, however the base model price cap of $45,000 on the $5,000 federal incentive excludes FCEVs at this time. The Province could also set up a support mechanism to incentivize the purchase of used fuel cell and battery electric vehicles. This would increase the overall demand for ZEVs and reduce the number of older, higher-polluting fossil fuel vehicles on the road. The availability of used ZEV purchase incentives could also make it easier for lower income households to purchase zero emission vehicles.

Other jurisdictions have had success driving adoption of ZEVs using non-financial incentives. In addition to incentives on the initial purchase price, Norway, offers discounted or free ferry travel, toll road access, and municipal parking to ZEV drivers as well as access to bus lanes. California has increased demand for ZEVs by allowing them access to HOV lanes with only a single occupant. China has expedited the vehicle registration process for ZEVs, reducing the wait time from as long as two years to as short as a single day. BC already allows ZEV drivers to register their vehicles for High-Occupancy Vehicle (HOV) lane access. It is recommended that the Province consider additional cost-effective measures to drive their adoption. Local governments can also play a role, through incentivizing in areas they control such as preferred parking.

86 *Hardman S, et al. (2018). A Review of Consumer Preferences of and Interactions with Electric Vehicle Charging Infrastructure. Transportation Research Part D 62: 508-523. Retrieved from https://phev.ucdavis.edu/wp-content/uploads/a-review-of-consumer-preferences-and-interactions-with-electric-vehicle-charging-infrastructure.pdf*

87 *Natural Resources Canada. Comprehensive Energy Use Database: Residential Sector – British Columbia. Retrieved from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive/trends_res_bc.cfm*

88 *On June 22, 2019 the Province's CEV incentive was reduced to $3,000 for battery, fuel-cell, and longer-range plug-in hybrid electric vehicles and to $1,500 for shorter-range plug-in hybrid electric vehicles.*

4.2.2.2 : Hydrogen Infrastructure

Lack of hydrogen fueling infrastructure in BC is a key barrier to the near-term adoption of FCEVs. California has had success stimulating fuel cell vehicle adoption by carefully and consistently expanding their network of stations and have determined that infrastructure expansion precedes vehicle adoption. In that state the process is overseen by the California Fuel Cell Partnership, who aggregate data from OEMs to determine how many vehicles will be on the road and plan the optimal location for new fueling stations. A similar body could help encourage growth in BC; significant infrastructure investment will be required to ensure FCEVs can be deployed as successfully in the Province as in California. Section 4.2.4 provides more detail related to infrastructure.

4.2.2.3 : Medium- and Heavy-Duty Vehicles

In most instances, medium- and heavy-duty trucks are better suited to hydrogen technology than batteries. There will be opportunities for battery powered trucks for applications with a limited daily range, like parcel distribution, but the heavy loads and long distances required of most applications are better suited to hydrogen fuel cells. A fuel cell truck would end up roughly the same weight as a conventional diesel truck, whereas a battery for a 40-ton truck would add about 3 tonnes of payload.[89] Fuel cell vehicles also require less raw materials, are cobalt free, and research targets are to use less platinum than a comparable diesel vehicle.[90]

Medium- and heavy-duty vehicle hydrogen fuel cell trucks have been demonstrated around the world but have not yet been widely deployed. It is recommended that the Province encourage near-term zero emission medium- and heavy-duty vehicle adoption in applications that have central fueling locations as an early means of deploying hydrogen in these segments.

DIESEL/HYDROGEN CO-COMBUSTION

Diesel/hydrogen co-combustion is a near-term path by which hydrogen could reduce emissions from medium and heavy-duty vehicles. BC-based Hydra Energy retrofits heavy-duty trucks with a co-combustion system that reduces diesel fuel consumption by 30%, and aims to scale up to 120 trucks by 2022.

Hydra plans to build out 350 bar hydrogen fuelling infrastructure that will be compatible with FCEVs in the long-term.

BC could seek to leverage work in other jurisdictions. China has experienced a rapid increase in the deployment of medium-duty hydrogen fuel cell trucks. Homologation efforts could speed technical readiness for deployment in the Province.

89 *Fuel Cells and Hydrogen Joint Undertaking. (2019). Hydrogen Roadmap Europe. Retrieved from https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*

90 *Ibid.*

4.2.2.4 : Public Transit

Public transit agencies around the world are shifting towards low and zero emission vehicles. Low emission technology includes CNG and RNG as a transit fuel. Zero emission transit options include BEBs and FCEBs. As is the case with light-duty vehicles, battery electric buses are most cost effective on relatively short routes. Fuel cell electric buses are advantageous on long routes with higher power requirements. Provincial support for a fuel cell electric coach bus program would provide an opportunity for BC's hydrogen and fuel cell cluster to lead that market segment in the near- to mid-term.

Hydrogen powered buses are more easily scaled than battery electric buses. Fuel cell buses can be refueled at comparable speeds and in a similar way as conventional diesel buses, whereas battery electric buses require much longer charging times. Battery electric buses are either charged over several hours, typically overnight in a depot, or through opportunity charging en-route. Opportunity charging typically requires a bus to be recharged over a shorter period several times a day. It allows for less onboard battery power, and therefore less weight, but increases the operational complexity and constraints. Feedback from transit authorities has been that while longer bus charging times are not an issue at demonstration scale, challenges of cost and complexity increase significantly at fleetwide scale.

California has adopted the ICT rule, which requires 25% of new bus purchases by large transit agencies to be zero emission by 2023, 50% by 2026, and 100% by 2029. By 2040 it requires all buses in operation to be zero emission. It is recommended that BC develop a similar policy. A support mechanism such as the province's Specialty-Use Vehicle Incentive Program[91] or a voucher system could mitigate the higher purchase prices for zero emissions buses. As in the ICT, policies should require transit agencies to develop plans for reaching 100% zero emission vehicle fleets. This will ensure fleet infrastructure needs, whether for electricity or hydrogen, are considered in a holistic, fleetwide manner, and ensure the most cost-effective technology mix is deployed.

91 BC's Special Use Vehicle Incentives are described at: https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/suvi

RENEWABLE NATURAL GAS FOR TRANSPORTATION

In April 2019, TransLink and FortisBC announced a partnership whereby FortisBC will supply Renewable Natural Gas (RNG) for TransLink's natural gas powered buses, which make up roughly a fifth of TransLink's bus fleet. The parties have signed an RNG-supply contract for up to 500,000 GJs annually within five years. This is expected to provide enough to fuel the existing natural gas bus fleet with 100 per cent RNG. Over the five-year period, the transition to RNG will reduce TransLink's greenhouse gas (GHG) emissions by 50,000 tonnes.

How does hydrogen fit?

By updating the B.C. Greenhouse Gas Reduction Regulation definition of RNG to include hydrogen, the Province can accelerate the decarbonization of the transportation sector for near-term opportunities such as Translink. While TransLink will purchase 100% RG, any hydrogen blended into the natural gas would be separated before filling the vehicles. There can be technical challenges in using a H_2/CNG blend in the vehicles related to tank embrittlement and NOx emissions. Separation of hydrogen at the point of use could lead to fueling stations with dual fuel sources – CNG and hydrogen. Pure hydrogen can be used in fuel cell vehicles or other applications that required pure hydrogen, and the buses will run on CNG. This is in essence a credit trading mechanism that will lead to real benefits in overall decarbonization of the transportation network.

4.2.2.5 : Long Haul Trucking

The past few years have seen heightened interest in fuel cells for class 8 long haul trucks, known colloquially as freight trucks, semi-trucks or tractor-trailers. Nikola Motor, Toyota and Hyundai are all developing fuel cell powertrains for this market segment. Cummins Inc. recently announced that it has entered into a definitive agreement to acquire Hydrogenics Corporation, which is a major move into the fuel cell space for this major diesel and natural gas engine OEM. A number of demonstration projects have been piloted, including the Alberta Zero-Emissions Truck Electrification Collaboration (AZETEC) project, which will trial class 8 fuel cell trucks on the corridor between Edmonton and Calgary.[93]

It is recommended that BC develop similar projects for this market, and it is noted that the CleanBC plan references a pilot project to switch 1,700 freight trucks to cleaner or zero-emission fuel. The larger quantities of hydrogen fuel consumed by these heavy-duty vehicles would have the additional benefit of increasing hydrogen demand within the Province; the increased hydrogen consumption should also help bring down retail hydrogen prices.

AZETEC PROJECT

The Alberta Zero-Emissions Truck Electrification Collaboration (AZETEC) project will include the design, manufacture, and deployment of two heavy-duty extended range hydrogen fuel cell electric trucks that will move freight between Edmonton and Calgary year round. The $15 million project is led by the Alberta Motor Transport Association and will receive more than $7.3 million from Emissions Reduction Alberta. Over the three-year lifespan of the project, the trucks will have travelled more than 500,000 km and carried about 20 million tonne-km of freight.[92]

92 Lowey, M. JWN. (2019). $15-million Project to test Hydrogen Fuel in Alberta's Freight Transportation Sector. Retrieved from https://www.jwnenergy.com/article/2019/3/15-million-project-test-hydrogen-fuel-albertas-freight-transportation-sector/

93 Ibid 92

4.2.2.6 : Rail and Marine

Given the range and power required, hydrogen fuel cells may have the potential to displace fossil fuels as a major energy source in rail and marine applications. Pilot projects are currently underway in Europe and Asia, but the technology and the infrastructure required to enable it is still at an early stage. In this report, only BC Ferries were considered as a possible use for hydrogen technology. It was assumed that other marine or rail projects will be undertaken in the Province before 2050. However, given the activity in other jurisdictions, the Province should support development through feasibility studies and pilot projects if suitable opportunities become available. The aforementioned South Fraser Community Rail proposal to revive commuter rail in the Fraser Valley through hydrogen rail could be a suitable lighthouse project.

HYDROGEN RAIL (HYDRAIL)

In 2018, the world's first commercial hydrogen powered trains entered service in Germany. There are currently two trains in operation and plans in place to deliver another 14 trains by 2021. The trains are capable of travelling 1,000 km without refueling, which is comparable to a diesel alternative.[94] The trains are being built by French train manufacturer Alstom and the fuel cells are being provided by Ontario-based Hydrogenics.[95]

While no hydrogen powered rail deployments currently exist in BC, an organization called South Fraser Community Rail is actively campaigning for a hydrogen powered commuter train project to connect Surrey to Chilliwack along the Fraser Valley corridor.[96]

94 *Agence France-Presse. (2018). Germany Launches World's First Hydrogen-Powered Train. Retrieved from* https://www.theguardian.com/environment/2018/sep/17/germany-launches-worlds-first-hydrogen-powered-train

95 *Hydrogenics. (2015). Hydrogenics and Alstom Transport Sign Agreement to Develop and Commercialize Hydrogen-Powered Commuter Trains in Europe. Retrieved from* https://www.hydrogenics.com/2015/05/27/hydrogenics-and-alstom-transport-sign-agreement-to-develop-and-commercialize-hydrogen-powered-commuter-trains-in-europe/

96 *Hernandez, J. CBC News. (2019). Transit Advocates Call for Hydrogen Trains on Century-Old Fraser Valley Rail Corridor. Retrieved from* https://www.cbc.ca/news/canada/british-columbia/transit-advocates-call-for-hydrogen-trains-on-century-old-fraser-valley-rail-corridor-1.5065117

4.2.3 : Adoption Scenarios

Projecting hydrogen technology adoption in the transportation sector is dependent on a wide range of economic, social, and technical factors, and inherently contains a high degree of uncertainty. As such, the approach used in this study sought to provide a realistic range of adoption that is bound by conservative and aggressive scenarios of technology development and policy implementation. Within the transportation sector, adoption was estimated for light-duty passenger vehicles, medium- and heavy-duty trucks, public transit and private coach buses, and ferries. Although hydrogen could also be used in rail and aviation applications, this analysis assumed hydrogen does not play a role in either category by 2050.

Hydrogen demand was modelled for each segment of the transportation sector based on the projected number of vehicles in operation, assumed kilometers driven per year, fuel economy of the gasoline/diesel baseline and hydrogen alternative. Figure 39, Figure 40, and Figure 41 show the modelled hydrogen demand in the conservative and aggressive scenarios for transportation from 2020 to 2050.

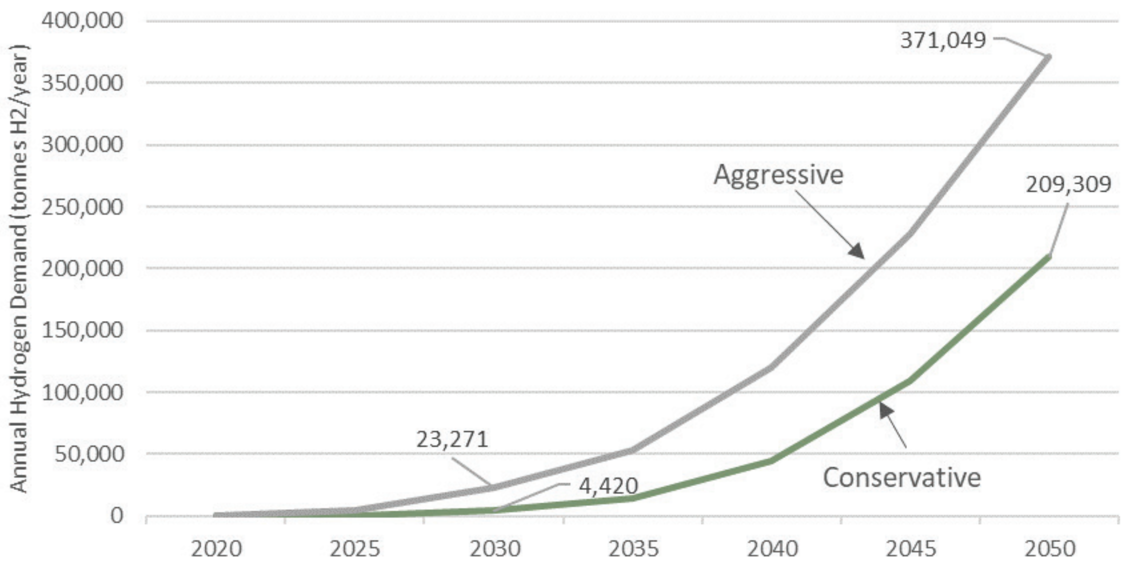


Figure 39. Transportation Conservative and Aggressive Hydrogen Demand (2020-2050)

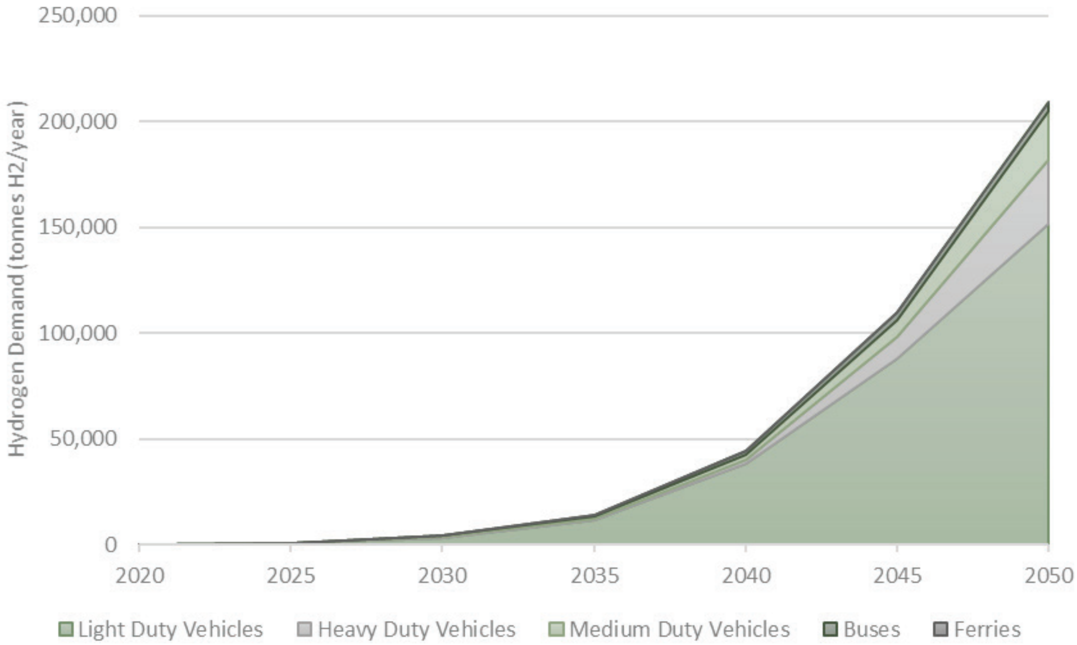


Figure 40. Transportation Conservative Hydrogen Demand by Vehicle Type (2020-2050)

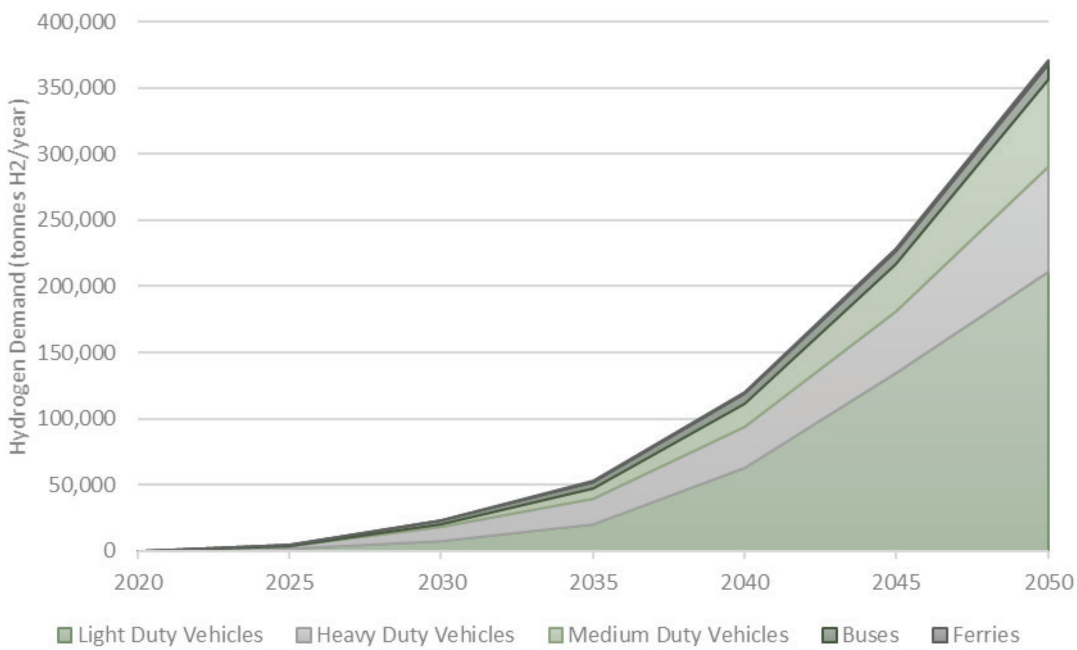


Figure 41. Transportation Aggressive Hydrogen Demand by Vehicle Type (2020-2050)

Figure 42 shows the modelled share of hydrogen demand for each vehicle type in 2030 and 2050 in the conservative and aggressive scenarios.

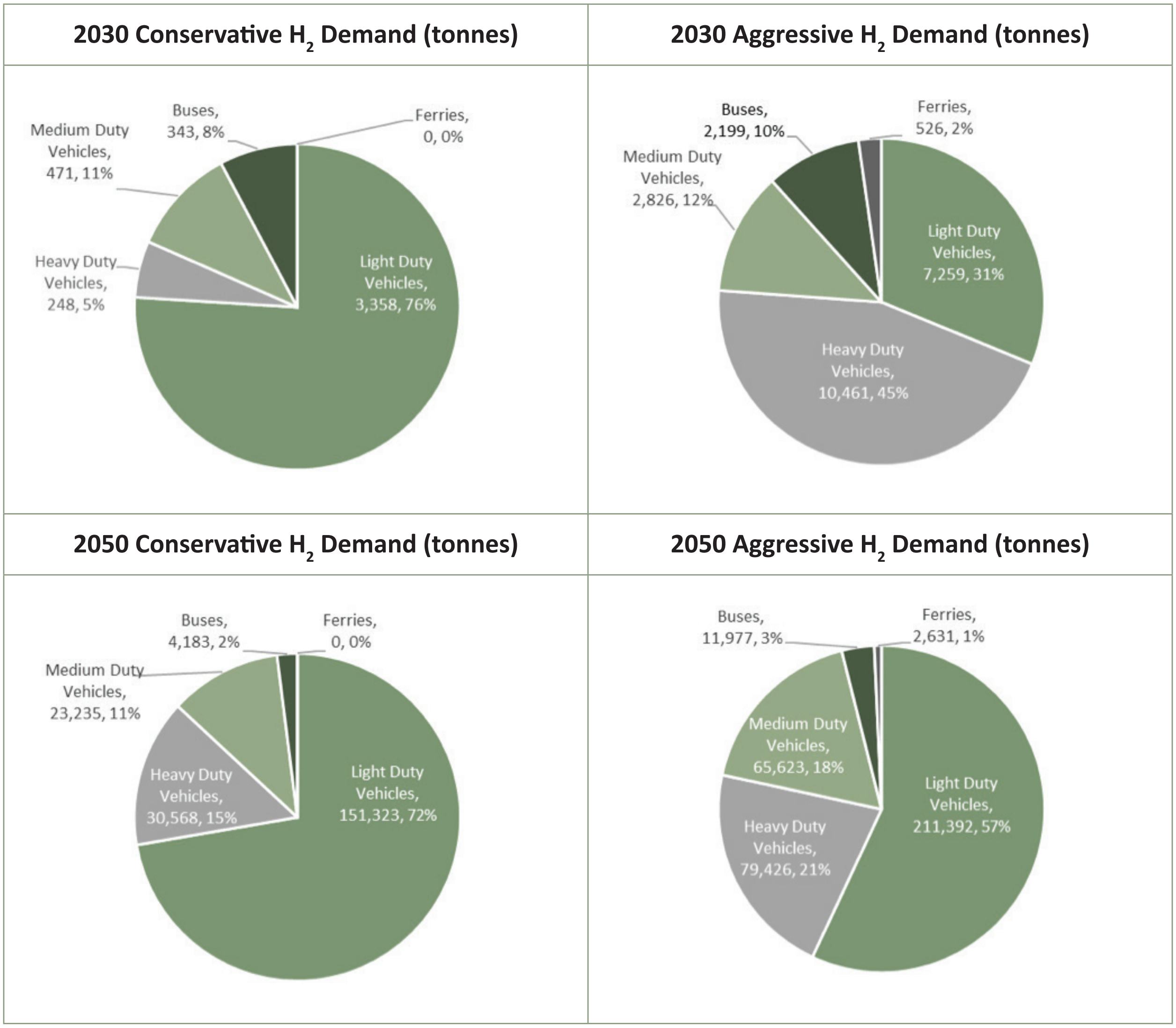


Figure 42. Conservative and Aggressive Transportation Hydrogen Demand in tonnes by Vehicle Type (2030 & 2050)

4.2.3.1 : Light-duty Vehicles

The upcoming ZEV mandate will drive the adoption of fuel cell light-duty vehicles in BC. The analysis considered both how the ZEV standard will impact the sales of vehicles across the industry and how it could impact OEMs individually based on their current offerings assuming a credit scheme similar to Quebec's ZEV standard is put in place.

From 2020 to 2030, FCEV sales are highly dependent on how the ZEV mandate is legislated. The aggressive scenario assumes that credits will be allocated per vehicle using the formulas currently in place in Quebec[97] and that each OEM will have to meet the sales targets outlined in the Zero-emission Vehicles Act (10% by 2025, 30% by 2030, 100% by 2040).[98] Under this scenario, FCEV adoption will be driven largely by each OEM's need to meet their credit requirement. The analysis considered annual new vehicle sales across the province,[99, 100] the approximate market share of OEMs offering FCEVs,[101] how many credits each FCEV would receive, and how many FCEVs would need to be sold to satisfy the ZEV mandate taking into account sales of BEVs and PHEVs. Toyota is expected to drive sales more than other OEMs because, unlike other major car brands that offer a BEV, they currently only offer the Mirai (FCEV, 3.6 credits) and the Prius plug-in hybrid (0.6 credits). The conservative scenario assumes the OEMs will not be required to meet targets through their own direct sales, but the ZEV legislation will drive adoption across the entire industry. This could occur if it is easy for OEMs to purchase credits from others that achieve greater ZEV sales than the target. In this conservative scenario, it is assumed that the Province falls short of its ZEV targets, reaching 8% of sales in 2025 and 20% in 2030. It was assumed that FCEV sales make up 8% of ZEV sales by 2030, which is 20% less than a model developed for ZEV deployment in Europe.[102, 103]

From 2030 to 2050, the estimates are not based on how a credit system could impact specific OEMs, since many of the OEMs will likely be offering different vehicle models by that time. The aggressive scenario assumes that the Province meets its ZEV targets of 100% sales by 2040, and that FCEVs make up 19% of ZEV sales in 2040 and 26% in 2050, which matches the model developed for Europe.[102] The conservative scenario assumes the Province falls short of its ZEV targets, reaching 80% of sales in 2040 and 100% in 2050, and that FCEV sales as a percent of ZEV sales are 80% lower than the penetration in the aggressive scenario (15% in 2040 and 21% in 2050).

In all scenarios it was assumed that total new vehicle registrations increase linearly based on the past five years of data at 7,711 new vehicles per year[104] and that vehicles remain on the road for an average of 13 years. There is considerable uncertainty in projecting vehicle sales growth through 2050 based on historical sales trends, given potentially disruptive changes to car ownership such as car-sharing, ride-hailing and autonomous vehicle technology. These could each result in a decrease in the number of registered vehicles on provincial roads in the future, though total vehicle km travelled might remain largely unaffected.

97 *Government du Quebec. (2019). The ZEV Standard in a Nutshell: Explanatory Leaflet. Retrieved from http://www.environnement.gouv.qc.ca/changementsclimatiques/vze/feuillet-vze-reglement-en.pdf*

98 *BC Ministry of Energy, Mines, and Petroleum Resources. (2019). Legislation to Guide Move to Electric Vehicles, Reduce Pollution. Retrieved from https://news.gov.bc.ca/releases/2019EMPR0011-000608*

99 *The number of new passenger vehicle registrations in BC were projected linearly based on new registrations over the past five years.*

100 *Statistics Canada. Table 20-10-0002-01 New motor vehicle sales, by type of vehicle. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2010000201*

101 *Scotiabank. (2019). Global Auto Report. Retrieved from https://www.scotiabank.com/content/dam/scotiabank/sub-brands/scotiabank-economics/english/documents/global-auto-report/GAR_2019-01-30.pdf*

102 *Cambridge Econometrics. (2018). Fueling Europe's Future: How the Transition from Oil Strengthens the Economy. Retrieved from https://europeanclimate.org/wp-content/uploads/2018/02/FEF_transition.pdf*

103 *The analysis in this report is based on historical data through 2018. In 2019, ZEV sales have accelerated in BC, largely driven by the newly available federal incentive and record high gas prices. The analysis was not revised to account for this increase in sales. At this time, FCEV sales are limited by supply and it is unclear if the uptick in sales will translate to FCEVs as they are not currently eligible for the federal incentive because of the cap on vehicle retail price.*

104 *Statistics Canada. Table 23-10-0067-01 Road motor vehicle registrations, by type of vehicle. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310006701*

The adoption scenarios were compared to past and projected adoption in California, the world leader in light-duty fuel cell passenger vehicle adoption. Since the passenger vehicle market in California is significantly greater than BC, the data was scaled to be proportional to the BC passenger vehicle market. Additionally, the California reference data was shifted by four years because the number of light-duty fuel cell vehicles on the road in California has been growing since 2015. Thus, the California reference value for 2019 is the number of light-duty fuel cell vehicles on the road in California in 2015 scaled by the passenger vehicle market, the value in 2020 is related to California in 2016, etc. From 2019 to 2022, the California reference values are based on the number of fuel cell vehicles on the road from 2015 to 2018.[105] From 2022 to 2028, the California reference values are based on California Air Resource Board projections of vehicles on the road in California from 2019 to 2024.[106] From 2028 to 2034, the California reference values are based on achieving the aspirational goal of 1,000,000 fuel cell vehicles on the road in California by 2030. The California reference case was not extended beyond 2034 (i.e., beyond the 1,000,000 vehicles in 2030 target).

Figure 43 shows the range of annual light-duty fuel cell vehicle new sales per year and Figure 44 shows total projected fuel cell vehicles on the road as well as hydrogen demand from 2019 to 2050. Hydrogen demand was estimated as 0.5 kg/vehicle/day, which is corresponds to a driving range of approximately 15,000 km/year.

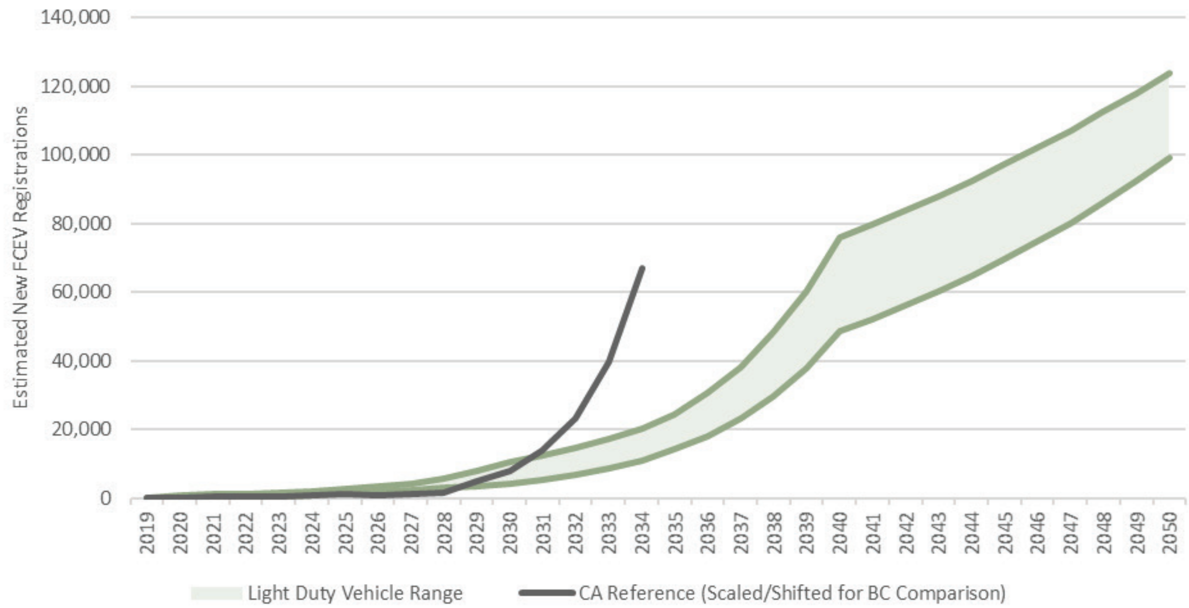


Figure 43. Light-duty Fuel Cell Passenger Vehicles Sales per Year (2019-2050)

105 *California Fuel Cell Partnership (2018). By the Numbers: FCEV Sales, FCEB, & Hydrogen Station Data. Retrieved from* https://cafcp.org/by_the_numbers

106 *California Air Resources Board. (2018). 2018 Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development. Retrieved from* https://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2018_print.pdf

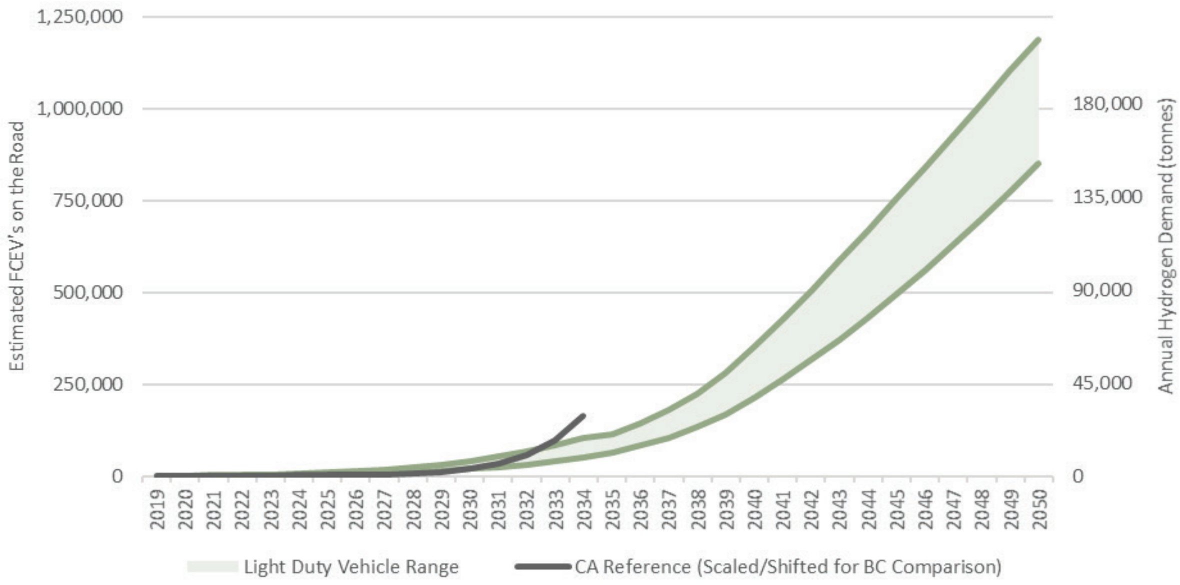


Figure 44. Light-duty Fuel Cell Passenger Vehicles on the Road per Year (2019-2050)

The number of fuel cell vehicles sold is expected to increase exponentially from 2019 to 2040. After 2040, the ZEV mandate will require all new vehicles sold to be ZEVs, so the growth continues linearly assuming the total number of vehicles sold continues to grow.

