Hydrogen in Remote Communities: Opportunities and Barriers for Displacing Diesel in British Columbia

by

Melissa Williams

Bachelor of Commerce, University of Victoria, 2018

Project Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Public Policy

in the
School of Public Policy
Faculty of Arts and Social Sciences

SIMON FRASER UNIVERSITY
Spring 2022

Declaration of Committee

Name:	**Melissa Williams**
Degree:	**Master of Public Policy**
Title:	**Hydrogen in Remote Communities: Opportunities and Barriers for Displacing Diesel in British Columbia**
Committee:	**Chair: Genevieve LeBaron** Professor, Public Policy
	John Richards Supervisor Professor, Public Policy
	Nancy Olewiler Examiner Professor, Public Policy

Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

a. human research ethics approval from the Simon Fraser University Office of Research Ethics

or

b. advance approval of the animal care protocol from the University Animal Care Committee of Simon Fraser University

or has conducted the research

c. as a co-investigator, collaborator, or research assistant in a research project approved in advance.

A copy of the approval letter has been filed with the Theses Office of the University Library at the time of submission of this thesis or project.

The original application for approval and letter of approval are filed with the relevant offices. Inquiries may be directed to those authorities.

Abstract

Hydrogen has the potential to displace diesel in remote off-grid communities for electricity production in British Columbia. Through an analysis of literature, case studies, and expert interviews this study demonstrates the benefits of utilizing hydrogen, as well as the barriers that exist for its adoption. Hydrogen is a versatile fuel that produces no emissions at the point of use. Some examples of challenges hydrogen faces are the high cost of hydrogen technologies, limited access to funding for remote communities, the risk of new technology, and limited local capacity for operations and maintenance. This study concludes with several policy recommendations. First, a Hydrogen Grant Program should be implemented with funding from the federal and provincial government. After this, three other policies should be implemented in priority order: 1) Training Programs for hydrogen system maintenance, 2) Low Carbon Fuel Standard, and 3) Reduction of Regulatory Uncertainty.

Keywords: Hydrogen; Remote; Communities; Diesel; First Nations; Off-grid; British Columbia

Acknowledgements

Thank you to all those who participated in interviews. I appreciate the time you took to share your knowledge, my capstone would not be the same without you.

I would like to acknowledge the Pacific Institute for Climate Solutions for funding this research under the Research Engagement Program (Project No. FT21CB).

I would also like to thank all the faculty and staff at the School of Public Policy who supported me. To my supervisor, John Richards, thank you for your time and insights. Thank you to Nancy Olewiler who participated as my external examiner and who has always supported me through this program.

Thank you to Coral Buitenhuis who has offered me nothing but encouragement through this process. And thank you to Technical Safety BC for supporting me over these last eight months.

I would also like to acknowledge all the people who were there for me through all the hard work that went into this project. Thank you to my fellow Master of Public Policy students, my family and my friends.

Table of Contents

List of Tables

List of Acronyms

BCUC	British Columbia Utilities Commission
CAES	Compressed Air Energy Storage
CEA	Clean Energy Act
DRIPA	Declaration of the Rights of Indigenous Peoples Act
EPA	Electricity Purchasing Agreement
GHG	Green House Gas
HOMER	Hybrid Optimization Model for Electrical Renewables
kWh	Kilowatt Hour
LCFS	Low Carbon Fuel Standard
NRCan	Natural Resources Canada
OGC	Oil and Gas Commission
PEM	Proton Exchange Membrane (electrolyser)
SDTC	Sustainable Development Technology Canada
SSA	Safety Standards Act
UCA	Utilities Commission Act

Executive Summary

Many off-grid communities in remote BC use diesel to generate electricity. This paper explores the opportunity for hydrogen to displace diesel in generating electricity. It examines the benefits to utilizing hydrogen as well as the barriers that exist for its adoption.

Current State of Remote Communities

Diesel is the main source of electricity generation in 55 of the 76 off-grid communities in BC (Natural Resources Canada, 2016). Diesel has many negative impacts, which has motivated communities and governments to promote a transition away from the fuel. Diesel generators produce high levels of GHG emissions and local air and noise pollution. Air pollution from diesel generators is associated with increased risk of asthma, bronchitis, allergies, lung function and heart problems (Zen and the Art of Clean Energy Solutions, 2019). There is a high risk of spills when transporting diesel as demonstrated in 2016 when the Nathan E. Steward ran aground, spilling over 100 000 litres of diesel fuel into coastal ecosystems (*The Impact of the Bella Bella Diesel Spill*, n.d.). Many diesel generators are used well past their lifetime, which increases possibility of community blackouts (He, 2021). Additionally, many communities want to move away from diesel to achieve energy self-sufficiency, which means communities able to supply their own energy to meet their needs (Rezaei & Dowlatabadi, 2016). Finally, diesel is often highly subsidized, and the price charged to customers usually excludes the negative impacts on ecosystems and communities. The true cost of diesel is obscured and can be difficult to accurately compare to alternative energy options, such as hydrogen (Lovekin & Heerema, 2019b).

Hydrogen in Remote Communities

Hydrogen can be used in off-grid communities in several ways, although it should be noted that each community is unique and may adjust these models as needed:

1. Hydrogen shipped into communities from production facilities outside the community.
2. Hydrogen produced in a community from renewable electricity such as solar, wind or run-of-river hydro. Hydrogen can be generated from

renewable electricity to be used as the sole energy source or in times of low electricity production or high demand.

Hydrogen has many benefits as a flexible energy carrier. It can reduce the need for expensive transmission wires. Transporting hydrogen, if needed, mitigates the risk of spills from diesel and can connect supply and demand when geography prevents the transmission of electricity via wires. It should be noted that transporting hydrogen does have its own risks, which include the fact that it is not an established value chain and it can be a technically complex process. Hydrogen is emissions free at the point of consumption and eliminates the local air or noise pollution from diesel. Hydrogen is also able to increase dispatchable energy, as a supplement to renewable sources unable to always meet demand. Additionally, when hydrogen is produced on site this can help communities achieve energy independence from diesel fuel (Zen and the Art of Clean Energy Solutions, 2019).

Hydrogen has also been shown to reduce the levelized unit cost of energy when used in conjunction with renewable projects in remote settings. A feasibility study conducted for Fort Hope, Ontario, demonstrated that including hydrogen in a hybrid run-of-river hydro project could reduce the levelized cost of energy from $0.39/kWh to $0.24/kWh. Although diesel use was reduced with this project, it was still a component (Magtibay & Wong, 2013).

Barriers to Hydrogen Adoption

Adoption of hydrogen still has many barriers to overcome, some of them particularly acute for First Nations. A selection of important barriers identified in this study are listed below:

- High Cost of Hydrogen Projects – Hydrogen projects have high upfront capital costs, although costs are dropping as the hydrogen economy develops.
- Access to Funding – Funding programs are often fragmented, competitive and have administrative requirements that are too onerous for a small community to manage.
- Risk of New Technology – New technologies are often riskier and are not looked upon favourably by communities, regulators or government.
- Energy Purchasing Agreements (EPA) – To enter into an EPA with BC Hydro the technology used in a project must be commercially available. Hydrogen currently does not meet this requirement.

- Community Capacity – Small communities often lack local individuals with expertise for project design, implementation and operations and maintenance.
- Public Acceptance – Hydrogen can be seen as volatile by a community and may not be trusted by citizens.
- Regulatory Clarity – The regulatory environment is unclear and difficult to navigate. Jurisdictional responsibility is often vague and codes and standards for hydrogen are still being developed.

Recommendations

In order to overcome the barriers to hydrogen adoption, this paper concludes with several recommendations. First a Hydrogen Grant Program should be implemented, funded by the federal and BC provincial governments. This program would administer $27 million in funding to projects with a hydrogen component with the aim of creating 3 projects in BC. The program will also prioritize First Nation applicants.

After the Hydrogen Grant Program is implemented, three other policies should be deployed in priority order. The First is a Training Program to increase the local hydrogen operation and provide knowledge of hydrogen system maintenance in communities. Next is expanding the Low Carbon Fuel Standard so that low carbon hydrogen producers can earn credits, which they can sell to high emitting producers. Lastly, regulatory clarity should be addressed. Regulators and the province should perform a regulatory mapping exercise to identify where gaps exist and how to fill those.

Hydrogen, despite its opportunity to reduce diesel consumption, is not right for every community. It is essential to avoid using hydrogen as a prescriptive solution. Particularly in First Nations, principles of reconciliation and Declaration of the Rights of Indigenous Peoples Act (DRIPA)should be upheld, and community priorities centred in any project design.

Chapter 1. Introduction

Diesel fuel accounts for most of the electricity production in remote off-grid communities in BC. Diesel has many negative effects, including high GHG emissions, local air and noise pollution, high risk of spills, negative impacts on energy self-sufficiency and subsidies obscuring its true cost. Hydrogen, as a versatile energy carrier, can help transition away from diesel. It is emissions free at the point of consumption, reduces air and noise pollution, and can increase the penetration of renewables. Additionally in hybrid style projects hydrogen has shown to reduce the levelized cost of energy.

This paper aims to explore the hydrogen opportunity and the barriers that exist for its adoption in both First Nation and settler communities. Some of these barriers may be unique in an Indigenous setting. This paper uses qualitative research methods, including literature review, to identify hydrogen benefits and challenges. It concludes with a multi-criteria policy analysis, which recommends several policies. The policies aim to overcome the high cost of hydrogen projects, community capacity issues, public acceptance, and regulatory clarity.

This paper does not recommend hydrogen as the only solution to reduce diesel consumption in off-grid communities. Hydrogen should be considered one tool in the clean energy tool box. This paper aims to highlight that there is an opportunity for hydrogen. Due to that opportunity and the large barriers hydrogen has to overcome for adoption, there is justification for government intervention and allocation of public funds to implement this technology.

Chapter 2. Background

2.1. Hydrogen Basics

Hydrogen is the most abundant element on earth, making up 27% of all mass. Hydrogen is a versatile energy carrier which generates electricity through a chemical reaction between itself and oxygen. There is no carbon emitted from this reaction, meaning at point of consumption hydrogen is emissions free. Hydrogen can also generate energy from heat in a combustion process (Government of Canada, 2020).

2.1.1. Hydrogen Production

Hydrogen can be produced through several pathways referred to as Grey, Blue and Green hydrogen. Grey hydrogen includes hydrogen which produces emissions but does not utilize carbon capture technology (Government of Canada, 2020). Often grey hydrogen refers to hydrogen generated via an existing industrial process, such as oil refining or chemical production. This production pathway represents the cheapest way of producing hydrogen but is the most carbon-intensive. Blue hydrogen is generated through the use of fossil fuels or biomass. Blue hydrogen is paired with carbon capture and storage technologies resulting in very low emissions. The addition of carbon capture technologies results in blue hydrogen being relatively expensive. Finally, through electrolysis, renewable electricity and water are used to create Green hydrogen. The renewable electricity can be solar, wind, hydroelectric, geothermal, etc. Electrolysis machines are modular and can be used in large- or small-scale production. There are currently two main types of electrolysis machines being used: Proton Exchange Membrane (PEM), and Alkaline Electrolysers. Electrolysis is the most expensive way to produce hydrogen, although costs can vary depending on the source of electricity (Zen and the Art of Clean Energy Solutions, 2019).

In BC, hydrogen is currently produced as an industrial by-product in three chemical plants located in North Vancouver and Prince George. (Zen and the Art of Clean Energy Solutions, 2019). There are several hydrogen production projects underway in BC and Canada. These include the Sundance project in Northeastern BC, The University of British Columbia’s Hydrogen Hub project in Vancouver, and HTEC’s 5-megawat electrolysis project in BC (Corpuz-Bosshart, 2021; HTEC, 2021; Renewable

Hydrogen Canada, n.d.-a). Quebec is set to develop one of the world’s largest green hydrogen production facilities, owned by Hydro-Quebec, in Varennes (Frangoul, 2021). In Fort Saskatchewan, Alberta, Suncor Energy and Atco have partnered to build a hydrogen plant capable of producing 300,000 tonnes per year (ATCO, 2021).

Globally, there is an expected tenfold increase in demand for hydrogen over the next three decades (Government of Canada, 2020). For rural and remote communities, this means declining costs of hydrogen as hydrogen production realizes scale economies.

2.1.2. Hydrogen Use

Hydrogen can be used in many ways – in transportation, industry, the built environment and off-grid communities. In the transportation sector, hydrogen can be a fuel to power fuel cell vehicles, which convert gas to electricity. It can also be used, less commonly, through combustion engines (Zen and the Art of Clean Energy Solutions, 2019). In industry, hydrogen is used as feedstock for many processes including ammonia and methanol production, oil and gas refining, steel making, the electronics industry and synthetic liquid fuel production (Government of British Columbia, 2021a). Hydrogen can blended into the natural gas supply to be used for heating buildings. (Zen and the Art of Clean Energy Solutions, 2019). Fortis BC has partnered with Renewable Hydrogen Canada to produce hydrogen, via electrolysis, to then inject into BC’s gas pipeline network (Renewable Hydrogen Canada, n.d.-b).

Many remote off grid communities rely on diesel generators for electricity. Some communities use hybrid systems that use clean electricity combined with diesel. Hydrogen may be used to displace diesel power generation and increase the penetration of renewables (Zen and the Art of Clean Energy Solutions, 2019).

2.2. Hydrogen in a Rural Context

A remote off-grid community is defined as a community that is not connected to North America’s integrated electrical or natural gas grids. The community must have been settled for 5 or more years and have at least 10 dwellings (Natural Resources Canada, 2013). There are currently 76 remote communities in British Columbia that fit this definition. 28 of those communities are identified as Indigenous; 55 communities rely on diesel generators as their main power source, the majority of which are provided by BC Hydro or an independent power producer (IPP) (Natural Resources Canada, 2016). Remote off-grid communities can be either single off-grid communities or part of a microgrid. There are four local microgrids in BC, which collectively provide power to 14 communities. These are all owned by BC Hydro. Three of these microgrids benefit from hydroelectric power (for 70-93% of electricity used) with backup diesel generators, while one relies solely on diesel generators. The majority of single off-grid communities rely solely on diesel. There are several remote communities that rely on run-of-river hydro, LNG, biomass or solar for at least some of their power generation (Zen and the Art of Clean Energy Solutions, 2019).

