Hydrogen for Remote Communities

FINAL REPORT

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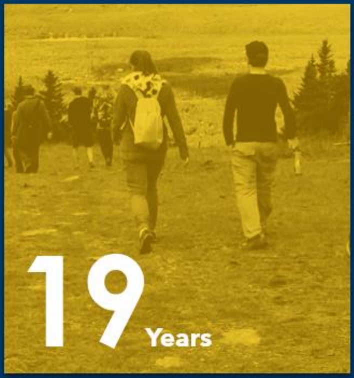
About Dunsky



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EXECUTIVE SUMMARY

Remote, off-grid communities and those at the end of transmission lines (“end-of-line communities”) in British Columbia (BC) continue to rely on diesel generators for their power and heating needs or as a backup source for the electricity they receive from the integrated grid. While diesel has historically served as a reliable energy source, its usage comes with a host of negative social, economic, and environmental ramifications. As such, the benefits of reducing diesel consumption are diverse, encompassing reducing greenhouse gas (GHG) emissions, economic development in remote communities, and fulfilling the province’s reconciliation commitments with Indigenous communities.

The province, via the CleanBC Remote Community Energy Strategy (RCES), has set forth an ambitious target to reduce diesel consumption in remote communities by over 80%, relative to 2019, by the year 2030.[1] However, achieving this ambitious goal is no small feat. Remote communities rely heavily on diesel for energy needs and face significant challenges in transitioning to cleaner sources of power. Despite its reliability, diesel's high cost and environmental and social impacts underscore the urgent need for alternative energy solutions. Renewable energy sources such as solar and wind undoubtedly play a pivotal role in decarbonization efforts. Yet, the transition to these sources presents their own technical, social, financial, and environmental challenges. Additionally, the integration of energy storage solutions such as lithium batteries, while promising in addressing many of these challenges, also faces its barriers.

In this context, hydrogen emerges as a potential contender, offering alternative pathways toward decarbonization in remote and end-of-line communities. To date, there has been limited exploration of the potential for hydrogen in remote communities. Accordingly, to address this research gap, the Fraser Basin Council has retained Dunsky Energy + Climate Advisors to undertake a study to explore the role of hydrogen in these communities. In particular, this study delves into the potential of hydrogen to drive decarbonization in remote communities by:

- Examining the various pathways for decarbonizing remote communities and the potential role hydrogen can play,
- Summarizing the diverse production pathways, storage and transport methods, and potential demand cases and end-uses and,
- Identifying the enabling conditions for establishing hydrogen ecosystems in remote communities.

Components of a Hydrogen Ecosystem

A hydrogen-based energy system commonly consists of three basic components: production, storage and distribution, and utilization. The practicality of a hydrogen system involves examining various production methods and the specific technologies and components necessary to support the selected hydrogen pathway, such as electrolysis using renewable

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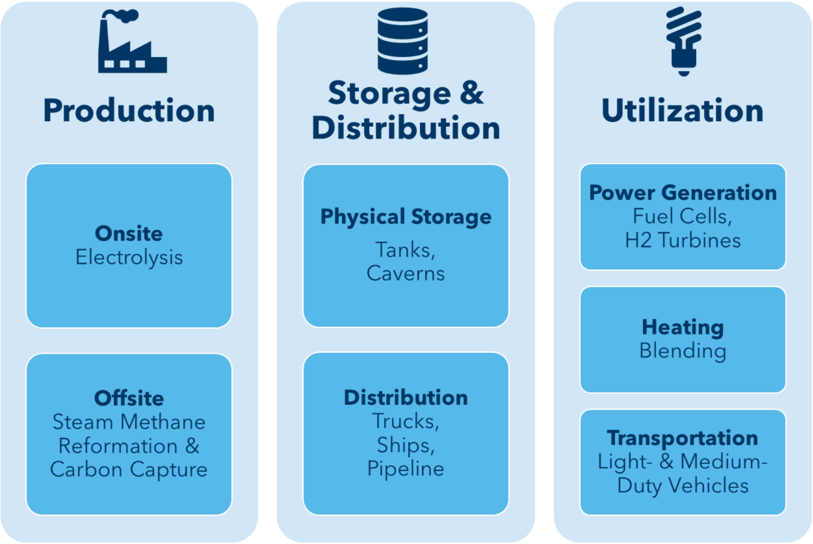
[1] CleanBC Remote Community Energy Strategy (RCES). Accessed February 2024. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/community-energy-solutions/remote-community-energy-strategy-rces

energy sources or importing hydrogen from other jurisdictions. This includes evaluating the applicability of various hydrogen technologies, scalability of hydrogen systems and their overall decarbonization potential, affordability of developing, operating, and maintaining a hydrogen system and, the operational reliability of a hydrogen ecosystem in community-specific conditions.