The sales targets of the BC ZEV mandate are more aggressive than the mandate currently in place in California, which is only defined through 2025. As a result, the projected fuel cell vehicles in BC exceed the California reference case in the near-term. However, for California to meet its 2030 target of 1,000,000 vehicles, sales will need to ramp up rapidly, which causes the California reference case to exceed the projected range for BC adoption.

Table 7 shows the estimated number of new vehicle registrations, FCEV new registrations, and FCEVs on the road per year from 2019 to 2050.

YEAR	VEHICLE REGISTRATIONS	FCEV NEW REGISTRATIONS		FCEV % OF NEW VEHICLE REGISTRATIONS		FCEV'S ON ROAD	
		Low	High	Low	High	Low	High
2019	237,251	30	50	0.0%	0.0%	33	53
2020	244,962	60	816	0.0%	0.3%	93	869
2021	252,672	118	1,084	0.0%	0.4%	211	1,953
2022	260,383	234	1,364	0.1%	0.5%	445	3,317
2023	268,093	464	1,656	0.2%	0.6%	909	4,973
2024	275,804	918	1,961	0.3%	0.7%	1,827	6,934
2025	283,514	1,581	2,835	0.6%	1.0%	3,641	9,210
2026	291,225	2,141	3,470	0.7%	1.2%	5,782	12,328
2027	298,935	2,524	4,254	0.8%	1.4%	8,306	16,582
2028	306,646	2,975	5,789	1.0%	1.9%	11,281	22,371
2029	314,356	3,503	7,856	1.1%	2.5%	14,784	30,227
2030	322,067	4,122	10,638	1.3%	3.3%	18,906	40,865
2031	329,777	5,287	12,506	1.6%	3.8%	24,190	53,368
2032	337,488	6,777	14,689	2.0%	4.4%	30,937	68,006
2033	345,198	8,681	17,238	2.5%	5.0%	39,558	84,428
2034	352,909	11,116	20,214	3.1%	5.7%	50,556	103,558
2035	360,619	14,227	24,352	3.9%	6.8%	64,549	113,112
2036	368,330	18,200	30,590	4.9%	8.3%	82,285	142,961
2037	376,040	23,273	38,408	6.2%	10.2%	104,640	179,919
2038	383,751	29,747	48,205	7.8%	12.6%	132,573	225,289
2039	391,461	38,006	60,477	9.7%	15.4%	168,438	282,296
2040	399,172	48,539	75,843	12.2%	19.0%	214,453	353,896
2041	406,882	52,205	79,771	12.8%	19.6%	263,683	428,482
2042	414,593	56,128	83,872	13.5%	20.2%	316,308	506,021
2043	422,303	60,325	88,154	14.3%	20.9%	372,511	586,445
2044	430,014	64,814	92,624	15.1%	21.5%	432,038	669,335
2045	437,724	69,614	97,289	15.9%	22.2%	494,875	754,373
2046	445,435	74,747	102,157	16.8%	22.9%	560,941	841,119
2047	453,145	80,235	107,237	17.7%	23.7%	630,060	928,979
2048	460,856	86,100	112,537	18.7%	24.4%	701,933	1,017,164
2049	468,566	92,368	118,065	19.7%	25.2%	776,101	1,104,639
2050	476,277	99,066	123,832	20.8%	26.0%	851,894	1,190,063

Table 7. LDV FCEV Registrations and Vehicles on the Road (2019-2050)

4.2.3.2 : Medium- and Heavy-Duty Trucks

Due to the required range and power, medium-duty vehicles (MDVs) and HDVs present one of the best opportunities for hydrogen technology. Outside of China, which is rapidly deploying MDV fuel cell vehicles, few hydrogen-powered MDVs and HDVs are currently in operation. Given the Province's technical expertise and commitment to reducing emissions, BC is well positioned to become a world leader in the deployment of hydrogen-powered MDV and HDV trucks. Crucially, leadership in this market segment would allow the Province's hydrogen and fuel cell cluster to gain insights from early local deployments. BC companies would then enjoy a competitive advantage over competitors from other jurisdictions, when slower-moving jurisdictions prepare their own deployments of zero emission medium- and heavy-duty trucks.

The aggressive scenario for medium- and heavy-duty hydrogen powered trucks assumes the Province supports multiple lighthouse projects to demonstrate the effectiveness of the technology by 2030 and wide scale adoption by 2050. In the near- to mid-term, it was assumed that diesel-hydrogen co-combustion proves effective for heavy-duty vehicle retrofits, leading to up to 1,700 retrofit heavy-duty hydrogen diesel co-combustion vehicles on the road. Under this scenario, we expect the deployments of hydrogen co-combustion vehicles will peak in 2040, after which fuel cell vehicles will dominate. The conservative scenario assumes small demonstration projects with medium- and heavy-duty fuel cell vehicles through 2030 leading to moderate adoption through 2050 and no diesel co-combustion vehicles.

HYUNDAI AND H_2E: 1600 TRUCK PROJECT – SWITZERLAND

Hyundai and H_2 Energy (H_2E) have established the Hyundai Hydrogen Mobility joint venture (JV) in Europe, focused on heavy-duty commercial hydrogen fuel cell vehicles. The goal of the JV is to deliver 1600 fuel cell heavy-duty trucks and supporting fueling stations in Switzerland between 2019 -2025.[107]

Hyundai Motor will deliver the trucks, and H_2E will be responsible for marketing the fleet as well as developing the infrastructure. A stringent road tax on diesel trucks imposed by Switzerland is incentivizing fleet operators to switch to zero emission vehicles. The road tax on commercial vehicles is meant to prevent diesel trucks from crossing through Switzerland as they traverse Europe, and depending on weight and distance the annual road tax can cost up to $50,000 per vehicle.[108]

After scaling up to meet the demand in Europe, Hyundai then plans to launch its fuel cell commercial vehicle businesses in other regions around the world, including the U.S. and domestic market in Korea.

107 Electrive.com. (2019). Hyundai & H_2E: 1,6000 Fuel Cell Trucks for Europe. Retrieved from https://www.electrive.com/2019/04/15/hyundai-h2e-1600-fuel-cell-trucks-for-european-market/

108 ZunMallen R. (2018). 1,000 Hyundai Fuel Cell Electric Trucks Headed for Switzerland. Trucks.com. Retrieved from https://www.trucks.com/2018/09/21/hyundai-fuel-cell-electric-trucks-switzerland/

Table 8 shows the estimated adoption schedule for MDV and HDV trucks from 2020 to 2050.

YEAR	NUMBER OF HYDROGEN POWERED VEHICLES ON THE ROAD					
	HDV FUEL CELL		HDV CO-COMBUSTION		MDV FUEL CELL	
	Conservative	Aggressive	Conservative	Aggressive	Conservative	Aggressive
2020	0	0	0	0	0	0
2025	10	125	0	125	25	100
2030	30	625	0	1,125	75	450
2035	70	1,375	0	1,625	175	1,275
2040	260	2,750	0	1,700	350	2,825
2045	1,240	5,250	0	700	1,300	5,775
2050	3,700	9,500	0	200	3,700	10,450

Table 8. Medium- and heavy-duty Vehicle Adoption Projections (2020-2050)

Figure 45 and Figure 46 show the projected hydrogen demand from medium- and heavy-duty hydrogen trucks in the conservative and aggressive scenarios from 2020 to 2050.

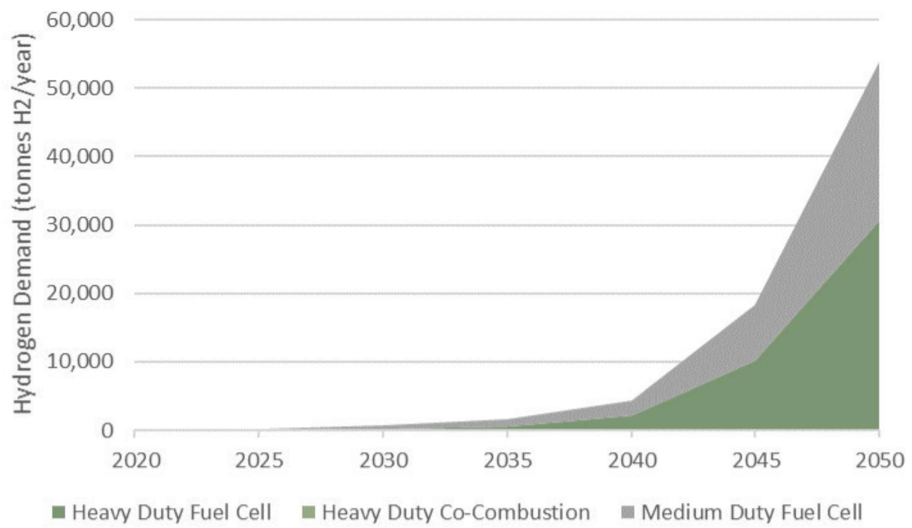


Figure 45. Conservative Projected Medium- and heavy-duty Truck Hydrogen Demand (2020-2050)

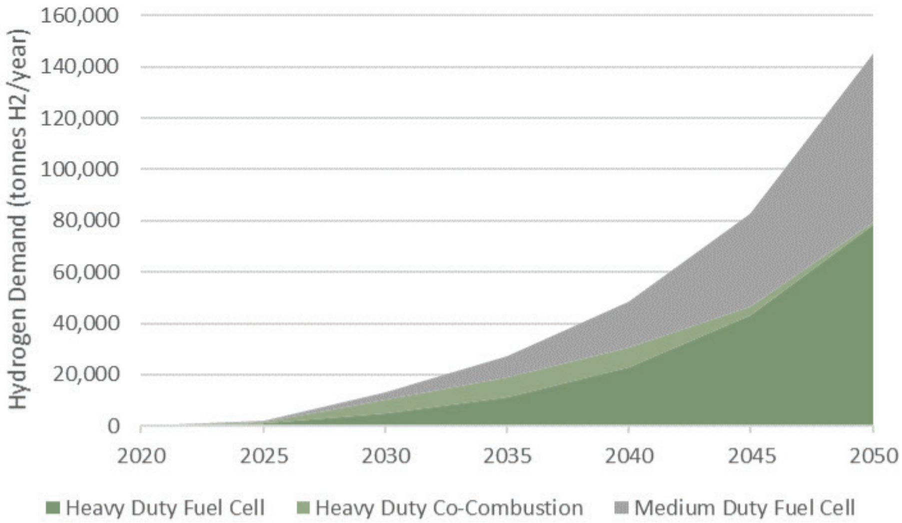


Figure 46. Aggressive Projected Medium- and heavy-duty Truck Hydrogen Demand (2020-2050)

4.2.3.3 : Buses

Transit agencies around the world are looking at reducing emissions through deployment of hydrogen fuel cell and battery electric buses. Though more expensive than conventional diesel buses, hydrogen fuel cell public transit buses are currently available on the market from several suppliers. The modelled scenarios are based on feedback from TransLink and BC Transit. The aggressive scenario assumes the Province institutes a zero-emission bus mandate similar to the Innovative Clean Transit regulation in California, leading to 25% of the Province's public transit fleet comprising fuel cell electric buses by 2035. The conservative scenario assumes slow adoption of fuel cell public transit buses, peaking at 12% of the fleet in 2050.

Hydrogen powered inter-city buses (also called "coaches" or "coach buses") are at an earlier stage of development than public transit buses, primarily due to technical challenges with current vehicle configurations that constrict hydrogen storage on the rooftops due to centre of gravity restrictions. This fuel storage technical challenge can be overcome with emerging technologies, and as with medium- and heavy-duty trucks, coach buses are well suited to hydrogen fuel cell technology because of the long ranges and short refueling times required for existing duty cycles.

It is assumed that there will be zero and low emissions regulations applied to these buses in the post-2025 period building on the regulation of transit buses. The aggressive scenario assumes a successful technology development program in BC leading to adoption of 15% of new sales by 2035 and 75% of new sales in 2050. The conservative scenario assumes moderate adoption of fuel cell coach buses beginning in 2030 and peaking at 25% of new sales in 2050.

Table 9 shows the estimated adoption schedule for public transit and coach buses from 2020 to 2050.

YEAR	NUMBER OF HYDROGEN POWERED VEHICLES ON THE ROAD			
	PUBLIC TRANSIT BUSES		COACH BUSES	
	Conservative	Aggressive	Conservative	Aggressive
2020	0	0	0	0
2025	0	20	0	65
2030	20	209	64	257
2035	62	522	192	577
2040	125	522	384	1,153
2045	188	522	576	1,923
2050	250	522	768	2,565

Table 9. Public Transit and Coach Bus Adoption Projections (2020-2050)

Figure 47 and Figure 48 show the projected hydrogen demand from public transit and coach buses in the conservative and aggressive scenarios from 2020 to 2050.

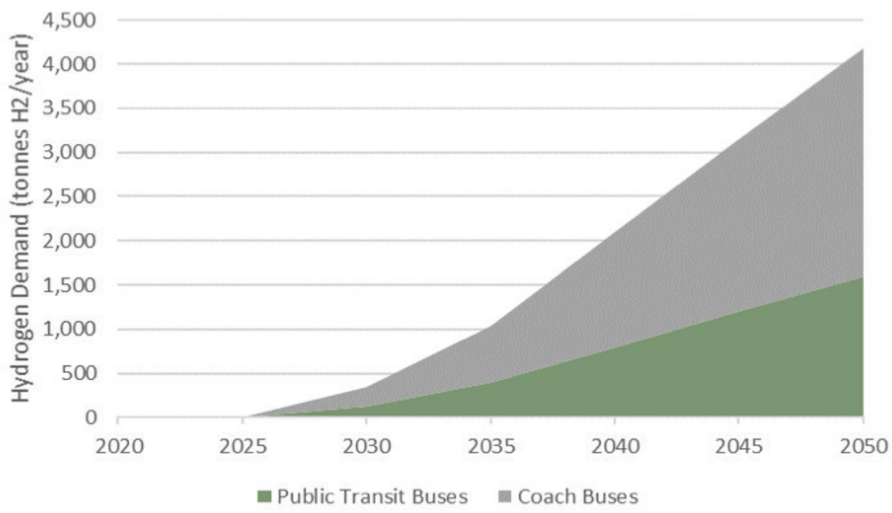


Figure 47. Conservative Projected Public Transit and Coach Bus Hydrogen Demand (2020-2050)

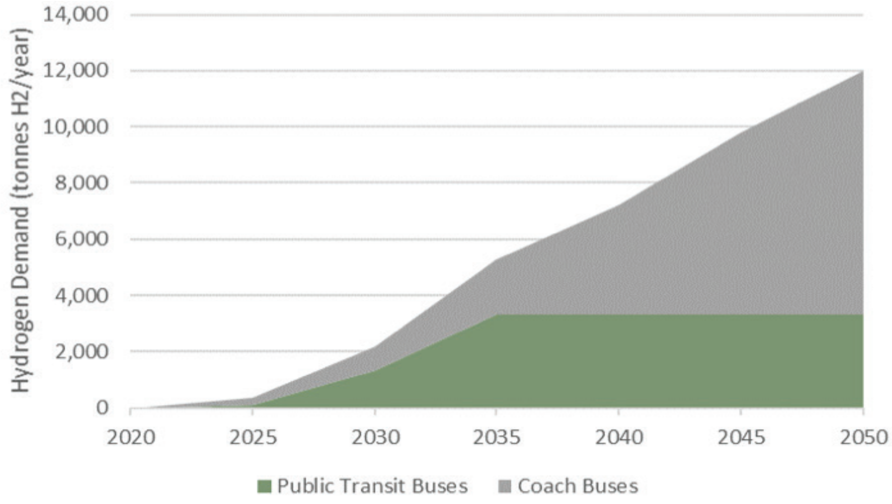


Figure 48. Aggressive Projected Public Transit and Coach Bus Hydrogen Demand (2020-2050)

4.2.3.4 : Ferries

BC Ferries is committed to reducing emissions and, though is at an early stage relative to road transportation applications, hydrogen fuel cell technology shows promise in marine applications. The aggressive scenario assumes a successful pilot project of a single ferry in 2030 leading to 3 vessels in the fleet by 2040 and 5 by 2050. The conservative scenario assumes no hydrogen powered ferries by 2050.

Table 10 shows the estimated adoption schedule for ferries from 2020 to 2050.

YEAR	NUMBER OF HYDROGEN POWERED VESSELS IN FLEET	
	Conservative	Aggressive
2020	0	0
2025	0	0
2030	0	1
2035	0	1
2040	0	3
2045	0	3
2050	0	5

Table 10. Ferry Adoption Projections (2020-2050)

Figure 49 shows the projected hydrogen demand from ferries from 2020 to 2050 in the aggressive scenario (the conservative scenario is not shown because there are no hydrogen powered vessels in the fleet).

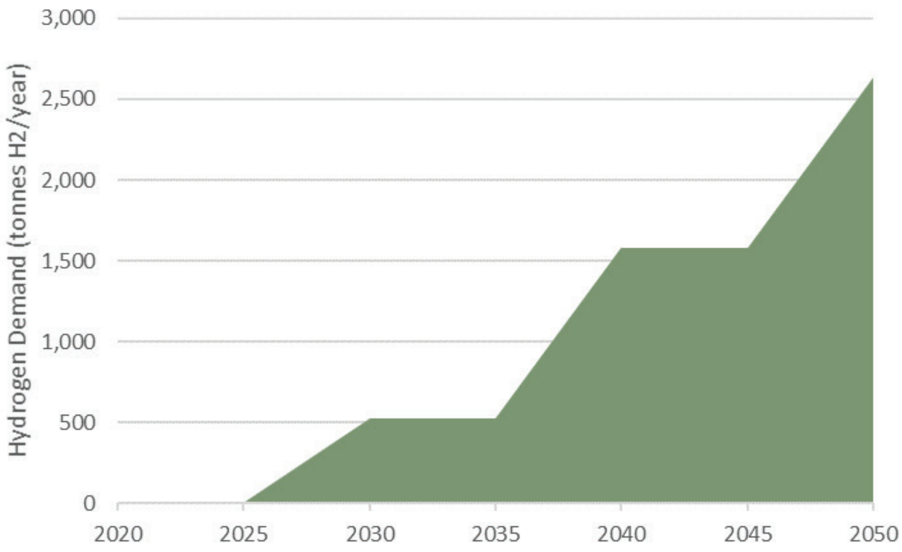


Figure 49. Aggressive Projected Ferry Hydrogen Demand (2020-2050)

Although there is potential for marine applications of hydrogen technology in BC other than ferries, the technology is still at a relatively early stage of development. For the purposes of this report, it was assumed that there will not be significant adoption of hydrogen for non-ferry marine applications before 2050

.

4.2.3.5 : GHG Emissions

The GHG emissions reduction for each vehicle type based on the average annual distance travelled, fuel economy, and diesel and gasoline emissions factors were modeled.[109] The assumed carbon intensities was 3.59 kg CO_2e/L for diesel in medium- and heavy-duty vehicles, 3.20 kg CO_2e/L for gasoline light-duty vehicles, 3.49 kgCO_2e/L for diesel in marine vessels.[110] Hydrogen as a transportation fuel was estimated to have an emissions factor of 15.9 g CO_2e/MJ (equivalent to 1.91 kg CO_2e/kg H_2) based on the weighted average carbon intensity of the pathways studied in this report based on their capacity in BC.

Fuel cell vehicles were assumed to have an energy effectiveness ratio (EER) of 1.9 compared to diesel engines and 2.5 compared to gasoline engines.[111]

Figure 50, Figure 51, and Figure 52 show the estimated GHG abated in the conservative and aggressive scenarios for transportation from 2020 to 2050.

109 *(S&T) Squared Consultants Inc. (2018). GHGenius 5.0d. Calculations conducted by BC Ministry of Energy, Mines and Petroleum Resources Low Carbon Fuels Branch. Retrieved from https://ghgenius.ca/index.php/downloads*

110 *Ibid.*

111 *British Columbia Provincial Government. (2017). Regulation 394/2008 O.C. 907.2008. Greenhouse Gas Reduction (Renewable and Low Carbon Fuel Requirements) Act. Retrieved from http://www.bclaws.ca/civix/document/id/lc/statreg/394_2008*

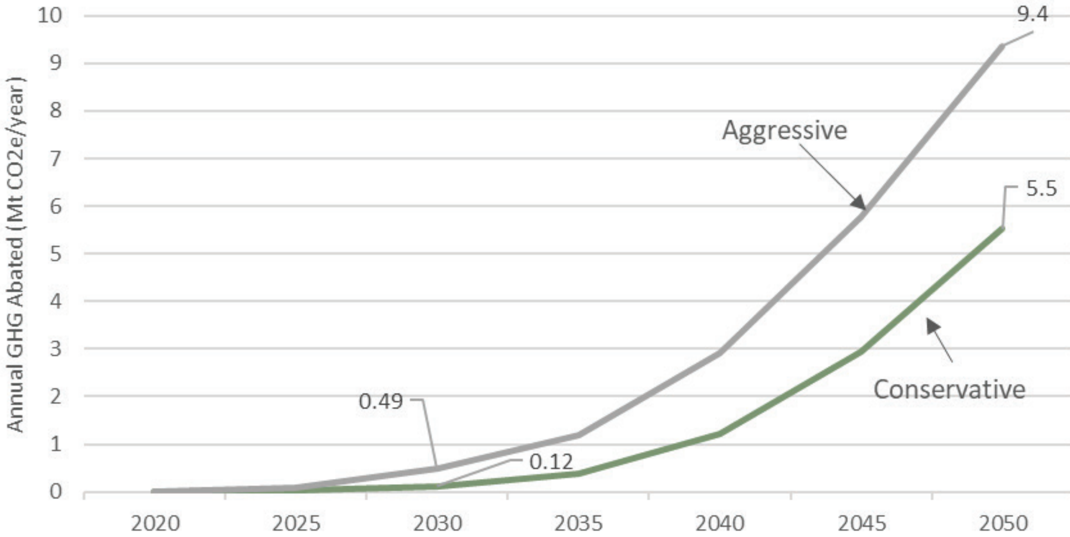


Figure 50. Transportation Conservative and Aggressive GHG Abated (2020-2050)

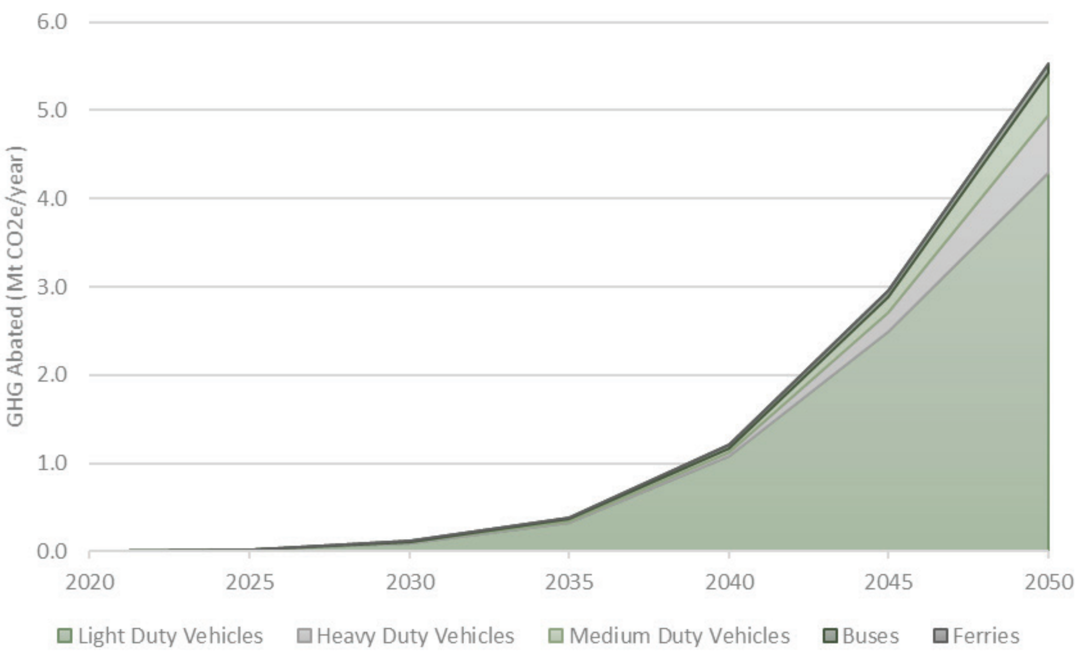


Figure 51. Transportation Conservative GHG Abated by Vehicle Type (2020-2050)

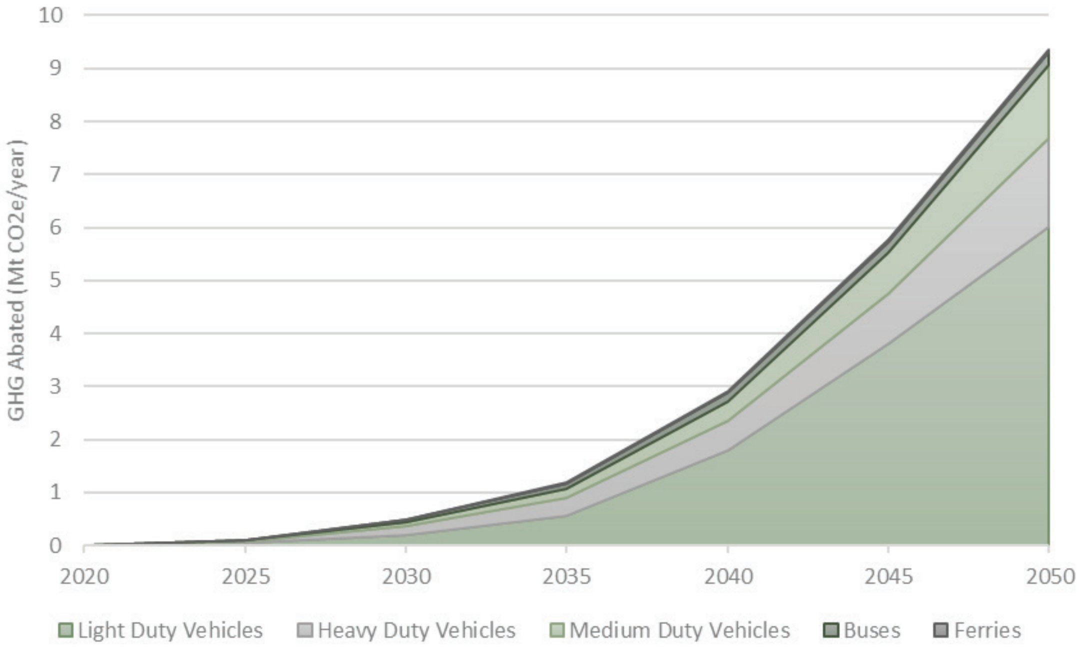


Figure 52. Transportation Aggressive GHG Abated by Vehicle Type (2020-2050)

Figure 53 shows the estimated share of GHG abated for each vehicle type in 2030 and 2050 in the conservative and aggressive scenarios.

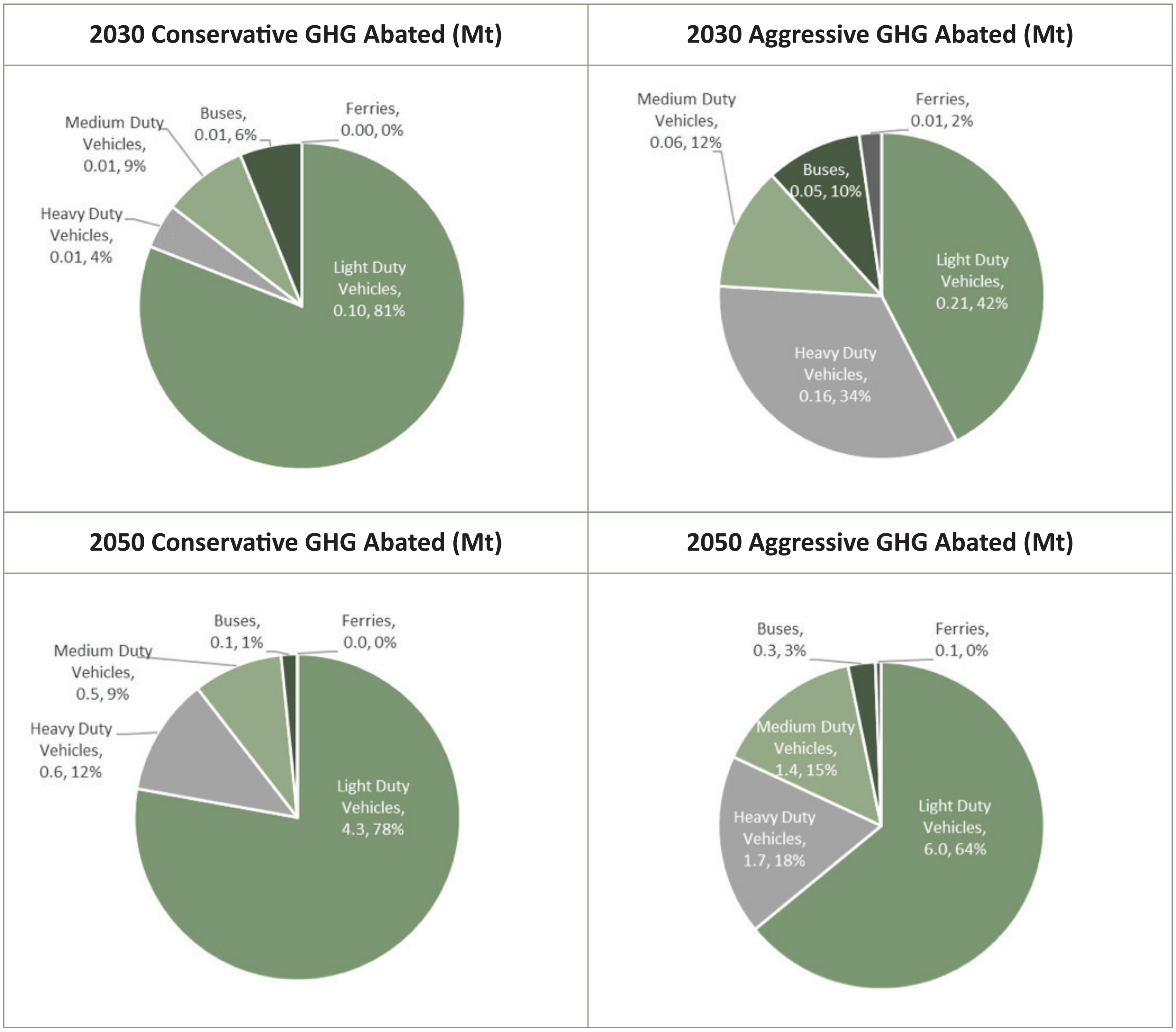


Figure 53. Conservative and Aggressive Transportation GHG Abated in Mt CO_2e by Vehicle Type (2030 & 2050)

In all cases, the deployment of light-duty FCEVs will have the greatest emissions reduction impact, driven primarily by the far larger vehicle populations under consideration. It is therefore recommended that in the near-term a strong credit system favouring FCEVs (to incentivize OEMs to preferentially supply FCEVs to the province) be implemented, and that the continued roll-out of light-duty vehicle hydrogen fuel infrastructure be strongly supported.

4.2.4 : Infrastructure to Support Adoption

4.2.4.1 : 2019 Current Status

BC has been a leader in developing and deploying hydrogen fuel cell technologies. In 2002, Powertech Labs installed the world's first 700 bar hydrogen refueling station in Surrey and in 2018, Hydrogen Technology & Energy Corporation (HTEC) opened Canada's first retail hydrogen fueling station at a Shell site in Vancouver. This is the first of 5 stations that HTEC intends to deploy over the next 18 months to support anticipated fuel cell electric vehicle operations in the Province. An additional station is being developed by the University of British Columbia, scheduled to open in the second half of 2020.

Figure 54. Hydrogen Infrastructure Map of Active and Planned Stations

Turning to heavy-duty vehicle infrastructure, since the Whistler Transit fueling station was decommissioned in 2014, the only operational fueling equipment for heavy-duty transportation equipment in the Province is a 250-bar Praxair dispenser used by Ballard Power Systems for testing buses and trucks out of their Burnaby facility.

4.2.4.2 : 2020 -2025 Lighthouse Project Adoption, Light-Duty Vehicle Growth

To support the vehicle adoption numbers outlined in section 4.2.3 under both the conservative and aggressive scenarios, the Province will need substantial infrastructure investment.

For light-duty vehicles, it is estimated that the currently planned and funded network will support approximately 1,000 vehicles based on 6 stations supporting an average of 150-200 vehicles per dispenser by mid-2020.