It's estimated that 3 million barrels of diesel are used every year for electricity generation in remote off-grid communities in BC. Due to colder climates and poor state of efficiency for buildings, electricity consumption is higher in remote communities compared to the Canadian average (Lovekin & Heerema, 2019a). It is estimated that annually in BC 33.47 kt of CO_2e are emitted from diesel electricity generation. This estimate uses data from the Natural Resources Canada Remote Community database and a 2011 report on the Status of Remote/Off-grid Communities in Canada (Zen and the Art of Clean Energy Solutions, 2019).

2.2.1. Why Not Diesel?

There are many reasons transitioning away from diesel in remote communities is important.

Health and Environmental

Diesel has high GHG emissions per kWh generated and contributes significantly to local air pollution. Some consequences of local air pollution are increased risk of asthma, bronchitis, allergies, lung function and heart problems. Hydrogen fuel cell generators do not emit local air pollution (Zen and the Art of Clean Energy Solutions, 2019). Additionally, transporting diesel over large distances with challenging terrain exposes communities to risk of oil spills. In 2016, Nathan E. Stewart, a tug boat, ran aground near Bella Bella spilling 100,000 liters of diesel fuel into coastal ecosystems (*The Impact of the Bella Bella Diesel Spill*, n.d.). Hydrogen does not pose the same risk to the environment, human health and wildlife health if it spills (Tae, 2021). Often, diesel generators are in use, well past their expiration dates, exposing communities to risk of generator collapse and blackouts (He, 2021).

Energy Self Sufficiency Power Independence

Energy self-sufficiency in this context means that communities are able to supply their own energy to meet their needs, it also includes the ability for a community to control its affairs as it relates to energy projects and infrastructure.

For many communities achieving energy self-sufficient is a major priority. It means they will not have to depend on an outside supply of diesel, which can be challenging to access in remote areas without year round road access (Zen and the Art of Clean Energy Solutions, 2019). Many First Nations see self-sufficiency as part of political autonomy and self-determination. First Nations want to have decision making power over all aspects of their communities, including energy (Rezaei & Dowlatabadi, 2016)

Economic

Despite the wide use of diesel in remote communities, it remains a very expensive fuel. In Canada, it is estimated, the unsubsidized cost of electricity from diesel generation is $1.30/kWh – compared to the average Canadian's electricity cost of about $0.7 - $0.17/kWh. In order for diesel to be affordable to many communities, it is highly subsidized. Under BC Hydro's Non-Integrated area rate plan, households pay $0.1028/kWh for the first 1,500 kWh per month and $0.1767/kWh for the remaining kWh per month. The base rate is the same as other grid-connected customers would be paying while the rate above 1,500 kWh is higher (Zen and the Art of Clean Energy Solutions, 2019). Although these subsidies are important in providing access to electricity, they also pose a problem in analyzing the real cost of diesel. Additionally, not all subsidies are visible. Many are indirect and take the form of costs related to respiratory illnesses from diesel pollution, costs related to environmental remediation of diesel impacts and costs related to diesel impact on loss of habitat, traditional hunting and Indigenous ways of life. This makes it difficult to compare the cost of diesel to other renewable forms of electricity such as wind, solar or hydrogen (Lovekin & Heerema, 2019a).`

Supply shocks also impact diesel prices, as can be seen by dramatic increase in fuel prices as a result of the conflict in the Ukraine and ongoing pandemic (Dawson, 2022).These fluctuation are difficult to predict and may impact the rates paid by consumers. Other factors such as the carbon tax will also lead to higher diesel prices (refer to Appendix B for more information). These rising fuel costs may lead to a more favourable environment for hydrogen power projects.

2.2.2. Hydrogen Opportunity

Hydrogen can be used as a low-carbon replacement for diesel in several ways. As discussed above, several communities rely on renewable electricity. One of the challenges with run-of-the-river hydroelectric, wind or solar projects is that they are only available at time of production (Roberts, 2020). At times of high demand or times of low production from renewable sources, communities must still rely on diesel. In a power-to-gas model, the renewable electricity would be converted on-sight, via electrolysis, into green hydrogen. The hydrogen would be stored and used in a hydrogen fuel cell generator when necessary. Hydrogen produced by a community could also be used solely as the power source. (Zen and the Art of Clean Energy Solutions, 2019). Another way to use hydrogen is to simply ship the hydrogen into communities. This would utilize hydrogen fuel cell technology as a replacement for diesel generators. Liquid hydrogen has a lower transport weight than diesel which would reduce transport costs. Additionally, hydrogen fuel cell generators do not emit the same local air pollution as diesel generators (Zen and the Art of Clean Energy Solutions, 2019). The hydrogen used in this type of model could come from any source.

2.2.3. Other Diesel Displacement Options

Although the opportunity for hydrogen to displace diesel in remote communities, this research does not recommend hydrogen for all contexts. Communities have different priorities, geography and circumstances. Off-grid communities may connect to the grid, implement dispatchable renewables, such as pumped hydro, or use other technologies to increase the penetration of non-dispatchable renewables. Some of these technologies could be batteries, flywheels or compressed air energy storage (CAES) (Masterson, 2021).

Pumped hydro, involves pumping water uphill to a reservoir during times of low demand. During times of high demand this water can then be utilized generate electricity. Recent advances in battery technology and decreasing costs have made them increasingly viable for utility scale electricity storage. Flywheels and compressed air storage are considered mechanical energy storage. They harness motion or gravity to store energy (Masterson, 2021).

In general hydrogen is more suitable for long term storage where batteries, flywheels and CAES are typically considered for storage only for a few days. Additionally hydrogen provides high power outputs, which tend to be a problem for lead-acid batteries (Chade et al., 2015).

2.3. Policy Context

The BC provincial government and the Canadian government aim to reach net-zero by 2050 (Government of Canada, 2020; Zen and the Art of Clean Energy Solutions, 2019). In 2019 the BC government, in partnership with Zen Clean Energy Solutions, published the BC Hydrogen Study. The study aims to capture what role hydrogen can play in BC's decarbonisation efforts and provides policy recommendations to realize that role (Zen and the Art of Clean Energy Solutions, 2019). In 2021 the BC government published the BC Hydrogen Strategy. This report sets a clear roadmap of actions for developing a hydrogen economy in the province (Government of British Columbia, 2021a). The Canadian government published the Hydrogen Strategy for Canada in 2020 including similar calls to action in the transition to hydrogen (Government of Canada, 2020). A target laid out in CleanBC aims to reduce diesel consumption by 80% by 2030 as the federal government attempts to eliminate diesel use for electricity production by 2030. Hydrogen can play an important role in this goal as outlined in the strategies mentioned above (Zen and the Art of Clean Energy Solutions, 2019).

In the effort to reduce reliance on diesel in remote off grid communities the BC government has implemented the Clean BC Remote Energy Strategy. This strategy focuses on capacity building, efficient and low carbon buildings and clean energy generation (Community Clean Energy Branch, n.d.).

Several parallel policies exist at the federal and provincial level to help support use of hydrogen. This is mostly through policy levers that increase the cost of consuming carbon intensive fuels. This ultimately reduces the cost of consuming low carbon fuels as economies of scale grow. For remote communities this means falling prices of hydrogen. Some examples of policies include the Clean Fuel Standard, Carbon Tax and Zero Emissions Vehicles Standard. These policies all exist, or are being implementing at the provincial and federal level. See Appendix B for more details.

2.3.1. Funding Programs

Both the federal and BC provincial government provide funding programs to support the transition to clean energy alternatives, such as hydrogen. The BC government also manages a Community Climate Funding Guide where communities can identify programs that are right for them (Government of British Columbia, n.d.-a). Descriptions of some available of programs can be found in the following tables.

Table 1: Federal Funding Programs

Program	Administering Organization	Description
Clean Energy for Rural and Remote Communities	Natural Resources Canada (NRCan)	Fund to reduce reliance on diesel for remote off-grid communities and industrial sites in Canada. $220 million will be distributed over 6 years (Natural Resources Canada, 2017).
Indigenous off Diesel Initiative	Impact Canada and NRCan	Aims to reduce reliance on diesel for heat and power in remote Indigenous communities. Clean energy champions identified through this initiative are eligible to receive up to $1.3 million in funding for their community project. An additional $9 million may be available for leading communities to support them over 2 years (Impact Canada, n.d.).
Emerging Renewable Power Program	NRCan	This program is aimed to expand commercially viable sources of renewable power in Canada. $200 million is available (Natural Resources Canada, 2018).
First Nations Infrastructure Fund	Indigenous Services Canada	Provides funding to upgrade and increase public infrastructure for First Nation communities, including energy systems. (Indigenous Services Canada, 2008b).
Community Opportunity Readiness Program	Indigenous Services Canada	Under the Community Economic Infrastructure stream of this program communities are eligible for up to $3 million in funding. This fund supports the pursuit of economic opportunities including electrical and energy systems (Indigenous Services Canada, 2008a).
Clean Fuels Fund	NRCan	Provides capital investment to clean fuel production facilities and supports feasibility and front end engineering and design studies for clean fuels. This program commits $1.5 billion over 5 years. It includes an Indigenous stream for investment into clean fuels for Indigenous businesses and communities (Natural Resources Canada, 2021).

Table 2: BC Provincial Funding Programs

Program	Administering Organization	Description
BC Indigenous Clean Energy Initiative	New Relationship Trust; Federal Government; BC Provincial Government	Funded through federal governments Strategic Partnership Initiative and Clean BC. Will provide up to $500,000 per clean energy project developed by an Indigenous community (New Relationship Trust, 2017).
Innovative Clean Energy Fund	Ministry of Energy, Mines and Low Carbon Innovation	The ICE fund has committed $108 million to support areas of BC's clean energy sector, including pre-commercial clean energy technology projects (Ministry of Energy, Mines and Low Carbon Innovation, n.d.-b).
First Nation Clean Energy Business Fund	Ministry of Indigenous Relations and Reconciliation	Aims to increase Indigenous participation in clean energy sector. The program provides capacity funding and equity funding as well as revenue sharing agreements (Ministry of Indigenous Relations and Reconciliation, n.d.).
Community Energy Leadership Program	Ministry of Energy, Mines and Low Carbon Innovation	Supports local governments and First Nations invest in clean energy projects. The goals of the program include reducing GHGs and stimulate economic activity in clean energy sector (Ministry of Energy, Mines and Low Carbon Innovation, n.d.-a).
CleanBC Communities Fund	Infrastructure Canada; BC Ministry of Environment and Climate Change Strategy	Targets public infrastructure and must accomplish one of the following: increase renewable management capacity, increase clean energy transport access, increase energy efficiency in buildings, and increase clean energy generation. Funding ranges from less than $100,000 to over $1 million per project (Government of British Columbia, n.d.-b).

2.3.2. Regulatory Environment

The BC Utilities Commission is an independent regulatory agency governed primarily by the *Utilities Commission Act* (UCA). The BCUC ensures safe, reliable, non-discriminatory and fairly priced energy services from public utilities. It also ensures that shareholders of utilities are able to attain a reasonable return on their investment. In regulating energy utilities, the BCUC reviews rate applications, construction plans for new facilities, energy supply contracts and issuance of securities (BC Utilities Commission, n.d.). The 2010 *Clean Energy Act* (CEA) outlines the provinces energy objectives which include "foster[ing] the development of first nation and rural communities through the use and development of clean or renewable resources". The

BCUC must consider these energy objectives while also upholding its other mandates (Morton et al., 2020).

In the province, Technical Safety BC is responsible for overseeing the safe installation and operation of technical systems as well as administering the *Safety Standards Act* (SSA) (Technical Safety BC, n.d.-c). Section 3 of this act identifies that this regulation does not apply to public utilities, as defined by the UCA, in functions directly related to generation, transmission and distribution of electrical energy (BC Utilities Commission, 2020).

Remote off-grid communities that generate clean energy may act as their own utility or sign an Electricity Purchasing Agreement (EPA) with BC Hydro. If they sign an EPA, BC Hydro will purchase the energy from the community and distribute it, through BC Hydro owned infrastructure, to electricity consumers in that community. EPAs ensure a revenue stream for a project, which is important when trying to secure financing (Kennedy, 2014).

2.3.3. Policy in Other Jurisdictions

Many provinces in Canada have been moving toward a hydrogen economy. Alberta, Ontario and Quebec have all either published or are developing a strategic plan which includes hydrogen (Hamelin et al., 2021).The International Energy Agency concludes that the number of policies and projects around the world related to hydrogen is expanding rapidly (International Energy Agency, 2019). Among the G20 and European Union nine countries have published national roadmaps for hydrogen, including Australia, The European Union, South Korea, Japan and others (Patel, 2021).

Chapter 3. Data Description

The purpose of this study is to analyze hydrogen as an option for displacing diesel, for electricity generation, in remote off-grid communities. The feasibility of implementing hydrogen is explored along with barriers to hydrogen adoption. The paper aims to recommend several policy options that will support communities in accessing hydrogen if they choose.

3.1. Methodology

This study uses several qualitative analysis techniques to identify opportunities and barriers when it comes to hydrogen adoption in remote off-grid communities. These include a literature review, case study analysis and expert interviews.

The literature review was conducted from September to December 2021. Publicly available government reports, peer reviewed articles, and reports published by non-government organizations were reviewed. The literature review helped to scope the issue, provide background information and identify key barriers for hydrogen adoption in remote communities.