Enabling Conditions of a Hydrogen Ecosystem

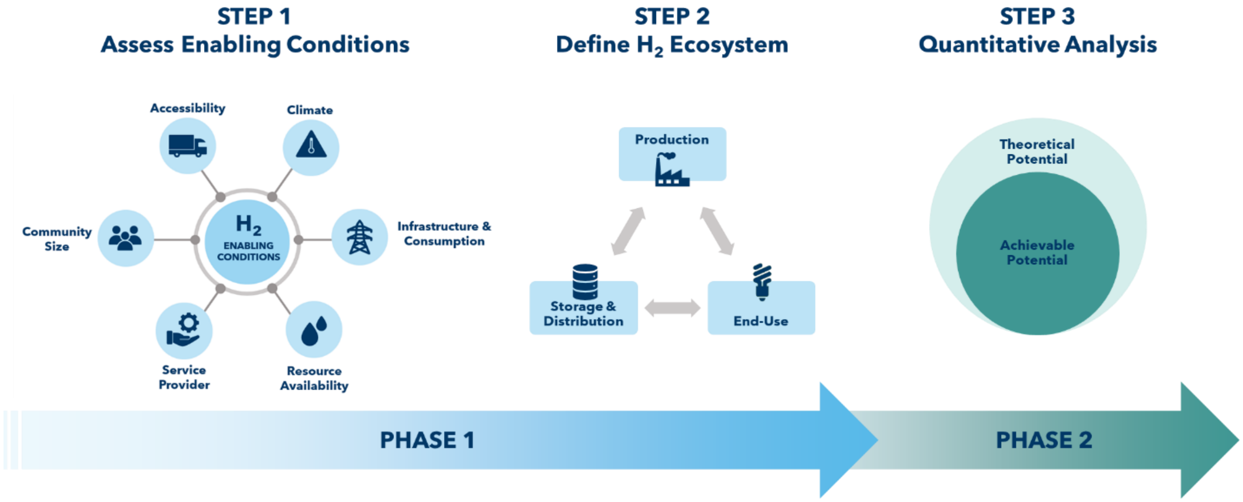
Remote communities are characterized by a set of enabling conditions that influences community-level ability to support the development and integration of new energy systems. Since energy supply in remote communities is strongly linked to various technical, social, economic, and health factors, these enabling conditions govern the viability of energy projects based on how they positively or negatively impact these factors. The degree to which each condition influences the feasibility of an energy system varies and is project dependent however, they can be measured based on how they affect the applicability, scalability, affordability, and reliability of a given technology. There are six key enabling conditions that exist in remote communities within BC.

Potential Role of Hydrogen in Remote Communities

Once the components and operating requirements of hydrogen ecosystems are well understood, a framework can be applied to assess their suitability in remote communities.

1. The first step involves identifying the enabling conditions for each community. This is essential for evaluating the feasibility of different hydrogen technologies and determining which conditions are permissive or prohibitive.
2. The second step is to define the hydrogen pathway(s) most suitable for the community based on the enabling conditions and how they fulfil the minimum requirements for operating different hydrogen components. Project proponents should consider various production, storage and distribution pathways and their ability to meet a community's energy demand needs or use cases.

Defining the most suitable hydrogen pathways based on community-specific conditions establishes a qualitative framework, akin to a pre-feasibility assessment, that can be applied across the diverse remote community classifications within the province. Moving forward, the next phase includes conducting a detailed quantitative analysis to validate the outcomes of the preliminary suitability assessment. This would offer insights into the technical and financial feasibility of specific hydrogen pathways, validating or disproving previously identified theoretical role of hydrogen.



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1. Introduction

Remote, off-grid communities and those at the end of transmission lines ("end-of-line communities") in British Columbia (BC) continue to rely on diesel generators for their power and heating needs or as a backup source for the electricity they receive from the integrated grid. While diesel has historically served as a reliable energy source, its usage comes with a host of negative social, economic, and environmental ramifications. As such, the benefits of reducing diesel consumption are diverse, encompassing reducing greenhouse gas (GHG) emissions, economic development in remote communities, and fulfilling the province's reconciliation commitments with Indigenous communities.

