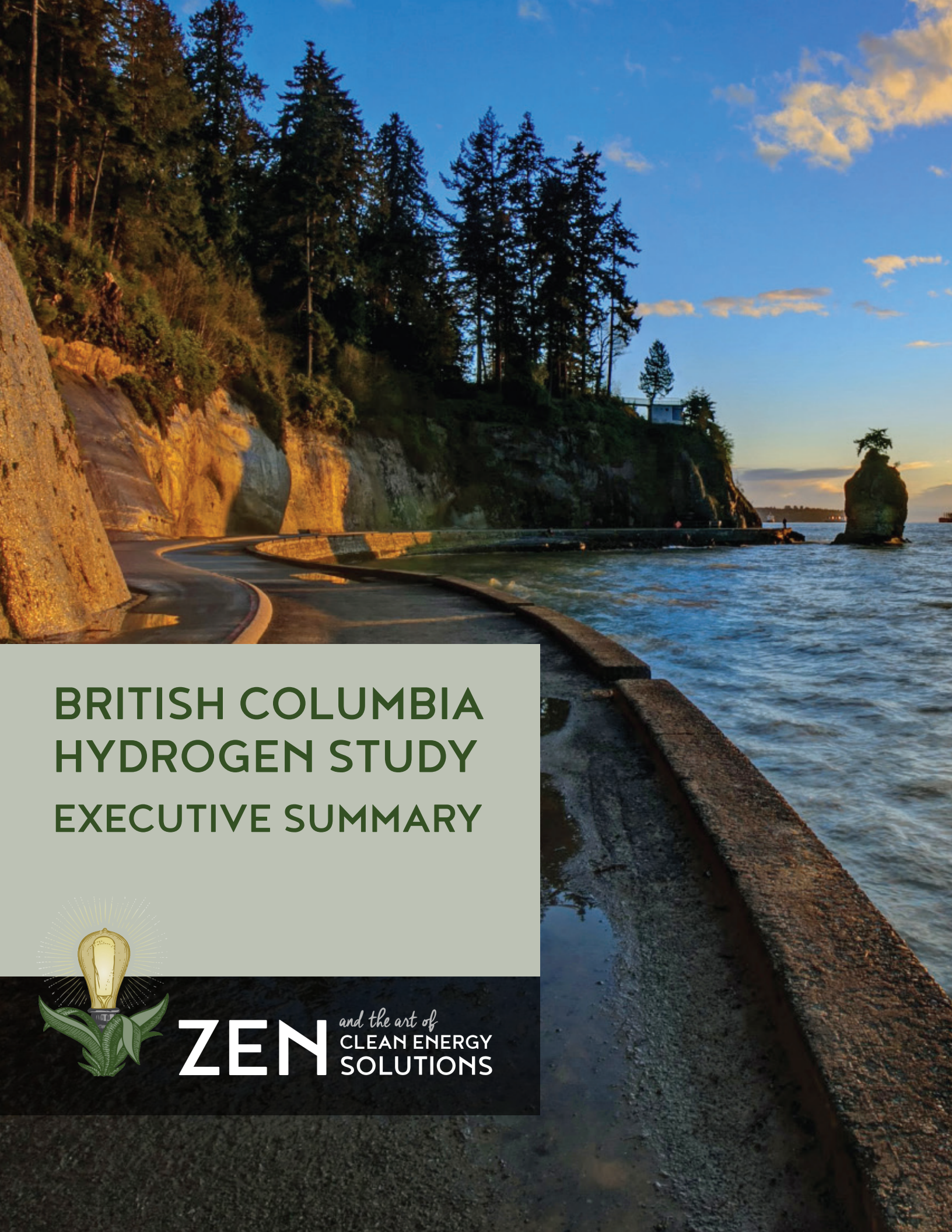
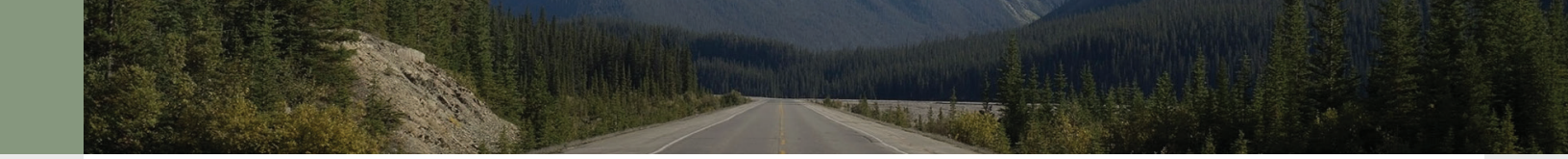


BRITISH COLUMBIA HYDROGEN STUDY

EXECUTIVE SUMMARY

ZEN and the art of CLEAN ENERGY SOLUTIONS



ACKNOWLEDGEMENTS

The BC Hydrogen Study was conducted by Zen and the Art of Clean Energy Solutions and project partners the Institute for Breakthrough Energy and Emission Technologies and G&S Budd Consulting Services. Work on the study ran from February 2019 to June 2019.