The Interviews were conducted from December 2021 to February 2022. Twelve experts participated with a range of expertise. For a full list of participants please refer to Chapter 5. Interviewees were given the option to remain anonymous and all agreed to share limited information about themselves including their position, organization and/or industry. The interviews were semi-structured which allowed for flexibility in the dialogue. Interviews were recorded and detailed notes were taken, which identified major themes summarized in Chapter 5.

The case study analysis used several peer reviewed articles, publicly available government documents and one internal government document to provide context on three case studies. These include the Hydrogen Assisted Renewable Power Project (HARP) in Bella Coola, the Grimsey Island feasibility study and the Fort Hope feasibility study. Each case study is reviewed based on its background, project design, project costs and results and lessons learned. The case studies provided key insights into the capital costs and levelized costs of energy for hydrogen projects.

Chapter 4. Literature Review

4.1. Economic Barriers

4.1.1. High Cost of Hydrogen Projects

Hydrogen, when used as backup power supply, faces higher upfront costs compared with diesel generators (International Energy Agency, 2019). The capital cost of diesel in an off-grid community is estimated to be $1,500 per installed kW. In contrast, solar or wind cost around $7,000 - $8,000 (Wilt, 2018). If a community wants to include hydrogen in its renewable solution, the costs will only increase.

Costs of hydrogen technologies are falling due to increased investment and expansion of the industry. In the future the high capital investment needed for a hydrogen project may be more affordable than it is today. (Hydrogen Council, 2020). For example it is estimated that total system cost, including power supply and installation costs, for PEM electrolysers will decrease from €1200/kW in 2017 to €700/kW in 2025. While Alkaline electrolysers are estimated to decrease from €750/kW in 2017 to €480/kW in 2025. This was estimated for a 20 MW system (IRENA, 2018).

4.1.2. Economies of Scale

Remote communities with small populations do not have the benefit of economies of scale. Communities still need to pay for engineering, project management, and permitting. It is difficult to develop a strong business case for outside investment with a small consumer base (Zen and the Art of Clean Energy Solutions, 2019).

4.1.3. Access to Funding

Many funding programs are fragmented and a single project may require upwards of 10 grants. The grant programs also require a great deal of administrative resources. Applying to grant programs at different levels of government with different requirements adds to the application complexity. Additionally, ongoing reporting required for many funding programs puts strain community resources which may already be limited (Kennedy, 2014).

4.2. Technical Barriers

4.2.1. Risk of New Technology

New technologies are always at a greater risk of failure when compared with established technologies (Jaccard, 2020). Hydrogen is relatively unproven in a remote off-grid setting and therefore poses a major risk for communities in terms of downtime and service interruptions. A generally accepted standard for implementation is that technologies need to have been tested for 3 years in 3 separate locations, to ensure reliability (Government of British Columbia, 2019). Although there have been some projects in remote settings, the technology has not been widely adopted. In 2009 the Hydrogen Assisted Renewable Power (HARP) project was conducted in Bella Coola. This project produced hydrogen from a run-of-river hydroelectric project to be used in times of peak demand or low run-of-river production. For more details on the HARP Project refer to Chapter 6. In general many of hydrogen products are not yet being manufactured at the level of other technologies such as those developed for internal combustion engines or battery systems (Hyfindr, 2021).

4.2.2. Community Capacity

Bringing in outside experts to remote off-grid communities is not always feasible. Community members need to be responsible for managing technically complex projects and ongoing maintenance (Zen and the Art of Clean Energy Solutions, 2019). Small populations limit the availability of skills needed to finance, manage and construct energy projects (Kennedy, 2014). Renewable energy technologies require specialized knowledge for installation and maintenance. These specially trained workers are often not present in remote communities (International Energy Agency, 2012).

4.2.3. Challenges of Additional forms of Energy

Adding additional forms of energy into a community's electricity system can be challenging for the system to ensure it is meeting demand. There is a need for enhanced control systems to ensure community members get the electricity that they need. This can increase the overall costs of the project as well as the demand on project team members to acquire and implement another project component (Zen and the Art of Clean Energy Solutions, 2019).

4.3. Regulatory Barriers

4.3.1. True Cost of Diesel

Defining the true cost of diesel can be difficult, due to several factors. The first is that diesel is heavily subsidized, to make it affordable in remote settings. This handicaps conversion to clean energy (Zen and the Art of Clean Energy Solutions, 2019). See section 2.2.1 for more details. Another factor is that the external costs of diesel (e.g., air pollution, GHG emissions) are often ignored in cost comparisons (Lovekin & Heerema, 2019b). This may impact a regulator's decision making when it comes to approving a clean energy project, such as one including hydrogen.

Several studies aim to quantify the true cost of diesel by including its social costs. The Gwich'in International Council estimated that the human and environmental cost of diesel is approximately 19.2 cents/kWh (CAD$2016). This was estimated through reviewing several studies looking at the social cost of thermal power using oil products or natural gas in the United States. In 2015, Price Waterhouse Cooper estimated several benefits of the Wataynikaneyap Power Project, which connected 16 Ontario communities to the central grid. These benefits included the present value of avoided GHG emissions, the present value of reduced adverse health impacts, present value of reduced damage to vegetation and the present value of avoided diesel spills. These estimated present value benefits totalled $832 million (CAD$2021) (Kennedy, 2014).

4.3.2. Regulatory Clarity

There has been limited investigation into regulatory oversight for hydrogen in BC. Several organizations have jurisdiction over safety including the BCUC, the BC Oil and Gas Commission (OGC) and Technical Safety BC (Government of British Columbia, 1980, 2008; Technical Safety BC, n.d.-b). Currently it is unclear who would have oversight over green hydrogen production, which includes electrolysis. The BC hydrogen strategy has identified the OGC as having jurisdiction over the production, storage and transport of hydrogen produced from fossil fuels (Government of British Columbia, 2021a). Hydrogen produced for use in electricity generation may encounter some regulatory overlap between the organizations. Hydrogen fuel cells, used for generating electricity may be under the jurisdiction of BCUC as they oversee the electricity generation for public utilities (BC Utilities Commission, n.d.).

Currently BCUC is conducting an inquiry into the regulation of safety to establish a better understanding of the BCUC's responsibilities as it relates to safety for utilities (BC Utilities Commission, 2020). As discussed in section 2.3.3 public utilities are exempt from the SSA for equipment used directly in generation, transmission and distribution of electrical energy. A possible gap exists for IPPs as they may be exempt from the regulatory oversight of the BCUC and Technical Safety BC (Technical Safety BC, 2021). This may impact IPPs who produce hydrogen. To make matters more complex there is a lack of comprehensive codes and standards that govern hydrogen technologies in Canada (Government of British Columbia, 2021a).

4.3.3. Water Regulation

One final regulatory barrier hydrogen faces is that currently the BC Water Sustainability Act does not include hydrogen production as an authorized industrial water use purpose. The BC Hydrogen Strategy does however cite this as an action to remedy in the short term (Government of British Columbia, 2021a).

Chapter 5. Interviews

A total of 12 interviews were conducted for this research. The following is a list of those experts.

- Program Manager, Indigenous Relations at BC Hydro
- Clean Energy Project Manager at Gitga’at First Nation
- Senior Policy Analyst, Energy Industry Decarbonization at the BC Ministry of Energy, Mines and Low Carbon Innovation
- Director, Community Clean Energy Branch at the BC Ministry of Energy, Mines and Low Carbon Innovation
- Commissioner at the BC Utilities Commission
- Policy Analyst, Nuclear Energy Division at Natural Resources Canada
- Senior Regulatory Affairs Analyst at Technical Safety BC
- Senior Safety Officer, Gas at Technical Safety BC
- Manager at Hydrogen BC
- Business Development Specialist at Powertech Labs
- VP, Sales and Marketing at HTEC
- Policy Analyst at a clean energy program

Interviews were conducted via Zoom or Microsoft Teams from the period of December 2021 to February 2022. The interviews were recorded, and detailed notes were taken. Key themes were identified from across interviews, many of which overlapped with themes in the literature but added enriching details and context.

5.1. Hydrogen Benefits

Participants cited many possible benefits to the use of hydrogen in a remote off-grid setting. Hydrogen is a versatile and adaptable energy carrier which can be produced in a decentralized fashion. One benefit is the avoided costs of expensive grid transmission and infrastructure expansion. Road access is required to build power lines, resulting in additional costs, complexity and time. Hydrogen can overcome this challenge by its ability to be transported, without the need for expensive power lines. If a community has a renewable source of electricity near-by, hydrogen can be used as the energy transport mechanism and transported via tank. This allows communities to have more energy independence, which as highlighted in the literature review is an important energy priority. Other benefits include avoided GHG emissions and the reduction in local air and noise pollution. Additionally, by acting as an energy carrier, hydrogen can help to solve the issue of dispatchable renewable electricity and can increase the penetration of renewables.

There is energy loss when you convert electricity to hydrogen and back again to electricity. Still, hydrogen has the opportunity in some settings to lower levelized unit cost relative to alternatives.

Participants noted however that hydrogen may not be right for every community. They emphasized that there is no golden ticket clean energy solution; solutions will be a combination of renewable options. Those options will depend on specific community requirements. Interviewees emphasized clean energy projects need to avoid being prescriptive, especially in Indigenous communities. There is a long history of failure in that area and it’s important to keep communities and first nations' interests at the heart of every project.

5.2. Barriers to Hydrogen Adoption

5.2.1. Economic Barriers

High Cost of Hydrogen Projects

Hydrogen projects, as identified in the literature and case studies, have very high upfront capital costs. Interviewees identified this issue, noting that these costs can be a difficult barrier to overcome. This is especially true when considering new risky technologies, which demand a high initial investment. Interviewees also noted that costs have been falling for hydrogen technologies. It was estimated that technologies now are 2-3 times less expensive than in 2013.

Access to Funding

Several issues relating to federal and provincial funding programs were identified by participants. The first is the extensive human resource and administrative capacity needed to apply for funding and the subsequent reporting required if awarded. Communities with limited administrative capacity may find it difficult to acquire government financing for clean energy projects, such as those including hydrogen. This is particularly true when considering all the other responsibilities that a First Nation government has. Interviewees expressed that they are severely under-resourced while the government continues to demand things from First Nations that are inappropriate.

Interviewees agreed that there is a challenge with small community projects being put into the same competitive pools as large established utilities. It makes it difficult to award funding to those communities when the utilities have more experience and capacity.

It was also noted that when First Nations turn to banks to acquire loan funding, the banks may refuse, citing the fact that the project is on a reserve. To the bank this means they would not have unimpeded access to the project assets as loan security. It's difficult to utilize on-reserve assets as collateral for bank loan.

Finally, interviewees mentioned that it's challenging for First Nations to engage with western colonial systems when attempting to access funding. This may result in a cultural barrier when navigating bureaucratic funding programs. It was noted that this should not be applied universally to First Nations as they all have unique circumstances.

5.2.2. Technical Barriers

Risk of New Technology

Interviewees highlighted the importance of reliability. Most communities will run with backup sources of energy because keeping the power on is essential – especially in the winter for heating and in summer for food preservation. In a First Nation community a power outage could destroy a whole season's worth of frozen meats for traditional diets. Interviewees also noted that power outages can have negative impacts on health and educational outcomes. Reliability is always top of mind for remote communities, and because of this, communities may not want to experiment with new technology.

Reliability is a concern for utilities, for example BC Hydro will only implement large scale commercially available technologies. Although, they may support pilot projects. Technologies, to be considered commercially available, need to be demonstrated in 3 instances over 3 years in North America. There are not many examples of modular hydrogen fuel cells used at a utility scale for power generation and is not considered commercially available. It can also be difficult to use international examples of hydrogen projects in off-grid settings. The remoteness and rugged terrain of BC is very different to places such as Europe.

In general, participants stated that hydrogen technologies for use in off-grid settings needed to become more commercially available before utilities would accept them as a reliable alternative to diesel electricity generation.

Community Capacity

Interviewees cited community capacity as a major barrier. Due to small populations in remote off-grid communities, often there are no qualified individuals who are permanent residents. It can be difficult to access electricians, gas fitters or engineers to solve issues or fix equipment. There is a risk of unqualified people performing work on hydrogen systems, which can increase safety risk. Communities need equipment that is robust enough to handle the rugged conditions and can be operated without a lot of onsite manpower.

In addition to capacity for ongoing maintenance there is also a lack of capacity when it comes to clean energy project planning. Identifying hydrogen as part the right solution for a community can be difficult when there may not be a dedicated staff member for clean energy.

Remoteness of Communities

The remoteness of communities was also identified as a major barrier by interviewees. As mentioned above, there is a need in this setting for equipment that is robust and can handle the rugged conditions. In remote BC, specifically northern BC, equipment will be exposed to much more extreme weather and there may not be year-round access to maintenance resources. Suppliers of hydrogen technologies may be located long distances from communities making it difficult to access systems in order to perform maintenance or repairs.

Remote communities also face a lack of access to broadband connection, which can be an essential element in project planning and ongoing project software.

Technological Readiness

Participants noted that hydrogen technology providers may find it more difficult in remote communities to provide the suite of hydrogen technologies that they need. There are few "off the shelf" solutions available for that type of environment. Although the concept of utilizing hydrogen in an off-grid setting, to displace diesel, has already been validated by the HARP project in Bella Coola, there is a need for more demonstration projects to develop more confidence in the technology in that setting. Refer to Chapter 6 for more information on the HARP project.

There are some existing containerized hydrogen systems that may be suitable for off-grid communities. Although they may require some alternations, such as larger storage tanks. These have been deployed for use in dispensing facilities, which dispense hydrogen to the public or industry. Interviewees predicted that producers of these types of systems would provide them to remote communities, despite the challenges of remoteness as long as producers weren't losing money on providing ongoing maintenance.