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In this context, hydrogen emerges as a potential contender, offering alternative pathways toward decarbonization in remote and end-of-line communities. To date, there has been limited exploration of the potential for hydrogen in remote communities. Accordingly, to address this research gap, the Fraser Basin Council has retained Dunsky Energy + Climate Advisors to undertake a study to explore the role of hydrogen in these communities. In particular, this study delves into the potential of hydrogen to drive decarbonization in remote communities by:

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- Summarizing the diverse production pathways, storage and transport methods, and potential demand cases and end-uses and,
- Identifying the enabling conditions for establishing hydrogen ecosystems in remote communities.

Moreover, the study underscores the importance of understanding the unique characteristics of remote communities, which can significantly influence the integration and efficacy of hydrogen energy systems. By developing a comprehensive framework, we aim to elucidate the potential role of hydrogen with varied attributes across communities and to delineate how it can drive progress towards decarbonization and reduce diesel dependency.

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[2] CleanBC Remote Community Energy Strategy (RCES). Accessed February 2024. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/community-energy-solutions/remote-community-energy-strategy-rces

2. Energy Use in Remote Communities

2.1 Definitions

In Canada, **remote communities** are considered off-grid settlements which are not currently connected to the North American electrical grid or piped natural gas network. They are permanent or long-term (five years or more) settlements with at least 10 dwellings.[3] The majority of remote communities in BC, as well as in Canada, are Indigenous.[4] These communities operate independently of centralized energy infrastructure and often rely on localized sources of power generation, predominantly diesel generators or sometimes renewable energy systems.

There are additional sub-classifications that apply to some communities which distinguish them from their counterparts.

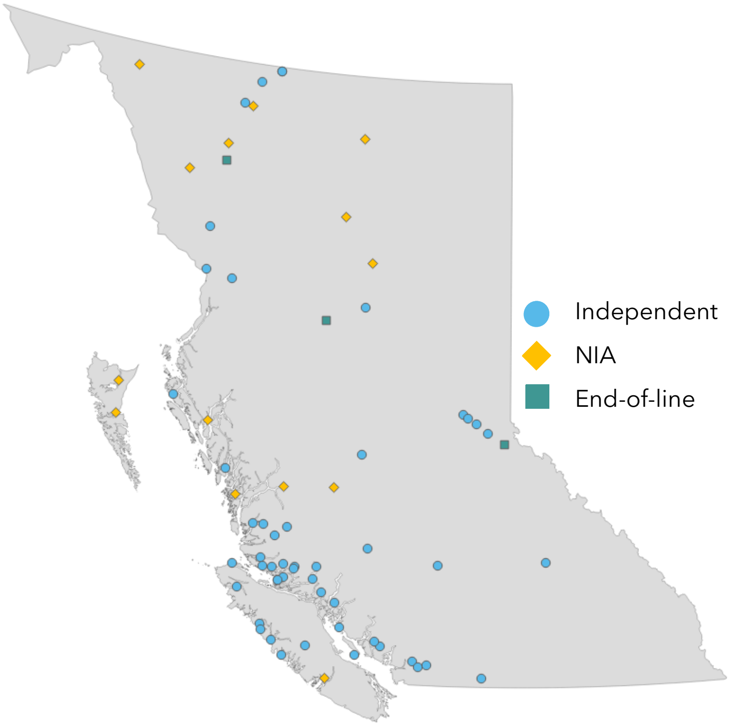

Figure 1. Location of remote communities in BC

Non-Integrated Areas (NIAs) represent a subset of remote communities served by BC Hydro's isolated microgrid systems. Like traditional remote communities, these microgrids are not connected to BC's primary transmission network or the broader North American grid. BC Hydro owns and operates the microgrids, which utilize various sources of electricity generation, predominantly hydro and diesel. An important differentiation between NIAs and conventional remote communities is that some NIA microgrids (but not all) provide energy to multiple off-grid communities. Currently there are 25 remote communities in the province that belong to and are serviced by 14 BC Hydro NIAs.