Based on the vehicle adoption modeling, the Province will need to begin adding retail fueling station capacity between 2021 and 2024, growing to 19 - 47 dispensers by 2025. During this period, stations with higher throughput capacity (larger storage tanks and compression sub-systems, and multiple dispensers) will be necessary. It is anticipated that geographic coverage will extend outside of Metro Vancouver and the Capital Region District to include clusters in other parts of the Province such as Kelowna and Whistler.

It must be noted that the current development cycle for deploying fueling station equipment in BC and elsewhere is approximately 18 -24 months from issuing the RFP, to the first vehicle fueling event. Solicitations would therefore need to be released in Q4 2019 to support the infrastructure requirements for the aggressive adoption scenario.

For medium- and heavy-duty vehicles, multiple lighthouse projects are recommended during this period, requiring both 350 and 700-bar infrastructure:

- *1x Port of Vancouver heavy-duty fueling station capable of supporting up to 50 vehicles including drayage and terminal tractors.*
- *2x heavy-duty fueling station (with multiple dispensers) capable of supporting up to 75 class 8 long-haul trucks within the Metro Vancouver Regional District (MVRD).*
- *1x heavy-duty fueling station (with multiple dispensers) capable of supporting up to 125 co-combustion, class 8 long-haul trucks in the Prince George region, to leverage the availability of by-product hydrogen from the Chemtrade plant.*
- *2x medium-duty fueling stations capable of supporting up to 100 class 6 delivery trucks within the GVRD.*
- *2x heavy-duty fueling stations to support 65 fuel cell electric coaches, one to be located in Metro Vancouver and the other to be located in a community outside of Metro Vancouver.*

BEV CHARGING FACILITIES

BEV charging facilities take far less time to plan and install than FCEV hydrogen fueling stations. The situation has an unexpected parallel in the renewable energy sector. There, utility-scale solar arrays can be planned and installed over a matter of months.

In contrast, wind farms of any scale frequently require two or more years, including a minimum of one year of data collection, owing to the unique complexities of each wind farm site.

Figure 55 below outlines an example of the network in BC that would be required to support the roll-out of fuel cell electric vehicles (conservative to aggressive range) and lighthouse projects (aggressive) for medium- and heavy-duty applications in the 2020-2025 timeframe.

Figure 55. Potential Hydrogen Infrastructure Map (2025)

4.2.4.3 : 2025 -2030 Light-Duty Vehicle Adoption, Medium- and Heavy-Duty Growth in Niche Applications

This five-year period will be characterized by an acceleration in the adoption rate of light-duty vehicles and an evolution in the market for medium- and heavy-duty vehicles from lighthouse projects to early market growth in specialized applications where fuel cell technology offers a positive value proposition relative to competing technologies.

For light-duty vehicles, it is assumed that dispenser capacity per station will dramatically increase to 2-3 dispensers per station to satisfy fuel demand. Based on the light-duty vehicle projections, 96 to 206 dispensers will be required by 2030, expanding into rural communities beyond the targeted clusters that will be the focus of the previous phase, and strategically intersecting major highways to facilitate travel.

It is anticipated that a number of these fueling stations will be containerized or "connector" stations that will be replaced and re-deployed as the demand for full-scale retail fueling stations is realized in different regions. Also, as car sharing businesses begin to incorporate fuel cell electric vehicles into their fleets, mobile fueling systems will be deployed to fuel vehicles in-situ as is currently happening with gasoline refueling. Based on BC Hydro capacity projections, this phase of deployment is where electrical generation and transmission will be significantly constrained in supporting battery electrical vehicle infrastructure, driving a higher percentage (6.4% - 8.0%) of new fuel cell vehicles relative to all new zero-emission vehicles deployed. As presented in 4.2.2.1, this range of dispensers is heavily influenced by the relative strength of the BC ZEV mandate, and the OEM's ability to deploy vehicles.

Medium- and heavy-duty vehicles, during this period, will transition from the testing and demonstration phase into early commercial adoption. Deployment will be focused on applications where the duty cycle for the vehicles offer a comparative advantage compared to other zero-emission technologies. Examples include Class 8 trucks with heavy payloads, inter-city buses for both transit and commercial operations, and goods movement equipment requiring short fueling times. Based on the medium- and heavy-duty projections, assuming 50 fleet vehicles per dispenser, it is expected that up to 48 medium- and heavy-duty dispensers will be required by 2030, each capable of supplying a minimum of 25 kg per fill.

QUEBEC CONTAINERIZED STATION

In 2019, the first 700 bar retail hydrogen station opened in Quebec. The station is fully enclosed in a 28-foot containerized package. It is capable of fueling four vehicles consecutively and is sized to fill 20 vehicles per day. The station was constructed by Powertech, a subsidiary of BC Hydro, and installed by North Vancouver based HTEC. Powertech has designed and constructed 16 other turnkey compressed hydrogen fueling stations across North America.

4.2.4.4 : 2030 -2050 Light-Duty, Medium- and Heavy-Duty Commercial Operation

It is easier to predict the energy demand for hydrogen during this time period than to predict the corresponding fueling model for energy delivery, as car sharing, ride hailing, and autonomous operation of private and commercial vehicles proliferate. In addition to these changes to vehicle operation, it is anticipated that fueling technology will change as well, moving to more energy dense fuel storage mediums such as liquid or cryo-compressed hydrogen.

Based on the light-duty vehicle projections, it is estimated that between 3,330 to 4,260 dispensing points will be required by 2050, distributed across every community across the Province. The network of fueling stations will need to become ubiquitous enough to allow convenient travel anywhere/anytime in the Province for commercial and private drivers.

Medium- and heavy-duty vehicle infrastructure will continue to grow in commercial volumes. Based on the projections, up to 278 medium- and heavy-duty dispensers will be required to support the trucks, goods movement equipment, transit and inter-city buses, passenger ferries and rail applications by 2050. Note that many of these dispensers will be co-located at fleet fueling facilities as the scale of deployment expands.

4.2.4.5 : Low Carbon Fuel Regulation

BC's Low Carbon Fuel Regulation has provided a funding mechanism for developers, such as North Vancouver's HTEC, to deploy the hydrogen infrastructure planned in the Province to date. Under the LCFR, credits can be approved by the Province based on the projected station capacity and displacement of fossil fuel emissions by hydrogen, then sold to fuel suppliers bound by the LCFR.

While credit sales have assisted, other sources of funding have been required; examples include the Province's CEV program and federal funding through Natural Resources Canada (NRCan) funding. OEMs have also invested in infrastructure in limited cases.

At present, this approach is that project development takes significant time and effort, and lacks a cohesive strategic direction supported by government. It is recommended that the Province take a more active role in guiding infrastructure development, including through the release of special prescriptive call for hydrogen LCFR Part 3 agreements, likely required every 2-3 years, until hydrogen infrastructure in the province is well established.

4.2.5 Recommendations

Structure the light-duty ZEV mandate to encourage OEMs to make FCEVs available in BC

- *Make British Columbia the world leader in credit value for FCEVs.*

Implement a Zero Emission Bus Mandate for public transit vehicles and a Voucher Program to offset incremental costs.

Strengthen funding to support rollout of hydrogen infrastructure in the Province

Support feasibility study for the use of hydrogen in Marine, Rail and off-road applications in BC.

Support lighthouse projects to deploy medium- and heavy-duty fuel cell vehicles in the Province.

- *Support a fuel cell electric coach pilot program.*
- *Create a large-scale, zero-emission heavy-duty vehicle program focused on Vancouver ports*

4.3 : Industry

4.3.1 : Baseline

BC industries that currently use hydrogen include the production of liquid transportation fuels and sodium chlorate and chlor-alkali plants. The two remaining refineries in BC, located in Burnaby and Prince George, use hydrogen as part of the refining process. Sodium chlorate plants are located in North Vancouver and Prince George while the only chlor-alkali plant is in North Vancouver.

The Parkland refinery in Burnaby, has a production capacity of 55,000 barrels per day (bbl/d) of light crude into a range of products including gasoline, diesel, aviation fuel, LPG and industrial fuel supplying ~ 25% of the Province's transport fuel needs. Hydrogen is produced from naphtha as an internal part of the refining process at a rate of ~ 26 tonnes/day or 10,000 tonnes/year.[112]

The Husky refinery in Prince George has a production capacity of 12,000 bbl/day of light crude into a range of products including gasoline, diesel, LPG/butane and industrial fuel supplying ~ 5% of the Province's transport fuel needs. The facility produces hydrogen from a steam methane reformer at a rate of 3.3 tonnes/day or 1,200 tonnes/year.[113]

Chemtrade operates both the chlor-alkali plant in North Vancouver and the sodium chlorate plant in Prince George. The North Vancouver plant produces hydrogen as a by-product but uses this during the production of HCl. To supplement this hydrogen demand, Chemtrade buys by-product hydrogen from the neighbouring ERCO sodium Chlorate plant. ERCO dechlorinates, compresses and sends the hydrogen via a dedicated hydrogen pipeline to the Chemtrade plant. The total ERCO by-product hydrogen production is approximately 15 tonnes/day or 5,500 tonnes/year of which ~50% is sold to Chemtrade and 50% or 7.5 tonnes/day is vented to atmosphere. This is sufficient to meet the needs of approximately 7,500 light-duty FCEVs.

The Chemtrade sodium chlorate plant in Prince George produces approximately 11 tonnes/day or 4,000 tonnes/year of by-product hydrogen,[113] enough to provide fuel for about 22,000 light-duty FCEVs. This hydrogen is currently vented however a portion of this capacity may be contracted to a potential customer in the near future.

Combined, the Parkland, Husky, and Chemtrade facilities produce 20,700 tonnes of hydrogen annually. This is equivalent to approximately 2.5 million GJ of energy.

The industrial sector in BC accounted for approximately 38% of natural gas consumption in the province as of 2017.[114] Natural gas is primarily used in industry for high-grade process heat, for space and hot water heating in industrial complexes, and as a chemical feedstock. The natural gas use accounts for GHG emissions of approximately 4.2 Mt CO_2e/year.

112 *Personal correspondence – Parkland April 26, 2019*

113 *Dalcor Consultants, Ltd. (2005). Canadian Hydrogen Survey - 2004/2005. Retrieved from http://ieahydrogen.org/Activities/Subtask-A,-Hydrogen-Resouce-Study-2008,-Resource-S/Canadian-H2-survey-2005.aspx*

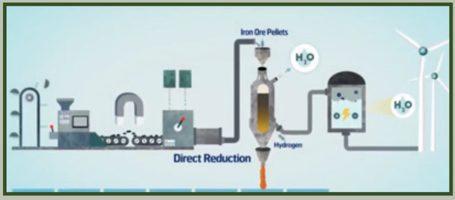
114 *BC Provincial Government. (2018). Production and Distribution of Natural Gas in BC Retrieved from https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-gas-oil/production-statistics/gasnew.xls*

ATTRACTION OF NEW INDUSTRY TO BC

Hydrogen is used as a feedstock in several major industrial processes. Establishment of large scale, low carbon intensity, and cost competitive hydrogen supply in the Province has the potential to attract new industry and drive economic growth in the Province. By-products in the hydrogen production process, such as oxygen in the case of electrolysis, and waste heat can also attract new industry.

Hydrogen is used in the following industrial processes:

- *Ammonia production (NH3), through the Haber-Bosch process which combines hydrogen and nitrogen together. Approximately 90% of Ammonia produced goes into fertilizer production.*
- *Processing crude oil into refined fuels, such as gasoline and diesel, and also removing contaminants like sulfur form these fuels.*
- *Steel-making – SSAB, LKAB and Vattenfall joined forces to create HYBRIT – an initiative that endeavours to revolutionize steel-making. HYBRIT aims to replace coking coal, traditionally needed for ore-based steel making, with hydrogen.*



- *In the electronics industry, it is widely employed as a reducing agent and as a carrier gas.*
- *In margarine production, for the hydrogenation of fats. It consists of adding hydrogen to compounds that contain multiple bonds.*
- *In methanol production or methyl alcohol production.*
- *In synthetic liquid fuel production.*

4.3.2 : Opportunities for Hydrogen

The greatest opportunity for hydrogen is in the production of low carbon or renewable liquid fuels. BC's renewable and low carbon fuel standard (LCFS) is a performance-based standard which specifies the GHG intensity and renewable content of fuels used for transportation. Part 3 of the LCFS calls for a 10% reduction in GHG intensity for transportation fuels sold in the province by 2020 relative to 2010. Part 2 of the Standard calls for a minimum of 5% renewable content for gasoline and 4% for diesel. Currently the renewable fractions are higher than the minimum which indicates that GHG intensity part of the standard is more stringent to meet.

The CleanBC plan further decreases the GHG intensity by another 10% by 2030 or a 20% reduction compared to 2010. This is projected to increase the production of renewable gasoline and diesel to 650 million litres per year by 2030 representing 8% of the total fuel demand.[115]

There are a number of ways to meet this projected fuel demand. Biomass based fuels such as corn ethanol, methanol and biodiesel can be produced. Ethanol and methanol can be mixed with gasoline and biodiesel can be mixed with or replace fossil produced diesel.

The pathways for biomass to produce renewable diesel are shown in Figure 56.

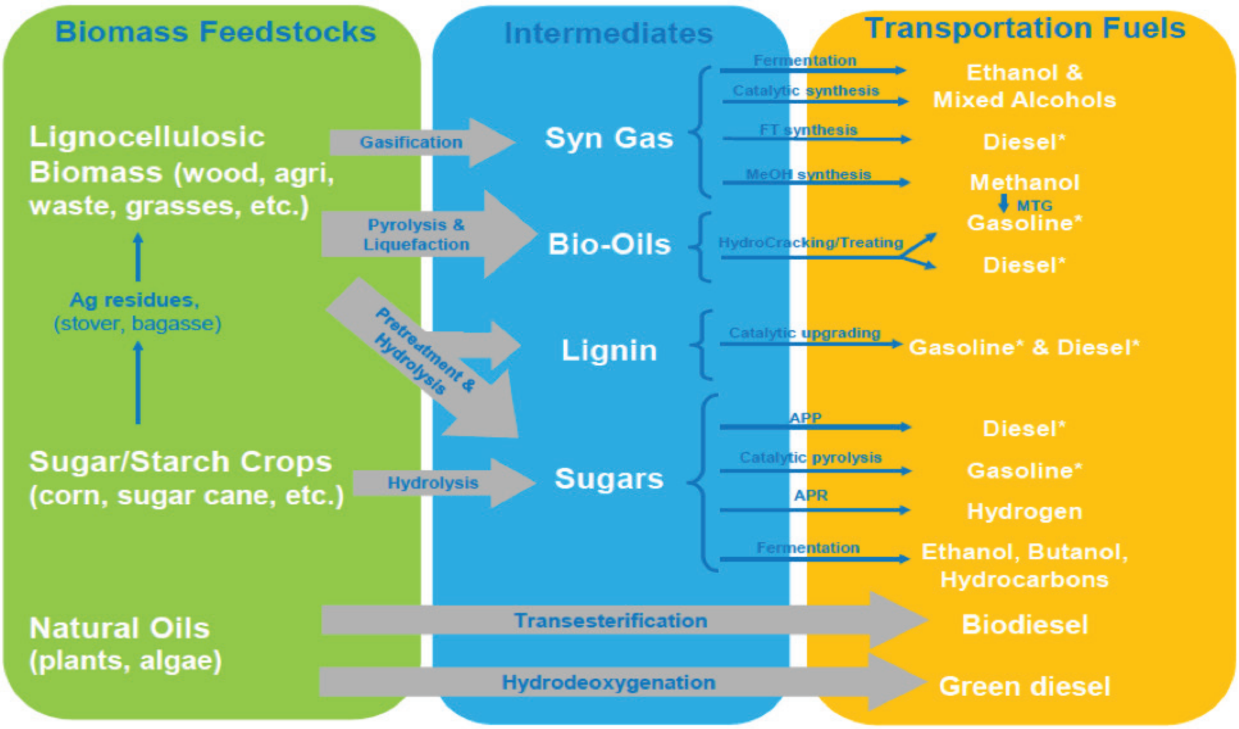


Figure 56. Biomass to Liquid Fuel Pathways

Current biomass feedstocks being investigated at the Parkland refinery include canola and tallow oil which are co-processed with fossil crude in the refinery. However, the available bio feedstocks will be insufficient to meet the projected demand.

115 BC Provincial Government. (2018). CleanBC: Our Nature. Our Power. Our Future. Retrieved from https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_2018-bc-climate-strategy.pdf

Forest residues are being considered as a biomass feedstock to meet the 2030 demand. This source of biomass contains a high proportion of oxygen and will require additional hydrogen during production. Parkland is currently investigating this pathway in their refinery but were unable to provide estimates of how much hydrogen would be required.

Another pathway to meet the LCFS proposed in BC is via the production of synthetic crude or fuels using low carbon or renewable hydrogen and CO_2 captured from the air. This pathway is shown in Figure 57.

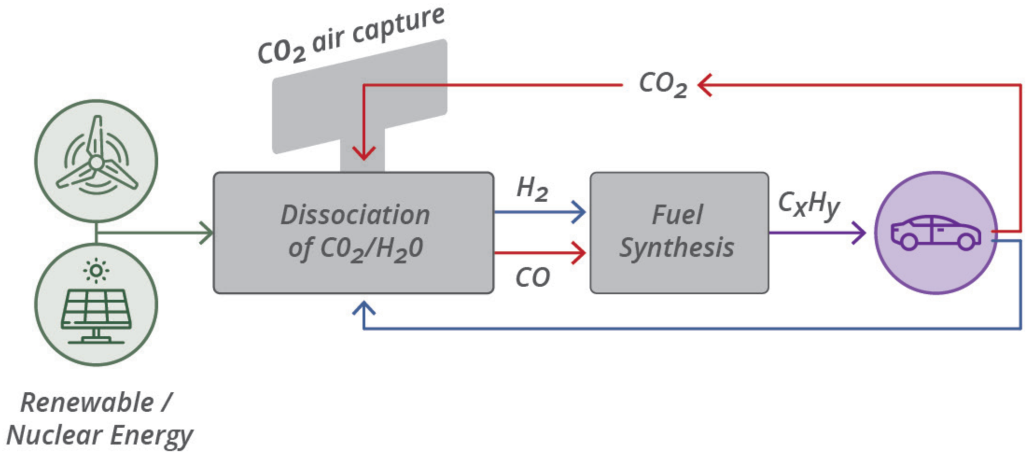


Figure 57. Synthetic Fuel Production Process

Carbon Engineering, based in Squamish, is developing an AIR to FUELS™ process whereby CO_2 from air and hydrogen are converted in conventional chemical processes to produce synthetic crude which can be processed in conventional refineries without any modifications. A commercial scale plant producing 100 million litres/year of synthetic crude would require 100 tonnes/day of clean hydrogen and 550 tonnes per day of CO_2 captured from the air. Depending on the GHG intensity of the hydrogen and the energy required in the direct air capture (DAC) process, the GHG intensity of the liquid fuels will be reduced by 70 – 90%.[116] If this hydrogen is produced by electrolysis, electrical input power would comprise approximately 250 MW[117] per plant for hydrogen production with another 8 MW for the DAC plant.[118] This is a significant electrical load, representing 23% of total Site C dam nameplate capacity.

By-product hydrogen produced by ERCO and Chemtrade provides a relatively small but low-cost hydrogen pathway of up to 18.5 tonnes per day. Due to their locations, the hydrogen must be either used on-site or transported to another location. Given the very high demand for low-cost hydrogen in the synthetic fuels production pathway, other sources of bulk, clean hydrogen and production will likely have to be constructed. Technology hurdles remain that will need to be overcome for synthetic fuel production to happen at scale in BC. In addition, as fuel cell electric vehicle adoption increases, the hydrogen market is likely to tip towards the more efficient pathway of directly using hydrogen for transportation, rather than using it to produce a synthetic fuel. That said, the synfuels pathway can immediately reduce the emissions of the existing vehicle fleet. Synfuels may also play a key role in helping to decarbonize emissions relating to marine and aviation transport.

An additional opportunity for hydrogen in the industrial sector is through the displacement of natural gas related to heating. This opportunity is discussed in Section 4.1 so is not treated further here.

116 *Personal Correspondence – Carbon Engineering April 3, 2019*

117 *Assumes 60 kWh/kg H_2*

118 *Keith et al. (2018). A Process for Capturing CO_2 from the Atmosphere. Joule 2, 1573–1594. Retrieved from https://www.cell.com/joule/pdf/S2542-4351(18)30225-3.pdf*

4.3.3 : Challenges and Barriers

Due to the quantity of low carbon fuels required by 2030, hydrogen production at large scale in the province will likely be required regardless of the method used to produce the low carbon fuel. These hydrogen plants may be located near existing refineries to support production of biofuels using lignocellulosic feedstocks such as forestry residue or located in other regions where hydrogen production is co-located with DAC plants to produce synthetic crude which is transported to the refineries by rail, truck or pipeline. The main challenges for installing these large-scale plants include long upfront delays to obtain the necessary permits required to build the plant, as well as the potential for protests if the hydrogen is produced from natural gas.

If the plants are located at the existing refineries, hydrogen production via SMR+CCS is not possible due to the lack of CO_2 storage at the refinery sites. Unless there is a local use for solid carbon, hydrogen production via pyrolysis may also not be feasible at refineries. Lastly, due to the large electrical demand for large-scale electrolysis, onsite multi-MW supply at these locations may not be available due to local electrical transmission constraints.

In either case, intermittent hydrogen production from wind – electrolysis is also not viable due to the likely requirement of continuous hydrogen supply. Therefore, it appears likely that large-scale hydrogen production to support low carbon fuels demand will be located remotely from the refinery.

Finally, in order for the cost of low carbon fuels to remain low, hydrogen must be supplied at a low cost. Hydrogen produced for a cost of $5/kg will likely be too expensive as the cost of hydrogen alone equates to almost $2/litre of fuel.

Policies that could help drive hydrogen demand in the province includes maintaining the performance basis of the LCFS. By creating lower GHG intensity fuels and not allowing producers to exceed the intensity by paying a fee, clean hydrogen demand will be increased significantly and result in GHG emissions reductions in the province. Also, Part 2 of the LCFS should be modified to increase the proportion of renewable content in the LCFS over the longer-term as costs for renewable feedstocks decrease. The province could also consider further decreases in the GHG intensity for transportation fuels beyond 2030.

The province should consider supporting an initial large-scale project to kickstart hydrogen production for LCFS production. This could be either an AIR to FUELS™ plant to produce synthetic crude or a forestry biomass fed plant to produce renewable diesel and/or gasoline.

4.3.4 : Adoption Scenarios

Adoption scenarios that project hydrogen demand to 2050 have been based on conservative and aggressive policies. Due to the unknown hydrogen requirements to produce liquid fuels from biomass feedstocks, hydrogen demand was estimated using Carbon Engineering's AIR to FUELS™ pathway for a 100 ML/year of synthetic crude oil facility. The GHG reduction potential for this pathway is assumed to be 90%.[119] Finally, the overall transport fuel demand in BC is assumed to stay constant based on actual 2017 demand.[120]

The conservative scenario assumes the CleanBC target of 20% reduction in GHG intensity for transportation fuels continues until 2050. In this scenario, synthetic fuels will only meet 5% of the low carbon fuel requirement by 2030 and produce approximately 76 million litres/year. By 2050, growth to 25% of the low carbon fuel requirement is projected, with production of 380 million litres/year.

In the aggressive scenario, the GHG intensity reduction continues past 2030 and reaches 30% below 2010 levels by 2050. In this case, it is projected that synthetic fuels meet 25% of the total low carbon fuel demand by 2030, the equivalent of 380 million litres/year. By 2050, synthetic fuels plants meet 75% of the total low carbon fuel demand with production of 1,710 million litres/year.

119 *Personal Correspondence – Carbon Engineering April 3, 2019*

120 *The Ministry of Energy, Mines and Petroleum Resources has provided a forecast that liquid fuel demand (gasoline, diesel) in BC will remain flat.*

The demand curves for Industry for these scenarios are given in the figure below.

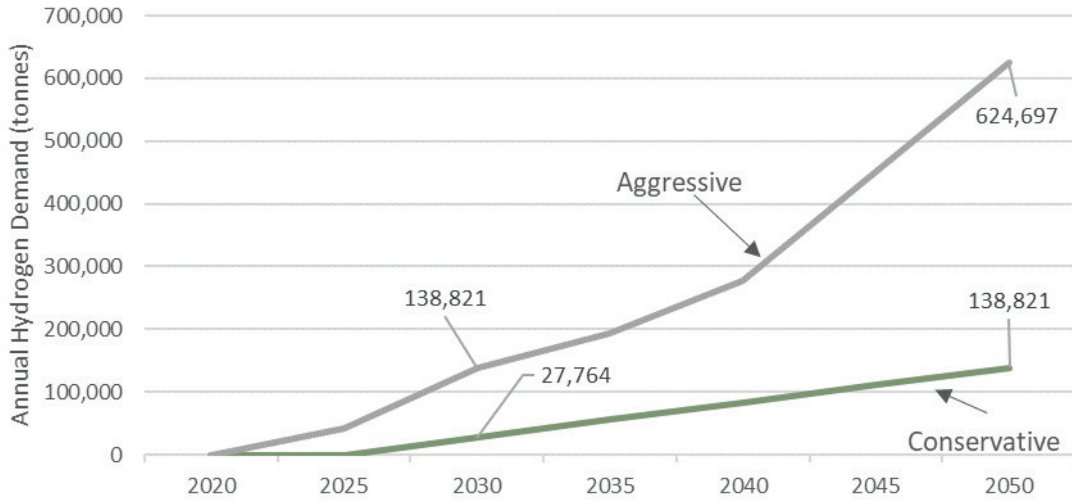


Figure 58. Hydrogen demand for Industry in BC

4.3.5 : Recommendations

Maintain the current performance base, GHG intensity reduction mandate of the LCFS

- *Include increasing proportion of renewable content over time*

Extend and Increase the proportion of low carbon fuels beyond 2030

- *Provides assurances to developers on a long-term market to justify large capital expenses*

Support a large-scale demonstration project in BC which uses clean hydrogen for the production of synthetic liquid fuels.

4.4 : Built Environment

4.4.1 : Baseline

The built environment makes up approximately 13% of total GHG emissions in BC. This sector can be divided into two broad categories as shown in Table 11.[121]

CATEGORY	DESCRIPTION
Residential	Personal residences (homes, apartment hotels, condominiums and farmhouses).
Commercial	Service industries related to mining, communication, wholesale and retail trade, finance and insurance, real estate, education, etc.; offices, health, arts, accommodation, food, information & cultural; Federal, provincial and municipal establishments; National Defense and Canadian Coast Guard; Train stations, airports and warehouses.

Table 11. Definition of Built Environment GHG Emissions Categories[121]

Figure 59 shows the GHG emissions from both built environment categories in BC from 1990 to 2016.

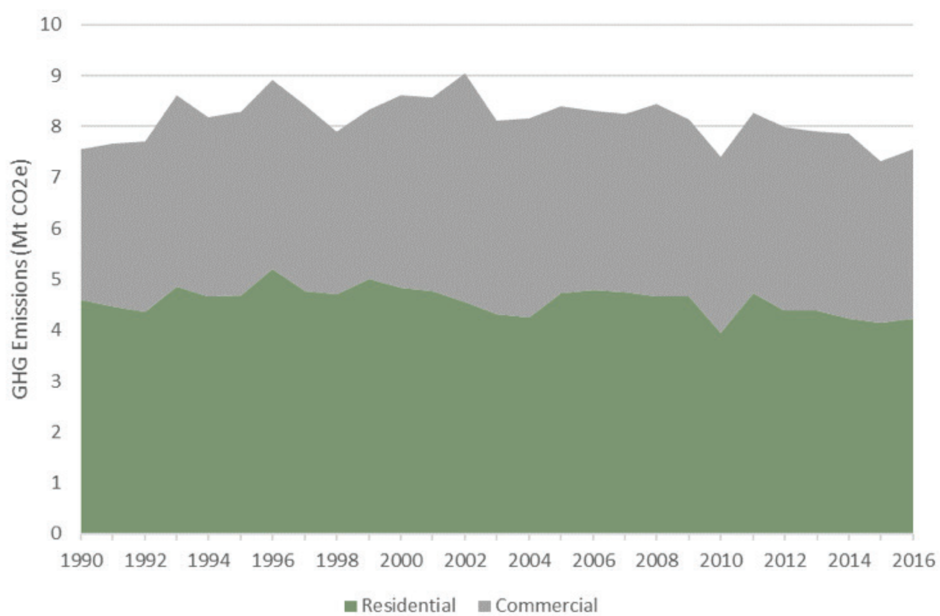


Figure 59. BC Built Environment GHG Emissions by Category (1990-2016)[121]

121 *Environment and Climate Change Canada. (2018). National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada, Annex 10. Retrieved from* https://open.canada.ca/data/en/dataset/779c7bcf-4982-47eb-af1b-a33618a05e5b

Total built environment GHG emissions trended slightly upward from 1990 to 2004 and have trended slightly downward since then. The split between residential and commercial/industrial has remained relatively consistent ranging from 61%/39% to 50%/50%. Figure 60 shows the percent of total built environment GHG emissions attributable to both categories in 2016.

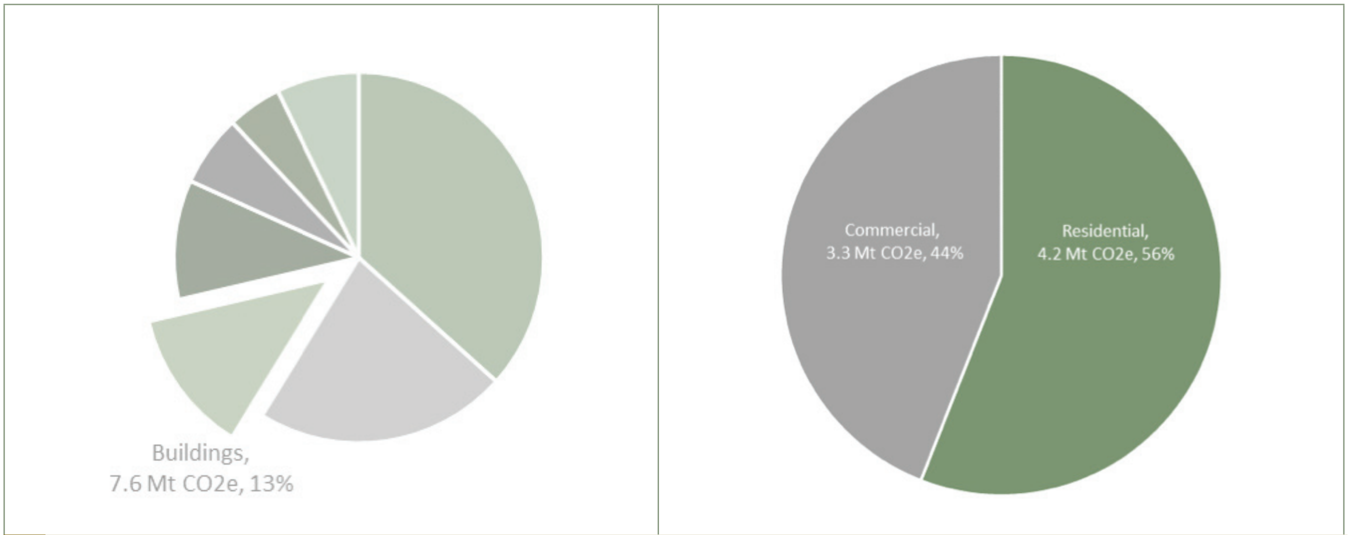
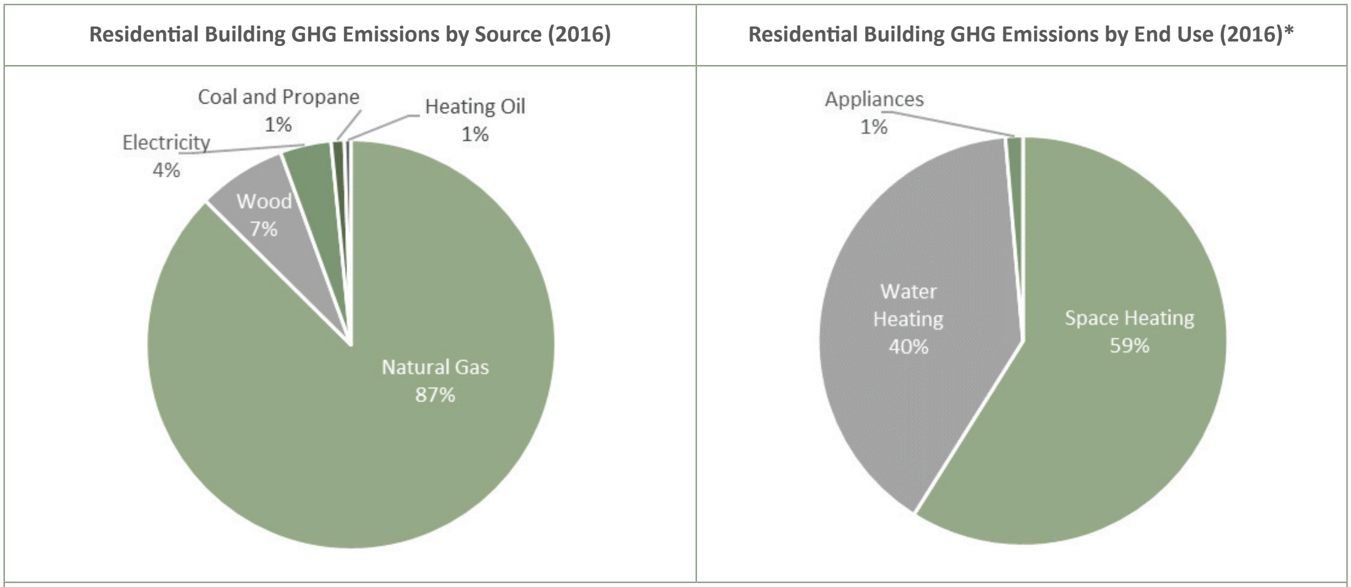


Figure 60. BC Built Environment GHG Emissions by Category (2016)[121]

4.4.1.1 : Residential Built Environment Baseline

Figure 61 shows residential building GHG emissions by source and end use (neglecting electricity).