Public Acceptance

Communities have fears around hydrogen and may see it as dangerous. Interviewees highlighted the importance of gaining social license in these communities and increasing the awareness of hydrogen. There is a need to highlight the role hydrogen can play and how robust safety systems are for the technologies. Education and training can increase community capacity, but also increase awareness of hydrogen's potential and safety. Participants noted that although the dominant electrolyser at the moment is the alkaline model it has caustic chemicals which can be difficult to manage in a remote setting if something went wrong. You may have an easier time winning community trust with a PEM electrolyser, which is more expensive but has fewer safety concerns.

Transport

Interviewees recognized that the transport of hydrogen is technically difficult. This would apply in a setting where hydrogen was not being produced on site, but possibly shipped in to a community. Transporting hydrogen is not a proven supply chain for remote communities. One interviewee noted that transporting hydrogen as ammonia is probably the cheapest pathway, as there is existing infrastructure for its shipping. Ammonia can then be converted to hydrogen once in the community.

5.2.3. Regulatory Barriers

True Cost of Diesel

As in the literature, interviewees detailed that new clean energy technologies are always compared against diesel, especially in terms of cost. These new technologies must prove to be roughly equivalent in costs and reliability to diesel. BCUC is mainly a financial regulator which means when they approve utility projects they focus on the cost and don't put much weight on environmental impacts. It was estimated by participants that diesel is considered at the cost to the rate payer, which may include subsidies that are not necessarily accounted for. Interviewees highlighted that if hydrogen is going to cost more than diesel then someone is going to pay for it. BC Hydro would have to ask BCUC to raise rates to accommodate new expensive fuels and technologies.

Overall, the BCUC has little experience adding in non-financial benefits into calculations. For example, the benefit of not transporting diesel means risks of spills is reduced. One interviewee detailed that communities are excited for diesel generators to be turned off because at night you can hear the sea otters splashing around which you can't hear with the diesel generator running. It's necessary to find a way to quantify those benefits. Although interviewees also noted that there is a general momentum in the province toward considering the full cost of diesel. They noted that this change will also be important for reconciliation and honoring Indigenous energy objectives.

Participants mentioned that in BC we have mostly renewable electricity. Remote communities, specifically First Nations, are often negatively impacted by those large projects which may flood territory or displace residents. It is unfair that off-grid communities are excluded from the renewable electricity generated. It was suggested that due to these projects the province, and BC Hydro, have an obligation to reduce diesel use and to pay for it.

Regulatory Clarity

Interviewees agreed that that there is a lack of clarity in the hydrogen regulatory environment. As described in Chapter 2 the BCUC, for the most part, regulates public utilities in the province. But this does not cover all types of communities. Interviewees described several types of power providers and how they would be regulated. This is summarized in the table below. Please note that this information originated from interviewees, who provided supporting evidence, which is referenced here.

Table 3: Summary of Power Providers and Regulatory Oversight

Utility Type	Utility Regulation	Safety Regulation
BC Hydro	BCUC regulates the rates, plans, projects and EPAs for BC Hydro. The BCUC is mainly an economic regulator so it ensures BC Hydro's actions are not unreasonable, unsafe, inadequate or unreasonably discriminatory. This is defined in the UCA (Government of British Columbia, 1980).	Public Utilities set their own safety standards but are overseen for safety by the BCUC, as set out by the UCA. There is currently an Inquiry into the Regulation of Safety being conducted by the BCUC, which may impact the oversight the commission has over safety for BC Hydro. BC Hydro submitted their final argument on Jan 12, 2022 and a reply argument to other intervenors on Jan 26 which outlines their position on BCUC jurisdiction over safety and how this is defined in the UCA (BC Hydro, 2022).
Other Public Utilities (ex. FortisBC)	BCUC regulates the rates, plans, projects and EPAs for other public utilities. This is defined in the UCA (Government of British Columbia, 1980).	Public Utilities set their own safety standards but are overseen for safety by the BCUC, as set out by the UCA. There is currently an Inquiry into the Regulation of Safety being conducted by the BCUC, which may impact the oversight the commission has over safety for Public Utilities. FortisBC submitted their final argument on Jan 12, 2022 (FortisBC, 2022). As noted by interviewees the BCUC has not historically asserted their jurisdiction over safety. Safety Regulation for the transport of natural gas which may be used by a utility, such as FortisBC, is overseen by the Oil and Gas Commission, Transport Canada and Technical Safety BC.
IPPs	BCUC regulates IPPs in the same manner as public utilities, unless otherwise exempted under the UCA. Exemptions are outlined in sections 22 and 88(3). Interviewees noted that sections 25, 38, 42 and 43 are not often exempted as they provide continued oversight over safety and other matters of public interest.	IPPs that are not otherwise public utilities are exempt from part 3 of the UCA as outlined by a Minister's Order. They are also exempt from the electrical SSA, regulated by Technical Safety BC. Resulting in a possible regulatory gap, which has been identified in Technical Safety BC's submission to BCUC's Inquiry into the regulation of safety (Technical Safety BC, 2021).

Utility Type	Utility Regulation	Safety Regulation
Municipal Utilities	Municipalities are exempt from oversight from the BCUC, as they are not defined as public utilities under the UCA. Municipalities provide oversight by staff and/or can set up local commissions for that purpose (e.g., New Westminster).	Technical Safety BC has safety oversight unless the municipality is exempted from gas or electrical safety oversight. There are 10 of these municipalities in BC (Technical Safety BC, n.d.-a).
Indigenous Utilities	Indigenous Utilities are currently under the purview of the BCUC but with the BCUC's Indigenous Utilities Regulation Inquiry this may change in the future (Morton et al., 2020). Potentially Indigenous communities could negotiate oversight of Indigenous utilities by the BCUC or may perform those regulatory functions on their own.	Safety regulation for Indigenous Utilities may also be negotiated as per the Indigenous Utilities Regulation Inquiry (Morton et al., 2020).
First Nations Reserves (Not served by BC Hydro)	First Nation reserves, who are not served by BC Hydro are regulated under the Indian Act. The federal government has oversight, although the focus is on capital funding. These tend to be utilities owned and operated by the community which sells power directly to homes and handles billing.	The SSA is provincial legislation which applies to reserve land unless a contrary treaty exists. Under this Technical Safety BC would have oversight, unless a treaty deemed otherwise.
Retailers (Ex. Natural Gas Retailer)	Retailers are regulated by the BCUC under the UCA. There is an established code of conduct and set of rules for retailers (BCUC, n.d.).	Similar to public utilities gas retailers are subject to the BCUC for safety regulation.
Contractors	N/A	Safety is regulated by Technical Safety BC which oversees installation and operational permits. Technical Safety also ensures that operations and maintenance are completed by properly licensed individuals.

Disclaimer: The information contained in this table does not represent the official views of the BCUC, Technical Safety BC, the OGC or Transport Canada. It is simply a summary of information provided by interviewees.

Participants also highlighted how regulation, specifically safety regulation, can in many cases only be determined in a case-by-case analysis. The circumstances by which a hydrogen project may be developed can impact the relevant regulatory bodies. Navigating this unclear environment may prove difficult for communities.

Another regulatory challenge is the lack of harmonized Canadian codes and standards, although participants noted there is a push to establish those. This comes in the form working groups, established by the federal government, drafting those regulatory documents.

Energy Purchase Agreements (EPAs)

Interviewees noted that communities hoping to implement hydrogen in their clean energy solution may find it challenging to acquire an EPA from BC Hydro. As detailed in the background, EPAs are important in ensuring a revenue stream for the project. An EPA means that communities don’t have to act as a separate fee-collecting utility. When BC Hydro is a service provider, electricity is more reliable and there is less administrative stress on the community.

Although BC Hydro does not have set requirements for EPAs, it does have basic guidelines: technologies must be commercially available, which means they must have 3 installations for 3 years in North America. Hydrogen in a remote community setting does not meet this criterion according to BC Hydro. One interviewee noted that projects may essentially be dead without this type of agreement unless another source of revenue is found.

5.3. Policy Options Proposed by Interviewees

Several policy options were discussed by interviewees, which are summarized below.

5.3.1. Low Carbon Fuel Standard

Interviewees suggested that the provincial government expand the Low Carbon Fuel Standard (LCFS) to include hydrogen. Under the LCFS firms can earn credits by producing fuels with emissions lower than the standard set in the regulation. They can then sell those credits to firms whose fuel production pathways result in emissions higher than the standard. It would mean that communities producing hydrogen would be able to generate credits for that low carbon fuel, providing additional economic opportunity.

Interviewees also suggested that diesel fuel for use in electricity production be included in the standard. This would force diesel produced for use in electricity generation to meet emissions targets set by the standard. Although diesel producers can apply for an exemption from the LCFS for diesel used for this purpose it generally is not done. It is very difficult to identify the end use of a fuel from the standpoint of a producer and for the small amount of diesel which ends up producing electricity, pursuing an exemption is deemed not worth it.

5.3.2. Pilot Projects

As discussed above hydrogen in an off-grid setting is not seen as commercially available. This makes hydrogen appear relatively risky to government and regulators and prevents communities acquiring EPAs for the technology. To overcome this, interviewees suggested pursuing pilot projects. This could be done through BC Hydro, the provincial government and/or the federal government. Interviewees noted that the provincial government does not have the capacity to take on a project on its own, utilizing funding from the federal government will be important. This will allow hydrogen to be proven in an off-grid scenario in terms of reliability and commercial availability. It will also off-load the risk of using new technologies from the community, who as mentioned above is not necessarily able to take that on.

5.3.3. Funding

Participants agreed that grant funding is critical to financing clean energy projects in remote communities, including those that utilize hydrogen. They mentioned several ways in which to improve the programs.

Funding programs should have an Indigenous stream, so that Indigenous communities are not competing with larger utilities. Next, funding programs should consider project lifecycle funding. The Community Clean Energy Branch at the Ministry of Energy, Mines and Low Carbon Innovation is currently considering a program that includes funding for each stage of the project – such as the energy plan, pre-feasibility studies, engineering studies, design phase and building phase. This is different from most funding which is aimed at only one step. When an applicant gets into the program, they have an informal internal application to go to the next stage, greatly reducing the application burden. Although it should be noted that not all are in support of lifecycle funding. There has been some criticism that this method may lead to uncertainty that all stages of the project will be funded if communities have to go back into a competitive pool for each stage of the project.

5.3.4. Energy Targets

One final policy recommendation is to expand BC's target for 100% renewables for integrated areas to include non-integrated areas. Under the UCA Utilities and BCUC must consider BCs energy objectives, which are laid out in the CEA, including the target for renewables. This would ensure the BCUC is considering the GHG reductions of energy projects for remote communities in their regulatory decision making, specifically when approving projects or EPAs. It's important to note that this would only apply to public utilities regulated by the BCUC. Other utilities may want to establish those targets for themselves.

Chapter 6. Case Studies

This section examines several case studies of communities who have implemented or are considering implementing hydrogen in their clean energy solution. Hydrogen in an off-grid setting is relatively new and there are few case studies particularly in BC passed the feasibility stage. This section mainly includes studies at the feasibility stage of implementation.

6.1. Hydrogen Assisted Renewable Power (HARP) Project

Bella Coola is a remote community located 400km north of Vancouver on the coast of BC (Grant & Sagoo, 2010). The population is 600 people (Magtibay & Wong, 2013). HARP, a government incentivised pilot project conducted between 2007 and 2012, was initiated to reduce diesel reliance in the community and to demonstrate the viability and reliable of renewable energy storage in a remote setting (BC Hydro, 2012).

6.1.1. Background

Before the HARP project was undertaken the community of Bella Coola relied on 8 diesel gensets and two run-of-river hydro units. The diesel generator units ranged in size from 300 kVA to 2500 kVA. These are located at the Ah Sin Heek generator station. The hydro units, located at Clayton Falls Hydro Plant, are rated to 700 kVA and 1400 kVA. Peak load for the community ranged from 4.3 MW and 2.3 MW during the winter and summer months (Hajimiragha & Zadeh, 2013).

The original system design lacked efficient utilization of renewable power from the run-of-river hydro units. The main objective of this project was to reduce diesel reliance by using hydrogen as a form of storage for surplus renewable energy. This would be done through creating hydrogen during times of high renewable energy generation for use during peak demand (Hajimiragha & Zadeh, 2013).

This project was conducted with the support of Sustainable Development Technology Canada (SDTC) and through a partnership between BCHydro, General Electric, and Powertech (Hajimiragha & Zadeh, 2013).

A hydrogen internal combustion engine truck was provided to the staff at the Bella Coola facility to familiarize them with hydrogen handling (Grant & Sagoo, 2010).

6.1.2. Project Design

To ensure efficient use of all components of this system a microgrid control and monitoring system was developed. This system includes an optimization based central controller, local controllers, a monitoring system, a water level controller and other automation equipment (Hajimiragha & Zadeh, 2013). Below is a summary of the hydrogen components of the project.

Table 4: Project Components

Project Component	Details
Hydrogen Storage Cylinders	100 kg Hydrogen Storage Can store approx. 3300 kWh of renewable energy
Electrolyser	Produces 5kg/h Min and max charging powers are 320 and 120 kW Provided by Hydrogenics Inc.
Fuel Cell	Proton Exchange Membrane Fuel Cell 100 kW 10kW fuel cell modules for redundancy Provided by Dantherm Power-Ballard
Compressor	Rated power of 50 hp Able to raise hydrogen pressure up to 2850 psi (197bar) Provided by Hydro-Pac Inc.

Source: Author's Adaptation from Grant and Sagoo (2010)

6.1.3. Costs

Unfortunately cost information for this project was unavailable. It will be important in the future for other projects in BC to review the cost information from the HARP project. Overall costs for the system were found to be quite high, but as hydrogen technologies mature and economies of scale are reached components will become less expensive (BC Hydro, 2012).

6.1.4. Results and Lessons Learned

The result of the project was a successful decrease of diesel consumption by 10%. This exceeded the initial target of the project, which was identified by the Sustainable Development Technology Canada (SDTC) at 0.75% (BC Hydro, 2012).