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

ZEN and the art of CLEAN ENERGY SOLUTIONS

G&S BUDD CONSULTING Ltd.
Business Development Renewable Energy

Project Sponsors

BC Bioenergy Network

BRITISH COLUMBIA
Ministry of Energy, Mines and Petroleum Resources

FORTIS BC™

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:

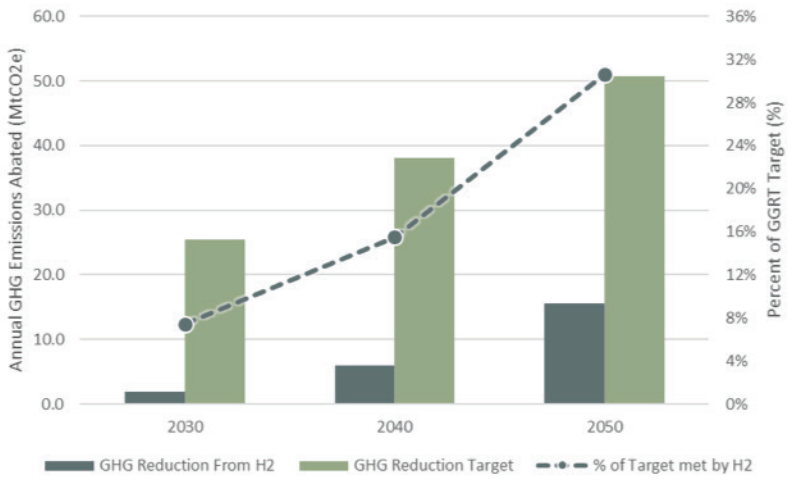
- *Decarbonization of hard-to-abate sectors of the economy such as heating and cooling, long-range transportation applications, and energy intensive industries;*
- *Economic growth and job creation through the development of BC's hydrogen supply chain and infrastructure, and supply to emerging export 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.

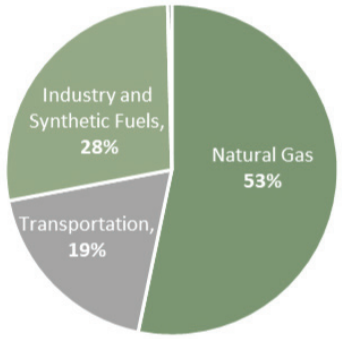


The opportunities where the greatest decarbonization impacts can be realized are: 1) through injection of low carbon hydrogen into the natural gas grid, which will have benefits in the built environment, transportation, and industry economic sectors in the Province; 2) through using low carbon hydrogen 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.

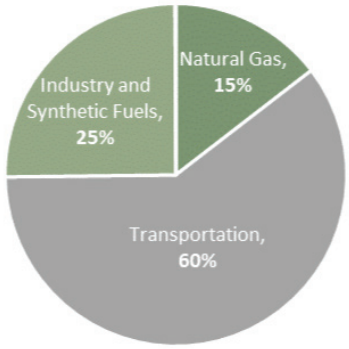
The relative benefits in these applications will shift over time. In the near-term, the easiest and lowest cost way to use hydrogen which will have the highest emission reduction potential in the Province is to inject it into the natural gas grid, and directly reduce emissions by utilizing the lower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

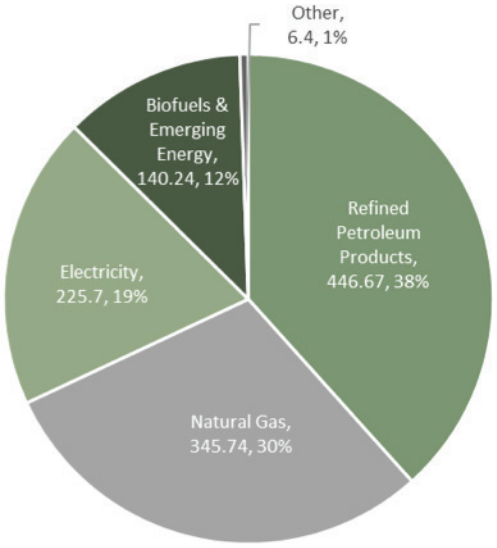
BC's economy is heavily dependent on the extraction, consumption, and export of natural resources, and hydrogen fits as a value-added future export resource that can support both local and international decarbonization efforts. Hydrogen is expected to become increasingly important in the world's energy 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.