**Neglects GHG emissions from electricity*

Figure 61. BC Residential Building GHG Emissions by Source and End Use (2016)[122]

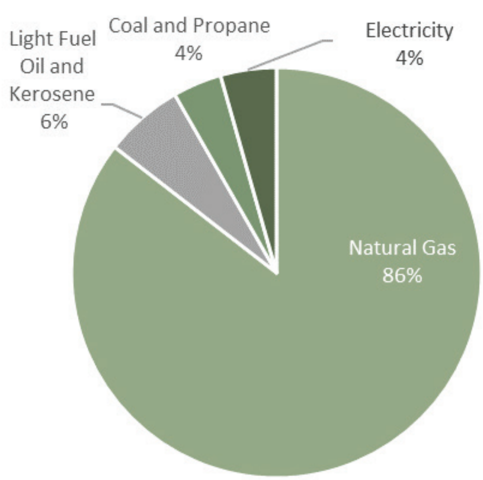
122 Natural Resources Canada. Comprehensive Energy Use Database: Residential Sector – British Columbia. Retrieved from http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive/trends_res_bc.cfm

The majority of residential GHG emissions results from natural gas consumed for space and water heating. The prevalence of heating oil has decreased significantly in BC, from 16.1% of GHG emissions in 1990 to less than 1% in 2016. Over the same period, emissions from water heating have increased while emissions from space heating decreased.[122]

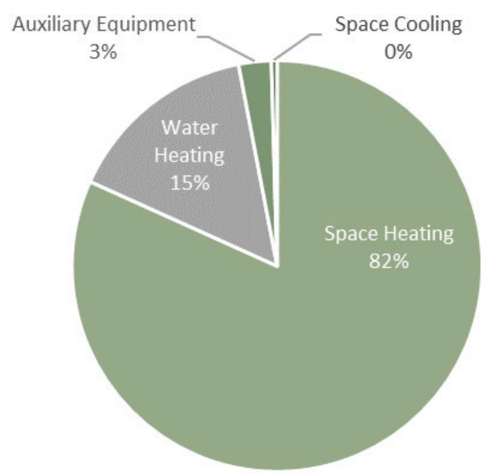
4.4.1.2 : Commercial Built Environment Baseline

The majority of GHG emissions from the commercial and industrial built environment results from the burning of natural gas for space heating (Figure 62). The proportions shown have stayed relatively constant over time.

Commercial Building GHG Emissions by Source (2016)



Commercial Building GHG Emissions by End Use (2016)*



**Neglects GHG emissions from electricity*

Figure 62. BC Commercial Building GHG Emissions by Source (2016)[122]

4.4.1.3 : Built Environment Hydrogen Baseline

Hydrogen is not currently in use to provide heating, cooling, or on-site electricity generation for the built environment in BC. The CleanBC plan primarily focuses on reducing emissions in the built environment by increasing the percent of natural gas that comes from renewable sources, improving the building code, investing in demand side management, and encouraging the installation of heat pumps.

4.4.2 : Opportunities and Challenges

The best opportunity for hydrogen to reduce GHG emissions in the built environment is through the displacement of natural gas in the grid. The built environment makes up approximately three quarters of the demand for natural gas across the Province. Achieving the CleanBC goal of 15% renewable gas by 2030 will result in significant emissions reductions, and hydrogen can play a pivotal role, as described in Section 4.1.

Off-setting natural gas consumption through the addition of hydrogen to the grid is particularly attractive for the built environment because at low concentrations it requires no action on behalf of the building occupants. Research suggests the natural gas stream feeding most domestic appliances could contain up to 20-30% hydrogen by volume without the need to separate the gases at their end use or making major changes to the grid or appliances.[123, 124, 125] Retrofitting buildings with improved insulation and weatherization, or installing energy efficient equipment like heat pumps or tankless water heaters requires effort and capital expenditure on the part of building owners. Adding hydrogen to the gas grid requires no action from the population at large, though it is likely to impact the rates paid.

Beyond the 20-30% range, the hydrogen/natural gas blend may become incompatible with domestic appliances like furnaces and stoves because of hydrogen's relatively low energy content, low density, and high burning velocity. To increase the hydrogen content beyond this level would require modifications to the pipe network as well as the appliances themselves. Though challenging, a major overhaul of this sort is not unprecedented. In 2009, Whistler underwent a transition from propane to natural gas, which involved similar retrofits of about 14,000 domestic appliances.[126]

Another opportunity for hydrogen in the built environment is stationary fuel cell systems that provide combined heat and power (CHP), sometimes called cogeneration, or cogen. These systems, which can run on natural gas, pure hydrogen, or a blend, have been successfully deployed at scale in Japan. However, they are not well suited to most regions in BC because of their relatively high capital cost and the availability of inexpensive renewable electricity in BC. Residential cogeneration systems might make sense if an entire community converted to 100% hydrogen, as described in Section 4.1 and Section 4.5.

4.4.3 : Adoption Scenarios

Hydrogen adoption in the built environment was not modeled independent of the natural gas pipeline (Section 4.1) and remote communities (Section 4.5). The hydrogen demand in both of those sectors will be largely consumed in the built environment. Figure 63 shows the natural gas demand by segment in 2017.

123 California Hydrogen Business Council. (2015). Power-to-Gas: The Case for Hydrogen White Paper. Retrieved from https://www.californiahydrogen.org/wp-content/uploads/2018/01/CHBC-Hydrogen-Energy-Storage-White-Paper-FINAL.pdf

124 Dentons. (2019). The Future of Gas: Transitioning to Hydrogen in the Gas Grid. Retrieved from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&ved=2ahUKEwilmbvrio3iAhWLqZ4KHd8mBBwQFjAFegQIBRAC&url=https%3A%2F%2Fwww.dentons.com%2Fen%2Fpdf-pages%2F-%2Fmedia%2Fef787bcd303a459dbbfa60677a3e7df1.ashx&usg=AOvVaw3oY6CfCFtG6Z6YsVhnHf_y

125 Jones DR, Al-Masry WA, Dunnill CW. (2018). Hydrogen-enriched Natural Gas as a Domestic Fuel: An Analysis Based on Flash-back and Blow-off Limits for Domestic Natural Gas Appliances within the UK. Sustainable Energy Fuels, 2, 710-723. Retrieved from https://pubs.rsc.org/en/content/articlelanding/2018/se/c7se00598a/unauth#!divAbstract

126 Fortis BC. Whistler Natural Gas Conversion. Retrieved from https://talkingenergy.ca/node/80

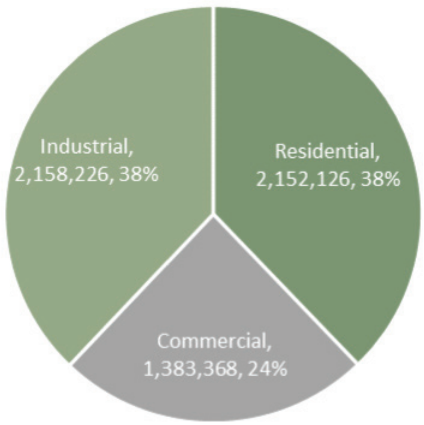


Figure 63. Natural Gas Demand in m³ in BC by Segment (2017)[127]

The modeling assumed the percent share of each segment remained constant through 2050, so the built environment represents approximately three quarters of the hydrogen demand projected in Section 4.1. Effectively all the hydrogen demand modeled for remote communities are attributable to the built environment.

4.5 : Remote / Off-Grid Communities

4.5.1 : Baseline

4.5.1.1 : Overview

A remote community is defined as a permanent community not connected to North America's integrated electrical or natural gas grids. It must have been settled for longer than 5 years, with 10 or more dwellings. The NRCan Remote Communities Energy Database[128] (based on 2017 or most recently available data) identifies 75 remote communities in BC, illustrated in Figure 64.

Fourteen remote communities rely on hydro with backup diesel generation for their electricity. Fifty-two communities rely on diesel as their primary power source. Six communities have unknown power sources.

127 *BC Provincial Government. (2018). Production and Distribution of Natural Gas in BC. Retrieved from https://www2.gov.bc.ca/gov/content/industry/natural-gas-oil/statistics*

128 *Natural Resources Canada. (2018). The Atlas of Canada – Remote Communities Energy Database. Retrieved from http://atlas.gc.ca/rced-bdece/en/index.html*

Figure 64. BC Remote Communities with Power Source

4.5.1.2 : Microgrids

A microgrid is a complete system (diesel generators or small-scale hydro, distribution wires/equipment, control systems) that provides electricity to a community; in some cases, they may provide power to surrounding communities as well. Fourteen of BC's remote communities are connected to one of four local microgrids owned by BC Hydro: Bella Bella, Bella Coola (Ah-Sin-Heek power plant) and Sandspit provide hydroelectric power with diesel as back-up, while Masset is 100% diesel generation.

NAME	#*	PRIMARY POWER	SECONDARY POWER	FOSSIL FUEL GENERATION (MWH/Y)	FOSSIL GENERATING CAPACITY (MW)	PEAK LOAD (MW) (2016)	NOTES ON POWER SOURCE
Bella Bella	4	Hydro	Diesel	983	4.90	4.30	93% hydro, diesel as backup
Bella Coola	3	Hydro	Diesel	7939	9.25	4.85	70% hydro, Clayton Falls Hydroelectric
Sandspit	4	Hydro	Diesel	5507	10.15	6.96	70-90% hydro, Moresby Lake Hydro Station
Masset	3	Diesel	n/a	26433	13.10	6.22	5 Generators, 10.455 MW capacity
*Number of communities supported							

Table 12. BC Hydro Local Microgrids

Diesel generators and small-scale hydro can provide consistent 24/7 electricity, facilitating the balancing of supply and demand. Variable renewable electricity, or VRE, composed of intermittent wind and variable solar, can provide intermittent power which can help reduce costs and emissions, but which increase the complexity of a microgrid system. Hybrid systems of hydroelectricity with diesel back-up can supply the majority of a community's power needs, providing lower-cost, cleaner electrical supply most of the time, while using diesel generators as back-up to ensure uninterrupted electricity supply.

For a microgrid without storage (generally lithium-ion battery, though in some cases flow battery), intermittent renewables penetration is estimated at 20-30%. As integration of renewable sources increases (bringing down the overall cost of generating the electricity), combined with falling battery prices, investing in storage options could become an economically viable option.

4.5.1.3 : Single Off-Grid Communities

Sixty-one (61) off-grid communities in BC are powered primarily by diesel, but also by small hydroelectric projects as well as demonstration projects for LNG, Biomass and solar.

Fifty-two (52) communities rely on diesel generation as their primary source for electricity, three communities get electricity from small local hydroelectric projects (run of river with no storage) and three additional communities use hybrid systems of Diesel with LNG, biomass or solar. Service is provided by BC Hydro (diesel generation from 10 stations and two small hydroelectric projects), Independent Power Producers (IPP) provide diesel electricity to 31 communities and ATCO Electric Yukon to a single community.

SERVICE PROVIDER	COMMUNITIES	PRIMARY POWER	SECONDARY POWER	FF* DEMAND (MWH/Y)	FF GEN** CAPACITY (KW)	NOTES ON POWER SOURCE
BC Hydro-2 IPP-1	3	Hydro	Diesel	348		Minimal diesel as backup
BC Hydro-8 IPP-30 Unknown-10 ATCO Electric YT-1	49	Diesel		92,513	58,514	100% diesel
BC Hydro	1	Diesel	LNG	6,649	3,550	50% diesel, 50% LNG
BC Hydro	1	Diesel	Biomass	2,963	1,800	20-25% biomass
IPP	1	Diesel	Solar	1,400	78	250 kW solar + 1 MWh storage; target 80% solar
Unknown	6	Unknown		Unknown		Small amounts of diesel, Propane, Gasoline, Small solar
** Fossil Fuel* ***Fossil Fuel Generation*						

Table 13. Power Source(s) for 61 Single Off-grid Communities

4.5.1.4 : Diesel GHG Baseline

Remote communities in BC and across Canada rely primarily on diesel for electricity, and efforts continue to reduce this reliance. Data on diesel use and the resulting GHG emissions remains limited. The Pembina Institute estimated that more than 90 million litres of diesel[129] are consumed in Canada's remote communities with BC communities estimated to use 3 million litres per year.

To establish a GHG baseline for BC's remote communities, information was gathered on annual diesel demand at the community level. Data was unavailable for some of the smallest communities, but these likely use 3 (or fewer) installed gensets with capacity well below 1MW. Data was gathered from the NRCan Remote Community database and an earlier report (2011) on the Status of Remote/Off-Grid Communities in Canada[130] prepared by NRCan and Aboriginal Affairs and Northern Development Canada (AANDC).

129 *Pembina Institute. (2019). Diesel, Renewables, and the Future of Canada's Remote Communities: Introduction to Microgrids. Retrieved from https://www.pembina.org/blog/remote-microgrids-intro*

130 *Natural Resources Canada. (2011). Status of Remote/Off-Grid Communities in Canada. Retrieved from https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/files/pubs/2013-118_en.pdf*

PROVIDER	FOSSIL FUEL GENERATION (MWH/Y)	FOSSIL GENERATING CAPACITY (MW)
BC Hydro	61,159	60.7[131]
IPP + Other	31,354	9.3
Total	92,513	70

BASELINE CO_2E EMISSIONS RESULTING FROM DIESEL ELECTRICITY GENERATION ANNUALLY IN BC REMOTE COMMUNITIES	
Annual FF electricity generation in BC Remote Communities (MWh/y)	92,513 MWh/year
Conversion Factors	
1 MWh = 3.6 GJ	
Diesel emission factor CO_2e = 100.5 kg/GJ[132]	
CO_2e emissions from FF generation in BC Remote Communities	**33.47 kt CO_2e/year**

Table 14. Annual Fossil Fuel Power Generation and Generating Capacity

4.5.1.5 : Diesel Issues – Economic, Environmental, Social

In Canada, the average cost of electricity is between $0.07-$0.17/kWh, while the unsubsidized cost of electricity from diesel generation is approximately $1.30/kWh[133]. BC has some of the lowest electricity costs in the country and under their Non-Integrated Area rate plan BC Hydro provides diesel energy to remote communities in BC at the following subsidized rates:[134]

- *$0.1028/kWh for the first 1,500 kWh per month,*
- *$0.1767/ kWh for remaining kWh per month;*

The initial rate is equivalent to the rate paid by grid-connected customers, while the second rate is higher, although much lower than remote communities pay in other parts of the country.

131 BC Hydro. (2018). BC Hydro Quick Facts. Retrieved from http://www.llbc.leg.bc.ca/public/PubDocs/bcdocs/358355/quick_facts_2018.pdf

132 (S&T) Squared Consultants Inc. (2018). GHGenius 5.0d. Calculations conducted by BC Ministry of Energy, Mines and Petroleum Resources Low Carbon Fuels Branch. Retrieved from https://ghgenius.ca/index.php/downloads

133 Wilt J. (2018). Canada's Commitment of @220 Million to Transition Remote Communities Off Diesel a Mere 'Drop in the Bucket.' The Narwhal. Retrieved from https://thenarwhal.ca/canada-s-commitment-220-million-transition-remote-communities-diesel-mere-drop-bucket/

134 Kennedy M. (2017). Energy Shift: Reducing Diesel Reliance in Remote Communities in BC. Simon Fraser University. Retrieved from http://summit.sfu.ca/item/17979

In general, the high cost of diesel is driven by the cost of transportation over long distances and often very challenging terrain. Without the highly subsidized rates from BC Hydro, the high cost of diesel would make it very difficult for any industry consuming even small amounts of electricity to operate economically in these remote communities. As well, residents of remote communities often live at a subsistence level with the high cost of electricity contributing heavily to this. Poor building energy efficiency and cold northern climate also increase overall electricity use in these communities.

In addition to the substantial GHG emissions from the diesel generation, transportation by truck, ship or plane creates additional GHG emissions, and long transport over rough terrain increases the risk of spills. Diesel generators are also noisy, disruptive, have unpleasant fumes and the emissions can contribute to health problems (asthma, bronchitis, allergies, lung function, heart problems)[135]. Finally, the unreliability of aging generators running at capacity increases the risk of power outages which negatively impacts services and businesses and can be dangerous in cold, remote locations.

4.5.1.6 : Other Power Sources

Micro Hydroelectric Projects

Run-of-river hydroelectric projects use the natural elevation, channeling water through a penstock to a downstream turbine. Water is diverted from the stream/river for a short distance and returned to the stream after the turbine. These projects have far less environmental footprint than a traditional dam, and there are many rivers and streams in BC, however these projects require over 50 permits, licenses, approvals and reviews by many Government agencies and consultation with First Nations and public groups. BC Hydro and one Independent Power Provider (IPP) operate 6 small hydro projects in the Province: 3 hydroelectric microgrids supporting 11 communities (See Table 12 above) and 3 single community micro hydro projects.

PROVIDER	ANNUAL GENERATION (MWH/Y)	CAPACITY (MW)
BC Hydro - Atlin	5,000	2.1
BC Hydro - Dease Lake	5,000	3.0
IPP - Klemtu/Kitsoo*	At capacity	1.7
** Klemtu/Kitsoo is installing small solar (23kW) to avoid using diesel as backup*		

Table 15. Single Community Micro Hydro Projects

LNG

BC Hydro is the power provider for the community of Anahim Lake and in the fall of 2016, began a 3-year pilot project, converting the largest of 5 diesel generators to operate with LNG, with the goal of reducing both GHG emissions and fuel costs. Cryopeak trucks LNG from FortisBC's Tilbury Island facility in Delta, stores it and regasifies it in Anahim Lake. Long-term expectations are that 60% of Anahim Lake's power could come from LNG. The NRCan remote community database estimates that 50% of the electricity is currently being generated by LNG.

135 Huter, H.-P., Kundi, M., Moshammer, H., Shelton, J., Kruger, B., Schicker, I., & Wallner, P. (2015). Replacing Fossil Diesel by Biofuel: Expected Impact on Health. Environmental & Occupational Health, 4-9.Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/24965323

Biomass

The community of Kwadacha First Nation (Tsek'ene) is using biomass gasification-to-electricity to reduce reliance on diesel. In April of 2017, the biomass system, consisting of three CHP biomass generators and a dryer, began operation, producing electricity for the majority of the community and heat for the local school and greenhouses. Each generator produces 45kW of electricity and 108KW of heat in the form of hot water.[136] The project is projected to reduce reliance on diesel by 20-25% (reducing GHG emissions by ~400 tonnes/year[137]) as well as reduce the use of propane for heat. BC Hydro provides the diesel generation and under a 20-year electricity purchase agreement, purchases power resulting from the biomass project and reduces diesel generation by an equivalent amount.

Solar

Xeni Gwet'in First Nation, located in south-central BC, is reducing their reliance on diesel through a solar installation project. The system includes 250 kW PV with 1,000 kWh storage that provides a full day of backup under cloudy skies and is expected to reduce diesel consumption by an estimated 143,000 litres/year, reducing GHG emissions by 382 tonnes/year.[138] While the system clearly reduces electricity cost and GHG emissions, replacement of the lithium battery storage in 15-20 years will be a significant cost.

Previous Hydrogen Related Projects

Hydrogen Assisted Renewable Power (HARP) Project in Bella Coola[139, 140]

The HARP project was a small demonstration project that ran from 2009-2013 and combined hydrogen production via electrolysis, hydrogen storage, and Fuel Cells. Renewable energy from the Clayton Falls hydro station was used to power an electrolyzer to create hydrogen which was then compressed and stored at 200 bar (20 MPa). PEM fuel cells converted the hydrogen into 100 kW of electricity during peak demand periods, offsetting diesel generation. The demonstration project used a microgrid control system to balance the electrical load between the renewable energy source, diesel generation, and the power provided by the fuel cells.

The project reduced diesel consumption by an estimated 10%, however, it came with very high costs and reliability issues. Not only was the fuel cell and electrolyzer equipment very costly, the 3-step process for generating electricity, (hydroelectricity generation, electrolysis, fuel cell) was very expensive with a system efficiency of only ~35%.

As well, at the time, a 100 kW fuel cell was unavailable, so 100x 1 kW fuel cells were connected in series creating a system with 100 discrete modules each with its own compressor, controls, etc. With so many components in the overall system, the number of failure points increased, and reliability became a significant issue.

The project demonstrated that the system was not ready for full deployment in real-world situations where equipment reliability is critical.

136 *Fredericks T. (2018). Kwadacha Nation Installs Wood Gasification System. Canadian Biomass. Retrieved from https://www.canadianbiomassmagazine.ca/news/green-gas-kwadacha-nation-installs-wood-gasification-system-6699*

137 *BC Hydro. (2017). Wood Chips Help Power Kwadacha First Nation, Cutting Carbon Emissions. Retrieved from https://www.bchydro.com/news/conservation/2017/kwadacha-biomass-ipp.html*

138 *BC Provincial Government. (2017). Hybrid Solar Power Burns Cleaner for Zeni Gwet'in. Retrieved from https://news.gov.bc.ca/releases/2017IRR0057-002106*

139 *Powertech Labs. Energy Storage Systems. Retrieved from https://www.powertechlabs.com/services-all/energy-storage-systems*

140 *Thompson C. (2017). Wuikinuxv Nation Receives Funding for Run-of-River Hydro Project. Coast Mountain News. Retrieved from https://www.coastmountainnews.com/news/wuikinuxv-nation-receives-funding-for-run-of-river-hydro-project/*

4.5.2 : Opportunities for Hydrogen

As part of the CleanBC plan, the Province has set a target of reducing diesel electricity generation in remote communities by 80% by 2030. This is an ambitious target and will require many solutions. Every remote community in BC differs in size, weather, geography, skill base and power requirements and solutions for reducing diesel dependence will be community and site specific.

Most of the remote communities in BC rely solely on trucked or barged in diesel fuel for their electricity supply and there is an opportunity to replace the diesel fuel imports with hydrogen imports. The hydrogen could supply a microgrid system, either centralized, or distributed with co-generation of heat and power. Renewable energy sources can also be incorporated to produce hydrogen using electrolysis, reducing reliance on imported fuel.

A hydrogen supplied microgrid offers significant advantages over diesel generation:

- *Eliminates GHG emissions*
- *Eliminates spill pollution risk*
- *Lower transport weight (in the case of LH_2 supply) reducing transport cost*

If hydrogen is produced for export and shipped through Kitimat, it may be possible to divert some of the hydrogen for delivery to remote communities in the northern part of the Province. This could provide a reliable and reasonably priced hydrogen source.

Compressed natural gas (CNG) also offers the opportunity to transition away from diesel to a cleaner burning fossil fuel. Hydrogen can play a role here as well, as it can be injected into the natural gas prior to compression, reducing the gas's carbon intensity and its associated emissions.

Each of these opportunities is discussed in more detail below.

Hydrogen Microgrid with Distributed Heat and Power Generation

In a distributed hydrogen micro-grid system, imported hydrogen is stored centrally and distributed via pipeline to local houses and buildings which are each outfitted with a local combined heat and power (CHP) generation system. The ENE-FARM system, shown in Figure 65, is an example of a CHP system being used in Japan, where over 300,000 units have been installed.[141]

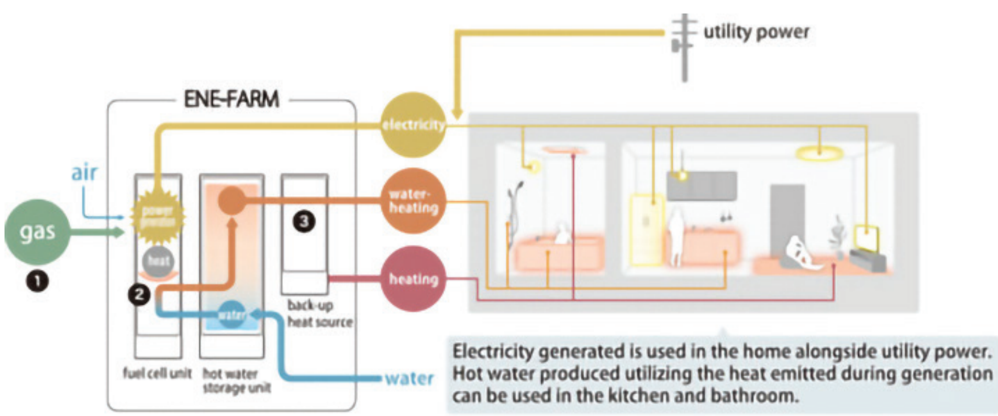


Figure 65. ENE-FARM System

141 FuelCellsWorks. (2019). FCW Exclusive: Tokyo Fuel Cell Expo 2019 – 300,000 Ene-Farms. Retrieved from https://fuelcellsworks.com/news/fcw-exclusive-tokyo-fuel-cell-expo-2019-300000-ene-farms/

The CHP system converts hydrogen into electricity as needed via a PEM fuel cell and heat produced during the process is captured and used to heat hot water for the building. By re-using the waste heat, CHP systems can be up to 95% efficient and significantly reduce overall electricity requirements. The up-front capital cost for a distributed micro-grid system is fairly high, but the higher efficiency would reduce overall hydrogen imports, lowering operating costs.

Hydrogen Microgrid with Centralized Power Production

Fuel cell generators running on pure hydrogen are becoming available and could offer a direct replacement for diesel gensets. In this scenario, hydrogen is imported and stored centrally, with hydrogen fuel cell generators creating power as needed and distributing it to homes and buildings. Hydrogen fuel cell generators are relatively new and higher cost than their diesel counterparts, but connection into the existing distribution lines, previously used by the diesel generators, would minimize the up-front capital costs of the system.

Electricity requirements, and hence hydrogen import requirements, are higher in this centralized microgrid scenario vs. a distributed system, as electricity must be generated for heat and hot water (via baseboard heaters and electric water heaters) as well as power. Efficiency of fuel cell generator systems is ~40% as heat generated by the fuel cells is not re-used.

Hydrogen Microgrid with Renewable Sources

A hydrogen microgrid, either centralized or distributed, can be combined with renewable energy sources, reducing both the amount of hydrogen imported and the GHG emissions due to transport.

Most remote communities are completely reliant on imported diesel for their power generation and transportation needs, and the transport costs make energy supply to these regions very expensive. As such, remote communities provide an attractive cost basis for new competing renewable electricity and hydrogen technologies that can offset imported fuel requirements.

Remote communities can take advantage of renewable energy sources such as wind, solar, and run-of-river hydro. The renewable energy source is connected to a microgrid controller to balance the supply and demand of electricity. In times of excess supply, hydrogen can act as an energy storage medium with surplus electricity fed into an electrolyzer to create hydrogen on-site, thereby reducing hydrogen import requirements.

The Raglan Nickel Mine in Northern Quebec is a successful example of wind energy and hydrogen storage reducing diesel consumption.

WIND POWER AND HYDROGEN STORAGE AT RAGLAN NICKEL MINE IN NORTHERN QUEBEC

At the Raglan Nickel Mine in Nunavik, hydrogen is used as an energy storage solution to reduce diesel consumption.

A 3MW wind turbine was installed and combined with a 3 tiered energy storage system. A flywheel and battery combination filters out large wind variations and transitions the system to diesel generator or 200kW fuel cell for back up power when needed.

A 315kW electrolyzer converts excess renewable supply into hydrogen for storage. A micro-grid controller manages the supply and demand, producing a smooth power output that has allowed wind to generate 50% of the mine's power requirements. The system has reduced diesel consumption at the mine by 2.4 million litres annually and the project can act as a flagship site for future wind development projects.

Source: https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/glencore-raglan-mine-renewable-electricity-smart-grid-pilot-demonstration/16662

CNG with Injected Hydrogen as a Transition Step

CNG is the cleanest burning fossil fuel and can support communities as they transition away from diesel. It provides a cleaner, lower cost alternative and poses much less risk to the environment as it vaporizes, eliminating any contamination or cleanup, in the event of a spill.

CNG generators or Jenbacher engines running on CNG could be used as direct replacements for diesel gensets. They could tie into existing distribution lines in a community and be coupled with renewable energy sources to reduce overall fuel import requirements.

Hydrogen can also play a role with CNG as low carbon hydrogen can be injected into the natural gas grid, reducing the carbon intensity of the CNG produced and shipped to remote communities.

4.5.3 : Challenges and Barriers

Transitioning to clean energy in remote communities can be difficult due to logistical, technical, financial and human capacity challenges that larger communities take for granted.

Geography and Remoteness

Logistically, transporting equipment long distances over difficult terrain can be challenging and expensive. Delays are common, pushing out project schedules and further driving up costs. Construction can be more challenging as infrastructure and equipment taken for granted in larger centres is limited or unavailable. And once a project is up and running, the remote location can limit quick access to technical service people and spare parts which can leave a system down for weeks.

Human capacity is also a huge concern for these projects. Communities often do not have the local technical expertise to plan, develop and support clean energy projects. If outside expertise is brought in to implement the project, the community runs the risk of being left without critical technical knowledge should that person ultimately leave the community.

These factors increase the costs and risks of projects making it difficult to get project financing.

System Complexity and Economies of Scale

Renewable energy sources present an opportunity for remote communities, but also come with challenges. The imbalance between electricity supply and demand must be managed. This means enhanced control systems to manage the intermittent supply sources, adding cost and technical complexity to a new clean energy system. The added complexity increases the risk of downtime and delays in accessing necessary spare parts and expertise to fix the system.

Maturity of technology is of critical concern to remote communities in order to avoid the risk of interruptions and downtime typical of new technology deployments. As such, technology being considered for implementation in a remote community must have been tested for 3 years in 3 separate locations to ensure the reliability of the technology. This requirement will make it challenging to deploy new technologies in the near-term.

Renewable energy projects are becoming more common and can have reasonable project economics when sized at 200-300 MW for wind, 50-100MW for solar and 10MW for small-scale hydro.[142] For remote communities, the system requirements are often an order of magnitude smaller, but still require all the typical project costs, such as engineering, project management and permitting, and thus have higher relative costs. The high costs and small project size make it difficult to get funding or attract private financing.

142 *Pembia Institute. (2018). Renewables in Remote Communities: 2017 Conference Proceedings. Retrieved from https://www.pembina.org/pub/renewables-remote-communities*

4.5.4 : Adoption Scenarios

The opportunity for hydrogen use in remote communities is very small in comparison to other sectors, but can provide significant and meaningful improvement to local air quality. For adoption, these communities require technologies to be more mature (three years of proven deployment) to make the costs and risks more realistic for small-scale deployments. In the near-term, remote communities will focus on energy efficiency improvements in local homes and buildings to reduce overall energy demands and therefore it is assumed that there will be no increase in diesel consumption beyond current levels. Communities will be encouraged to investigate clean energy opportunities such that by 2025 some technologies supporting hydrogen use start to be deployed.

In developing scenarios for hydrogen use in remote communities, it is assumed that hydrogen microgrids will be adopted with centralized diesel gensets replaced by either centralized hydrogen fuel cell generation systems, or distributed small-scale (~ 1-3 kW) cogeneration systems fed through a hydrogen pipeline, similar to the long-term vision for the Japan ENE-FARM project.

Because the CleanBC plan is focused on the 22 largest diesel operations (12 BC Hydro operations and 10 Indigenous Services Canada stations which combined provide ~75% of all diesel generation for BC remote communities), diesel use for these operations was considered separately from the remaining communities. Conservative and aggressive scenarios were developed by estimating the diesel reduction percentage, and the percentage of this reduction that will be attributed to hydrogen.

Conservative Scenario

In the top 22 communities, diesel reduction is assumed to increase gradually from 20% in 2025 to 80% in 2050, with hydrogen responsible for 25% of the reduction. In the remaining communities, diesel reduction increases from 5% in 2025 to 30% in 2050 with no use of hydrogen technologies.

Table 16 summarizes the demand reduction and hydrogen use assumptions for the Conservative Scenario, and the resulting hydrogen demand and GHG reduction.

CONSERVATIVE SCENARIO						
	Top 22 Communities		Remaining Communities		Total	
Year	Diesel Demand Reduction	Energy Use Reduction from H_2	Total Diesel Demand Reduction	Energy Use Reduction from H_2	Total H_2 Demand (t)	GHG Abated (t CO_2e)
2020	0%	0%	0%	0%	0	0
2025	20%	25%	5%	0%	55	1,251
2030	40%	25%	10%	0%	110	2,502
2035	50%	25%	15%	0%	137	3,128
2040	60%	25%	20%	0%	165	3,753
2045	70%	25%	25%	0%	192	4,379
2050	80%	25%	30%	0%	220	5,004

Table 16. Conservative Scenario - Remote Community Hydrogen Demand (2020-2050)

Aggressive Scenario

In the top 22 communities, diesel reduction increases aggressively to 80% by 2030 to achieve the target reduction laid out in the CleanBC plan and then a much more gradual increase to 95% occurs between 2030 and 2050. Hydrogen is assumed to be responsible for 50% of the reduction. In the remaining communities, diesel reduction increases from 10% in 2025 to 60% in 2050 with 10% reduction attributed to hydrogen technologies.