There is a need to conduct thorough pre-testing before deployment of a system to the project site. There can be challenges with system components communicating with one another and pre-testing can ensure issues are resolved before moving to a remote area (Grant & Sagoo, 2010).

The weather conditions in remote communities should be taken into account early in the planning stage (Grant & Sagoo, 2010). Climate change and its impacts on major weather events should also be considered. Forest fires in 2009 closed highway 20, an important transport route for the project and resulted in the evacuation of the Bella Coola valley. Additionally a 100 year floor impacted the initial delivery of equipment (BC Hydro, 2012). Bella Coola also experienced challenges in accessibility, for example moving equipment such as a 55T crane and 6 flat deck trucks of heavy equipment was difficult. It is hard to find replacement equipment so a project should be prepared if equipment fails (Grant & Sagoo, 2010).

The people involved in the project are key to project success. Extensive operational and safety training needs to be conducted in advance of the project. Emergency plans also need to be in place and understood by the operational team (Grant & Sagoo, 2010).

6.2. Grimsey Island

Grimsey Island is an Arctic island located 40km north of Iceland. The island is 5.3 km^2 and has a population of 76 people with 40 buildings. In 2015 a feasibility study was undertaken to investigate a wind-to-hydrogen system for the island (Chade et al., 2015).

6.2.1. Background

Several projects have been proposed for the island of Grimsey to move away from diesel consumption. Connection to the national Icelandic grid was not possible due to the high costs and technical barriers. Large and small scale wind projects have been investigated as well as the possibility of geothermal and wood biomass for Grimsey Island.

The island is motivated to move away from diesel generators due to the fact that this power generation is highly subsidized by Icelandic public funds. It was estimated in 2011 that subsidies are upwards of $400,000 for that purpose.

At the time of the study the island was producing electricity via three 220 kW diesel generators. Peak electrical load was estimated to be 175 kW with a daily load average of 2.4 MWh (Chade et al., 2015).

6.2.2. Project Design

Hybrid Optimization Model for Electrical Renewables (HOMER) was used as a modeling tool to assess several project designs. These include wind-diesel, wind-diesel-hydrogen and wind-hydrogen. These projects should not necessarily be viewed as separate but as a roadmap. With each project stage further reducing the island's reliance on fossil fuels (Chade et al., 2015).

Table 5: Project Components

Project Component	Size	Lifetime
Hydrogen Tank	85kg	20 (years)
Electrolyser	294kW	10 (years)
Wind Turbine	100kW	20 (years)
Fuel Cell	100kW	60,000 (operating hours)
Converter	300kW	20 years)

Source: Author's Adaptation from Chade et al. (2015)

6.2.3. Costs

The price of diesel for this study was assumed to be $2.39/L which is higher than the price of diesel on the mainland.

Table 6: Project Component Costs

Project Component	Capital ($)	Operations and Maintenance ($/year)
Hydrogen Tank	40,000	2000
Electrolyser	326,000	6300
Wind Turbine	360,000	3800
Fuel Cell	55,000	2000
Converter	225,000	0

Source: Author's Adaptation from Chade et al. (2015)

Table 7: Levelized Cost per kWh of electricity

System Type	Cost of Energy ($/kWh)
Diesel	0.648
Wind-Diesel	0.535 – 0.469
Wind-Hydrogen-Diesel	0.295
Wind-Hydrogen	0.434

Source: Author's Adaptation from Chade et al. (2015)

All scenarios reduce the cost of energy compared to a diesel only system. The Wind-Diesel system reduced the levelized cost of energy to between $0.535 and 0.469/kWh. This estimate is based on one to six turbines. The Wind-Hydrogen-Diesel system resulted in the lowest levelized cost of energy at $0.295/kWh with four wind turbines. It did substantially increase the initial investment needed but operational costs were dramatically decreased. The Wind-Hydrogen system also reduced operational costs but the initial investment increased greatly. Moving from 92% to 100% renewable system would double cost of initial investment. The levelized cost of energy for this scenario was $0.434/kWh. During winter months hydrogen storage can be full with no additional capacity to store excess electricity. Here communities may consider using hydrogen for onsite purposes such as boats, heating and vehicles. This additional onsite demand may improve the economics of this scenario (Chade et al., 2015).

6.2.4. Results and Lessons Learned

The wind-diesel system obtains about 40% to 89% of energy from renewables. This reduced diesel use by 23% to 64%. The wind-hydrogen-diesel system is estimated to achieve 92% of electricity obtained from a renewable source. This significantly reduces emissions as diesel consumption goes down by about 85%. The Wind-Hydrogen system uses 100% renewables, resulting in no diesel consumption (Chade et al., 2015).

6.3. Fort Hope

Fort Hope is a reservation of the Eabamtoong First Nation in northern Ontario, 360km north of Thunder Bay. It has a population of 1,420. In 2013 a feasibility study was conducted to investigate a hybrid renewable system for Fort Hope (Magtibay & Wong, 2013).

6.3.1. Background

Fort Hope spends roughly $1.58 million on diesel fuel each year for power generation, which accounts for 7% of the community's budget. This is calculated using their consumption of 1.23 million litres of diesel per year at a price of $1.28/L. In 2007 the estimated total output of electricity was 3.45 GWh resulting in emissions of 3,416 t-CO_2e. Total community demand is expected to exceed capacity in 2043, which will result in load restrictions prior to that year. These load restrictions can limit the community's opportunities for economic growth. Using the data from 2007 the output and emissions were estimated for 2012 using the HOMER system. Total power output for the year was estimated at 5,203 MWh and emissions were estimated to be 3,800 t-CO_2e.

Fort Hope's relatively large population made it suitable for this study. The community has access year round, but road access is seasonal (Magtibay & Wong, 2013).

6.3.2. Project Design

The project is comprised of several components including a 636 kW run-of-river hydro generator, two diesel generators, and a hydrogen system. The diesel generators have a capacity of 650kW and 375kW. The hydrogen components of the project are listed in the below table. HOMER was used to model the project design.

Table 8: Project Components

Project Component	Size
Hydrogen Storage	150 kg
Hydrogen Electrolyser	80 kW
Fuel Cell	150 kW

Source: Author's Adaptation from Magtibay & Wong (2013)

This design results in a 54% renewable energy penetration for overall electricity production. The Hydrogenics electrolyser that was used for this system has limited capacity so multiple units were used (Magtibay & Wong, 2013).

6.3.3. Costs

The project results in a decrease in the levelized cost of energy for the community, as you can see in Table 6.7.

Table 9: Total Project Costs

Cost Type	Amount ($)
Capital	4.6 million
Operation and Maintenance (annual)	990,000
Net Present Cost of System	17 million

Source: Author's Adaptation from Magtibay & Wong (2013)

Table 10: Levelized Cost of Energy

Scenario	Cost ($/kWh)
Baseline	0.39
Project	0.24

Source: Author's Adaptation from Magtibay & Wong (2013)

6.3.4. Results and Lessons Learned

There was a 54% reduction in diesel consumption projected for this project. Although the diesel generators still operate 91.3% of the year the hydrogen system is able to supplement the energy system enough that typically only the 375 kW generator would be in operation. The reduction in diesel also results in a reduction of emissions of 54%. CO_2 is expected to reduce by 1,964 tonnes annually and NO_x is expected to be reduced by 44 tonnes annually.

The hydrogen storage system is projected to have an energy storage capacity of 5,000 kWh. Hydrogen produced by the electrolyser is projected to be 3,144 kg/year.

The study identifies that the high capital cost of this project will be a barrier for communities to pursue such a system. It is extremely expensive for remote communities to transport and install infrastructure and equipment. The study also notes that there can be great variability in costs over time as diesel prices fluctuate and the cost of hydrogen technologies are reduced. There is potential for a 55% reduction in the capital and operating costs of hydrogen storage systems. (Magtibay & Wong, 2013).

6.4. Summary of Case Studies

These case studies demonstrate several important points. Firstly, as discussed in the literature review, diesel has much lower upfront capital costs than a hydrogen project. Although the cost of hydrogen technologies is falling, financing a hydrogen project in a remote community may well be impossible without a grant. Despite this, hydrogen does have the potential to lower the levelized cost of energy for a community. The case studies show that the levelized cost of energy is the lowest for a hybrid style project, which includes diesel as a backup. Hybrid options also include more complex maintenance and regulatory hurdles than diesel. Including more technologies in a project can increase the requirement for trained individuals, testing time for pre-integration and overall maintenance demands. Additionally, weather can be unpredictable and harsh in these remote communities, which may be exacerbated by future climate change.

Chapter 7. Policy Options

Based on the literature review, interviews and case studies, several policy options were identified and have been assessed in this chapter. The biggest barrier to adoption seems to be cost of hydrogen technologies. To address this the analysis will take a tiered approach. First, funding-based policies to overcome the challenge of the high cost of hydrogen projects will be assessed. It is unlikely that other policies will be implemented or effective if that barrier is not first overcome and hydrogen is implemented in an off-grid setting. Next, several policies addressing other barriers will be analyzed. They will be recommended in priority order established by the total scores they receive based on the criteria and measures.

7.1. Funding-Based Policies

7.1.1. Hydrogen Grant Program

This policy proposes a grant program funded by the federal and BC provincial government. The grant program will be designed to fund clean energy projects in BC that have a hydrogen component. Grants can be allocated at any stage of the project, including feasibility studies, engineering studies and design, environmental assessments and/or capital expenditure. Applicants can also apply for end-to-end funding from this program. Once an applicant has been awarded funding for any stage of a project they only need complete a fast tracked application for another stage. This program will prioritize First Nations, although it will accept non-Indigenous applicants as well.

A total of $27 million will be allocated over the next 5 years for this program. The capital costs from the Fort Hope case study, adjusted for inflation, are today approximately $5.5 million. The operating and maintenance costs per year were $1.18 million, adjusted for inflation. (This was estimated using an inflation rate of 2.01 %.) This fund would be sufficient to cover the capital and operation and maintenance costs of three hydrogen projects, for three years. This is the baseline for commercial availability as identified by BC Hydro.

7.1.2. Pilot Project Program

This policy option proposes a pilot project be undertaken by BC Hydro and the provincial government to implement hydrogen for electricity generation in a First Nation community. This project should build on HARP's success in demonstrating hydrogen could be implemented in a remote setting to reduce diesel consumption by increasing the commercial availability of hydrogen technologies. As the provincial government may not have the funding capacity to take on the entire project, the provincial and federal government should work together to provide funding for the pilot program.

It should also be noted that when choosing a First Nation community to conduct this pilot project, the project should be undertaken in a community that has decided hydrogen is right for them and has not been assigned hydrogen as a prescriptive solution. The principles of the *Declaration on the Rights of Indigenous Peoples Act* (DRIPA) should be central in a collaborative approach to this project.

7.2. General Policies

7.2.1. Training Programs

This policy option would provide funding from the provincial government, to technical institutions such as BCIT, the Nicola Valley Institute of Technology and the University of the Faser Valley to design programs, where students can learn the skills needed to maintain and operate hydrogen technologies. The federal government may also provide funding via student scholarships. Indigenous students will be given priority admittance to this program, although non-Indigenous students will also be accepted. Additionally, Indigenous students will not pay any fees for the program. Students will have mandatory in person field days where they visit a hydrogen facility to gain hands on knowledge of the technology.

7.2.2. 100% Renewable Electricity Target for Non-Integrated Areas

British Columbia plans to adopt a 100% Clean Electricity Delivery standard which mandates the province to only use electricity produced from renewable sources by 2030. As outlined in the recently published Roadmap to 2030, this target is only applicable for integrated areas and does not apply to non-integrated areas(Government of British Columbia, 2021b). This policy option would expand that target to include both grid connected and non-grid connected areas of BC. It would also propose that the target be adopted into the CEA, as part of the province's energy objectives. Under section 71 of the UCA, the BCUC must take into consideration the province's energy objectives when determining if an EPA is in the public interest (Government of British Columbia, 1980). Having a target for 100% renewables in off-grid communities would incentivize BCUC to approve projects that switch communities from diesel electricity generation to renewable sources. This would include green hydrogen on its own as well as a supplement to other renewables to increase their penetration. It is important to note that this would only apply to communities who are served by BC Hydro or who are otherwise under the jurisdiction of the BCUC. Communities such as those with Indigenous utilities or municipal utilities may want to set their own renewable targets.

As this option was explored by interviewees, it is mentioned here but is not feasible for implementation. It does not effectively remove any barriers to hydrogen adoption. As identified through case studies and interviews, it is too risky to exclude all diesel generators in a renewable energy system, even with hydrogen. It is essential to have several backups to avoid blackouts and provide reliable electricity in remote areas. Having diesel as part of an energy system can support the transition to more renewable sources. As identified in the case studies, the levelized cost of energy is lowest when hydrogen is used in a hybrid system, which includes hydrogen and diesel.

7.2.3. Low Carbon Fuel Standard

The low carbon fuel standard sets a decreasing level of acceptable emissions for fuel producers in the province. Producers able to produce fuels with lower emissions than the standard earn credits, which they can sell to high emitting producers. Currently under section 6 of the *Greenhouse Gas Reduction (Renewable and Low Carbon Fuel Requirements) Act,* hydrogen is not permitted as a fuel for which credits can be earned (Greenhouse Gas Reduction (Clean Energy) Regulation, 2012). This policy proposes that the regulation be expanded to allow green hydrogen producers to earn credits.

7.2.4. Reduce Regulatory Uncertainty

This policy proposes that regulatory bodies with jurisdiction in BC ensure they are up to date on the development of the hydrogen industry. First regulatory bodies should adopt harmonized codes and standards as they are published. Additionally, regulatory bodies should work towards increased clarity as it relates to hydrogen regulation. Technical Safety BC, the BCUC, Transport Canada and the OGC should work together with the province to undertake a regulatory mapping exercise to understand the current state of oversight, identify major gaps and develop a plan to mitigate those gaps. These organizations should be prepared as communities begin to adopt hydrogen to identify for the community the responsible regulatory entity.