End-of-line communities are located at the terminus of provincial transmission lines. These are communities that are connected to BC Hydro's transmission network and receive electricity directly from the grid. However, they are also connected to isolated diesel microgrids owned and operated by BC Hydro, occasionally relying on diesel generators for backup generation when demand exceeds supply from the grid or during instances of grid

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[3] Natural Resources Canada. Clean Energy for Rural and Remote Communities Program. Accessed January 2024. https://natural-resources.canada.ca/reducingdiesel

[4] Natural Resources Canada. The Atlas of Canada - Remote Communities Energy Database. Accessed January 2024. https://atlas.gc.ca/rced-bdece/en/index.html

outages or isolation.[5] Due to their size, isolation, and reliance on diesel as a backup source of energy, these communities exhibit many similarities and subsequently experience similar barriers as conventional remote communities. There are three end-of-line communities in BC: McBride, Iskut First Nation (Eddontenajon), and Takla Lake First Nation.[2]

The remaining remote communities in BC are considered **independent**. These communities independently own and operate their own energy systems or have partnerships with private entities that do not include BC Hydro.

These three unique classes reflect the diverse energy landscapes and infrastructure arrangements found within remote communities in BC. Understanding these distinctions is crucial for developing tailored energy solutions and addressing the unique challenges faced by each type of community in terms of energy access, reliability, and sustainability. A summary of remote communities by classification is provided in Appendix B.

For ease of use and the remainder of this report, the term "remote community" will be used to reference all of remote, NIA, and end-of-line communities unless otherwise distinguished.

2.2 Diesel Use in Remote Communities

The majority of remote communities rely on diesel to support their energy needs either as a primary or secondary source of energy. While diesel has many drawbacks, it offers several critical benefits, which have contributed to its dominance as the primary source of energy within these communities, including:

- Diesel is known for its reliability, providing a stable power supply capable of operating in cold and harsh environmental conditions or during extreme weather events, ensuring that essential services such as heating, lighting, and communication remain operational. Many remote communities often face extreme isolation, with some only accessible by plane, boat, or having seasonal road access. A loss of power when projects fail in these settings, means communities may lose access to electricity and the consequences can become life threatening.
- Diesel fuel is also easily stored and transported, making it practical for remote communities with limited access to transportation networks. Portable fuel tanks can be used to store diesel on-site, ensuring a continuous supply of fuel even in the most remote locations. From a technical perspective, diesel generators are relatively easy to install and deploy, making them suitable for emergency situations or temporary energy needs in remote areas.
- Diesel generators are scalable and adaptable to varying energy demands, allowing remote communities to adjust power generation according to their needs. Generator units can be added or removed as required, providing flexibility in energy management. Notably, diesel generators can also provide quick motor starts necessary to meet instantaneous load demand functions that renewables systems (in

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[5] The Rocky Mountain Goat. When the lights go out: How BC Hydro manages back-up power in the Robson Valley. Accessed January 2024.

absence of storage and inverters) have not yet been proven to provide in the context of remote microgrids.[6]

- There is often a sense of comfort and familiarity with diesel fuel within these communities. Diesel is well-established and widely used, making it a known and trusted quantity that community members, technicians, and operators can depend on. Spare parts and maintenance services for diesel generators are generally more accessible compared to newer or specialized energy technologies, ensuring timely repairs and maintenance.

Despite its widespread use and benefits, there is a clear and compelling justification, as well as a pressing desire to transition away from diesel, towards cleaner forms of energy. The consumption of diesel fuel is unavoidably linked to a myriad of harmful health, environmental, climate, and social effects including:

- Diesel combustion emits both air and noise pollution that contributes to environmental degradation, which can disrupt ecosystems, and impair the quality of life for residents in remote communities. Emissions from diesel generators contain toxic pollutants that can lead to respiratory problems, cardiovascular diseases, and other health issues. Additionally, accidental diesel spills and leaks during transportation, storage, or handling can contaminate soil, ground- and surface-water sources, posing long-lasting environmental consequences and risks to human health.
- Diesel combustion releases carbon dioxide (CO2), a potent GHG that contributes to climate change. Remote communities that are forced to rely on diesel generators for electricity and heating contribute to carbon emissions. In 2019, BC remote communities consumed approximately 19.1 million litres of diesel, emitting the equivalent of 51,784 tonnes of CO2.[7]
- Diesel fuel prices are both expensive and volatile, requiring significant subsidization to maintain affordability among remote communities (Figure 2). In some communities, subsidies reduce the cost of diesel by 10 to 30 times.[8] Additionally, these diesel subsidies are not well tracked. Coupled with carbon tax exemptions from regulations, this obscures the true cost of diesel, making it difficult determine the avoided cost (of diesel) from proposed clean energy projects- complicating their business case and discouraging diesel replacement.

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[6] Microgrid Stability with Intermittent Renewables: Renewable Energy Penetration Analysis. GNWT, 2021. Accessed February 2024.