Table 17 summarizes the demand reduction and hydrogen use assumptions for the Aggressive Scenario, and the resulting hydrogen demand and GHG reduction.

AGGRESSIVE SCENARIO						
	Top 22 Communities		Remaining Communities		Total	
Year	Total Diesel Demand Reduction	Energy Use Reduction from H_2	Total Diesel Demand Reduction	Energy Use Reduction from H_2	Total H_2 Demand (tonnes)	GHG Abated (tonnes CO_2e)
2020	0%	0%	0%	0%	0	0
2025	40%	50%	10%	10%	223	5,087
2030	80%	50%	20%	10%	446	10,174
2035	85%	50%	30%	10%	477	10,882
2040	90%	50%	40%	10%	508	11,590
2045	95%	50%	50%	10%	539	12,299
2050	95%	50%	60%	10%	543	12,381

Table 17. Aggressive Scenario - Remote Community Hydrogen Demand (2020-2050)

The results from both the Conservative and Aggressive Scenarios are shown in Figure 66. The potential for hydrogen demand in remote communities in 2050 is estimated to range from 220 to 540 tonnes annually, with GHG reductions in the range of by 5,000-12,400 tonnes CO_2e/year.

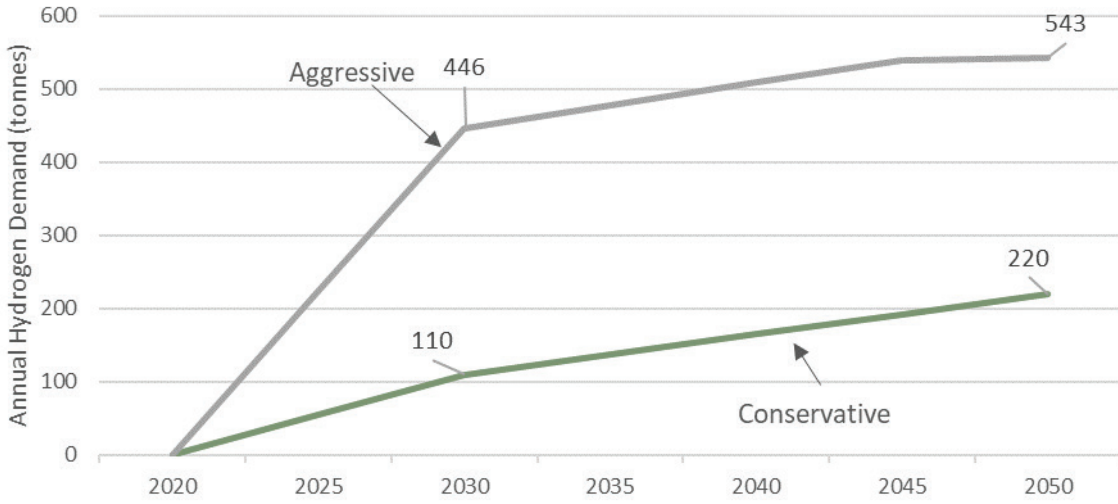


Figure 66. Remote Community Conservative and Aggressive Hydrogen Demand (2020-2050)

4.5.5 : Recommendations

Encourage development of hydrogen microgrids

- *For communities that rely entirely on trucked or barged in energy supply, encourage development of microgrids that utilize a 100% hydrogen distribution grid with local combined heat and power (CHP) generation such as the ENE-FARM program in Japan*

Work with remote communities to develop plans to implement hydrogen related projects and make it easier for communities to own and operate their own facilities

- *Provide a 'hydrogen toolkit' including: support to navigate funding opportunities; technical expertise for planning, implementation and operations; and database with technical and cost details of successful hydrogen projects*

Create access to financing for cleaner fossil fuel-based systems that utilize a CNG / hydrogen blend

5.0 Power to Gas and Energy Storage

5.1 : Power to Gas

Power to Gas (P2G) is the process of converting surplus renewable electricity into hydrogen gas through electrolysis. It is a use case for electrolysis technology discussed in section 3.1.2.

The hydrogen can then be injected into natural gas pipeline networks or for other applications such as a transportation fuel. As shown in Figure 67, hydrogen is versatile once generated, and can be converted into methane or even liquid fuels. (As noted in section 4.1.2, the economics for such transformations may be challenging.)

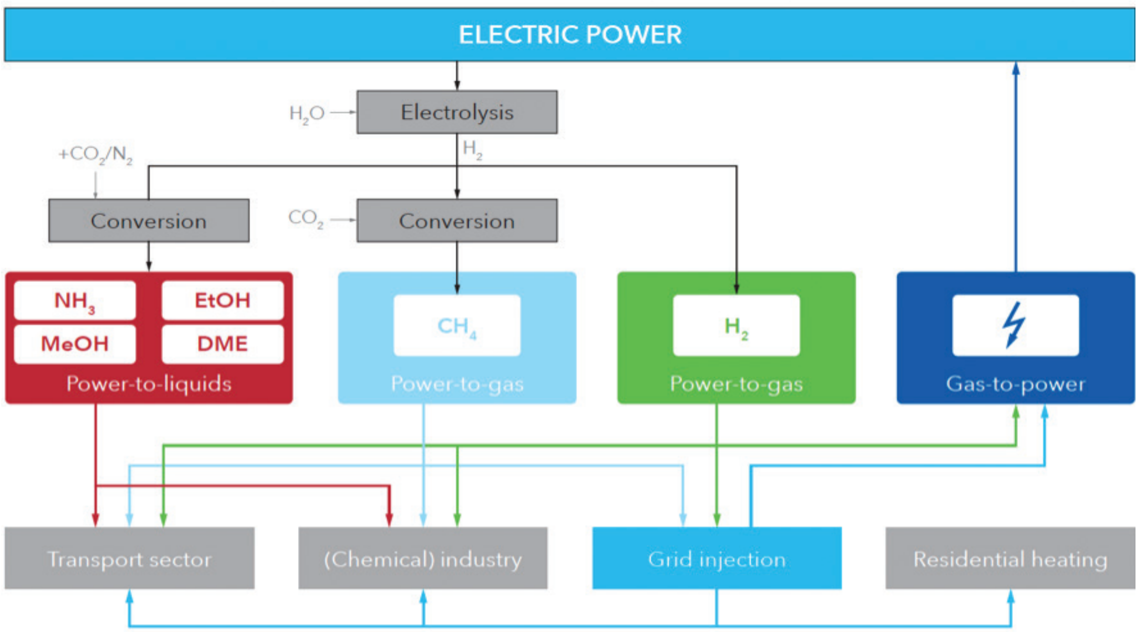


Figure 67. Options for Hydrogen Generated via Power to Gas. Source DNV GL.

Given that hydrogen can be injected into natural gas networks, P2G is sometimes described as a means of connecting the electric and natural gas energy systems; it can also be a key enabler of the transition from a fossil natural gas grid to a decarbonized one.

Rising P2G interest in Europe has been driven by aggressive GHG reduction targets and an increasing supply of variable renewable electricity (wind and solar). Figure 68 shows a DNV GL projection for power generation capacity in Europe. It should be noted that while capacity factors for solar and wind are known to be low, their proliferation has displaced thermal power generation ("combustibles" in the Figure) such that thermal power plants' own capacity factors have begun to decrease over time.

REGENSBURG UNIVERSITY

In 2008 the Regensburg University of Applied Sciences and the Centre for Solar Energy and Hydrogen Research in Ulm jointly developed the concept of power to gas for energy storage. The German government energy agency established a P2G strategy in 2011. There are currently more than 45 P2G projects in Europe.

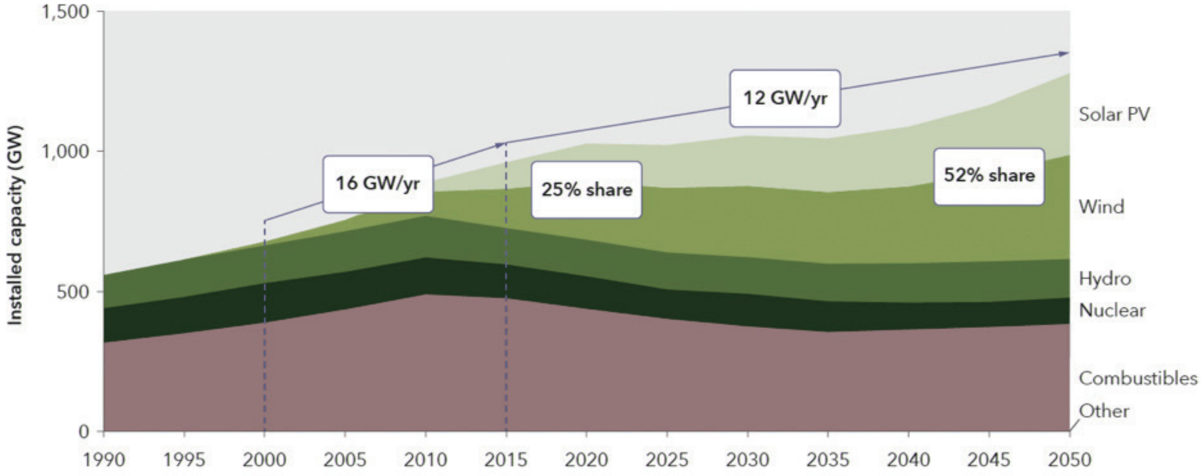
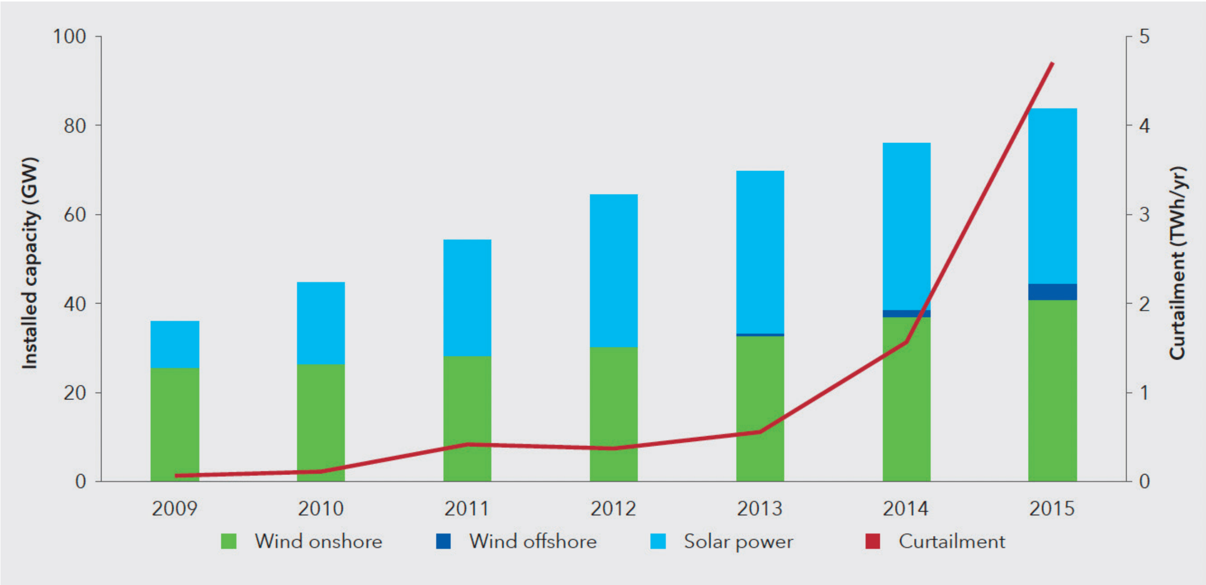


Figure 68. Historic & Future Installed Power Generation Capacity Projections for Europe. Source: DNV GL.

Figure 69 shows the case of Germany, where in 2015 a total of 4.7 TWh of electricity was curtailed, the overwhelming majority from renewables, impairing economic returns for the sector. (4.7 TWh is the amount of electricity that would be generated by a 540 MWh generator operating 24/7/365.)



Germany had an installed capacity of 44.5 GW of wind turbines and 39.3GW of solar power at the end of 2015. The average load profile in Germany fluctuates between 50 and 80GW on a work day and 40 and 60GW during weekends. When both renewable sources produce electricity at full capacity in periods of a lower load profile, there is surplus electricity generation. This situation occurred various times in 2015 resulting in 4.7 terawatthours (TWh) of electricity being curtailed (93% wind and solar power). The network operators had to pay compensations in total of €315 million (m). This amount is expected to increase in the coming years as grid extensions do not have the necessary velocity.

Figure 69. Wind and Solar Deployment and Annual Electricity Curtailment in Germany. Source: Bundesnetzagentur

5.1.1 : Advantages of P2G Deployment

Advantages of P2G deployment include a reduced need to expand or upgrade electricity transmission networks, and the facilitation of electric grid balancing through demand response and ancillary services. P2G can also help reduce the carbon intensity of natural gas supply, as discussed in section 4.1, and can leverage natural gas infrastructure and storage facilities.

Finally, P2G – as an application of electrolysis – can also facilitate the production of low carbon hydrogen as a zero-emission transportation fuel. In this application hydrogen has a much higher value than when used in natural gas networks, where it is valued purely on heat content.

5.1.2 : Barriers to P2G Deployment

A variety of barriers to P2G have impeded their greater deployment. Barriers have included:

Technology: the PEM electrolyzers best suited to P2G applications remain an early-stage technology.

Economics: though capital costs are expected to fall significantly, they remain high, limiting business cases for deployment.

Carbon pricing: carbon tariffs generally remain too low to incentivize commercial P2G efforts.

Lack of collaboration: a lack of collaboration between the electricity and natural gas grids has impeded P2G's use as a bridge linking the two energy infrastructures.

5.1.3 : P2G in Europe

Figure 70 shows the locations of 45 P2G demonstration projects underway in Europe as of October 2018. Germany is home to more than 30 of the demonstration P2G projects, comprising an electrolysis load capacity of approximately 25 MW.

The main challenges have related not to the technology, but to achieving commercial cost targets. Equipment cost reductions, efficiency improvements and policies such as renewable energy tariff structures are believed necessary for P2G to be viable beyond demonstration projects. (The CleanBC target for 15% Renewable Gas is an example of such a policy.)

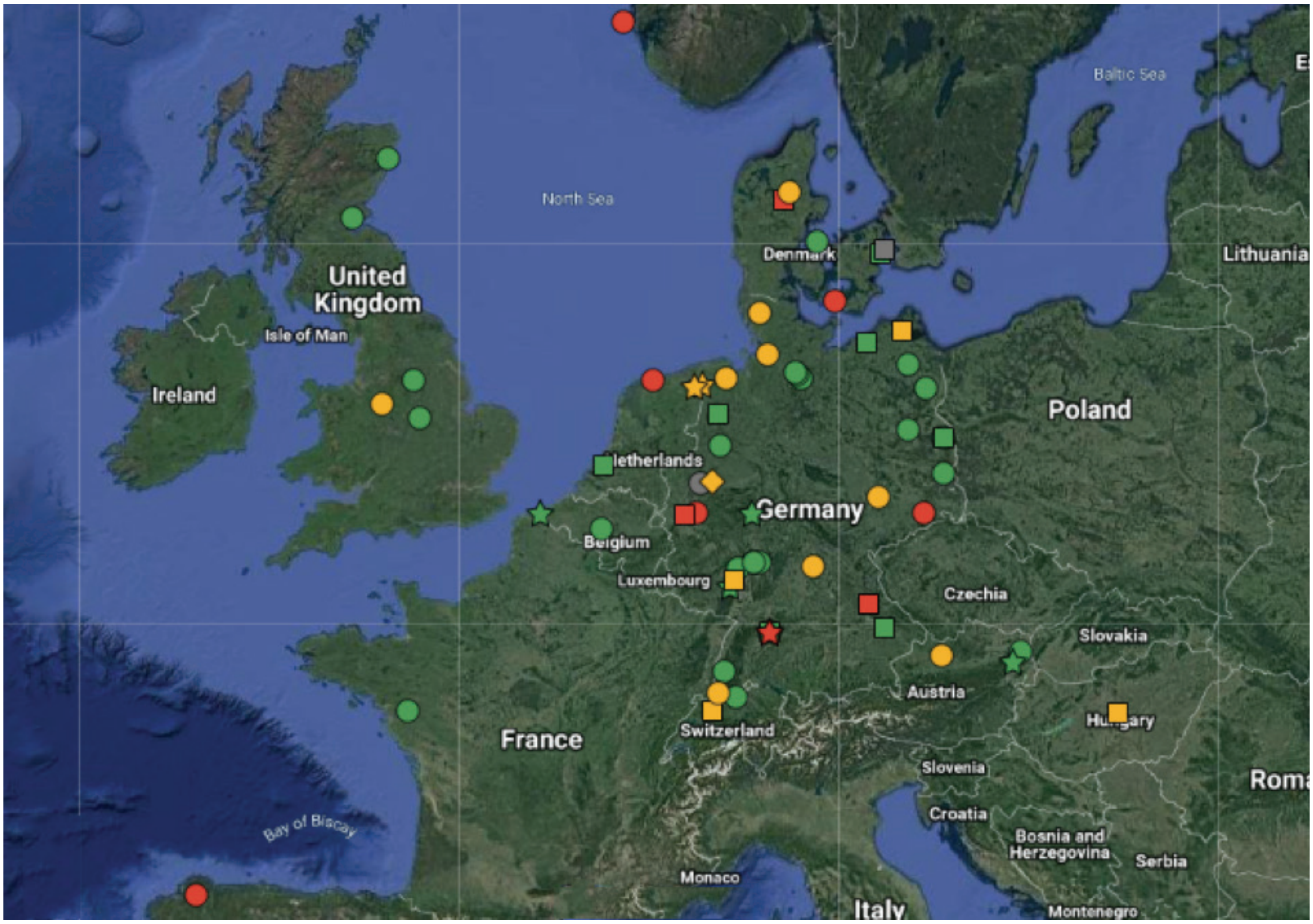


Figure 70. P2G Projects in Europe. Source: Europeanpowertogas.com

5.1.4 : P2G in North America

North America's first P2G facility began operations in Ontario in July 2018 when a 2.5 MW PEM electrolyzer from Hydrogenics was installed under contract to the Ontario Independent Electricity System Operator (IESO). The electrolyzer will provide grid energy demand response functions to the IESO and the hydrogen produced will be injected into the Enbridge gas distribution network.

In the United States, California utility SoCalGas has teamed with other organizations to run an electrolyzer powered by solar photovoltaics and inject renewable hydrogen into the campus power plant at UC Irvine. The utility has also established a partnership with the U.S. Department of Energy's National Renewable Energy Laboratory to install the United States' first biomethanation plant, located at the Energy Systems Integration Facility in Golden, Colorado.

5.2 : P2G Opportunities in BC

BC's geography provides an abundant supply of clean, renewable hydroelectricity, which with other renewables provides more than 90% of BC Hydro's annual production. Equally importantly, hydroelectric dams serve as a reservoir for storing and discharging energy. As variable renewables are added to the grid, hydroelectric dams alleviate the need for energy storage in the near-term.

There remain advantages to producing hydrogen via electrolysis in BC for use as a bridge linking the electric and natural gas energy systems. As an example, hydrogen produced via electrolysis could be used directly by utilities such as BC Hydro and FortisBC to optimize the use of their utility infrastructure.

5.3 : Recent P2G Developments

Hydroelectric utilities in the U.S. Pacific Northwest are developing plans to produce hydrogen to complement their energy offerings. The states of Washington and Oregon have conducted studies to determine opportunities for decarbonizing their energy systems, and the production of clean hydrogen from hydroelectricity for transportation fuels was found to be a strategic opportunity.

In April 2019, Substitute Senate Bill 5588 was signed in Washington State authorizing Public Utility Districts (PUDs) to produce, distribute and sell renewable hydrogen.[143] Douglas County PUD announced plans to be the first utility to do so; during periods of high river flows, solar and wind generation, it had resorted to spilling excess water. Hydrogen production would be a means of creating value.

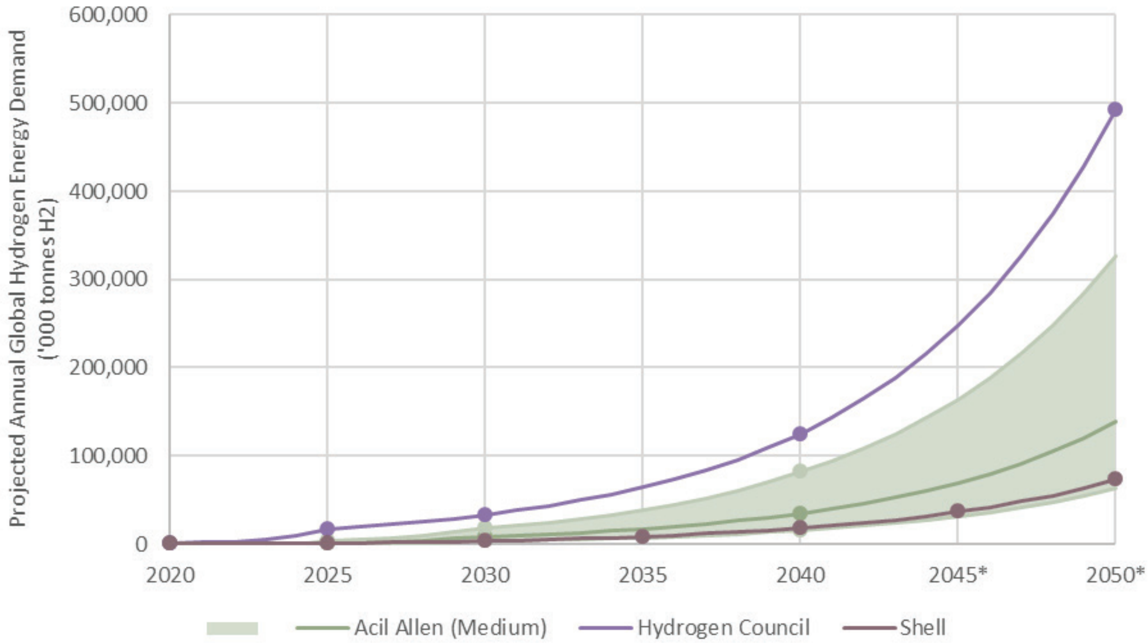
It is anticipated that similar benefits could be realized by BC's utilities, so it is recommended that energy storage/ hydrogen production opportunities be evaluated further through pilot demonstration projects. Expanding the mandate of utilities to include the production, distribution and sale of hydrogen could also be a key enabler for increasing hydrogen supply in the Province.

143 *Washington State Legislature. (2019). Authorizing the production, distribution, and sale of renewable hydrogen. SB 5588 – 2019/20. Retrieved from https://app.leg.wa.gov/billsummary?BillNumber=5588&Year=2019&Initiative=false*

6.0 : Global Demand and Market Potential for Hydrogen

6.1 : Global Hydrogen Demand Projections to 2050

Hydrogen is expected to become increasingly important in the world's energy economy, though projections vary significantly based on assumptions around technology development and policy adoption. Figure 71 compares recent global hydrogen energy demand estimates from Acil Allen, the Hydrogen Council, and Shell.[144, 145, 146] Note that it does not include hydrogen use in industry.



**Acil Allen projections only provided to 2040. The 2050 values were estimated based on the year over year growth from the Hydrogen Council and Shell reports.*

Figure 71. Estimated Annual Global Hydrogen Demand (2020-2050).[144, 145, 146] Hydrogen consumption in industrial processes is not included.

144 Acil Allen Consulting. (2018). Opportunities for Australia from Hydrogen Exports. Retrieved from https://arena.gov.au/assets/2018/08/opportunities-for-australia-from-hydrogen-exports.pdf

145 The Hydrogen Council. (2017). Hydrogen Scaling Up: A Sustainable Pathway for the Global Energy Transition. Retrieved from http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf

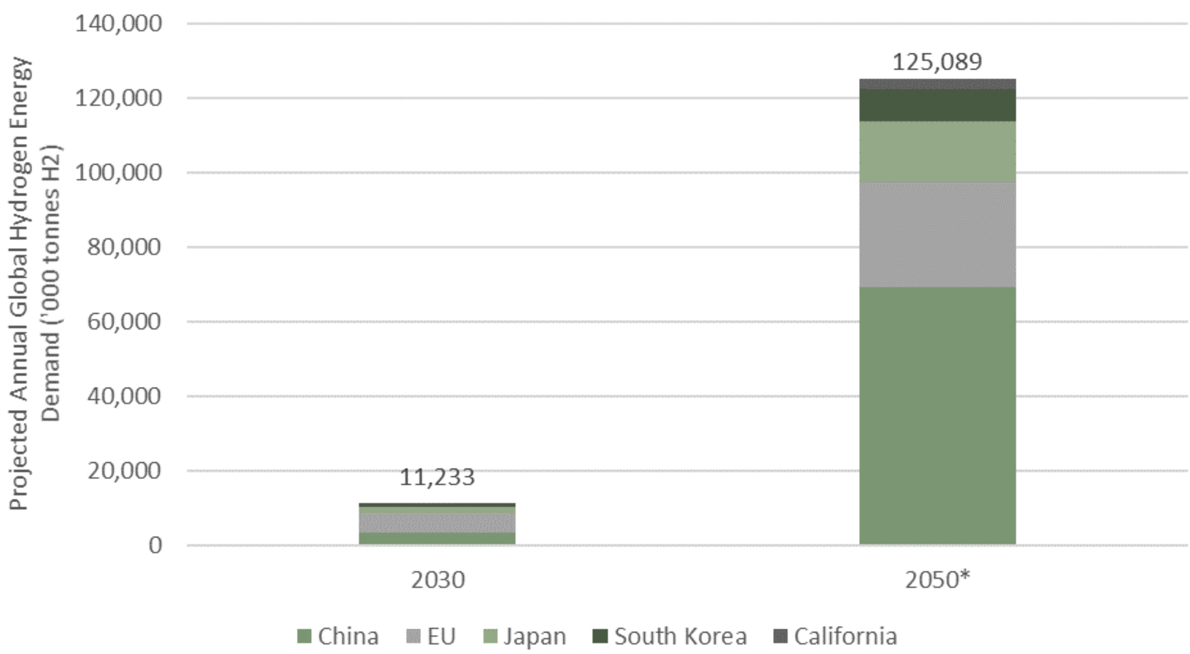
146 Shell. (2018). Shell Sky Scenario: Meeting the Goals of the Paris Agreement. Retrieved from https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenario-sky.html

Acil Allen provides low, medium, and high hydrogen uptake scenarios based on assumptions around the afore-mentioned technology development and policy adoption, as well as climate change and alternative fuel prices.[144] The Hydrogen Council projection is based on an ambitious vision in which hydrogen accounts for 18% of total energy demand in 2050.[145] Shell's Sky Scenario projects a slower uptake of hydrogen technologies, but still expects hydrogen to emerge as material energy carrier after 2040, resulting in 800 million tonnes of hydrogen demand for energy by 2070.[146]

Figure 72 shows the medium range estimate of hydrogen demand for regions which have placed the greatest emphasis on hydrogen technologies in 2030 and 2050. Figure 73 shows a range of estimates for each region individually. Demand projections for China, Japan and South Korea were based on Acil Allen.[144] EU projections were from FCH-JU[147] and California projections were from UC Irvine.[148]

Japan, China and South Korea – the world's three largest importers of liquefied natural gas (LNG) – have each embarked on ambitious hydrogen initiatives, which could explain the more aggressive projections. In California, the projections plateau around 2050 assuming hydrogen reaches its full market penetration potential.

Looking at these markets together, in 2030 and 2050 the total market size, based on the medium projection for each region, are 11.2 million tonnes per year and 125.1 million tonnes per year, respectively.



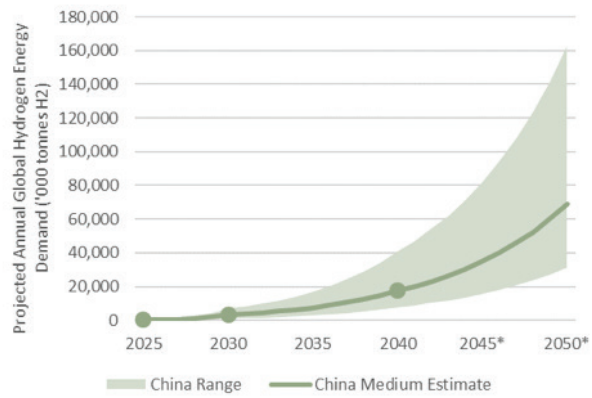
**Acil Allen projections only provided to 2040. The 2050 values were estimated based on the year over year growth from the Hydrogen Council and Shell reports.*

Figure 72. Medium Range Estimated Annual Hydrogen Energy Demand of Selected Countries (2025-2050)[144, 147, 148]

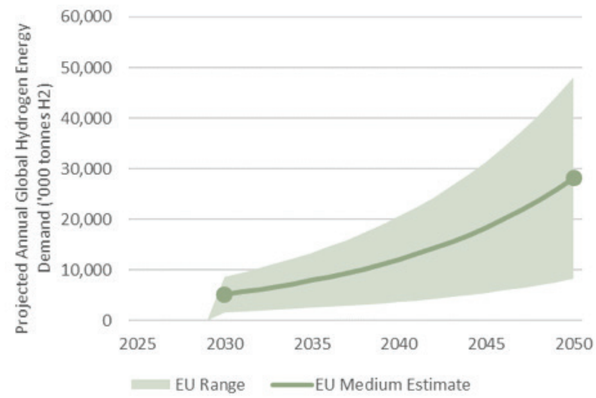
147 *Fuel Cells and Hydrogen 2 Joint Undertaking (2019). Hydrogen Roadmap Europe: A Sustainable Pathway for the European Energy Transition. Retrieved from https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf*

148 *UC Irvine/Advanced Power and Energy Program. (2019). Renewable Hydrogen Transportation Fuel Production. Retrieved from https://efiling.energy.ca.gov/GetDocument.aspx?tn=227515&DocumentContentId=58764*

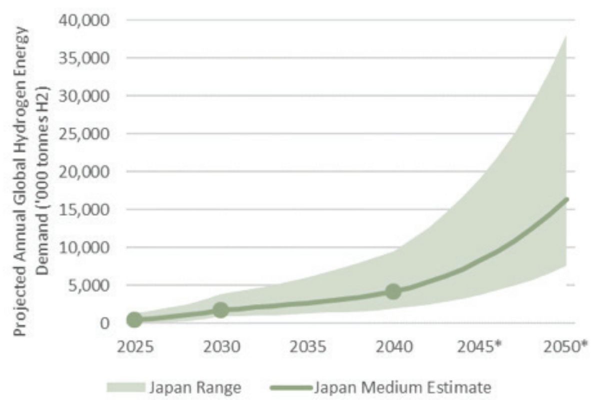
China[144]



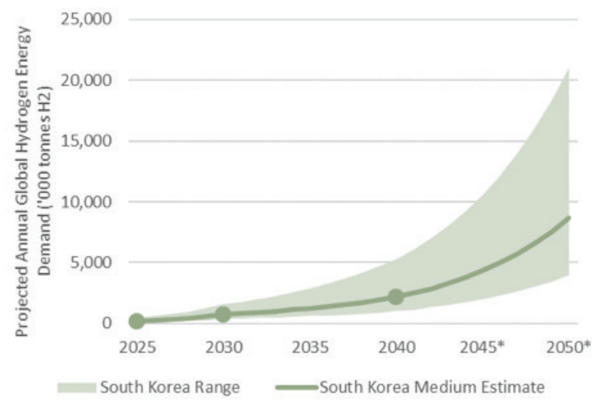
EU[147]



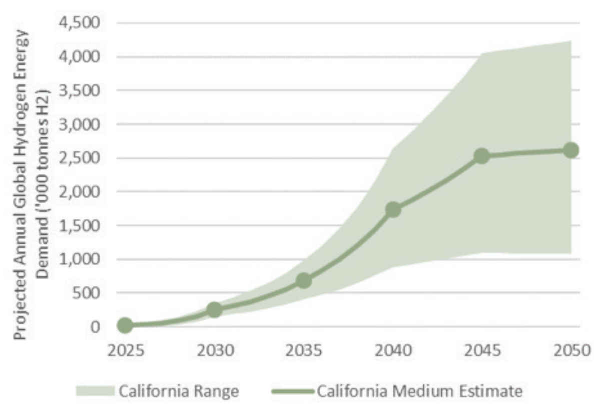
Japan[144]



South Korea[144]



California[148]



**Acil Allen projections only provided to 2040. The 2050 values were estimated based on the year over year growth from the Hydrogen Council and Shell reports.*

Figure 73. Estimated Annual Hydrogen Energy Demand of Selected Countries (2025-2050)

6.2 : Hydrogen Export Opportunity

As discussed in Section 3.0, BC has the potential to produce vast amounts of low-cost, low carbon hydrogen, leveraging the Province's abundant renewable electricity and natural gas resources.