Chapter 8. Criteria and Measures

8.1. Effectiveness

This criterion will be applied differently to Funding-Based policies versus General policies. For Funding Based Policies, effectiveness will be assessed by the extent to which policies will result in adoption of hydrogen in an off-grid setting. This will be based on the number of communities able to adopt hydrogen. A high score will reflect policies which result in implementation in more communities and are predicted to generate a high level of future investment. For General Policies, effectiveness assesses in a remote off-grid setting the extent to which a policy option reduces the barriers to adopting hydrogen-based power. Please refer to Appendix A for a summary of barriers. Scores for this criterion will be based on the number of barriers a policy addresses as well as how well the policy might address them. A high score will be awarded to policies that effectively remove many barriers.

8.2. Fairness, Justice and Equity for First Nations

This criterion assesses whether a policy option addresses inequities in terms of First Nations accessing clean energy, such as hydrogen. Policy options which include contingencies to reduce inequalities to accessing clean energy for First Nations will receive a score of high while policy options which do not will receive a score of low.

8.3. Administrative Complexity

This criterion is an estimate of the deployment complexity of each policy. Some policies may require synchronicity across departments and/or levels of government. Some policies may include a great deal of administrative change while others only require adjustments to existing programs or policies. Policies will be scored as high, medium or low depending on the level of complexity that they require.

8.4. Cost to Government

This criterion assesses the resource burden to all levels of government in the form of publicly assumed costs. Policies will be scored as high, medium and low depending on the level of resources and government spending they require.

8.5. Capacity Building

This criterion is an assessment of how well a policy builds lasting capacity in a community. This capacity could refer to financial capacity, administrative capacity, human resource capacity, local maintenance and operational capacity, etc. Policies will be ranked from high to low depending on the breadth and depth of capacity-building components. The breadth refers to how many dimensions of capacity the policy addresses as well as in how many communities and the depth is how long lasting that capacity will be. Capacity in many areas and over a long time horizon is preferred.

8.6. Summary of Criteria and Measures

Table 11: Summary of Criteria and Measures:

Criteria	Description	Measure
Effectiveness	**Funding Based Policies:** This criterion assesses the extent to which a policy is predicted to results in hydrogen adoption and future investment in remote hydrogen projects.	**High:** Policy option which results in a relatively high number of communities predicted to adopt hydrogen and in high future investment in remote hydrogen projects. **Medium:** Policy option which results in a relatively lower number of communities predicted to adopt hydrogen and relatively lower future investment in remote hydrogen projects. **Low:** Policy option which results in the lowest number of communities predicted to adopt hydrogen and to result in the lowest amount of future investment in remote hydrogen projects.

Criteria	Description	Measure
	General Policies: This criterion assesses the extent to which a policy option reduce the barriers to adopting hydrogen in a remote off-grid setting.	**High:** Policy options which reduce a 3 or more barriers **Medium:** Policy options which reduce 2 barriers **Low:** Policy options which reduce 1 or less barriers
Fairness, Justice and Equity for First Nations	This criterion assesses if the policy option addresses inequities when it comes to First Nations accessing clean energy solutions, such as hydrogen.	**High:** Includes contingencies, which reduce inequalities to accessing clean energy, for First Nations **Low:** Does not include contingencies for First Nations
Administrative Complexity	This criterion is a measurement of the complexity of each policy when it comes to its deployment.	**High:** requires 1-2 ministries and only one level of government. **Medium:** requires several or more ministries or organizations but only one level of government **Low:** requires multiple ministries and organizations and multiple levels of government
Cost to Government	This criterion assesses the resource burden to all levels of government in the form of costs, for each policy.	**High:** low costs **Medium:** medium costs **Low:** high costs
Capacity Building	This criterion is an assessment of how well a policy builds lasting capacity in a community.	**High:** long term capacity with more than 1 capacity building area addressed **Medium:** medium term with at least one capacity building area addressed **Low:** no capacity building areas are addressed

Note: A measure of high is considered the desirable outcome in each of the criteria

Chapter 9. Evaluation

This chapter assesses each policy option posed in Chapter 7, based on the criteria and measures identified in Chapter 8. First, an evaluation of the funding-based policies has been conducted in order to increase investment in and implementation of hydrogen in an off-grid setting. Then, the general policies have been evaluated resulting in a priority list. The policies are assessed qualitatively and are assigned a score from high to low for each criterion. As this research has a focus on overcoming the barriers to adopting hydrogen in remote communities, including the barrier of high cost, the effectiveness criterion has been given double weight. A score of high is considered the desirable outcome of each criterion. To determine differences between the high to low categories, each criterion will also be assigned a numerical score. See the below table for details.

Table 12: Score Summary

High	Medium	Low
7-9	4-6	1-3

9.1. Funding-Based Policies

9.1.1. Effectiveness

Policy	Score	Description
Hydrogen Grant Program	9 (High)	This policy option receives a high score of 9 for effectiveness. It is aimed to invest grant funds in several projects around BC. The program is designed to provide enough funding to finance at least three projects. Some communities may apply for funding for one or two stages of the project process, leaving funding to be invested in more hydrogen opportunities in remote communities. This policy is considered to result in launching a relatively high number of hydrogen projects. It should be noted a risk exists that not all projects, which receive funding under this program, will reach completion. This is mitigated by the fact that not all projects will need funding for all stages and the grant program allows for investment from private entities. Private involvement may also lead to greater innovation and future investment into hydrogen. Additionally, having 3 projects in place is the standard for BC Hydro to consider the technology commercially available. This may increase support from the utility and from BCUC. It also demonstrates for other communities that hydrogen projects are viable and provides valuable lessons learned for further implementation. This may result in a relatively high degree of investment into hydrogen in remote communities over the next several years.
Pilot Project	6 (Medium)	This policy option receives a medium score of 6 for effectiveness. This policy option most likely results in a smaller number of communities adopting hydrogen in an off-grid setting in BC. The pilot project aims to provide at least one complete hydrogen implementation in an off-grid setting. It also results in less future investment. It does work towards achieving the standards of 3 projects in BC, but only by completing one single project. This will still encourage some degree of investment and interest as it moves the industry towards commercial availability.

9.1.2. Fairness, Justice and Equity for First Nations

Policy	Score	Description
Hydrogen Grant Program	7 (High)	This policy option receives a high score of 7 for fairness, justice and equity for First Nations. This grant program will prioritize First Nations but will also accept non-Indigenous applicants. It does not guarantee First Nation communities will be chosen.
Pilot Project	9 (High)	This policy option receives a high score of 9 for fairness, justice and equity for First Nations. The pilot project aims to be conducted in a First Nation community. Although it must be a community for which hydrogen is a priority and not one who has been prescribed hydrogen as a clean energy solution. The project must center DRIPA in a collaborative approach.

9.1.3. Administrative Complexity

Policy	Score	Description
Hydrogen Grant Program	3 (Low)	This policy option receives a low score of 3 for administrative complexity. It is highly administratively complex as it involves both the provincial and federal levels of government. There will be a great deal of complexity in designing the program and well as administering it. It is however relatively less complex than a pilot project as it only focuses on the funding side of hydrogen projects and will not be involved in the technical or project implementation side.
Pilot Project	1 (Low)	This policy option receives a low score of 1 for administrative complexity. Funding for the pilot project requires the provincial and federal governments to collaborate and align in their priorities. The project will also require collaboration from industry groups to provide technology and expertise. This project will also include participation from BC Hydro as the utility as well as providing expertise and support. And finally all those groups will need to collaborate with the community and prioritize their needs.

9.1.4. Cost to Government

Policy	Score	Description
Hydrogen Grant Program	1 (Low)	This policy option receives a low score of 1 for cost to government. This policy option would be very costly to government as it requires $27 million, the grant program's total, as well as the human resources to implement the program.
Pilot Project	3 (Low)	This policy option receives a low score of 3 for cost to government. As described in case studies, the upfront costs of a hydrogen project are high. In the case of Fort Hope the capital costs are estimated to be $5.5 million (allowing for inflation) for a hybrid hydrogen system that included run-of-river hydro, a hydrogen electrolyser, fuel cell and diesel generators. The cost to government of this policy option will also include the resource cost of operations and staffing for the project. It should be noted that over the lifetime of the project the levelized cost of electricity is expected to go down. In Fort Hope it was expected to be reduced from $0.39/kWh to $0.24/kWh.

9.1.5. Capacity Building

Policy	Score	Description
Hydrogen Grant Program	9 (High)	This policy option receives a high score of 9 for capacity building. This program will build financial capacity in the community to be used to implement hydrogen in their clean energy solution. Over the long term this solution has the potential to reduce the levelized costs of energy, as identified in case studies, for the community. This will also build its financial capacity. The program is also designed to reduce administrative burden by implementing a phased approach to funding applications. Once a community has been awarded funding, it will then be fast tracked when applying for funding for another phase of the project. This frees administrative capacity to focus on other areas. Finally, this program will increase financial and administrative capacity for several communities.
Pilot Project	7 (High)	This policy option receives a high score of 7 for capacity building. Similar to grant programs the funding provided to implement a hydrogen project will increase the financial capacity of a community. The decrease in the cost of energy will sustain that long term. Additionally, the hands-on support that the community will receive for this program will build local maintenance and operational capacity. This policy option only builds this capacity for one community, which is why it receives a relatively lower score than the hydrogen grant programs.

9.1.6. Evaluation Result Summary

The following table provides a summary of each policy option and how it scored for the criteria. No option satisfied all the criteria and each had critical trade-offs. The goal of the analysis is to choose one funding based policy for recommendation.

Table 13: Funding Based Policies Evaluation Results

Criteria	Policy Option	
	Hydrogen Grant Program	**Pilot Project**
Effectiveness (x2)	High 9	Medium 6
Fairness, Justice and Equity for First Nations	High 7	High 9
Administrative Complexity	Low 3	Low 1
Cost to Government	Low 1	Low 3
Capacity Building	High 9	High 7
Total	38	32

9.2. General Policies

9.2.1. Effectiveness

Policy	Score	Description
Training Program	5 (Medium)	This policy option receives a medium score of 5 for effectiveness. It addresses two barriers for hydrogen adoption. 1. **Community Capacity** Training programs will increase the knowledge base in a community and increase the capacity to operate and maintain hydrogen equipment. 2. **Public Acceptance** As identified in interviews having trusted members of a community be familiar with hydrogen technologies can help assuage any fears community members may have and build confidence that hydrogen is safe.
Low Carbon Fuel Standard	4 (Medium)	This policy option receives a medium score of 4 for effectiveness. It addresses two barriers for hydrogen adoption. 1. **High Cost of Hydrogen Projects** Expanding the Low Carbon Fuel Standard to green hydrogen will allow communities producing hydrogen from renewable electricity to earn credits. They can then sell these credits to carbon intensive fuel producers in the province. This policy may improve the economics of a hydrogen project by providing a source of income for the project. In January 2022 the average price per credit was about $486 (Ministry of Energy, Mines and Low Carbon Innovation, 2022). 2. **Capacity Building** This policy results in a marginal increase in a community's financial capacity as it is able to earn credits for hydrogen production.
Reduce Regulatory Uncertainty	4 (Medium)	This policy option receives a medium score of 4 for effectiveness. It addresses two barriers for hydrogen adoption. 1. **Regulatory Clarity**

Policy	Score	Description
		This policy addresses jurisdictional uncertainty by recommending a regulatory mapping exercise to define the nature of regulatory responsibility and fill in gaps that may arise. It also recommends adopting Canadian codes and standards as they are published further reducing uncertainty in regulation. **2. Capacity Building** This policy builds administrative capacity in a community undertaking a hydrogen project as it reduces the burden on the community to navigate an unclear regulatory environment.

9.2.2. Fairness, Justice and Equity for First Nations

Policy	Score	Description
Training Program	9 (High)	This policy option receives a high score of 9 for fairness, justice and equity for First Nations. The training program has an emphasis on admitting Indigenous students and will prioritize their acceptance, although non-Indigenous students will also be admitted. Additionally, Indigenous students will have all program fees waved.
Low Carbon Fuel Standard	1 (Low)	This program does not have contingencies for First Nations, it therefor receives a low score of 1.
Reduce Regulatory Uncertainty	1 (Low)	This program does not have contingencies for First Nations, it therefor receives a low score of 1.

9.2.3. Administrative Complexity

Policy	Score	Description
Training Program	5 (Medium)	This policy option receives a medium score of 5 for administrative complexity. In funding training programs this policy would involve mainly one level of government, the provincial government, and technical institutions such as BCIT. The federal government may provide funding in the form of student bursaries or scholarships. Although this policy option is focused on funding for this program, and not it's design, it should be noted that other organizations may be involved in that phase to provide expertise and input.

Policy	Score	Description
Low Carbon Fuel Standard	9 (High)	This policy option receives a high score of 9 for administrative complexity This is a relatively straight forward policy option which only includes the provincial government expanding the existing Low Carbon Fuel Standard Regulation. This is an already established process.
Reduce Regulatory Uncertainty	3 (Low)	This policy option receives a low score of 3 for administrative complexity. It would require two level of government, several regulatory organizations and industry. The provincial government, Technical Safety BC, the BCUC, the OGC and other industry organizations should work together to map the regulatory environment for hydrogen and identify jurisdictional responsibility and any gaps that may exist. It also requires regulatory organizations such as Technical Safety BC to work with the federal government to develop harmonized codes and standards for adoption in the province. It should be noted that these are discussions that are already happening and do have some established frameworks for this type of work, which is why this policy scores a 3.