[7] BC Government EMLI. Remote First Nations communities advance clean-energy projects. Accessed February 2024.

[8] World Wildlife Fund. Diesel Subsidies for Remote Communities – Simplified. Accessed February 2024.

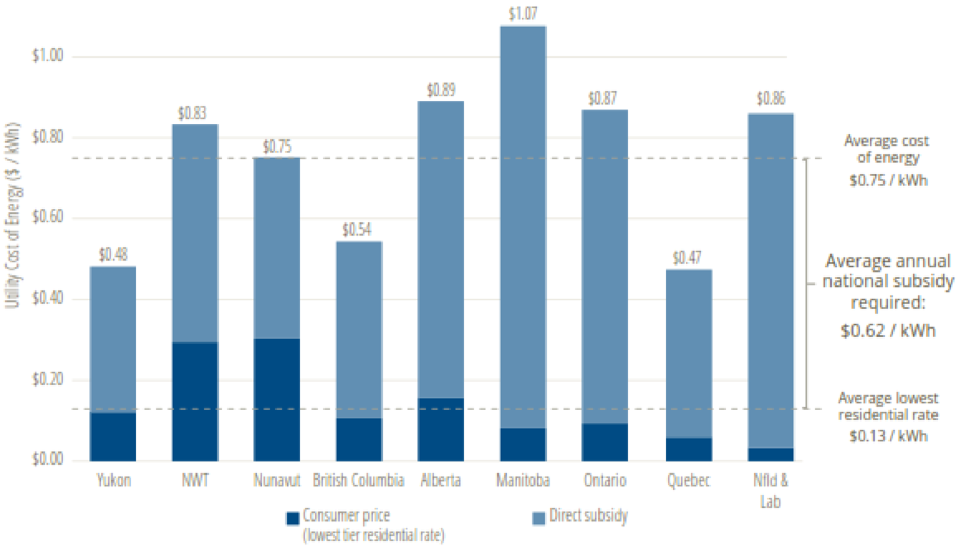

Figure 2. The cost of diesel energy for various utilities compared to the lowest residential rate prices, and levels of subsidization.[8]

2.3 Decarbonization Pathways

Four main pathways to decarbonization in remote communities have been explored to date.[9]

- **Energy efficiency:** Energy efficiency measures involve optimizing energy use to reduce overall consumption and waste. In remote communities, this includes retrofitting buildings with insulation, upgrading heating and cooling systems, and promoting energy-efficient appliances and lighting. By improving energy efficiency, communities can lower energy demand, decrease reliance on fossil fuels, and cut GHG emissions while also saving on energy costs. As part of the Community Energy Diesel Reduction by the Government of BC, remote communities can receive funding for clean energy initiatives including the DSM funding stream which provides funding for retrofit upgrades that results in improved energy efficiency and load management.[10]
- **Renewable electricity:** Generating electricity from renewable sources like solar, wind, and hydro is a key pathway to decarbonization in remote communities. Renewable electricity systems, such as solar PV arrays, wind turbines, and micro-hydro systems, can supply clean and sustainable energy to meet local demand. Renewable electricity contributes to GHG reduction, energy security, and economic development by replacing diesel generators or grid-connected fossil fuel-based power plants. Reductions in diesel fuel consumption has been achieved by integrating small/medium-scale clean and renewable energy projects into remote communities, forming hybrid energy systems. However, the decarbonization progress in the remote communities (excluding end-of-lines) remains slow, with less than 15 communities

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[9] Pembina Institute. Diesel Reduction Progress in Remote Communities Research summary. Accessed January 2024.

[10] New Relationship Trust. Community Energy Diesel Reduction (CEDR). Accessed January 2024.

meeting greater than 50% of their energy demand with renewable resources (Appendix B and C).

- **Renewable heat:** Renewable heat technologies utilize sustainable energy sources such as solar thermal, biomass, geothermal, and heat pumps to provide heating and hot water. In remote communities, where heating demand is often high, transitioning to renewable heat systems helps reduce reliance on fossil fuels like heating oil.
- **Grid interconnection:** Grid interconnection involves connecting remote communities to regional or national electricity grids. This provides communities with access to cleaner and more diverse energy sources, including renewable electricity generated elsewhere. It enhances energy reliability, stability, and resilience by balancing supply and demand across interconnected grids. Moreover, grid interconnection can also facilitate the integration of renewable energy resources and supports the transition to low-carbon electricity systems in remote areas. In BC, there are no instances of remote community grid interconnection.