BC's strategic advantages for producing hydrogen for export include:

- *Deepwater harbour accessible locations for the production and supply of large quantities of hydrogen to export markets, such as California, Japan, the Republic of Korea and China;*
- *An abundance of a very low carbon electricity with which to produce hydrogen through electrolysis;*
- *Large quantities of fresh water available for electrolysis; and*
- *An abundance of low-cost natural gas with which to produce hydrogen through SMR+CCS and pyrolysis.*

6.2.1 : Key Markets

Four key markets have been identified as viable export market for BC hydrogen: California, Japan, the Republic of Korea, and China. They are in closer proximity to BC than to other likely hydrogen exporters and have defined policies and programs to grow the development and use of clean hydrogen as an energy vector.

6.2.1.1 : California

California's projected hydrogen demand is expected to be as large as 1 to 4 million tonnes by 2050. The state is also a prime candidate to be an importer of renewable hydrogen in the future and has strong Governmental regulations and supportive funding for the initiation of a hydrogen supply infrastructure and deployment of fuel cell powered mobility.

6.2.1.2 : Japan

The Ministry of Economy, Trade and Industry (METI) from the Japanese Government developed the "Basic Hydrogen Strategy" (December 2017) for a plan of action until 2030, and, a future vision up to 2050. The prognosis for 2050 is for demand of between 5 to 35 million tonnes of hydrogen per year. The country is expected to be a very large importer of hydrogen and has already begun investigating supply options for importing large quantities of clean hydrogen in the future.

6.2.1.3 : The Republic of Korea

The Korean government has recently published its National Hydrogen Economy Roadmap. The prognosis for 2050 is for a demand of between 4 to 20 million tonnes per year.

6.2.1.4 : China

China is currently the leading region for the growth of renewable hydrogen and fuel cell market segments. The Chinese government is financially supporting these industries at the federal, provincial and municipal levels. The prognosis for 2050 is a demand of between 18 to 160 million tonnes per year.

6.2.2 : Storage and transport technologies

Hydrogen storage and transport from production hubs to users' sites will be one of the more challenging obstacles for the large-scale global adoption of hydrogen as a renewable energy vector. Liquefaction and chemical storage, in the form of chemical carriers, are treated in section 2.2.

6.2.3 : BC's Positioning

BC currently lacks a clear position on the importance of developing a hydrogen export market, in part because the demand for hydrogen is just starting to grow. In addition, BC has not currently developed any sources of hydrogen supply.

Australia would be a major competitor to BC in the Asian target markets identified above and has developed both a national roadmap and a strategy to guide development of a hydrogen export sector. It can also leverage decades of experience as an LNG exporter.

The size of the potential hydrogen export market for BC is significant. In 2030 and 2050, respectively, the total market size of the four combined target markets of China, Japan, Korea and California is expected to be $87 billion and $305 billion, respectively. If BC were to capture just 5% of these markets, this would represent export revenue potential of $4 billion in 2030 and $15 billion in 2050. Not only would this bring new export revenue to the Province, but it would stimulate local employment growth and would likely attract foreign capital investment.

The development of large-scale hydrogen export markets would create high enough production volumes that the cost of hydrogen in the Province would decrease. This would stimulate additional in-Province deployment, as lower cost hydrogen would improve the business case of switching from fossil fuels.

A SWOT (strengths / weaknesses / opportunities / threats) analysis is presented in Table 18 below.

STRENGTHS	WEAKNESSES
◆ *Abundance of renewable electricity for electrolytically produced hydrogen* ◆ *Relativley low-cost electricity for hydrogen production* ◆ *Abundance of water for electrolysis* ◆ *Close proximity to numerous large import markets via ocean freight* ◆ *Large source of natural gas supply for the production of clean hydrogen using SMR and CCS* ◆ *Export focused communities and sites along the BC West Coast* ◆ *Availability of deep water harbours to handle large ocean going vessels for export*	◆ *Clearly defined government policies, objectives and strategies to support and grow the clean hydrogen export markets* ◆ *The need to develop additional incentives to support the competitive production and supply of clean hydrogen to export markets* ◆ *Cost reductions in the production of clean hydrogen production technologies required to meet the various target prices for clean hydrogen in numerous global markets and related segments*
OPPORTUNITIES	**THREATS**
◆ *Business and job growth for local, remote communities and First Nations in BC* ◆ *Large future demand markets including California, Japan, Republic of Korea and China relatively close to BC* ◆ *The opportunity for multinationals involved in the clean energy economies to invest in BC* ◆ *Growth of the BC hydrogen related research and technology development* ◆ *The ability for BC to play a positive role in the reduction of GHG by producing and exporting large quantities of renewable hydrogen* ◆ *A large hydrogen export economy in BC will support low-cost domestic market needs*	◆ *Competition from Australia that has established a clear government-led strategy to produce and export large quantities of renewable hydrogen in the future* ◆ *Loss of the strong hydrogen and fuel cell resource base in BC to competitive regions around the globe*

Table 18. BC Hydrogen Export SWOT Analysis

7.0 : BC's Competitive Advantages and Disadvantages in Hydrogen and Fuel Cells

Canada's hydrogen and fuel cell sector is recognized as a global leader. In 2018, the industry generated revenue of $207 million and was responsible for 2,177 jobs. British Columbia, as the "cradle of the modern fuel cell industry", is home to Canada's largest hydrogen and fuel cell industry cluster as shown in Figure 74.

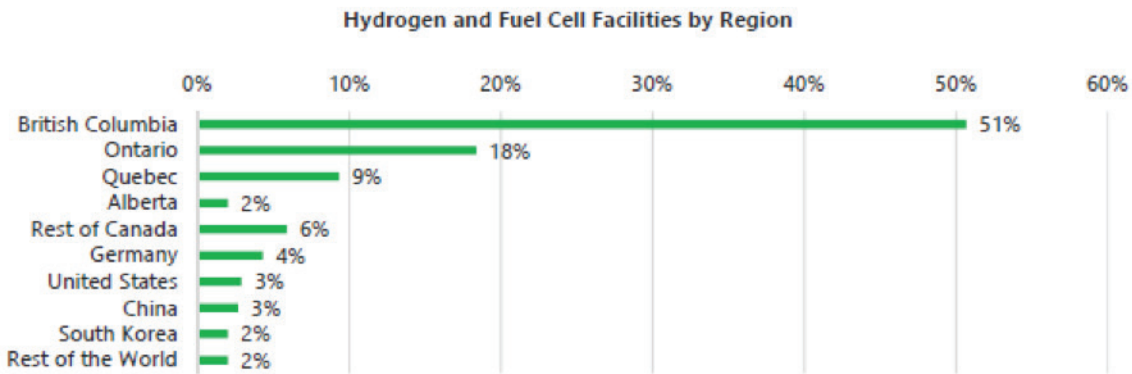


Figure 74. Hydrogen and Fuel Cell Facilities by Region[150]

BC's cluster has advanced technologies for hydrogen production and processing, equipment and systems testing, has undertaken world-leading research, development and commercialization, and has played a leading role in standards development. The Province is also home to world-class academic institutions supporting the clean tech sector. Centres of Excellence have been established at the University of British Columbia (UBC), the University of Victoria (UVic), Simon Fraser University (SFU) and the University of Northern British Columbia (UNBC).[149]

7.1 : Competitive Advantages and Recommendations

7.1.1 : Fuel Cells

BC is a global leader in the fuel cell sector, the industry cluster having been formed around Ballard Power Systems 40 years ago. Industry-academic collaborations and state of the art research and development facilities have created a recognized talent pool and recently led Austrian automotive consulting company AVL to establish its fuel cell research and development centre in Burnaby. Canadian companies such as Ballard Power Systems, Loop Energy, Hydrogen Technology and Energy Corporation (HTEC) and Powertech are also recognized as international leaders.

149 UBC: Centre for Energy Systems Applications, Centre for Interactive Research on Sustainability and the Institute for Resources, Environment and Sustainability. SFU: School of Mechatronics. UVic: Institute for Integrated Energy Systems. The aforementioned and UNBC are all involved with the Pacific Institute for Climate Change Solutions.

150 CHFCA. (2018). Canadian Hydrogen and Fuel Cell Sector Profile. Retrieved from http://www.chfca.ca/media/CHFC%20Sector%20Profile%202018%20-%20Final%20Report.pdf

7.1.2 : Potential Producer of Hydrogen – Natural Resources

BC is well positioned to become a bulk producer of hydrogen given its:

- *clean, renewable, low-cost hydroelectric resources;*
- *abundant, low-cost natural gas and supporting distribution network;*
- *proximity to major markets.*

The carbon intensity of BC Hydro's electricity generation is one of the lowest in North America, meaning hydrogen produced through electrolysis would have a very low carbon footprint.

As noted in prior sections, BC's low-cost natural gas can provide another path for supplying cost-competitive hydrogen, even when CCS costs are factored in.

Finally, BC's coastal access and relative proximity to leading markets such as California, Japan, South Korea and China put the Province in an excellent position to become an exporter of clean hydrogen. The Province's economy is heavily dependent on the export of natural resources, and hydrogen is a means by which BC can provide energy exports without emissions.

7.1.3 : Hydrogen Infrastructure

Vancouver is home to the first public hydrogen refueling station in Canada, part of a network of stations being built in the Metro Vancouver and Capital Region Districts. As demonstrated in California and elsewhere, fuel infrastructure leads the deployment of fuel cell electric vehicles, resolving the so-called "chicken-and-egg" dilemma. BC's investments in hydrogen fueling infrastructure provide a signal for auto manufacturers to make their FCEVs available for sale in this province.

7.1.4 : Recommendations

7.1.4.1 : Provincial Project Deployments

Products from BC's hydrogen and fuel cell industry cluster are deployed in the United States, Europe and Asia, but there are currently no deployments of BC hydrogen and fuel cell technology within the Province.

Local deployments of technology are key to maintaining employment, technical expertise and intellectual property in-province; ownership also tends to shift to where deployments occur. A recent case is that of BC's Corvus Energy, a pioneer in the use of battery energy storage systems for marine applications. Norway was home to many of its early product deployments, and by 2017 ownership stakes had been taken by Hydro and Statoil Technology Invest (both Norwegian) and BW Group (headquartered in both Norway and Singapore).[151]

It is strongly recommended that the Province deploy hydrogen and fuel cell technology from its own cluster, within-province. This would help root BC's sector expertise in British Columbia and would encourage international participants to locate themselves in-province as well. Deployments and pioneering lighthouse projects would strengthen the local cluster, provide additional opportunities for collaboration between industry and academia, and help BC businesses develop world-leading expertise they can export to slower-moving jurisdictions.

151 *Corvus Energy. (2017). Global Aluminum Supplier Makes Significant Investment in Corvus Energy. Retrieved from* https://corvusenergy.com/global-aluminum-supplier-makes-significant-investment-in-corvus-energy/

7.1.4.2 : Lead a Coordinated BC Cluster Strategy

Although BC is recognized as a centre of hydrogen and fuel cell expertise, companies involved in the sector operate very independently. At the federal level, the Canadian Hydrogen and Fuel Cell Association (CHFCA) provides a mechanism to pull companies in the sector together, but more is needed at the Provincial level to encourage and support stronger joint initiatives locally.

An organization similar to the California Fuel Cell Partnership (CaFCP) or Hydrogen Valley in Denmark could help coordinate industry and academia collaborations and work to ensure that companies are operating in step with each other as technology is brought to market. A provincial association could assist with initiatives to help Academia develop curriculum that will support talent development to grow the cluster. The association could also provide coordinated media efforts and outreach activities to educate the public about hydrogen and fuel cell initiatives occurring locally in our Province as well as abroad.

A Stream 5 Application through the Strategic Innovation Fund[152] could also be developed to support a coordinated cluster strategy for hydrogen and fuel cells.

7.2 : Competitive Disadvantages

7.2.1 : No Deployments in the Province

Despite being a leader in hydrogen and fuel cell R&D, there are no current technology deployments in the province. Local deployment of technology is key for BC companies to showcase their technology to attract investment, increase their scale of operations, improve their market readiness and support continued industry advancement.

Deployments of fuel cell buses, using world class fuel cell technology developed in BC, are well established in Europe, China and the US. Unfortunately, locally, there are no fuel cell bus deployments and no support from local transit authorities to consider fuel cell technology as a clean energy alternative. Support is needed to encourage technologies developed in BC to be demonstrated locally.

Without local project deployments, critical technical skill sets in manufacturing and operations, necessary for scaled up operations and commercialization, are not being developed. And although local academic institutions have supporting clean energy programs, relevant practical training, necessary for students to succeed in fuel cell sector jobs, is not being provided. An integrated project deployment with collaboration of industry and academia, could guide academia to develop appropriate curriculum to meet future skill set requirements in the sector. It would also ensure that knowledge and hands-on technical skills required to grow the sector beyond the R&D phase are created within the province.

The high cost of living in Vancouver also contributes to scarcity of technical personnel as it makes it difficult to both attract, and keep, skilled personnel.

152 Innovation, Science and Economic Development Canada. (2019). Stream 5: National Ecosystems. Retrieved from https://www.ic.gc.ca/eic/site/125.nsf/eng/00017.html

7.2.2 : Lack of Provincial R&D Funding

Investment is needed to maintain the province's leadership role in hydrogen and fuel cell R&D. Mid-TRL level projects are the most effective in developing technology and creating jobs, but currently in BC, there is no funding to support these types of projects.

Local organizations require access to funding that can be leveraged to access greater funds from outside entities. For example, a recent federally funded Ballard Power R&D project was moved from BC to Ontario because there was no provincial funding available in BC, which was required to access the federal funds.

NRCan no longer funds R&D and funding that is available, such as IRAP on a federal level, is spread thinly, with relatively modest sums. Funding can also be limited for larger companies or those with large parent companies. For example, AVL opened a fuel cell technology R&D centre in Vancouver because Vancouver has the largest cluster of fuel cell expertise in the world and can provide a solid base on which to further develop their fuel cell technology and commercialization plans. By locating in Vancouver, AVL creates additional jobs in the cluster and advances the technology, but because of its large parent company, is not eligible for funding.

Ballard has also hit the small to medium-sized enterprise (SME) limit on their eligibility to access local funding as their company size now exceeds 500 employees. As a result, Ballard is opening a Fuel Cell Centre of Excellence at their facility in Hobro, Denmark which will allow them to take advantage of $900 Million in funding available for European projects. Denmark will benefit from the jobs and technical skills developed at this CoE.

7.2.3 : Competitive Threat from China

China is investing heavily in hydrogen and fuel cell technologies and is preparing to deploy on a massive scale. It has aggressively pursued investment in foreign technology, and with its requirement for local content, foreign companies are establishing joint venture facilities in China.

Ultimately, China's large-scale development of fuel cell technology will drive down costs, benefitting the entire

BALLARD DEVELOPING NEXT-GEN FUEL CELL WITH ONTARIO UNIVERSITIES

The Canadian Urban Transit Research and Innovation Consortium (CUTRIC) is funding a collaborative project between industry, academia and government to develop low-cost, high performing durable fuel cells for next generation transit and automobile applications.

Project Partners: *University of Waterloo (Principal Investigator), Western University, Ballard Power Systems Inc.; and, StarPower ON Systems Inc.*

Funding: *CUTRIC, NSERC CRD, Industry Partners.*

BALLARD ESTABLISHING COE IN EUROPE

Ballard will establish a Marine Centre of Excellence (CoE) at its engineering, manufacturing and service facility in Hobro, Denmark.

The CoE will focus on development of next generation heavy-duty fuel cell module targeted for European marine applications with commercial launch planned for late 2019.

BALLARD-WEICHAI POWER COLLABORATION IN CHINA

Ballard has entered a strategic joint venture with Weichai which will see Ballard's next generation LCS fuel stack and fuel stack modules for buses and heavy-duty trucks manufactured in China.

industry, however, it comes at the expense of jobs and IP being created in China. As an example, Ballard is entering into a strategic joint venture with Weichai Power in China which will allow them to take advantage of the investment opportunities and enormous market size that China has to offer.

7.2.4 : Recommendations Moving Forward

(1) **Identify Hydrogen and Fuel Cells as a Priority Sector**

Despite its global leading status in fuel cell technology, this sector has not been explicitly identified as a priority by the Province. During discussions involving clean technology, such as zero emission vehicles, the focus is often entirely on BEVs, with FCEVs left out of the discussion altogether. As an example, the current Federal incentive cap of $45,000 for Zero Emission Vehicles eliminates fuel cell vehicles as an eligible option as the technology is still pre-commercial and no FCEVs fall within this threshold.

The Province needs to communicate strongly and consistently to the Federal Government that hydrogen and fuel cells are an important priority sector for BC.

(2) **Provincial R&D and Deployment Funding Support**

It is important for the Province to commit to research, development and deployment funding over the longer-term. Local organizations should have access to funding that can be combined with matching funds from the Federal government or leveraged to access greater funds from outside entities. Companies in the Province also struggle with reduced federal R&D funding, as NRCan has shifted its focus from R&D to infrastructure deployment.

The ARC program supports BC companies operating in the clean electric vehicle (CEV) sector and encourages international investment. The ARC fund could be expanded to support technologies beyond transportation and provide a base for matched federal funding.

(3) **Support for Maintaining Leadership**

It is recommended that the Province adopt an industrial policy of assisting BC companies in navigating the Chinese market. In the case of fuel cells, the BC sector would be advised to identify competitive advantages, such as the manufacturing of highly automated parts, that cannot be easily replicated by Chinese competition. Investment and policy support are necessary to keep the companies, jobs and technical knowledge in BC.

Canada has strong federal support organizations that may be able to assist in facilitating technology exchanges between China and BC. Establishing "sister province" initiatives with projects operating in parallel may provide a mechanism to overcome China's strong preference to localize manufacturing.

7.3 : Opportunities for Innovation Leadership

The areas for BC innovation leadership can be divided into the categories of policy, investment and technology.

(1) **Policy**

BC 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. Any policy needs to maximize the GHG reduction impact, manage the cost issues associated with the change-over and allow the market to act in terms of technology selection. BC is rich in two key natural resources for the production of clean hydrogen: natural gas reserves and renewable hydroelectricity. Our policies should set BC as the global leader in hydrogen production from both of these assets with a clear understanding of how their inherent cost structure will drive market adoption. Specifically, decarbonized hydrogen from hydrocarbon sources will be cheaper and thereby adopted earlier, but at the same time, the policies should encourage the gradual transformation from the lower cost natural gas-sourced hydrogen to the more expensive fully renewable hydrogen as the finite hydrocarbon sources are depleted over time.

(2) **Investment**

BC can strongly drive innovation leadership by where and how it chooses to invest its capital. BC has had global innovation leadership over hydrogen and fuel cells in the past and there continues to be key innovation resources resident in BC to this day. However, because there has been only ad-hoc investment continuity, other areas in the world have largely taken over this innovation leadership position.

These competing regions include China – who have been actively hiring BC experts to bolster their own innovation leadership; Japan and Korea – countries who have declared their commitment to developing a hydrogen economy and are heavily investing in low-cost hydrogen production technologies, import systems, and hydrogen and fuel cell vehicles; the UK is conducting public trials of using hydrogen in NG networks; Germany is focussing on storing excess renewable energy using power-to-gas.

BC does well in the generation of large clean energy companies such as Ballard Power Systems, Carbon Engineering, InvenTys and General Fusion largely because of past investments in fuel cell and hydrogen through Ballard and other initiatives in the past. This had the effect of creating highly experienced, clean technology venture professionals who have spurred other innovation and venture creation. The Province can become a global leader in the development of hydrogen economy by investing in:

1) ***Revitalization of the Innovative Clean Energy (ICE) Fund***. The ICE fund plays an important role in the early stage infrastructure of BC's clean technology community and more funding will be essential to help foster the next generation of innovative clean energy companies.

2) ***Development of large H_2 infrastructure initiatives***. Large programs such as those being enacted in the UK and Japan will catalyze and concentrate the technology innovation required to execute these programs in sustainable techno-economic fashion. Examples of programs that could be enacted in BC are listed below. For each of these programs, there should be 'customer requirements' such as carbon intensity (CI) limits and cost targets established to which the sector must innovate.

    a. Build large decarbonized hydrogen production and CO_2 sequestration facilities in the Peace Region where BC can utilize its NG resources to provide decarbonized hydrogen into the NG grid for provincial or export use.

    b. Convert government fleets to fuel cells and hydrogen with stricter carbon intensity limits and cost criteria than the previous bus program in Whistler.

    c. Convert an entire community or area (such as UBC or a remote community) to hydrogen including production, storage, delivery and end use (vehicles, power, and heat) with a zero GHG emission target

    d. Build large LH_2 liquefier(s) in the province to help support low-cost transport of hydrogen fuel to market demand sites.

    e. Establish pilot facilities co-located at the Kitimat NG export terminal for the export of hydrogen produced in BC to the emerging global markets.

3) ***Tax incentives*** – Provide all investors in hydrogen and clean technologies with tax exempt status for their investments and create tax credits for business and individuals buying hydrogen and hydrogen related projects.

(3) **Technology Innovation**

a. ***Low-Cost Green and Blue Hydrogen Production***

Innovation is required to develop new production methods that can produce industrial quantities of hydrogen at a cost structure that is as low as current NG costs plus BC's CO_2 avoidance incentives. This means that the hydrogen will likely need to be under \$10/GJ (equivalent to \$1.20/kg H_2) to get industrial, commercial and residential consumers to take up the fuel without forcing regulations. In addition, if these costs can be achieved, the use of hydrogen as a vehicle fuel or as an input to the production of renewable synthetic fuels will become more widespread.

The specific areas of innovation include:

- *Low-cost NG pyrolysis technology to produce hydrogen and solid carbon from NG and other hydrocarbon feedstocks.*
- *Technologies and processes to utilize and monetize the emerging and plentiful carbon feedstocks to help offset costs of NG pyrolysis H_2 production methods.*
- *Lower cost and higher efficiency electrolysers including those that can operate at vehicle refueling pressures.*
- *Lower cost and less energy intensive technologies to convert renewable CO_2 and H_2O into H_2 and CO as feedstocks for renewable synthetic fuels.*

b. ***Hydrogen storage and delivery***

H_2 delivery and storage are key parts of any hydrogen economy. Hydrogen needs to be transported to the consumer as either a liquid or a gas. Areas of innovation include:

- ***Liquefaction** – Low-cost H_2 liquefaction will be essential for the delivery of H_2 to different customer sites, particularly refueling sites. Liquid hydrogen (LH_2) is transported and delivered at a much lower cost than compressed H_2 (CH_2). As BC develops a H_2 economy, it is possible that BC could become a net exporter of hydrogen to the world energy markets and would have further incentives to develop low-cost LH_2 liquefiers. Large baseload LNG plants are approaching ideal efficiencies but H_2 liquefaction costs are high and energy intensive – there is a long way to go. As well, technical innovation will be required on how to best recover LH_2 exergy since it is much higher than LNG due to lower liquefaction temperatures and ortho to para conversion. The Institute for Integrated Energy Systems at the University of Victoria (IESVic) has been researching novel hydrogen liquefaction and exergy recovery technologies since 1990 and is well suited to play a key role.*
- ***Pipelines** – A hydrogen economy will use as much of the sunk infrastructure as possible. In the case of the NG grid, BC already has a fully developed mature gaseous fuel distribution system. At present, BC can likely inject up to 10-15% of H_2 by volume in the NG grid without modification. To get to higher hydrogen utilization, the pipelines will either have to be replaced with pipelines made with hydrogen compatible materials or we will innovate a way to modify the existing pipelines in-situ in a cost-effective way.*
- ***Gas Separation** – The production and distribution of hydrogen requires separation of hydrogen with other gases. In typical cases, this can be accomplished with mature pressure swing absorption (PSA) technology. However, in certain production methods, H_2 will need to be separated from combusted gases and nitrogen which is not as straightforward. When H_2 is mixed with NG in the grid, there will likely be many instances where it will be advantageous to separate the H_2 at sites where demand is the highest and these sites are unlikely to correspond with pressure let down stations where PSA technology could be used. There needs to be innovation in low-cost hydrogen separation technologies such as membranes and electrochemical methods.*
- ***Other Hydrogen Storage** – LH_2 is an important way to store hydrogen but suffers from high capital costs. Other innovative storage technologies include cryo-compression, solid state storage, liquid organic storage, adsorbents, and non-carbon chemical carriers such as ammonia.*

c. ***Grid optimization using electrolysis hydrogen***

The electrolysis hydrogen production pathway offers unique opportunities to connect the electric grid and natural gas energy infrastructure in an optimized and efficient system. Innovative technology development includes grid monitoring and control systems, integration technologies that span the electrical and gas grid control systems, predictive Artificial Intelligence (AI) technologies that anticipate intermittent power production and storage variables.

d. ***Fuel cells***

BC still arguably holds an innovation edge in fuel cell technology. However, that hold is tenuous at best as other jurisdictions around the world ramp up their programs, particularly China. Increased R&D support for fuel cell materials, components, and systems is important for BC to maintain its position at the forefront of the industry.

e. ***Carbon and CO_2 sequestration***

The production of low-cost hydrogen from NG will produce either carbon or CO_2. Currently, CO_2 sequestration technology is mature. However, exploration of other sequestration sites in BC such as the off-coast sea beds will be important to create a network of sequestration sites that are closer to H_2 production sites. Innovation in carbon utilization methods will also be important. The amount of carbon created over the next decades will be substantial. Economic carbon use such as agriculture land applications, construction materials, and power production will require innovation. As well, further innovation for sequestration of solid carbon (Pyrogenic CCS[153]) without CO_2 production on land and in oceans is required.

f. ***Renewable synthetic gaseous and liquid fuels***

Renewable or decarbonized hydrogen and CO_2 from renewable resources are the most important feedstocks to renewable synthetic gaseous and liquid fuels. Currently, both of these feedstocks are too expensive. Opportunities for technology innovation leadership for these fuels are:

a. Low-cost decarbonized or renewable hydrogen (discussed above),

b. Low-cost environmental carbon dioxide capture from both the atmosphere and the oceans for CO synthesis,

c. Electrolysis, photo-electrolysis and other advanced methods for processing both water and renewable CO_2 together into H_2 and CO. Depending on the technology, the amount of hydrogen required for synthetic diesel for example could be reduced by up to 1/3 if the CO_2 reduction method can entirely avoid the reverse water-gas-shift reaction to produce the CO.

153 *Wikipedia. (2019). Pyrogenic Carbon Capture and Storage. Retrieved from https://en.wikipedia.org/wiki/Pyrogenic_carbon_capture_and_storage*

8.0 : Mid-term And Long-Term Hydrogen Cost Potential and Demand in BC

8.1 : Hydrogen Demand

As described in Section 4.0, hydrogen demand was estimated in the natural gas, transportation, industrial, and remote community sectors based on aggressive and conservative scenarios. Hydrogen used in the built environment was also considered, but the only significant use of hydrogen in the built environment is expected to be through injection in the natural gas grid. To avoid double counting, this hydrogen was attributed to the natural gas sector. The estimated demand in each sector should be considered a projection of what will occur in BC but represents what demand could be if certain policies are adopted and given certain rates of technology development.

Each sector was considered in isolation from the others, so the resulting demand is not necessarily additive. The most significant example of this is the interaction between industry and transportation. The estimated hydrogen demand in the industry sector is based on the production of synthetic fuel that will reduce the carbon intensity of liquid fuels to satisfy the Renewable & Low Carbon Fuels Program. In our analysis, the demand for liquid fuel remained constant from year to year. However, if hydrogen fuel cell and battery electric vehicles reach mass adoption, as predicted in the transportation sector in this analysis, liquid fuel demand in BC is likely to reduce significantly over time.

Figure 75 shows the estimated aggregate demand in the Province for the aggressive and conservative scenarios from 2020 to 2050. In the aggressive scenario in 2050, demand could reach as high as 1,445 kilotonnes/year annual demand. This number is less than half the estimated annual supply.

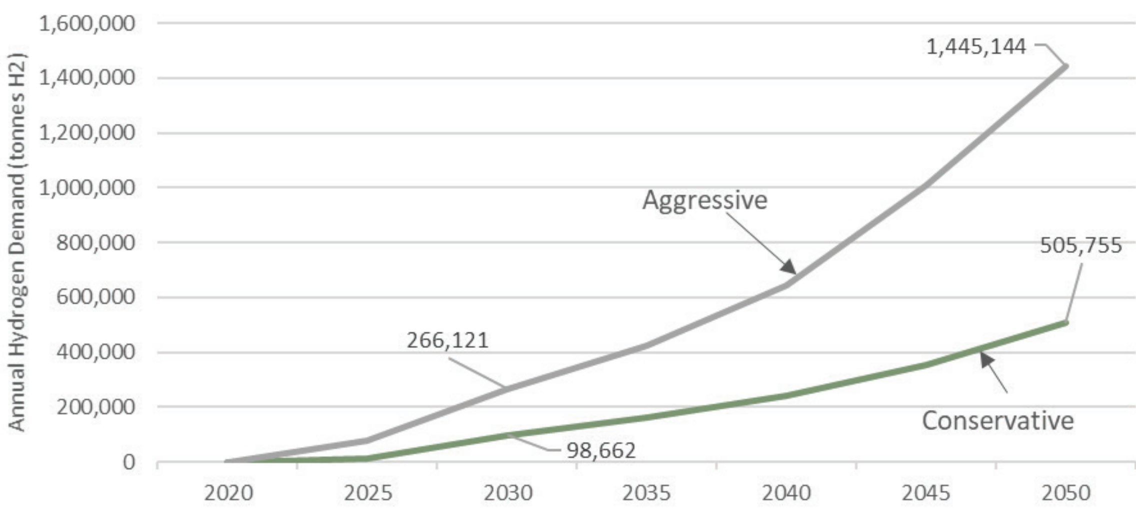


Figure 75. Aggregate Conservative and Aggressive Hydrogen Demand (2020-2050)

Figure 76 and Figure 77 show the conservative and aggressive hydrogen demand scenarios from 2020 to 2050 by sector, and Figure 78 shows the detailed breakdown by sector in 2030 and 2050.

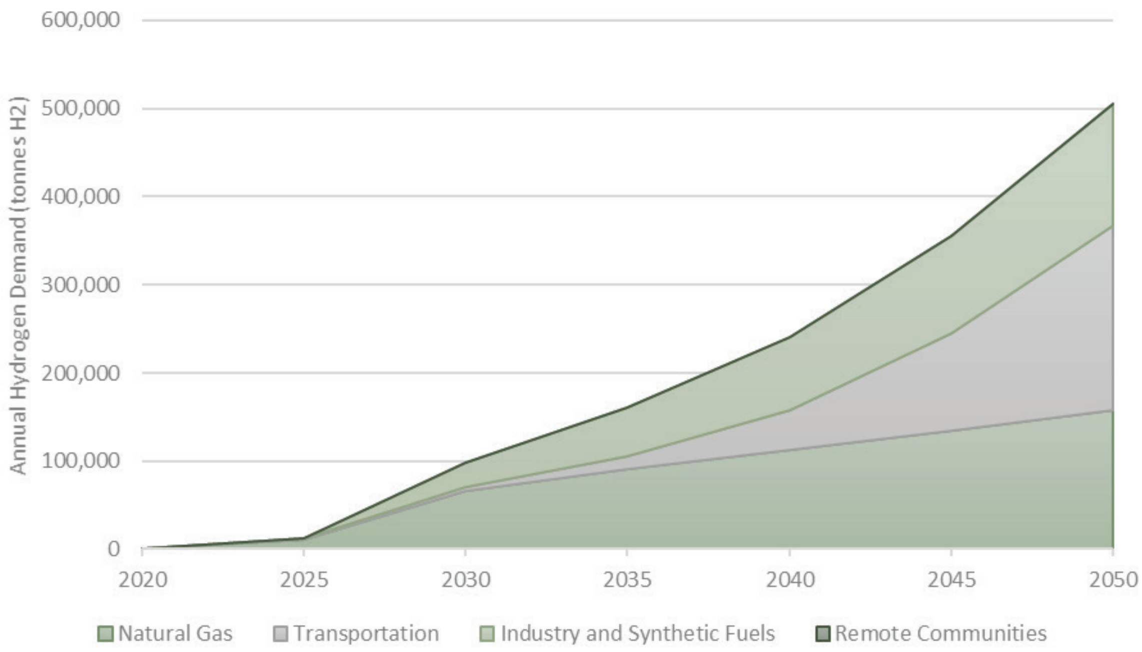


Figure 76. Conservative Aggregated Hydrogen Demand by Sector (2020-2050)

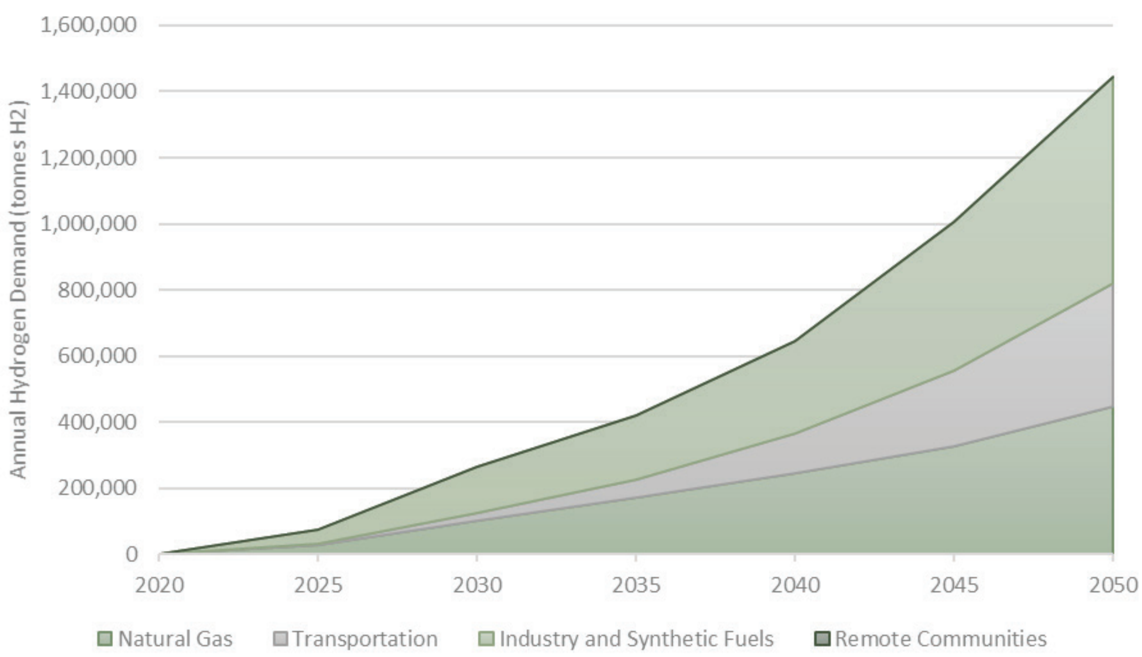


Figure 77. Aggregate Aggressive Hydrogen Demand by Sector (2020-2050)

Initially, the industry and natural gas sectors offer the greatest potential for hydrogen consumption, but by 2050, the transportation sector will play a significant role.