9.2.4. Cost to Government

Policy	Score	Description
Training Program	5 (Medium)	This policy option receives a medium score of 5 for cost to government. This program will require funding from the federal government as well as some human resource support to implement. The Circuit Rider Training Program is a federal program which provides training to First Nations for water and waste-water system operators. Indigenous Services Canada invest approximately $12 million per year into the program (Indigenous Services Canada, 2011). As water and waste water treatment are essential in all communities and hydrogen training will only be relevant to those communities who take on projects costs will likely be significantly lower. This result in the medium score for cost to government.
Low Carbon Fuel Standard	9 (High)	This policy option receives a high score of 9 for cost to government. This is relatively inexpensive as it will only require the human resource and administrative capacity from the government to expand the existing Low Carbon Fuel Standard regulation.
Reduce Regulatory Uncertainty	7 (High)	This policy option receives a high score of 7 for cost to government. This policy would require only some human resource expenditure from the government to accomplish the regulatory work of developing codes and standards and regulatory mapping. It would also have some costs from monitoring and enforcement.

9.2.5. Capacity Building

Policy	Score	Description
Training Program	6 (Medium)	This policy option receives a medium score of 6 for capacity building. The training program is aimed to build capacity in one area which is local maintenance and operational capacity. It does this through providing hands on training to community members. This capacity building will be over the medium term. This training will need to be re-administered as new community members take on the task. Additionally, if there are system upgrades, training will need to be updated, or risk expertise being out of date.
Low Carbon Fuel Standard	4 (Medium)	This policy option receives a medium score of 4 for capacity building. It marginally builds financial capacity in the community as the low carbon fuel standards will allow them to earn credits which can then be sold to high emitting fuel producers. Although depending how much hydrogen a community is producing this may be relatively small. This increase will not be over the long term though as we transition away from high emitting fuels. With the increasing in stringency of the low carbon fuel standard, the zero-emission vehicle standard and the carbon tax there may be fewer high emitting producers looking to purchase credits.
Reduce Regulatory Uncertainty	4 (Medium)	This policy option receives a Medium score of 4 for capacity building. It aims to provide regulatory clarity for communities taking on hydrogen projects. This can reduce the administrative burden on communities attempting to navigate that regulatory environment. This additional administrative capacity can be maintained over the long term as codes and standards and regulatory bodies stay up to date over the lifetime of a hydrogen project.

9.2.6. Evaluation Result Summary

The following tables provides a summary of each policy option and how they scored for the criteria. No option satisfied all the criteria and each had critical trade-offs. The goal of the analysis is to prioritize each of the policies.

Table 14: General Policies Evaluation Results

Criteria	Policy Options		
	Training Programs	**Low Carbon Fuel Standard**	**Reduce Regulatory Uncertainty**
Effectiveness (x2)	Medium 5	Medium 4	Medium 4
Fairness, Justice and Equity for First Nations	High 9	Low 1	Low 1
Administrative Complexity	Medium 5	High 9	Low 3
Cost to Government	5 Medium	High 9	High 7
Capacity Building	Medium 6	Medium 4	Medium 4
Total	35	31	23

Chapter 10. Recommendations

10.1. Funding Based Policies

A comparison of funding-based policies revealed a high score of 38 for the hydrogen grant program. Although, the hydrogen grant program and the pilot project, performed similarly for most of the criteria. They both have contingencies for First Nations, are relatively complex, come with high costs, and build lasting capacity in communities. The major difference between the two policies is the effectiveness of the programs. A hydrogen grant program results in more hydrogen projects and incentivizes more investment than a pilot project. Although it should be noted that a pilot project still scored a medium for effectiveness.

Overall, the hydrogen grant program serves to increase investment in hydrogen, provide valuable learnings for future projects and ultimately results in the implementation of hydrogen in an off-grid setting. This will serve as an important step as we consider the general policies, discussed below.

10.2. General Policies

It is recommended that all of the general policies be implemented, with the exception of one, in the priority order described below.

Training programs had the highest score and are therefore the highest priority for implementation. This policy scored the highest for Fairness, Justice and Equity for First Nations as it was the only general policy to have contingencies for Indigenous communities. It scored in the medium range for all other criteria. This policy is essential for building capacity and for providing the operation and maintenance knowledge that communities need to run projects with a hydrogen component. The Low Carbon Fuel standard is recommended as the second priority policy for adoption. It scored only 4 points lower than the training programs. It performed well in terms of cost and administrative complexity. This policy is relatively simple to implement but could provide some financial incentives, through low carbon credits, for communities to adopt hydrogen. Its impact will be modest, which is reflected in its medium score for effectiveness.

Finally, reducing regulatory uncertainty is ranked third in priority for adoption. This policy is important to removing the barrier of regulatory uncertainty, especially in creating codes and standards, which is essential for hydrogen adoption. It does have some limitations in scope as it specifically targets only one barrier, although it may have some effect on community capacity. It's low cost to government but relatively complex to implement and does not have any contingencies for First Nations.

10.3. Limitations

There are several important limitations to consider. Firstly, the case studies are mostly feasibility studies. There was a lack of research on completed projects, which have a hydrogen component. Additionally, the HARP project, the only project in a BC setting, did not have financial information available to me.

This analysis focused on Indigenous and non-Indigenous communities. Although this study did attempt to encompass the differences between the two contexts, it is a wide scope to cover. First Nations exist within different environments and have different priorities, unique from one another. Delving deeper into the First Nation context could be a whole area of study in itself. This research may not have covered all the nuances of the Indigenous setting.

Although the interviews did include some technical experts, this paper is focused on a policy analysis. There may be important technical implications not included in this research.

Chapter 11. Conclusion

Hydrogen has the opportunity to a part of the transition away from diesel, for electricity generation, in remote off-grid communities,although, it still faces many barriers to adoption. Many of these challenges can be overcome with government policy and the expansion of the hydrogen economy.

Hydrogen as a flexible energy carrier can be used in remote settings in several ways. It can be transported into communities to be utilized in electricity generation through fuel cells or through combustion. It can also be generated in the community via electrolysis from renewable electricity. Based on case studies, a hybrid hydrogen solution seems to be the most common and feasible project design. This usually means a combination of renewable electricity, hydrogen and diesel power sources. Case studies show that this hybrid design can reduce the levelized cost of energy in communities and reduce the use of diesel, which as detailed in Chapter 2 has many damaging effects.

Implementation of hydrogen in a remote setting still has many barriers, which include high capital costs of hydrogen projects, significant risk from hydrogen as a new technology, a lack of clarity when it comes to the hydrogen regulatory environment and an absence of local community maintenance and operational expertise. These barriers can be especially pronounced for First Nation communities, which face a different landscape for clean energy adoption. For a complete list of barriers refer to Appendix A.

Overall, this study concludes that a hydrogen grant program be implemented to spur investment into hydrogen projects in off-grid communities. Additionally, three general policies are recommended in priority order. These are training programs, Low Carbon Fuel Standard and reducing regulatory uncertainty. Please refer to Chapter 10 for details on the final recommendations.

Hydrogen is not right for every community. There are many options for clean energy solutions and implementation must be based on what is right in each community setting. This is particularly true for First Nations where it is essential that government not be prescriptive. Nations must decide for themselves if hydrogen will work in their unique circumstance. Tennets of reconciliation and DRIPA must be centred in any hydrogen project which includes First Nations.

References

ATCO. (2021). *Suncor and ATCO partner on a potential world-scale clean hydrogen project in Alberta*. ATCO. https://www.atco.com/en-au/about-us/news/2021/122920-suncor-and-atco-partner-on-a-potential-world-scale-clean-hydroge.html

BC Hydro. (2012). *Hydrogen Assisted Renewable Power Project—Unpublished Report*.

BC Hydro. (2022). *Final Argument on behalf of British Columbia Hydro and Power Authority*. https://docs.bcuc.com/Documents/Arguments/2022/DOC_65303_2022-01-12-BCH-Final-Argument.pdf

BC Utilities Commission. (n.d.). *What We Do—Energy Utilities*. BC Utilities Commission. Retrieved February 22, 2022, from https://www.bcuc.com/WhatWeDo/EnergyUtilities

BC Utilities Commission. (2020). *British Columbia Utilities Commission – Inquiry into the Regulation of Safety – Regulatory Timetable*. https://docs.bcuc.com/Documents/Proceedings/2020/DOC_59260_A-1-G-241-20-Regulatory-Timetable.pdf

BCUC. (n.d.). *Natural Gas Customer Choice Program*. BC Utilities Commission. Retrieved March 9, 2022, from https://www.bcuc.com/WhatWeDo/NaturalGas

Chade, D., Miklis, T., & Dvorak, D. (2015). Feasibility study of wind-to-hydrogen system for Arctic remote locations – Grimsey island case study. *Renewable Energy*, *76*, 204–211.

Community Clean Energy Branch. (n.d.). *CleanBC Remote Community Energy Strategy (RCES)*. Government of British Columbia; Province of British Columbia. Retrieved February 22, 2022, from https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/community-energy-solutions/remote-community-energy-strategy-rces

Corpuz-Bosshart, L. (2021, May 5). *UBC breaks ground on $23 million renewable energy hub*. UBC News. https://news.ubc.ca/2021/05/05/ubc-breaks-ground-on-23-million-renewable-energy-hub/

Dawson, T. (2022, March 8). As gas prices soar in wake of Ukraine war, Canadians could see cost of goods go up. *National Post*. https://nationalpost.com/news/canadian-economy-faces-inflationary-trend-as-gas-prices-soar

Environment and Climate Change Canada. (2018, October 23). *Carbon pollution pricing systems across Canada* [Government of Canada]. https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work.html

Environment and Climate Change Canada. (2020a, December 11). *A Healthy Environment and a Healthy Economy* [Government of Canada]. https://www.canada.ca/en/environment-climate-change/news/2020/12/a-healthy-environment-and-a-healthy-economy.html

Environment and Climate Change Canada. (2020b, December 18). *What is the clean fuel standard?* Government of Canada. https://www.canada.ca/en/environment-climate-change/services/managing-pollution/energy-production/fuel-regulations/clean-fuel-standard/about.html

FortisBC. (2022). *Final Submission of FortisBC Energy Inc. And FortisBC Inc. On Stage 1 Issues*. https://docs.bcuc.com/Documents/Arguments/2022/DOC_65301_2022-01-12-FortisBC-Final-Argument.pdf

Frangoul, A. (2021, January 19). Canada is set to have one of the world's biggest green hydrogen plants. *CNBC*. https://www.cnbc.com/2021/01/19/canada-is-set-to-have-one-the-worlds-biggest-green-hydrogen-plants.html

Government of British Columbia. (n.d.-a). *BC Community Climate Funding Guide*. Community Climate Funding. Retrieved February 22, 2022, from https://communityclimatefunding.gov.bc.ca/

Government of British Columbia. (n.d.-b). *CleanBC Communities Fund*. Community Climate Funding. Retrieved March 14, 2022, from https://communityclimatefunding.gov.bc.ca/funding/7a359a9e-7f9c-eb11-b1ac-000d3a09c32e

Government of British Columbia. (1980). *Utilities Commission Act*. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/96473_01

Government of British Columbia. (2008, May). *Oil and Gas Activities Act*. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/08036_01

Greenhouse Gas Reduction (Clean Energy) Regulation, B.C. Reg. 102/2012 (2012). https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/102_2012

Government of British Columbia. (2019). *British Columbia Hydrogen Study*. https://www2.gov.bc.ca/assets/gov/government/ministries-organizations/zen-bcbn-hydrogen-study-final-v6.pdf

Government of British Columbia. (2021a). *BC Hydrogen Strategy*. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/electricity/bc-hydro-review/bc_hydrogen_strategy_final.pdf

Government of British Columbia. (2021b). *CleanBC Roadmap to 2030*. https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/cleanbc/cleanbc_roadmap_2030.pdf

Government of Canada. (2020). *Hydrogen strategy for Canada*. https://epe.lac-bac.gc.ca/100/201/301/weekly_acquisitions_list-ef/2021/21-10/publications.gc.ca/collections/collection_2021/rncan-nrcan/M134-65-2020-eng.pdf

Grant, A., & Sagoo, B. (2010, July). *Hydrogen Assisted Renewable Power (HARP) Project in British Columbia*. Vancouver 2010 Symposium on Microgrids, Vancouver Fairmont Pacific Rim. http://microgrid-symposiums.org/wp-content/uploads/2014/12/vancouver_grant-sagoo.pdf

Hajimiragha, A. H., & Zadeh, M. R. D. (2013). Research and development of a microgrid control and monitoring system for the remote community of Bella Coola: Challenges, solutions, achievements and lessons learned. *2013 IEEE International Conference on Smart Energy Grid Engineering (SEGE)*, 1–6. https://doi.org/10.1109/SEGE.2013.6707898

Hamelin, P., Dube, N., Cajvan, P., Stano, M., Rochon, Q., Hobbs, E., & Van Soelen, L. (2021). *The Frontier comes into view: Canadian governments' hydrogen strategies*. Gowling WLG. https://gowlingwlg.com/en/insights-resources/articles/2021/canadian-governments-hydrogen-strategies/

He, E. (2021). *Reducing emissions from diesel generators in remote communities* (p. 8). https://www.pembina.org/reports/reducing-emissions-diesel-remote-communities.pdf

HTEC. (2021, April 20). HTEC has partnered with Mitsui & Co. (Canada), Ltd, to develop electrolytic hydrogen production project in British Columbia that will provide fuel to HTEC's network of fueling stations and help decarbonize local natural gas use. *HTEC*. https://www.htec.ca/htec-has-partnered-with-mitsui-co-canada-ltd-to-develop-electrolytic-hydrogen-production-project-in-british-columbia-that-will-provide-fuel-to-htecs-network-of-fueling-stations-and-hel/

Hydrogen Council. (2020). *Path to Hydrogen Competitiveness*. Hydrogen Council. https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf

Hyfindr. (2021, March 21). Technology Readiness Level in the Hydrogen Economy. *Hyfindr - Knowledge Hub*. https://hyfindr.com/technology-readiness-level/