Key Challenges

The integration of renewables faces several technical, economic, and social barriers and resultingly, progress on diesel reduction is slow, experiencing many challenges. Some of the fundamental challenges unique to renewable energy in remote communities are summarized in the table below.

Table 1. Challenges to renewable energy integration in remote communities

Technical Challenges
Resource availability: Renewable resources may not be consistently available in some communities. Intermittent energy production can pose challenges for meeting continuous energy demand, requiring effective energy storage solutions. **Integration:** Limited grid capacity and technical constraints may restrict the integration of renewable energy into existing electricity networks. Maintaining electric reliability while transitioning to renewable energy sources requires careful planning and investment in grid infrastructure.[11] **Impact on diesel infrastructure:** The need to maintain diesel backup systems alongside renewable energy installations adds complexity and cost. Scaling down diesel usage can negatively affect existing diesel infrastructure. As annual diesel consumption is reduced, diesel infrastructure maintenance requirements may not see corresponding reductions.[12] **Remote and climate:** There are complex logistical challenges with ensuring reliable operation of renewable energy systems in harsh climates and extreme temperatures or weather conditions. The lack of readily available equipment and components designed to withstand these environments complicates the adoption of renewable energy technologies.[13]
The **Colville Lake Solar Project (NWT)** comprises 136.5 kW solar PV plus 200 kWh battery storage. The system is also connected to 350 kW of diesel generator backup capacity and supplies energy to a community of approximately 160 people.[14] Access to the community is seasonal and through a winter road available for a mere few weeks each year.[15] The project's primary goal was to reduce the instances of power outages occurring in the community. While the project has successfully reduced the total outages annually, that number has fluctuated between 10 – 26 annually.[16] The cold, northern climate, combined with complex control systems, has also led to reliability issues and a learning curve in which charging and draining the batteries entirely would lead to operational issues.[14]**Error! Bookmark not defined.** Resultingly, the project has fallen short of it goal to supply 20% of Colville Lake's annual power. Trying to get the battery system and diesel generators to communicate "has been the biggest learning curve in terms of us operating the system".[17]
Economic Challenges
Upfront investment costs: Renewable energy alternatives require significant upfront investment, which can be prohibitive for remote communities with limited financial resources.

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[11] Microgrid Stability with Intermittent Renewables: Renewable Energy Penetration Analysis. GNWT, 2021. Accessed January 2024.
[12] Towards Renewable Energy Integration in Remote Communities: A Summary of Electric Reliability Considerations. NRCan, 2018. Accessed January 2024.
[13] Wind Energy in Cold Climates. NRCan, 2017. Accessed January 2024.
[14] Pembina Institute. Solar PV Case Study: Colville Lake, Northwest Territories. Accessed January 2024.
[15] NWT Power Corporation. Colville Lake Solar Project. Accessed January 2024.
[16] Northern climate poses challenge for Colville Lake's hybrid power system. Accessed January 2024.
[17] Towards Renewable Energy Integration in Remote Communities: A Summary of Electric Reliability Considerations. Accessed January 2024.

Subsidies and carbon tax exemptions: Unclear diesel subsidies lead to distorted business cases for renewable projects, and carbon tax exemptions from regulations discourage diesel replacement. [18, 19]

Limited access to capital: Remote communities, particularly those with small populations and limited economic activity, face challenges in accessing affordable financing options from traditional lenders or financial institutions- hindering investment in renewable energy infrastructure.[20] Of note, initiatives from the Canada Infrastructure Bank (Indigenous Community Infrastructure Initiative) and Government of BC (Community Energy Diesel Reduction) have increased access to funding for remote communities in recent years.

Difficulty achieving economies of scale: Small communities face higher costs for renewable energy infrastructure due to lack of scale. Projects require large upfront investment and larger project sizes lead to a decrease in the cost per unit of energy generated.

Social Challenges

Provincial- and utility-community relationships: The relationships between governments, utilities, and remote communities may be collaborative in some cases but challenging in others. Historically, these relationships may have lacked trust or effective communication, and some communities may prefer to work with Indigenous representatives.

Community capacity: Remote communities may have inadequate workforce capacity to implement and maintain renewable energy systems. Finding a reliable employee can take years if there is limited local capacity.[21]

Familiarity/support for diesel: A top concern for remote communities is energy reliability, and the benefit diesel provides is that it is a known and trusted quantity.[22] Some residents may be accustomed to relying on diesel for power generation and heating, making it difficult to garner support for completely eliminating diesel.