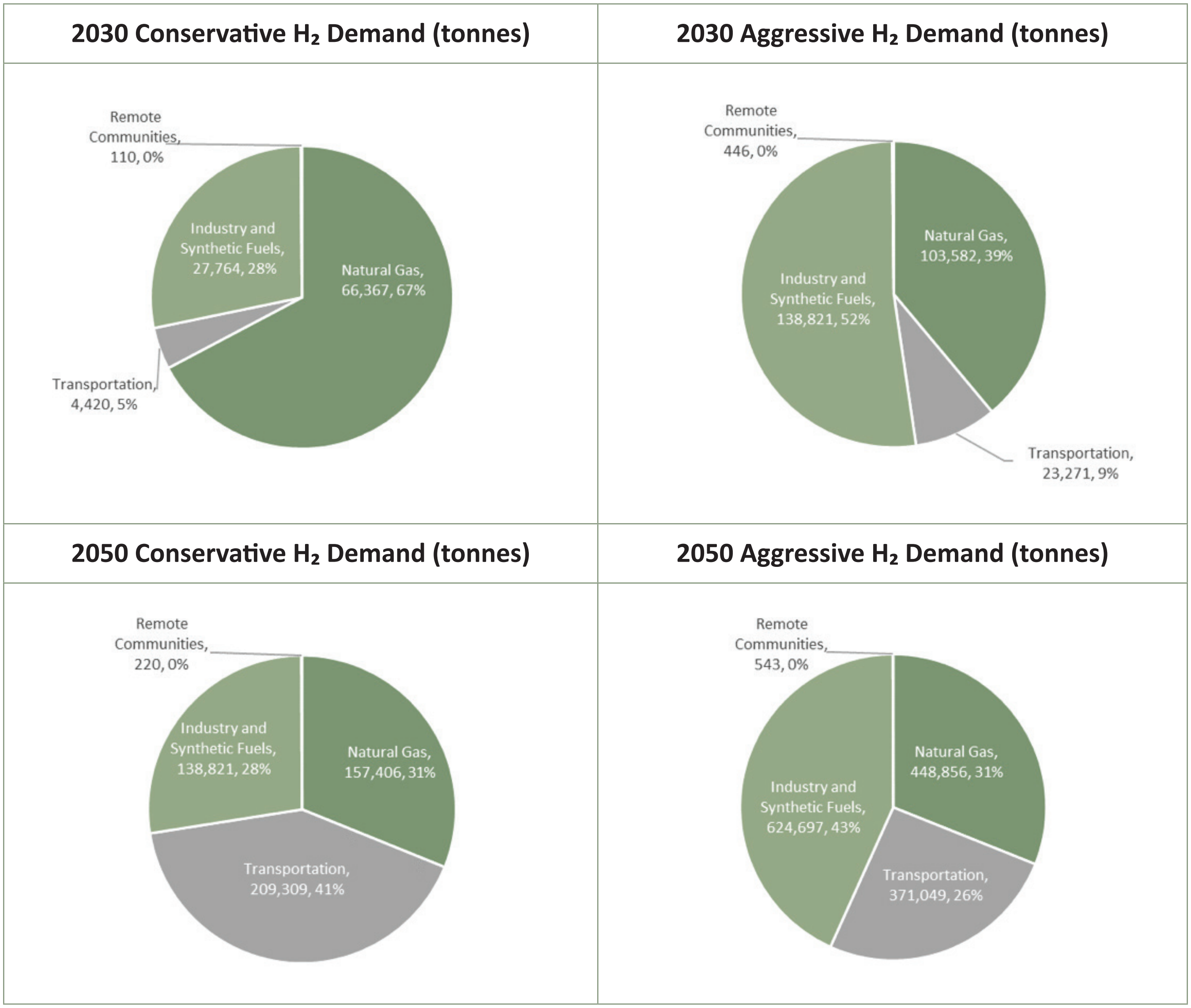


Figure 78. Conservative and Aggressive Aggregate Hydrogen Demand in tonnes by Sector (2030 & 2050)

8.2 : GHG Emissions Abatement

As described in detail in Section 4.0, hydrogen has the potential to reduce GHG emissions from each sector investigated in this study. Figure 79 shows the estimated aggregate GHG emissions that could be abated in the Province for the aggressive and conservative scenarios from 2020 to 2050. In the aggressive scenario in 2050, the reduction is 15.6 Mt CO_2e, which represents 31% of the Province's target to reduce emissions by 80% compared to a 2007 baseline. The conservative scenario estimates the reduction to be 7.2 Mt CO_2e, which represents 14% of the Province's target.

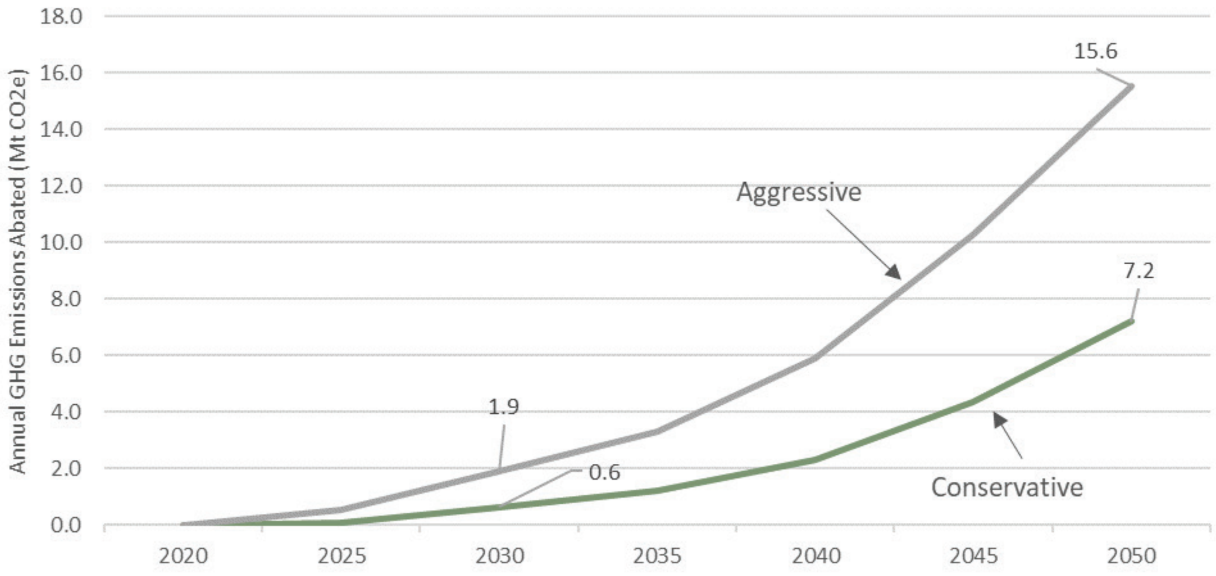


Figure 79. Aggregate Conservative and Aggressive GHG Emissions Reduction (2020-2050)

Figure 80 and Figure 81 show the conservative and aggressive GHG emissions reduction scenarios from 2020 to 2050 by sector, and Figure 82 shows the detailed breakdown by sector in 2030 and 2050.

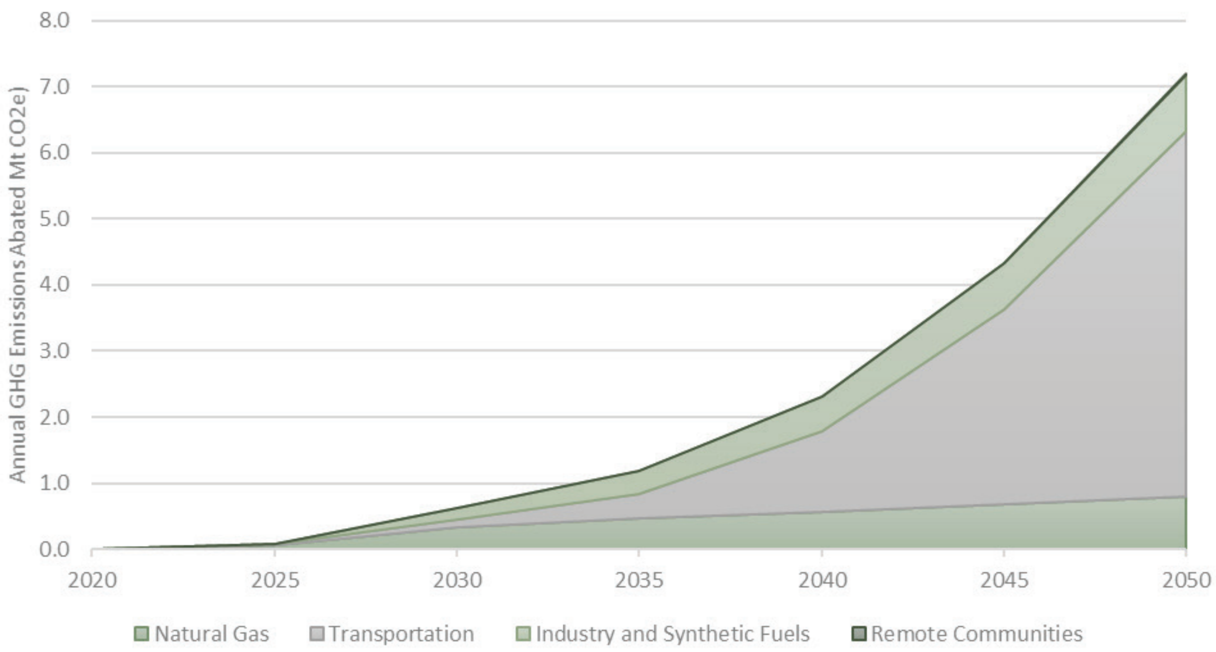


Figure 80. Conservative Aggregated GHG Emissions Reduction by Sector (2020-2050)

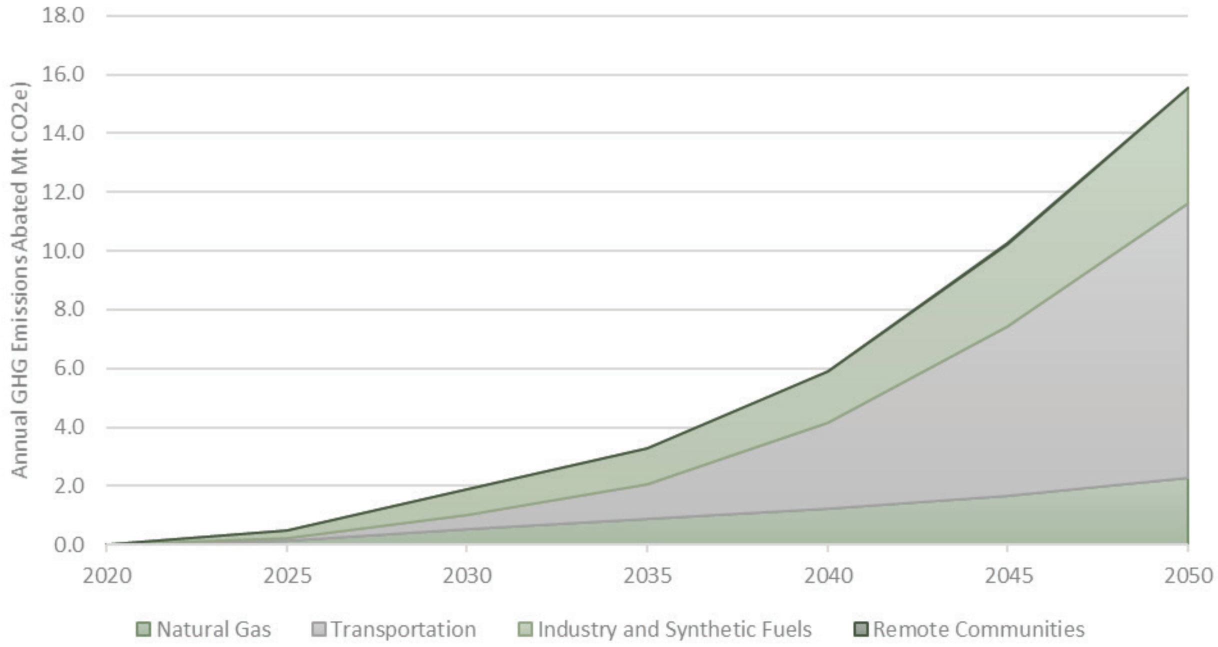


Figure 81. Aggressive Aggregated GHG Emissions Reduction by Sector (2020-2050)

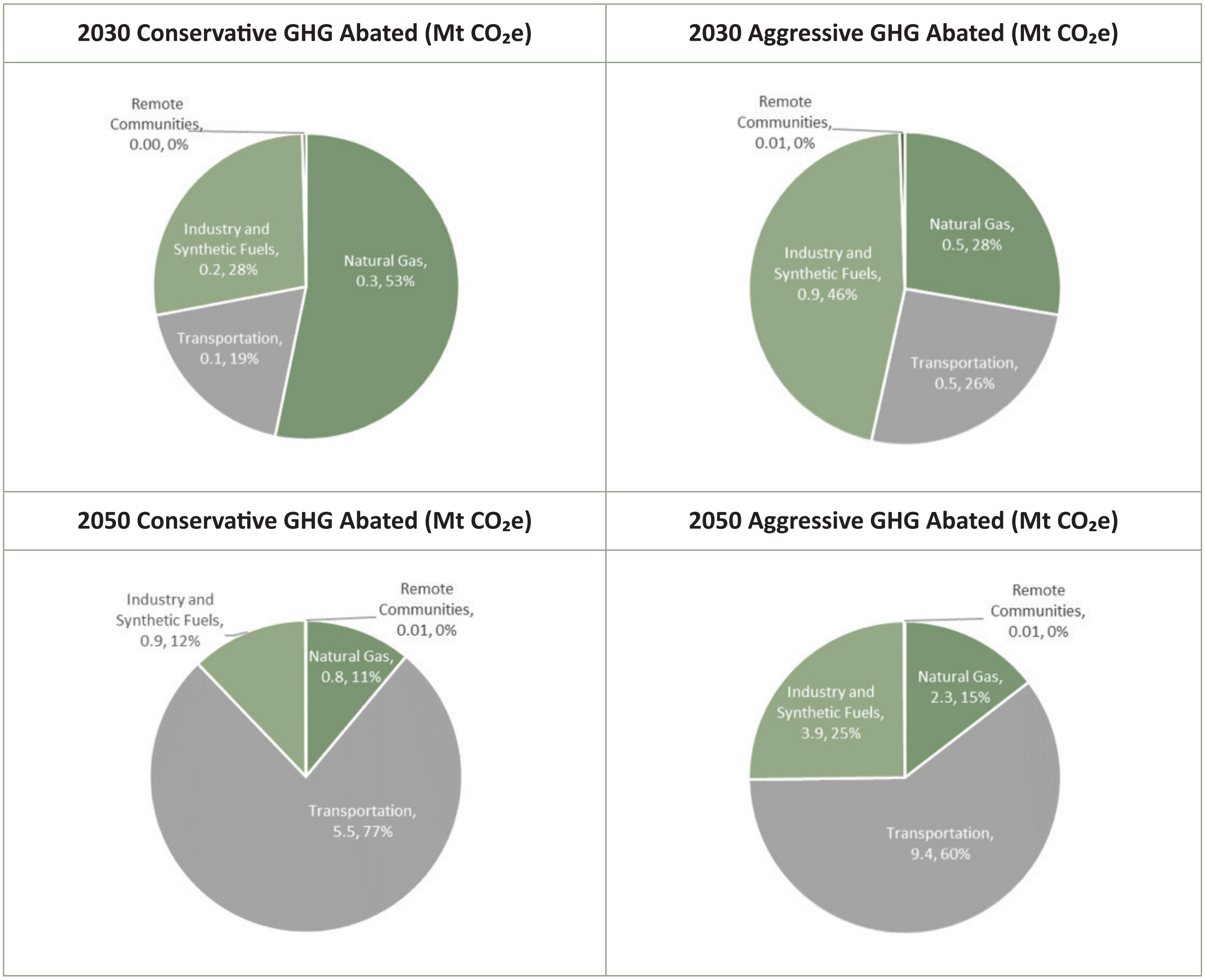


Figure 82. Conservative and Aggressive Aggregate Hydrogen Demand in tonnes by Sector (2030 & 2050)

Initially, natural gas offers the greatest potential for GHG emissions reduction, but by 2050 the transportation sector is expected to dominate savings. This occurs for two reasons. First, it will take time to build up the hydrogen transportation sector because of the large number of gasoline and diesel vehicles on the road and because of the time needed to develop the technology and scale up performance. In contrast, the natural gas grid can begin incorporating hydrogen immediately. Second, most transportation applications will be powered by fuel cells, which offer a significant efficiency improvement compared to burning the hydrogen. This analysis assumed the hydrogen injected into the natural gas grid will be burned directly, so the savings potential is greater in transportation applications.

8.3 : Hydrogen Supply

In the near-term, the majority of hydrogen produced in the Province is expected to come from electrolysis. As described in Section 3.1.2, electrolysis can produce hydrogen at a cost of approximately $5 to $7 per kilogram. Facility design is highly scalable, allowing for distributed generation based on local demand. The capital expenditure to build an electrolysis facility is low relative to SMR, so it will be more palatable for investors while demand is low.

By-product hydrogen is expected to become available in the mid-term. This will be the lowest cost pathway for hydrogen production (less than $1 per kilogram as described in Section 3.1.1). However, the provincewide supply of by-product hydrogen is limited and localized to two regions: North Vancouver and Prince George. Industrial suppliers are also hesitant to provide the hydrogen at small scale, so it will not be available until sufficient demand exists.

In the mid-term, hydrogen can also be produced by decarbonizing natural gas through SMR with carbon capture and storage and pyrolysis. This approach leverages BC's abundant natural gas supply while reducing emissions and limiting the amount of new electrical generation capacity that would otherwise be needed to meet the Province's GHG emissions reduction targets. As described in Section 3.1.4, hydrogen produced in this way will be relatively low cost (approximately $2 per kilogram) and can be generated in large quantities. However, this hydrogen pathway is only viable at large scale. Building the infrastructure to produce and distribute the hydrogen will require significant investment and will take a minimum of three to five years to deploy, and therefore, a project would need to be initiated in the near-term to be available by 2025.

In the long-term, all three pathways are likely to continue. By-product hydrogen will reach its maximum capacity and continue at a consistent rate indefinitely. Hydrogen from natural gas will remain a major source as demand increases and new technologies, like pyrolysis, are commercialized. Electrolysis will likely continue to grow throughout the Province over this period as costs drop and regulation pushes towards renewable energy.

9.0 : Instruments and Policies to Develop Hydrogen Supply Chains in BC

9.1 : Jurisdictional Scan of Leading Markets

To inform the policy recommendations in this report, the project team conducted a review of jurisdictions leading the world in hydrogen technology development and deployment. Figure 83 summarizes hydrogen technology deployments in three key regions: North America, Europe, and Asia.[154]

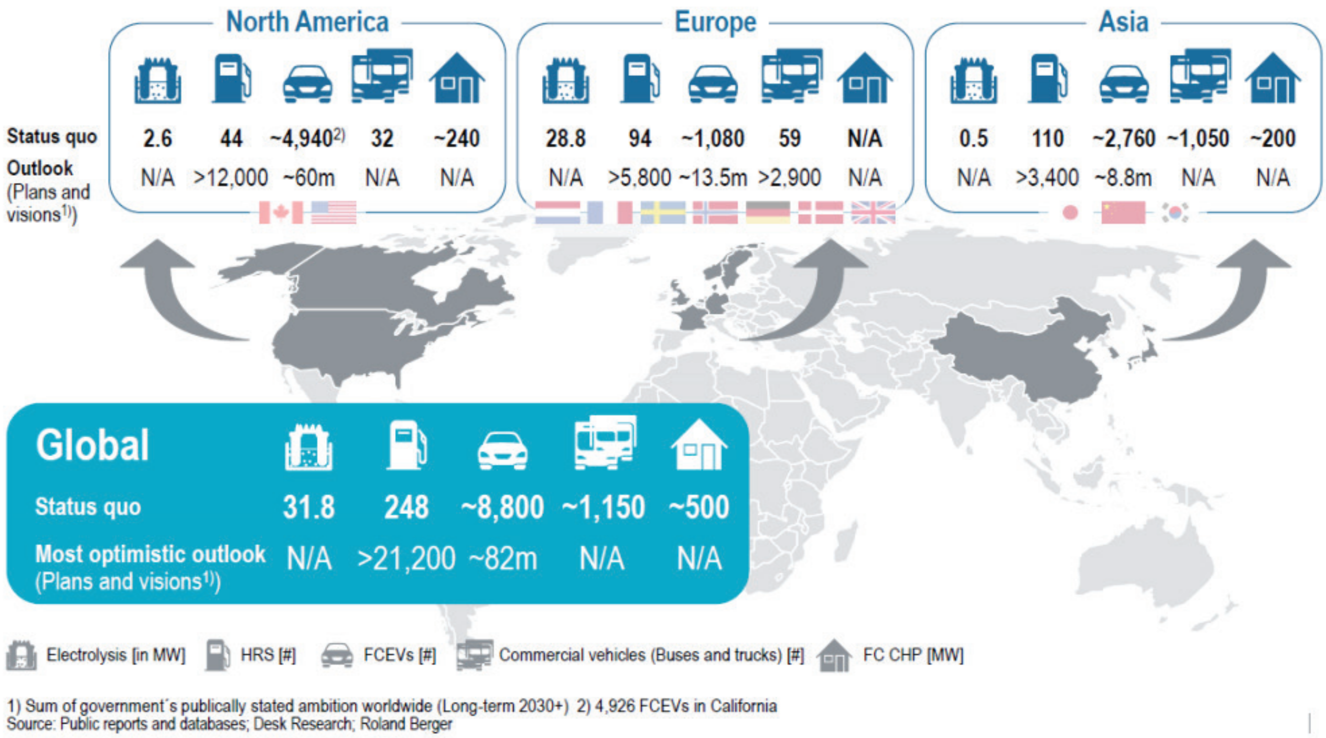


Figure 83. Status and Publicly Stated Plans of Hydrogen Technology Deployments by Continent. Source: Hydrogen Council.

Complementing the hydrogen deployment data, Figure 84 shows the International Energy Agency (IEA) summary of the number of countries offering policy support towards these deployments. IEA estimates that 10 to 15 countries already offer policy support for each of hydrogen fuel infrastructure, fuel cell passenger vehicles and buses. Some jurisdictions have also extended policy support towards the use of hydrogen in the built environment (building heat and power) and industry.

154 The Hydrogen Council. (2019). Fostering Deployments – Next Steps. Retrieved from https://www.iea.org/media/workshops/2019/2019hydrogen/Session4-3-FRANC.pdf

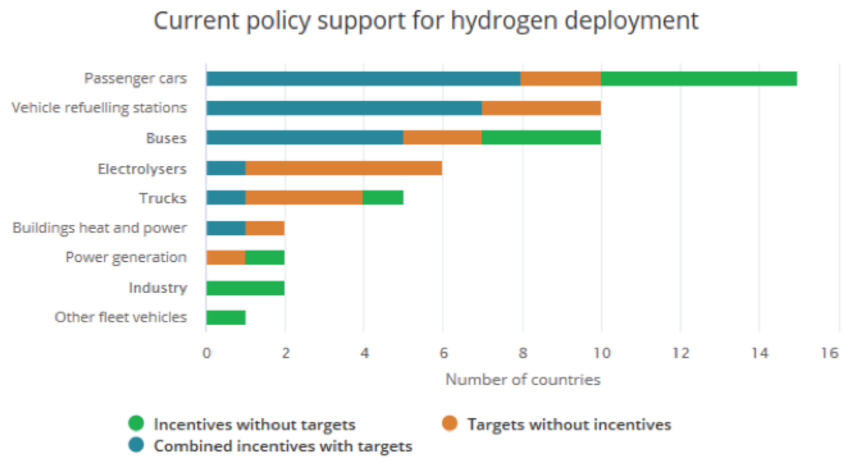


Figure 84. Number of Countries Offering Policy Support for Hydrogen Deployment. Source: International Energy Agency.

The review yielded several key insights:

- *Jurisdictions leading in hydrogen technology adoption have clearly laid out plans to incorporate hydrogen into their energy systems and well-defined targets to measure success.*
- *Jurisdictions are exploring hydrogen technologies to achieve different goals, such as energy security, local air quality, climate change mitigation, economic growth, and energy storage.*
- *Roughly 90% of hydrogen is currently produced from fossil fuels, but hydrogen combines well as an energy storage medium with variable power renewable sources. The carbon intensity of hydrogen production from fossil fuels could also be dramatically decreased through carbon capture and sequestration.*
- *Asia and California are expecting to dramatically increase hydrogen demand in the coming decade and will need to set up international supply chains to deliver clean hydrogen.*
- *Led by China, Asia is investing heavily in hydrogen fuel cell technology and is rapidly scaling up vehicle deployments, particularly in medium-duty trucks. Japan and the Republic of Korea are currently the only two countries producing light-duty fuel cell vehicles that are available for purchase in BC.*
- *Jurisdictions leading in light-duty fuel cell vehicle adoption have focused on building up fueling infrastructure, providing incentives (monetary and non-monetary), and tightening emissions standards. California, which leads adoption, also implemented a ZEV mandate.*
- *Europe has put the greatest emphasis on power-to-gas projects to better utilize intermittent renewable energy sources. Efforts there can be leveraged to inform safe levels of hydrogen injection and the most effective approach to improving the pipeline network.*

A series of one-page summaries outlining the current status of deployments in eight jurisdictions leading the world in adoption of hydrogen technologies is available in Appendix D: Jurisdictional Review summaries. These summaries include policies, incentives, and regulations in place in these jurisdictions.

Notable insights not featured in the one-page summaries included the following:

- *Switzerland's Lump-sum and Performance-based Heavy Vehicle Charges have greatly improved the competitiveness of zero emission trucking solutions. The Heavy Vehicle Charges apply to all vehicles with a permissible laden weight of more than 3.5 metric tonnes; certain vehicle types are exempted, including vehicles with electric drivetrains.*[155, 156] *They provide for the recovery of previously-externalized costs of diesel use based on the "polluter pays" principle*[157] *and are believed to have been pivotal in Hyundai's decision to deploy 1,600 hydrogen fuel cell-powered commercial trucks in the alpine country.*[158]
- *The United States has used tax credits to great effect in growing several clean energy technologies, including wind energy, solar photovoltaics, and fuel cells. US Federal incentives for the purchase of zero emission vehicles also take the form of tax credits instead of purchase subsidies. A key lesson from the US experience has been that long-term policy certainty is required for industries to benefit; among other factors, sales cycles can be lengthy. As shown in Figure 85, the American wind industry experienced several boom/bust cycles when its Production Tax Credit was allowed to repeatedly expire, then was repeatedly offered one-year extensions.*
- *Norway's spectacular success with ZEV adoption – plug-in electric vehicles accounted for 49% of passenger vehicle sales in calendar 2018 and accounted for 10% of the country's passenger vehicle stock – underscores the lesson of long-term policy commitments. Long before they were mass-produced in great numbers, ZEVs received exemptions from import taxes (1990), road tolls (1997), parking fees (1999), value-added tax (2001) and passenger ferry fees (2009). Other incentives included reduced annual registration taxes (1996) and nationwide bus lane access (2005). One insight could be to introduce policy measures before vehicles are sold in great numbers. While it is too late to do so for plug-in electric vehicles in British Columbia, there remains time to craft comprehensive incentives for hydrogen fuel cell vehicles.*
- *China's industrial policy, having established world leadership in batteries for battery electric vehicles, has shifted decisively in favour of hydrogen fuel cells.*[159] *While battery electric vehicle incentives are expected to end in 2020, hydrogen and fuel cell incentives remain generous: federal incentives amount to $40,000 CAD for fuel cell passenger vehicles and $100,000 CAD for heavy duty fuel cell vehicles, both of which can be supplemented by state or city incentives, covering up to 50% of the vehicle's purchase price. To offer a sense of scale of China's ambitions, BloombergNEF identified $17 billion USD in hydrogen and fuel cell investment commitments in China through 2023.*[160]

155 *Swiss Confederation, Federal Customs Administration. HVC - General / Rates. Retrieved from: https://www.ezv.admin.ch/ezv/en/home/information-companies/transport--travel-documents--road-taxes/heavy-vehicle-charges--performance-related-and-lump-sum-/hvc---general---rates.html*

156 *Swiss Confederation, Federal Customs Administration. Lump-sum heavy vehicle charge (PSVA) for Swiss vehicles. Retrieved from: https://www.ezv.admin.ch/ezv/en/home/information-companies/transport--travel-documents--road-taxes/heavy-vehicle-charges--performance-related-and-lump-sum-/lump-sum-heavy-vehicle-charge--psva--for-swiss-vehicles.html*

157 *Swiss Confederation, The Federal Council. Federal Council amends Heavy Vehicle Charge Ordinance. 23 September 2016. Retrieved from: https://www.newsd.admin.ch/newsd/message/attachments/45467.pdf*

158 *Reuters. Hyundai signs deal to sell 1,000 hydrogen powered trucks in Switzerland. 19 September 2018. Retrieved from: https://www.reuters.com/article/us-hyundai-motor-hydrogen-truck-idUSKCN1LZ1VI*

159 *Bloomberg. China's Father of Electric Cars Says Hydrogen Is the Future. 12 June 2019. Retrieved from: https://www.bloomberg.com/news/articles/2019-06-12/china-s-father-of-electric-cars-thinks-hydrogen-is-the-future*

160 *Bloomberg. China's Hydrogen Vehicle Dream Chased With $17 Billion of Funding. 27 June 2019. Retrieved from: https://www.bloomberg.com/news/articles/2019-06-27/china-s-hydrogen-vehicle-dream-chased-by-17-billion-of-funding*

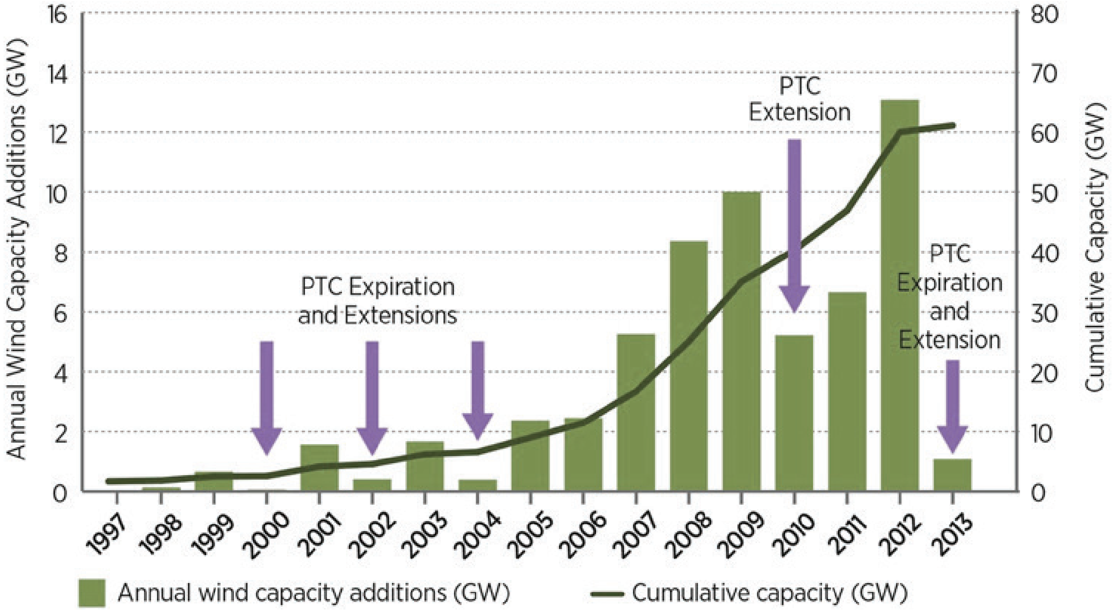


Figure 85. The Effect of Repeated Cycles of Production Tax Credit (PTC) Expiration and Extensions on US Wind Capacity Additions. Source: US Department of Energy.[161]

Based on the review, the project team assigned ratings from 0 to 4 to quantify the strength of each region in 5 categories: current adoption, future adoption, incentives, policy support, and financial commitment. The project team also assigned a rating of 0 to 4 indicating how great a priority the following 5 factors are for the jurisdiction: hydrogen exports, hydrogen imports, local power-to-gas adoption, local fuel cell vehicle adoption, and technology export. The results are summarized in Figure 86 and Figure 87.