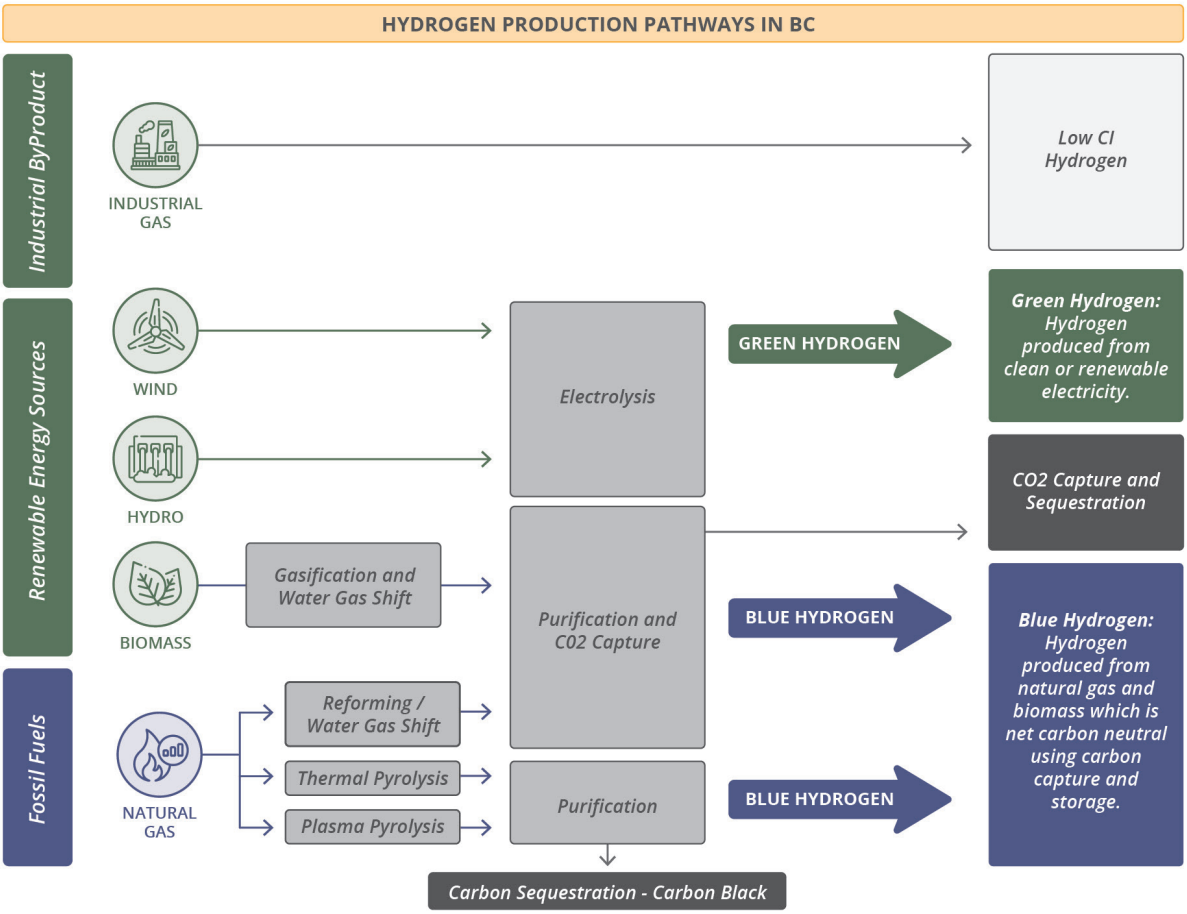
2016 BC End Use Energy Demand[2]