Currently under development, the **Tu Deh-Kah Geothermal Project** will be a 7-15 MW system on an old, depleted gas field in Fort Nelson, BC, with expected completion in 2026. The project is 100% owned by the Fort Nelson First Nation and is poised to become the "first commercial-scale geothermal electricity generating plant in BC."[23] The (remote) community, situated in the northeastern portion of the province, has experienced several challenges due to its isolated location. This includes difficulties acquiring all the necessary materials and finding enough qualified staff.

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[18] The True Cost of Energy in Remote Communities: Understanding diesel electricity generation terms and economics.

[19] Reducing emissions from diesel generators in remote communities, Pembina, 2021.

[20] The Next Generation: Innovating to Improve Indigenous Access to Finance in Canada.

[21] Barriers to and Opportunities for Private Investment in Rural Alaska Energy Projects. UAF, 2016.

[22] Nicholas Mercer et al. (2020). "That's Our Traditional Way as Indigenous Peoples": Towards a Conceptual Framework for Understanding Community Support of Sustainable Energies in NunatuKavut, Labrador"

[23] Tu Deh-Kah Geothermal, Barkley Project Group.

2.4 Potential Roles for Hydrogen

Hydrogen has the potential to significantly contribute to the decarbonization of our economy and energy infrastructure, while complementing renewables. It can address and alleviate challenges associated with traditional decarbonization pathways, particularly the technical challenges associated with integrating renewables in remote communities. Hydrogen possesses aspects that make it a viable clean energy fuel for remote communities.

1. **Scalability.** Electrolytic production of hydrogen is a scalable and clean process that only requires water and clean electricity. As renewable energy sources become cheaper and more accessible, the scalability of hydrogen produced from renewable electricity increases. This means that hydrogen production can be adjusted to match fluctuations in demand, making it adaptable to different community sizes and energy needs.
2. **Versatility:** Hydrogen is a clean fuel that offers optionality in its applications, making it suitable for multiple uses in remote communities. It can be used for heating, power generation, transportation, and storage. Its versatility enables it to meet the energy requirements of various communities. Furthermore, hydrogen can complement existing low-carbon pathways by providing an additional option for integrating renewable energy sources into the energy mix of remote communities.
3. **Reliability:** Hydrogen is a physical fuel that can be stored as a backup fuel. This makes it a reliable option for remote communities, particularly those who face unstable power grids and energy supply challenges. Hydrogen has the potential to be a dependable energy source during times of low renewable energy generation or high energy demand. It can contribute to the overall resilience and reliability of the community's energy infrastructure.

While hydrogen holds significant promise for decarbonizing remote communities through its scalability, versatility, and reliability, it faces notable challenges. Firstly, the nascency of hydrogen technologies presents a hurdle. As an emerging sector, hydrogen energy systems lack the maturity and widespread adoption seen in more established renewable technologies, leading to gaps in knowledge, experience, and supportive policies. Secondly, cost and competitiveness remain significant barriers. Currently, the production, storage, and distribution of hydrogen, particularly electrolytic hydrogen, are more expensive than conventional energy sources and some renewable alternatives. Achieving cost parity with these sources is critical for hydrogen to become a viable option for widespread adoption. Lastly, infrastructure and supply chain needs pose a substantial challenge. Developing the necessary infrastructure for hydrogen production, storage, distribution, and utilization requires substantial upfront investment and coordination. This includes establishing electrolysis facilities, safe storage solutions, and a reliable distribution network that effectively serves remote communities.

Addressing these challenges will be crucial for leveraging hydrogen's full potential, calling for collaborative efforts among government, industry, and communities, alongside strategic investments and supportive policies. By integrating technical knowledge of hydrogen systems with an understanding of community attributes, stakeholders can tailor decarbonization strategies effectively, ensuring maximum benefits while addressing specific challenges and constraints.