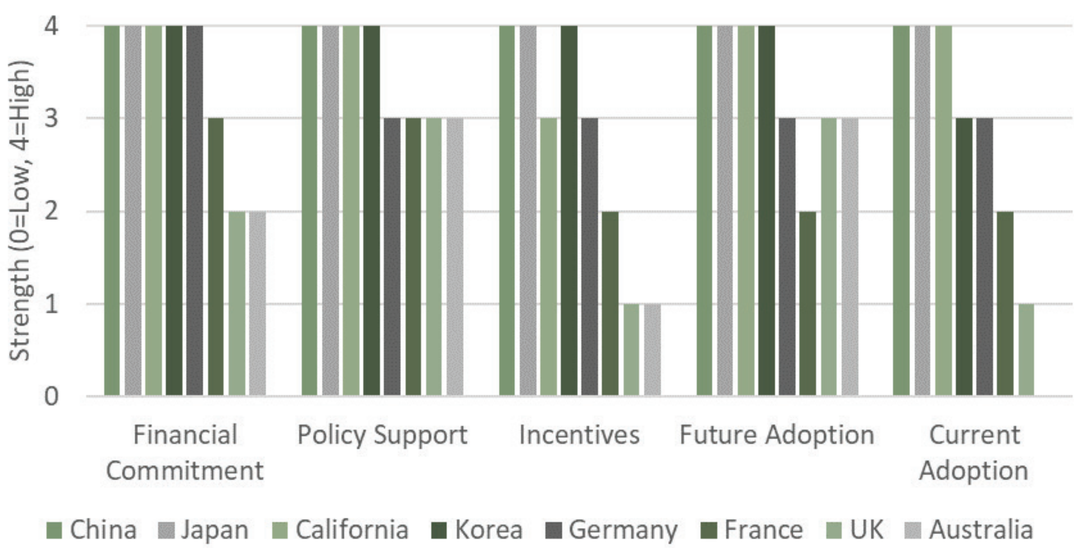


Figure 86. Strengths of Key Jurisdictions Relating to Hydrogen Technology Adoption and Development

161 US Department of Energy, Office of Energy Efficiency & Renewable Energy, Wind Energy Technologies Office. Production Tax Credit and Investment Tax Credit for Wind. Retrieved from: https://windexchange.energy.gov/projects/tax-credits

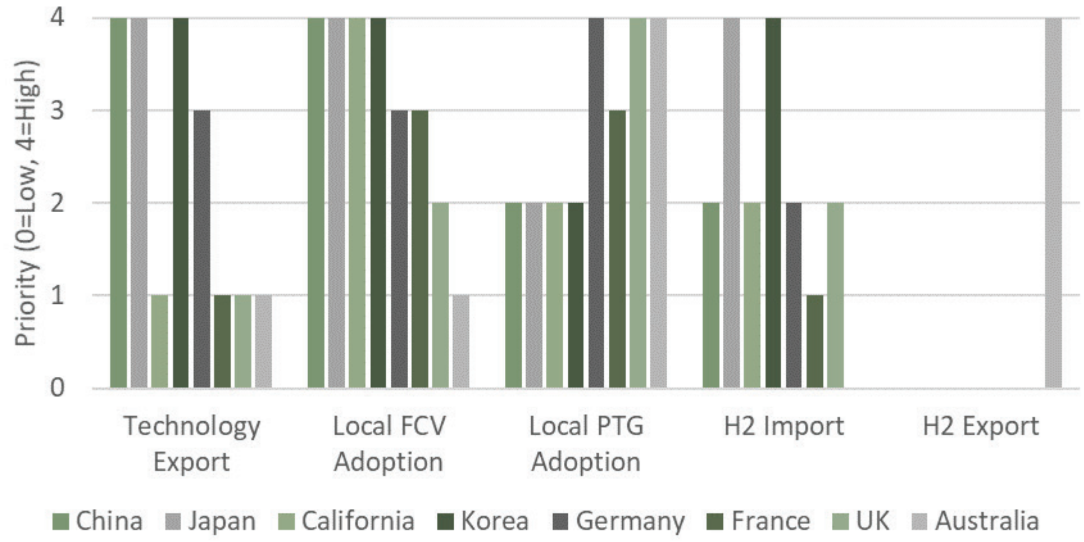


Figure 87. Priority of Key Jurisdictions Relating to Hydrogen Technology Adoption and Development

9.2 : Recommended Instruments and Policies for BC

The following instrument and policy recommendations highlight critical actions in the 2020 – 2025 timeframe that will support the development of a hydrogen economy in BC. Supporting details and rationale are documented in relevant sections of the report and are summarized here for simplicity.

Hydrogen Production Pathways

1 Allow all sources of 'Clean Hydrogen' to qualify as 'Renewable Gas' under CleanBC goal for 15% Renewable Gas by 2030.

There is an immediate urgency to decarbonize BC's energy supply across all industry sectors. Hydrogen produced at scale from natural gas currently offers the lowest cost and highest availability of low carbon hydrogen when coupled with carbon capture and storage technology. Restricting to renewable sources of hydrogen would limit hydrogen production to electrolysis and biomass gasification pathways, which are currently higher cost and have limited supply in BC based on available resources. Restricting to renewable sources only would slow market penetration of hydrogen in BC.

BC's low carbon hydrogen production pathways include:

a. *'Green' hydrogen produced by electrolysis powered by renewable electricity sources such as hydro, wind, geothermal, or solar;*
b. *'Blue' hydrogen produced by steam methane reforming (SMR) with carbon capture and storage (CCS), biomass gasification with CO_2 sequestration, or hydrocarbon dissociation with solid carbon storage/utilization.*
c. *Hydrogen by-product from industry such as hydrogen produced in the chlor-alkali process.*

'Clean hydrogen' should be defined based on an overall carbon intensity value with clearly defined methodology for calculating the carbon intensity (CI). CI < 36.4 g CO_2e/MJ is the recommended threshold. For clarity, the term 'Renewable Gas' could potentially be modified to 'Low Carbon Gas' in the CleanBC goal and Greenhouse Gas Reduction Regulation.

The LCFR awards credits based on carbon reduction, and hence is already aligned with this recommendation.

2 Support longer-term transition to renewable hydrogen by setting required renewable content in CleanBC's 'Renewable Gas' target and providing incentives for renewable pathways in the LCFR.

Ultimately BC must transition to sustainable energy sources. While the Province has abundant natural gas reserves, these fossil fuel reserves are not sustainable energy sources given the timeframe to replenish these reserves is so great. If there is no required percentage of renewable content, it is possible that current economics could drive developers towards large SMR plants with CCS that could inhibit the development of renewable pathway projects with higher hydrogen production costs. The Province needs policy to drive adoption of multiple pathways in near and mid-term, as well as long-term, in order to ensure both decarbonization and ultimate sustainability goals are met.

It is recommended that the Province add a requirement to the 15% Renewable Gas goal that states that a certain percentage of the hydrogen (e.g. 33% in California) must come from renewable sources, where renewable sources include: electrolysis powered by hydro, wind, or solar; biomass gasification with CO_2 sequestration; and by-product hydrogen capture. It is recommended that the Province classify by-product hydrogen as renewable, given in BC the grid is 90% hydroelectric and is the original power source for this pathway. The LCFR is currently only focused on carbon intensity of the fuel and does not provide extra credit for renewable sources of fuel in relation to hydrogen used in transportation. It is recommended that the Province consider a mechanism to incentivize for the longer-term transition to renewable sources of transportation fuels by closing the gap on production costs between fossil based and renewable pathways. For example, the LCFR could provide base credits based on CI of pathway, with additional credits awarded for renewable sources.

3 Set a threshold for the CI of the hydrogen for all provincially funded projects and stipulate that there must be a transition plan for hydrogen to be produced within the province during the project.

In the past large demonstration projects like the Whistler bus fleet imported hydrogen to demonstrate end use applications. This resulted in negative public perception and did not drive the long-term build-out of hydrogen production infrastructure in the province which is critical to the growth of deployments following pilot demonstration periods. Where possible, it is recommended that projects use renewable pathways when demonstrating end used applications, and this should be reflected in project scoring criteria. In some cases, demonstration projects may need to use imported fuel for a period of time while local fuel supplies are developed for the project.

4 Work with BC Hydro and BCUC to develop rate tariffs that make hydrogen production via electrolysis more economically viable.

There are strategic benefits to encouraging the development of grid connected electrolysis projects in the Province. At the current industrial electricity rates of ~$60/MWh, the economics for electrolysis are challenging and development of projects will be limited. The existing rate structure does not reflect the benefits that electrolysis installations offer.

The electrolysis hydrogen production pathway offers unique opportunities to connect the electric grid and natural gas energy infrastructure in an optimized and efficient system. BC's natural gas infrastructure can be used simultaneously as a clean energy storage and transmission system for the electric system. Utilizing the gas system for electricity storage through power-to-gas conversion can improve electricity system efficiency and load factor, provide a mechanism for BC Hydro to offer dispatchable capacity by having large electrolysis demand loads that can be turned down on demand, minimize costs for end users, and create new delivery channels for low carbon fuels. Electrolysis also enables a distributed model of hydrogen production that is inherently scalable. The electrolysis pathway is currently the most expensive hydrogen production pathway for at-scale hydrogen production in the province. The big cost driver is electricity, making up approximately 70% of the levelized cost of hydrogen based on BC Hydro's current industrial electricity rates. There are a number of potential special rate structures that could support the economic viability of hydrogen production via electrolysis. It is therefore recommended that the Province work with BC Hydro and BCUC to evaluate potential rate tariffs that would reflect the benefits of electrolysis projects. Rate structures to be considered include:

- *Introduce a special rate for electrolysis plants. This could be accomplished by introducing a mechanism to put a value on carbon reduction when presenting proposed rate tariffs to BCUC.*
- *Support permanent adoption of the Freshet Rate Schedule (1892), which would enable higher capacity production and reduced costs during certain times of the year.*
- *Support development of rate programs for interruptible power demand, which fits well with electrolyzer load following capability.*
- *Reconsider BC Hydro's proposal for a Load Attraction rate but consider restricting this rate program to projects that support the Province's decarbonization goals.*
- *Consider a rate structure based on time of use charge, such that electrolyzers can be controlled to operate only in off-peak periods and reduce demand charges.*
- *Investigate the potential to offer retail access to power for electrolyzer operators. This could be limited to purchase of power within the province.*

5 Develop a special funding program to support hydrogen production projects that directly lead to decarbonization within the province.

This program could be either specific to electrolysis pathways and administered by BC Hydro (e.g. similar mechanism to Power Smart to fund a portion of project capital such as interconnection costs) or could be broader and less technology specific and administered by the Province. Program funding is a less restrictive way to make the economics for hydrogen production more commercially viable in the near-term.

6 Investigate the possibility of regulated utilities in the Province (e.g. BC Hydro, FortisBC, and PNG) having expanded mandate to include option to produce, distribute and sell hydrogen.

Electrolyzers present an opportunity to improve the load factor on power generation assets and provide a means by which energy systems can be highly optimized and integrated. Fleets of electrolyzers can provide a mechanism for BC Hydro to offer dispatchable capacity through large demand loads that can be turned down rapidly. If BC Hydro owns and operates the electrolysis infrastructure, it could enable greater optimization of the grid. This would require a mandate change for BC Hydro, and it is recommended this be explored first via a pilot demonstration project. Utilities in Washington state are now able to produce hydrogen through recently passed legislation.[162]

7 Support development of a hydrogen liquefaction plant and distribution assets in the Province, via a P3 arrangement.

A liquefaction plant is a strategic infrastructure asset in BC required to support the wider spread adoption of hydrogen and transport fuel cost effectively throughout the province. Transportation of gaseous hydrogen over long distances is expensive compared to transportation of volumetrically dense cryogenic liquid hydrogen. For example, transporting gaseous hydrogen over a 500 km distance will add approximately $10/kg to the cost of the fuel, versus $3/kg to transport liquid. A liquefaction plant would have to be located next to a large-scale hydrogen production plant with access to various modes of transportation including highway and rail. It is recommended that the initial plant be located in the metro Vancouver area if possible, to create an economical supply of hydrogen to support critical lighthouse projects and early deployments in the 2020-2025 timeframe.

8 Lighthouse project: Support a study to look at the potential for centralized hydrogen production and transport from the Peace region of BC, both through the NG pipeline and as liquid through liquefaction plant.

This region is very strategic for the Province in terms of potential to generate large volumes of low-cost hydrogen. The region is unique as it brings together key resources that could enable bulk centralized production of hydrogen that would support rollout in the Province. Strategic regional assets include:

- *BC Hydro Peace Canyon Project, which includes the Williston reservoir – 7th largest reservoir in world - powering the W.A.C. Bennett Dam and the associated Gordon M. Shrum Generating Station and the Peace Canyon Dam;*
- *Montney gas basin –enormous gas reserves and potential sites to inject and store sequestered carbon;*
- *Major transmission infrastructure for both electricity and natural gas; and*
- *Significant wind resources.*

Centralized large-scale hydrogen production and distribution infrastructure will be critical to enabling hydrogen to play a significant role in decarbonizing BC's industry sectors in the coming years. Government investment in this strategic infrastructure asset will be required to drive down hydrogen production costs in the Province and to de-risk private investment in large installed capacity while the markets are still developing. In the near-term, a plant in the Peace Region could focus on using the NG transmission system to store and transport hydrogen, and there is already demand from Fortis to meet the 15% RG target by 2030. As higher value markets emerge, economics will support alternative transport and delivery methods, such as liquid cryogenic hydrogen. In addition to supporting hydrogen rollout in the province, this project could support regional economic development in the Peace Region.

162 See footnote 143.

Natural Gas

9 **See Recommendation #1 and #2 above for hydrogen definition related to CleanBC Renewable Gas Target.**

10 **Lighthouse project: starting with a feasibility study, support a hydrogen community demonstration that shows the benefits and synergies of integrated hydrogen production, storage, and end use applications in a single region of the Province. The concept would evaluate conversion of a full community to hydrogen.**

There are two approaches to achieving the Province's 15% Renewable Gas target for the Province. One approach is to inject RG into the broad network and achieve this average throughout. A second concept is to target specific regions for a full conversion to RG, and focus efforts in concentrated areas to achieve the overall target goals. Other regions around the world are evaluating or moving forward with similar concepts. For example, H21 North of England is planning for the full conversion of the North of England to hydrogen over the 2028-2034 timeframe, starting with Leeds. It is recommended that the Province evaluate the pros and cons of fully converted hydrogen communities compared to bulk hydrogen adoption throughout the Province. A community such as Revelstoke, which runs an isolated grid on LPG, could be considered for such a concept.

11 **Develop standards that enable hydrogen injection into the NG grid: create a mandate for technical bodies to address hydrogen injection into the NG grid in relevant codes, standards, and protocols**

The current regulatory framework governing BC's gas production, transmission, and distribution sectors is not fit-to-purpose for the inclusion of hydrogen. The current mix of federal and provincial acts, regulations, statutory codes and standards do not specify the exact constituents of natural gas or renewable gas and their allocable percentages. The framework is spread over multiple layers of authority, including the National Energy Board, Canadian Standards Association, BC Oil and Gas Commission, the BC Utilities Commission, and Technical Safety BC. In order to introduce hydrogen into the natural gas pipeline system, a combination of code and regulatory changes will be required. It is recommended that the province take a leadership role to develop the required regulatory framework by convening the relevant agencies and driving progress.

12 **Consider changing provincial codes to ensure all future gaseous pipelines are compatible with 100% hydrogen, develop plans to transition other critical components to support increasing volumes of hydrogen in the grid.**

In order to enable a potential transition to 100% hydrogen in the NG distribution system, it is important to ensure materials are compatible. The incremental costs to make pipelines 100% H_2 compatible during new construction and/or planned replacement are relatively small compared to digging up and replacing.

Other components in the system will also have to transition to material and design compatibility for hydrogen. It will be important to signal the timeframe by which other components (valves, turbines, appliances) will need to be hydrogen compatible in order to ensure a smooth and timely transition.

13 Support innovation related to injection of hydrogen into the natural gas grid through establishing a specific and dedicated funding tranche.

Under the current regulatory framework, Fortis is unable to invest in precommercial activities related to technologies, including hydrogen, required to meet the 15% Renewable Gas target. There are still considerable technological and practical gaps to deploying hydrogen at scale in the natural gas network. Dedicated funding to support pilot projects, studies, and research initiatives will be critical to enabling hydrogen to reach its potential in the decarbonization of the NG system. Fortis is currently working to establish an innovation fund that would be funded through the multi-year rate application which would also complement the proposed provincial fund.

Pilot demonstrations that could be supported by this fund would help to identify and develop solutions for existing regulatory barriers and would help to accelerate hydrogen adoption.

Transportation (General)

14 Support and collaborate with progressive municipalities in the development of zero emission zones (e.g. regions with no combustion vehicles allowed by 2040).

Progressive municipalities could provide a focal point for hydrogen and fuel cell deployment at scale, similar to certain regions in China. Coordination of federal, provincial, and municipal government efforts in these regions would be critical. Cities with aggressive targets will help drive development and adoption of medium- and heavy-duty vehicles that are not covered by the light-duty ZEV mandate in BC.

15 Establish a prescriptive call for hydrogen infrastructure LCFR Part 3 Agreements to support the development of hydrogen infrastructure.

Similar to past prescriptive calls to develop infrastructure for emerging technologies, such as the call for E85 fueling stations, a prescriptive call focused on funding for hydrogen fueling infrastructure is a key enabler to support the expansion of the hydrogen fueling infrastructure to support vehicle deployments in the province. Regions such as California have learned through experience that the development of infrastructure must lead vehicle deployment for successful rollout of fuel cell electric vehicles. Station developers must currently compete with a wide range of other projects, and this uncertain funding environment makes it challenging for developers to plan expansion of the network.

16 Strengthen funding to support rollout of hydrogen infrastructure in the Province.

It is critical to support the deployment of hydrogen fueling stations in the Province in order to attract vehicles and support the business case for station owners. The CEV program has some existing funding mechanisms in place, but further funds will be required in order to support the projected station requirements. Better communication of existing funding sources is also recommended.

Transportation (Light-duty)

17

Implement a zero-emission vehicle mandate in the province for light-duty vehicles that recognizes the incremental value of longer-range passenger vehicles, with shorter fueling times. Make British Columbia the world leader in credit value for hydrogen fueled vehicles

The biggest impediment to the deployment of fuel cell electric passenger vehicles in the province over the near- to mid-term is the availability of supply. OEMs must choose between regulated markets when determining which jurisdictions to supply vehicles. Fuel cell electric vehicles are currently manufactured at a different scale than battery electric vehicles, therefore the marginal cost of deploying these vehicles in regulated markets is higher for OEMs seeking to demonstrate compliance with these vehicles.

Current credit schemes in California and Quebec provide higher credit values for longer range, which favours fuel cell vehicles. For example, a Toyota Mirai (FCEV) receives 3.6 credits (502 km range) while a Chevrolet Bolt (BEV) receives 2.9 credits (383 km range) and a Nissan Leaf (BEV) receives 1.3 credits (135 km range). Input from the OEMs indicate these credit "adders" are insufficient to make up the difference in cost. The Province should consider increasing the impact of range in determining the credits per vehicle and/or adding credits based on vehicle fueling/charging time. This would be more impactful than increased subsidies to the end users in the near- to mid-term.

18

Fund and foster a centralized platform for the exchange of information between FCEV OEMs, the provincial and federal governments, and hydrogen infrastructure providers.

Like the California Fuel Cell Partnership, this body would be the formal clearing house for determining vehicle supply for the Province from participating OEMs and tracking infrastructure roll out. Volumes could be aggregated to ensure confidentiality. This body could set clear targets for the deployment of light-duty fuel cell electric vehicles within the Province and drive and track progress toward the goal.

The Province would take the lead to support an independent modeling effort to strategically identify where hydrogen infrastructure should be deployed in the Province. The vehicle OEMs would provide market rollout projections, as well as insight into target customers and markets. An independent group would aggregate this data and build out an analytical model that would identify regions for infrastructure rollout to support the vehicle projections. Government solicitations would fund stations in specific regions, similar to how the California Energy Commission (CEC) deploys funds in line with the California Air Resources Board (CARB) modeled areas of focus.

19

Create incentives that provide operational benefits to ZEV drivers that encourage the adoption of FCEVs and BEVs.

Other jurisdictions, such as Norway, California, and China, have had success driving adoption of ZEVs through "soft" incentives that provide benefits to the driver beyond reducing the initial capital cost. In addition to allowing lone ZEV drivers to use the HOV lane, the Province could consider measures like reduced tolls and ferry travel benefits (discounted travel, free reservations, a percentage of reservation space only available to ZEV drivers, preferred loading, etc.). These types of incentives can be low cost to the Province while still impactful in the decision-making process for consumers.

20 **Extend CEV incentive to cover early rollout of FCEVs (5% of current annual sales) and initiate a program to incentivize purchase of second-hand FCEVs and BEVs.**

The Province's CEV incentive was designed to support early adoption of zero emission vehicles in the Province. To date that initiative has cost ~$60 million and has gone primarily to BEVs and PHEVs. Now that those technologies are in a more commercial stage, it is recommended the CEV vehicle incentive roll over to cover FCEVs in a similar total program amount to stimulate early adoption.

A common criticism of ZEV incentives is that they subsidize expensive cars for wealthy people. Bolstering the market for second-hand ZEVs would make it easier for low-income households to purchase them and drive demand away from older fossil fuel vehicles, which generate the greatest emissions. CEV incentives are currently limited to new vehicles purchased in BC.

Transportation (Medium-Duty)

21 **Create a Province-to-Province program with other jurisdictions (e.g. China, Japan, Korea) that facilitates the deployment of BC and foreign technology in both jurisdictions focused on medium-duty trucks for city use.**

Support homologation efforts to enable the import of medium-duty (delivery trucks) from China, or other jurisdictions, that will provide load for the BC hydrogen infrastructure, export opportunities for local industry (e.g. Ballard, Loop) and competition for North American OEMs that will drive costs down. This would include demonstration programs to validate vehicle performance in BC.

Transportation (Heavy-Duty)

22 **Implement a Transit Bus zero-emission fleet rule in the province similar to the Innovative Clean Transit rule in California.**

The creation of a zero-emission transit fleet rule would require TransLink and BC Transit to outline a plan and move beyond the testing phase for battery electric and fuel cell electric buses. Fuel cell electric buses are not competitive in comparison to other technologies in small-scale demonstrations, primarily due to the cost of the fueling infrastructure. For this reason, agencies tend to choose the easier pathway to demonstrate autonomous zero-emission operations to meet near-term board or policy objectives. The implementation of a zero-emission transit fleet rule would require these agencies confront the realities of scaling up the fueling infrastructure for both battery electric and fuel cell technologies.

23 Create a fuel cell electric coach pilot program in the Province, open to both private and public bus operators. This program should fund both rolling stock and fueling infrastructure.

Fuel cell electric coaches require an operating range that disqualifies battery electric buses for many/most routes. TransLink operates a limited number of coaches within its fleet and has indicated an interest in pursuing fuel cell electric buses for this application where funding for the incremental costs are available. The coach bus configuration is different than transit buses, in that the hydrogen cannot be stored on the roof due to centre of gravity. Funding support is required to develop and trial a first fleet of prototype units that could lead to significant rollout in the Province.

24 Develop a targeted voucher program to subsidize the incremental capital costs of zero-emission buses and fueling infrastructure.

Distribute these vouchers regionally to ensure that a diverse set of communities has access to zero-emission transit. Vary the value of the vouchers between technologies to address the cost differences proportionally. This is similar to CARB's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) voucher program which subsidizes technologies that are beyond the development stage but are not yet commercially viable due to cost and scale.

Fuel cell electric and battery electric transit buses are at a sufficient technology readiness level, with hundreds of vehicles deployed globally, that demonstration projects are no longer necessary to prove out the functionality. Cost is the primary impediment to adoption, and a targeted voucher program -in conjunction with a transit fleet rule -will drive the scale of deployments, providing the scale to reduce costs.

25 Create a large-scale, zero-emission heavy-duty vehicle program focused on Vancouver ports that includes both hydrogen and battery electric technology. This program should fund both rolling stock and fueling infrastructure for both technologies.

Hydrogen powered goods movement equipment such as drayage or yard trucks are still relatively immature. A large-scale (10+ vehicle) program will encourage consortia to form, creating new product configurations, with enough volume to spread the non-recurring engineering costs across multiple units. The hydrogen demand will also drive innovation on the production, distribution and dispensing systems and substantially scale the volume of fuel being produced for passenger vehicles.

26 Review the results of the pilot co-combustion vehicle study. If emissions reduction benefits warrant, remove the fuel cell specification of the Motor Tax and Low Carbon Fuel Standard.

Hydrogen co-combustion technology being developed in BC offers near-term potential for hydrogen in the heavy-duty sector and provides a path to retrofit existing vehicles. The technology and GHG reduction claims need to be validated before other incentives are considered. Given the near-term potential of this technology, it is recommended that any language that specifically excludes this technology be carefully considered and removed where warranted.

27

Support feasibility study for the use of hydrogen in marine, rail and off-road applications in BC.

In demand modeling discussion it was agreed that by 2030-2050 timeframe there should be some adoption in marine and rail based on international pilot projects underway. Other industries in BC, such as mining and forestry, use large diesel-powered off-road vehicles that are also well suited to conversion to hydrogen. Feasibility studies would be precursors to funding pilot demonstration projects for these applications.

Industry

28

Maintain strong and ongoing low carbon fuel standards to show project developers that investment in hydrogen production for these markets will be sustained over the long-term to justify the high up-front capital investment.

The low carbon fuel standard is driving the forecasted demand for hydrogen in synthetic fuel production and refining.

29

Support and encourage longer-term R&D projects and scaled up demonstration projects for synthetic fuel production utilizing low carbon hydrogen in the province.

This is an area of potential innovation leadership for the Province.

Built Environment

30

Focus hydrogen efforts for the built environment in the reduction of carbon emissions through injection of hydrogen in the NG grid for use in heating and domestic hot water.

Focusing hydrogen efforts for the built environment in this area will result in the strongest benefits. Hydrogen backup power systems or distributed power generation systems do not provide a compelling business case in the province given the low cost and carbon emissions profile of electricity.

31

Encourage new construction to select future proof appliances which allow for increasing hydrogen content with no or minor changes.

Remote Communities

32 **For communities relying solely on trucked or barged in energy supply, encourage studying potential development of micro grids which utilize 100% hydrogen distribution grid and local combined heat and power (CHP) generation.**

A Hydrogen supplied grid offers significant advantages over diesel generation to help remote communities. Benefits include: elimination of spill pollution and local air pollutants, lower transport weight (in the case of LH_2 supply), ability to self-generate a portion of energy demand via renewables to H2 technologies, and higher overall efficiencies. Moreover, remote communities are often completely reliant on imported fuels for their power generation and transportation, and transport costs make energy supply to these regions expensive. As such, remote communities provide an attractive costs basis for new competing renewable electricity and hydrogen technologies that can offset imported diesel and generate environmental benefits.

33 **Provide information resources to remoted communities related to hydrogen options, and support education outreach in remote communities.**

Every remote community is different and solutions for reducing diesel dependence will be community and site specific. Many communities do not have the human capacity with the technical know-how to even start the planning process, let alone develop and implement a project. Provide a 'hydrogen toolkit' including support to navigate funding opportunities, technical expertise for planning, implementation and operations, and a database with technical and cost details of successful clean energy projects involving hydrogen that can provide information for communities just starting the planning process.

Export

34 **Support export market studies and pilot programs in BC, particularly where international investment can contribute to production capacity that also benefits the local market.**

BC's natural resources, including low carbon renewable hydroelectric reserves, natural gas reserves, and fresh water supply, coupled with coastal access and relative proximity to leading markets such as California, Japan, and South Korea, uniquely position the region to be an exporter of clean hydrogen. While study stakeholders indicated that there is insufficient hydrogen supply in the Province to meet local demand and decarbonization objectives, international investment for large-scale hydrogen production has the potential to benefit local markets as well as generate significant revenue. BC's economy is heavily dependent on export of natural resources, and hydrogen fits as a future export resource that can support both local and international decarbonization efforts. A successful export market will likely rely on producing hydrogen from natural gas reserves coupled with CCS technology, as other pathways tend to be more expensive and in limited supply.

35 Support a thorough analysis of the carbon intensity of various BC pathways, and start lobbying / marketing efforts which target export markets, and California in particular.

California has been identified as the most viable export market on an economic and access basis in the near-term. Market development will in part be reliant on BC having hydrogen produced via electrolysis, either through hydro or wind, to be considered renewable hydrogen toward the state's 33% requirement. For project developers to be able to sell to California, it will likely be necessary to convince them that BC hydrogen made via electrolysis from Hydro should qualify as renewable and low carbon.

Sector support

36 Identify hydrogen and fuel cells as a priority sector for BC and communicate this clearly and consistently to Federal Government.

The importance of hydrogen in the Province must be elevated. Clear and consistent messaging about the role and strategic importance is critical for both internal alignment and prioritization at the provincial level, and for communicating and driving support at the federal level.

37 Support targeted outreach initiatives related to hydrogen technology deployment.

The recommended outreach initiative would be a collaborative effort with industry and government partners to lead outreach to groups such as municipalities, first responders, and community leaders in a coordinated and effective way, similar to the California Fuel Cell Partnership. This could be managed through a working group in an existing organization such as CHFCA.

38 Provide provincial R&D funding in support of hydrogen and fuel cell technology that can be combined with matching funds from the Federal Government or other nations.

Investment is needed to maintain the province's leadership role in hydrogen and fuel cell R&D. Local organizations should have access to funding that can be leveraged to access greater funds from outside entities. For example, a recent federally funded Ballard Power R&D project was moved from BC to Ontario because there was no provincial funding available in BC, which was required to access the federal funds. The ARC program could be expanded to meet this need, or a new fund formed that isn't tied specifically to clean energy vehicles.

9.3 : Investment Required

Government investment is needed to establish a hydrogen economy in BC and support the abovementioned recommendations. That investment will provide the necessary infrastructure and sector support to allow industry to establish a foundation from which to grow commercial deployments. Government investment will yield necessary decarbonization benefits for the Province, economic growth potential, and long-term diversity and security of our energy systems.

Our analysis recommends a total spend from the Province in the order of $176,000,000 over the next five years, which is approximately $35,200,000 per year. This funding would be focused primarily on supporting lighthouse projects and studies, funding critical infrastructure development, providing subsidies for the rollout of light-duty FCEVs, and supporting the sector through establishing dedicated R&D funding. It is anticipated that this Provincial funding would be leveraged with federal and industry match funding, thereby amplifying the benefits of this investment in the Province. A high-level estimate of funding is included in Table 19.

BC Investment Summary 2020-2025	R#	Amount
Lighthouse Projects and Studies		
Central Production Study - Peace Region	8	$ 250,000
Hydrogen Community Study	10	$ 250,000
Marine, Rail and Specialty Vehicle Study	28	$ 250,000
Coach Program with Heavy Duty Fueling Stations	24	$ 6,800,000
Port Program with Heavy Duty Fueling Stations	26	$ 13,300,000
Medium Duty Delivery Vehicle Program	22	$ 7,500,000
Infrastructure Deployment		
Modeling initiative for infrastructure deployment	19	$ 375,000
Liquefaction Plant	7	$ 5,000,000
Distributed Electrolysis Supply - Program Funding	5	$ 20,000,000
Light Duty and Medium Duty Fueling Stations	17	$ 22,500,000
Central Hydrogen Production Plant, Peace Region	8	$ 30,000,000
Vehicle Subsidies		
Extension of CEV for FCEVs, used vehicle incentive	21	$ 50,000,000
Voucher program for transit and intercity buses	25	$ -
Research and Development, Outreach		
Innovation support for hydrogen into NG grid	11, 13	$ 12,000,000
Hydrogen and fuel cell R&D funding	39	$ 2,500,000
Synthetic fuel, CCS R&D	30	$ 5,000,000
Support targeted outreach initiative	38	$ 275,000
Total		**$ 176,000,000**
Annual Spend, 2020-2025		$ 35,200,000

Table 19. Investment in 2020-2025 Timeframe to Support Recommendations