Impact Canada. (n.d.). *IndigenousIndigenous Off-diesel Initiative*. Government of Canada. Retrieved February 28, 2022, from https://impact.canada.ca/en/challenges/off-diesel

Indigenous Services Canada. (2008a, November 3). *Community Opportunity Readiness Program (CORP)*. Government of Canada. https://www.sac-isc.gc.ca/eng/1100100033417/1613659339457

Indigenous Services Canada. (2008b, November 3). *First Nation Infrastructure Fund*. Government of Canada. https://www.sac-isc.gc.ca/eng/1100100010656/1533645154710

Indigenous Services Canada. (2011, August 15). *Circuit Rider Training Program*. Government of Canada. https://www.sac-isc.gc.ca/eng/1313424571273/1533818103401

International Energy Agency. (2012). *Renewable Energies for Remote Areas and Islands (Remote)*. IEA- Renewable Energy Technology Deployment. http://iea-retd.org/wp-content/uploads/2012/06/IEA-RETD-REMOTE.pdf

International Energy Agency. (2019). *The Future of Hydrogen*. https://iea.blob.core.windows.net/assets/9e3a3493-b9a6-4b7d-b499-7ca48e357561/The_Future_of_Hydrogen.pdf

IRENA. (2018). *Hydrogen from renewable power: Technology outlook for the energy transition*. International Renewable Energy Agency. https://www.irena.org/-/media/files/irena/agency/publication/2018/sep/irena_hydrogen_from_renewable_power_2018.pdf

Jaccard, M. (2020). *The Citizen's Guide to Climate Success*. Cambridge University Press. 10.1017/9781108783453

Kennedy, M. (2014). *Energy Shift: Reducing Diesel Reliance in Remote Communities in BC* [Simon Fraser University]. http://summit.sfu.ca/item/17979

Lovekin, D., & Heerema, D. (2019a). Diesel, renewables, and the future of Canada's remote communities. *Pembina Institute*. //www.pembina.org/blog/remote-microgrids-intro

Lovekin, D., & Heerema, D. (2019b). *The True Cost of Energy in Remote Communities* (p. 7). https://www.pembina.org/reports/diesel-cost-backgrounder-2019.pdf

Magtibay, M., & Wong, D. (2013). *Design of a hybrid renewable energy system for a northern ontario community*. IEEE. https://ieeexplore-ieee-org.proxy.lib.sfu.ca/document/6713648

Masterson, V. (2021). These 4 energy storage technologies are key to climate efforts. *World Economic Forum*. https://www.weforum.org/agenda/2021/04/renewable-energy-storage-pumped-batteries-thermal-mechanical/

Ministry of Energy, Mines and Low Carbon Innovation. (n.d.-a). *Community Energy Leadership Program*. Government of British Columbia; Province of British Columbia. Retrieved March 8, 2022, from https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/community-energy-solutions/community-energy-leadership-program

Ministry of Energy, Mines and Low Carbon Innovation. (n.d.-b). *Innovative Clean Energy (ICE) Fund*. Government of Canada; Province of British Columbia. Retrieved March 1, 2022, from https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/innovative-clean-energy-solutions/innovative-clean-energy-ice-fund

Ministry of Energy, Mines and Low Carbon Innovation. (n.d.-c). *Zero-Emission Vehicles Act*. Government of British Columbia; Province of British Columbia. Retrieved February 22, 2022, from https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/zero-emission-vehicles-act

Ministry of Energy, Mines and Low Carbon Innovation. (2022). *Renewable and Low Carbon Fuel Requirements Regulation Monthly Credit Market Report – January 2022*. Government of British Columbia. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/transportation/renewable-low-carbon-fuels/monthly_credit_market_report_-_2022-01.pdf

Ministry of Indigenous Relations and Reconciliation. (n.d.). *First Nations Clean Energy Business Fund*. Government of British Columbia; Province of British Columbia. Retrieved March 8, 2022, from https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/consulting-with-first-nations/first-nations-clean-energy-business-fund

Morton, D. M., Brewer, C., Fung, A. K., & Lockhart, E. B. (2020). *Indigenous Utilities Regulation Inquiry*. BC Utilities Commission. https://www.ordersdecisions.bcuc.com/bcuc/decisions/en/470256/1/document.do

Natural Resources Canada. (2013, June 20). *Status of Remote/Off-Grid Communities in Canada*. Natural Resources Canada. https://www.nrcan.gc.ca/energy/publications/sciences-technology/renewable/smart-grid/11916

Natural Resources Canada. (2016, September 12). *Remote Communities Energy Database*. Government of Canada; Natural Resources Canada. https://atlas.gc.ca/rced-bdece/en/index.html

Natural Resources Canada. (2017, July 4). *Clean Energy for Rural and Remote Communities: BioHeat, Demonstration & Deployment Program Streams*. Government of Canada; Natural Resources Canada. https://www.nrcan.gc.ca/reducingdiesel

Natural Resources Canada. (2018, January 16). *Emerging Renewable Power Program*. Government of Canada; Natural Resources Canada. https://www.nrcan.gc.ca/climate-change/green-infrastructure-programs/emerging-renewable-power/20502

Natural Resources Canada. (2021, June 16). *Clean Fuels Fund*. Government of Canada; Natural Resources Canada. https://www.nrcan.gc.ca/climate-change-adapting-impacts-and-reducing-emissions/canadas-green-future/clean-fuels-fund/23734

New Relationship Trust. (2017, May 2). *BC Indigenous Clean Energy Initiative*. New Relationship Trust. http://www.newrelationshiptrust.ca/initiatives/bcicei/

Patel, S. (2021, February 1). Countries Roll Out Green Hydrogen Strategies, Electrolyzer Targets. *POWER Magazine*. https://www.powermag.com/countries-roll-out-green-hydrogen-strategies-electrolyzer-targets/

Renewable Hydrogen Canada. (n.d.-a). *Renewable Hydrogen Canada*. RH2C. Retrieved February 21, 2022, from http://www.renewableh2canada.ca/

Renewable Hydrogen Canada. (n.d.-b). *Renewable Hydrogen Project Fact Sheet*. Retrieved February 21, 2022, from http://www.renewableh2canada.ca/uploads/1/2/2/3/122301472/sundance_renewable_hydrogen_project-_factsheet.pdf

Rezaei, M., & Dowlatabadi, H. (2016). Off-grid: Community energy and the pursuit of self-sufficiency in British Columbia's remote and First Nations communities. *Local Environment*, *21*(7), 789–807. https://doi.org/10.1080/13549839.2015.1031730

Roberts, D. (2020). Renewable energy and 100% clean power targets: The missing puzzle piece. *Vox*. https://www.vox.com/energy-and-environment/2020/3/28/21195056/renewable-energy-100-percent-clean-electricity-power-to-gas-methane

Tae, C. (2021, January). *Hydrogen Safety: Let's Clear the Air*. NRDC. https://www.nrdc.org/experts/christian-tae/hydrogen-safety-lets-clear-air

Technical Safety BC. (n.d.-a). *Jurisdiction*. Technical Safety BC. Retrieved March 9, 2022, from https://www.technicalsafetybc.ca/about-us/jurisdiction

Technical Safety BC. (n.d.-b). *Regulatory Framework*. Technical Safety BC. Retrieved December 17, 2021, from https://www.technicalsafetybc.ca/about-us/regulatory-framework

Technical Safety BC. (n.d.-c). *Technical Safety BC Jurisdiction*. Technical Safety BC. Retrieved February 22, 2022, from https://www.technicalsafetybc.ca/about-us/jurisdiction

Technical Safety BC. (2021). *BCUC Inquiry into the Regulation of Safety—Technical Safety BC Submission*. https://docs.bcuc.com/Documents/Proceedings/2020/DOC_59774_C12-2-TechnicalSafetyBC-submission.pdf

The Impact of the Bella Bella Diesel Spill. (n.d.). Retrieved December 16, 2021, from https://canadac3.ca/en/video/impact-bella-bella-diesel-spill/

Transport Canada. (2021, June 29). *Building a green economy: Government of Canada to require 100% of car and passenger truck sales be zero-emission by 2035 in Canada*. Government of Canada. https://www.canada.ca/en/transport-canada/news/2021/06/building-a-green-economy-government-of-canada-to-require-100-of-car-and-passenger-truck-sales-be-zero-emission-by-2035-in-canada.html

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

Zen and the Art of Clean Energy Solutions. (2019). *British Columbia Hydrogen Study*. https://www2.gov.bc.ca/assets/gov/government/ministries-organizations/zen-bcbn-hydrogen-study-final-v6.pdf

Appendix A. Summary of Barriers to Hydrogen Adoption

The literature review and interviews uncovered many important barriers for hydrogen adoption in off-grid communities in BC. The case studies provided additional context and detail for those barriers. Below is a summary table of the barriers.

Table A.1: Summary of Barriers

Barrier	Description
Economic Barriers	
High Cost of Hydrogen Projects	Identified by the literature review and interviewees hydrogen projects have high upfront capital costs when compared to diesel projects. The Fort Hope case study estimated that a hybrid run-of-river hydro, diesel, and hydrogen project could be $4.6 million. Although the cost of hydrogen technologies is falling. One interviewee estimated that the cost of a hydrogen project would be 2-3 times lower now than it was in 2013 during the HARP project.
Economies of Scale	Communities with small populations cannot realize economies of scale. They still face the same project costs but a smaller consumer base.
Access to Funding	Despite the availability of funding programs for clean energy solutions they are not always easily accessed for small remote communities. Funding programs are often fragmented and require a significant amount of administrative capacity to complete the applications and reporting required. Additionally, small communities are often put into the same pools as large established utilities which are difficult to compete with.
Technical Barriers	
Risk of New Technology	New technologies are often riskier than more established technologies. Implementing hydrogen technologies in a remote setting can pose a greater risk of blackouts and system failures.
Community Capacity	Due to the remoteness and small community size in a remote setting there is a lack of local maintenance and operational expertise.
Challenges of Additional Forms of Energy	Additional forms of energy in a community's energy system can result in a need for enhanced control systems. This can increase the financial demand for the project as well as the need for local expertise.
Technological Readiness	Hydrogen technologies in a remote off-grid setting are not considered commercially available. Additionally there are few off the shelf solutions available for implementation, although some existing systems could be modified for use in off-grid communities.
Remoteness of Communities	Remote communities can experience extreme weather which requires technology to be robust. Additionally the long distance from urban settings can be problematic for access to the community for maintenance or even shipping equipment there for installation.
Public Acceptance	Lack of awareness of hydrogen technologies and fear of hydrogen combustion can prevent communities from accepting this technology.

Barrier	Description
Transport	Transporting hydrogen into a community is difficult and there is not an established supply chain to deliver hydrogen to communities.
Regulatory Barriers	
True Cost of Diesel	The cost of diesel does not always include the non-financial costs to communities and the environment. This makes it difficult to compare with hydrogen as it may seem cheaper without the inclusion of its damaging effects. Additionally subsidies may obscure the true cost of diesel.
Regulatory Clarity	There is a lack of regulatory clarity when it comes to jurisdictional responsibility. There is also a lack of Canadian codes and standards relating to hydrogen.
Water Regulation	The Water Sustainability Act lacks a legislated use of water for producing hydrogen. Something that is needed so communities are able to produce hydrogen on site from renewable electricity.
Energy Purchasing Agreements (EPAs)	Hydrogen is not considered commercially available by BC Hydro. This means communities are unable to acquire EPAs which can be essential in providing a guaranteed purchaser for the hydrogen they produce.

Appendix B. Summary of Parallel Policies

Table B.1: Federal Parallel Policies

Policy	Description
Clean Fuel Standard	Requires liquid fuel (gasoline, diesel, home heating oil) suppliers to lower the carbon intensity of their supply over time. The goal is to achieve a 13% decrease, below 2016 levels, in carbon intensity by 2030. This regulation is set to be published in spring 2022 (Environment and Climate Change Canada, 2020b).
Federal Carbon Tax	Puts a price on carbon to ensure the true cost of emissions is reflected in the price of fuel. It aims to create an economic environment where low carbon fuels are more affordable. This tax comes into effect in provinces that do not have an equivalent policy (Environment and Climate Change Canada, 2018).
Low Carbon and Zero Emissions Fuel Fund	$1.5B fund to support domestic production and use of low carbon fuels in Canada (Environment and Climate Change Canada, 2020a).
Zero Emissions Vehicles Standard	Standard which requires all new sales of light-duty cars and passenger trucks to be zero emissions by 2035 (Transport Canada, 2021). This standard can help to develop the low carbon fuel economy, including hydrogen.

Table B.2: BC Provincial Parallel Policies

Policy	Description
Low Carbon Fuel Standard	Requires fuel suppliers to decrease the average carbon intensity of their fuels by 20% relative to 2010 levels by 2030. Additionally, through the Part 3 Agreement Program suppliers can receive credits for projects that increase the use of low carbon fuels sooner than would otherwise happen (Government of British Columbia, 2021a).
BC Carbon Tax	Puts a price on carbon to ensure the true cost of emissions is reflected in the price of fuel, aims to create an economic environment where low carbon fuels are more affordable (Ministry of Environment and Climate Change Strategy, n.d.).
Zero Emissions Vehicles Act	Requires Automakers to meet an escalating annual percentage of new light duty ZEV sales and leases. Reaching 100% by 2040 (Ministry of Energy, Mines and Low Carbon Innovation, n.d.-c).
Clean Industry and Innovation Rate	Clean Industry and Innovation Rate – BC Hydro offers a discounted rate of electricity for hydrogen production (Government of British Columbia, 2021a).
Greenhouse Gas Reduction Regulation	This regulation, under the Clean Energy Act, allows government to set out prescribed undertakings to reduce greenhouse gas emissions that utilities may choose to carry out and still recover the cost in their rates. Specifically it allows utilities to produce or purchase hydrogen for the displacement of fossil fuels (Greenhouse Gas Reduction (Clean Energy) Regulation, 2012).