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*

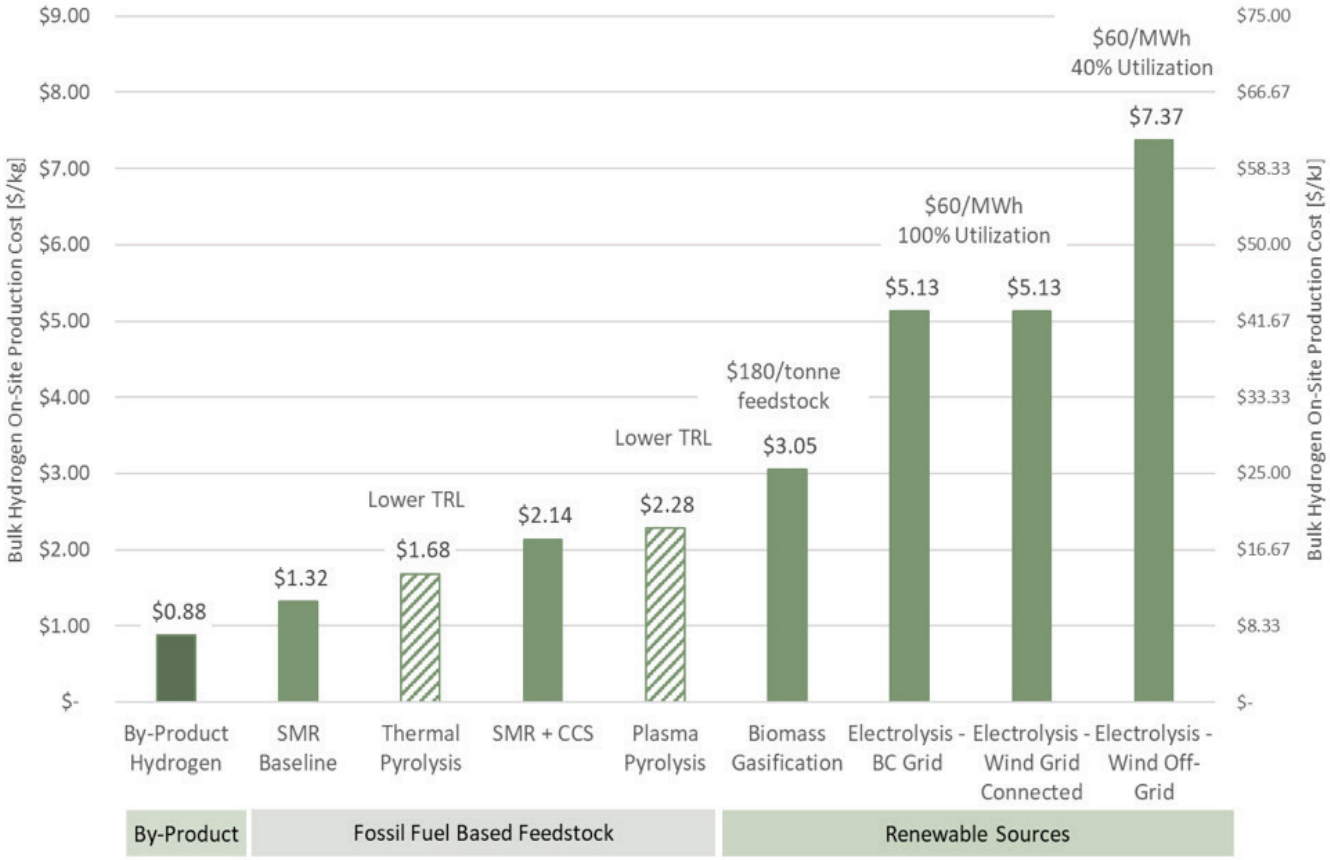


Hydrogen produced at scale from natural gas offers the lowest cost source of low carbon intensity hydrogen when coupled with carbon capture and storage technology. BC has substantial natural gas reserves in the Northeast of the Province, estimated at 525 trillion cubic feet and sufficient to meet 315 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.

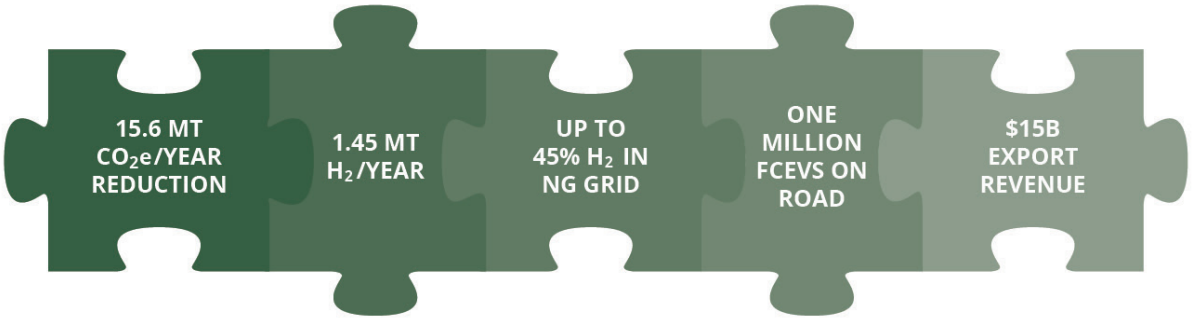
There is an immediate urgency to decarbonize BC's energy supply across all industry sectors, and low carbon intensity hydrogen from fossil fuels is seen as a key enabler to cost effective deployment of hydrogen in the intermediate period. The Province needs policy to drive adoption of multiple energy 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.