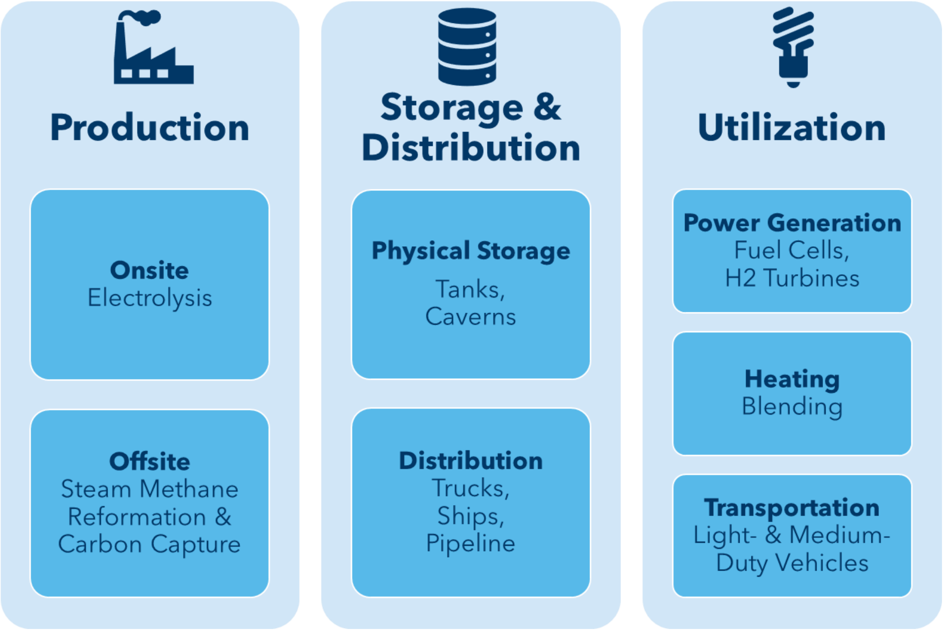
The next two sections of this report outline the components and enabling conditions of hydrogen ecosystems and their relevance within the remote community landscape.

3. Components of a Hydrogen Ecosystem

A hydrogen-based energy system commonly consists of three basic components:

- **Hydrogen Production** involves the generation of hydrogen gas through methods such as electrolysis (using electricity to split water into hydrogen and oxygen), steam methane reforming (extracting hydrogen from natural gas) with carbon capture, or thermochemical processes (leveraging high-temperature reactions with natural gas renewable feedstocks such as biomass).
- **Hydrogen Storage and Distribution:** Hydrogen storage involves methods like high-pressure gaseous and cryogenic liquid storage in tanks or geological storage in caverns, aquifers, and depleted oil wells. Hydrogen distribution, on the other hand, involves the transportation of hydrogen from production sites to end-users via pipelines, trucks, trailers, or on-site production.
- **Hydrogen Utilization** refers to the various applications[24] of hydrogen as a fuel for energy end-uses within transportation, building heat and electricity generation.

The following sections highlights key options within each part of the hydrogen value chain and outlines corresponding considerations and limitations for their applicability in remote communities.



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[24] Hydrogen can also be utilized in industrial applications such as oil refining, ammonia production, and steel production however, since it is not a relevant application in remote communities, it is excluded from this report.

3.1 Hydrogen Production

This section explores the various hydrogen supply options, focussing on their suitability in remote communities. From a decarbonization perspective, this study focuses on electrolytic and hydrogen produced from fossil fuels with carbon capture from for remote communities.[25]

Electrolytic Hydrogen

Electrolytic Hydrogen refers to hydrogen produced through the process of electrolysis, a chemical reaction that uses an electric current to split water molecules into hydrogen (H_2) and oxygen (O_2). This method is highly suitable for remote communities, especially those with access to abundant renewable resources and limited accessibility. In such cases, establishing local electrolysis facilities that are powered by nearby renewable energy sources or the local grid is the typical supply option for electrolytic hydrogen. The production and overall costs of electrolytic hydrogen relies on the availability of a continuous, stable, and reliable electricity supply. The decision on which source to use depends on various factors, such as the availability of renewable resources, grid connectivity, and local conditions. Based on the source of electricity, here are two ways likely to produce hydrogen electrolytically:

- **Co-located Renewables:** Hydrogen is produced through electrolysis using renewable energy sources and is nearly emissions-free.[26] Wind, solar, and hydroelectric power represent three of the most promising renewable energy sources for hydrogen production in remote communities. Depending on the available resources, either one or a combination thereof can be used to power electrolyzers.
- **Grid Electricity:** Hydrogen is produced through electrolysis, using electricity from the grid. Its emission intensity varies depending on the generation mix, and it is used when the grid energy mix is not fully renewable.

The key components of the electrolytic hydrogen supply are **Feedstock**, **Electrolyzer,** and **Ancillary Components** such as Power Balancing/Quality, Compressor and Oxygen Handling Unit.

1. Feedstock

The process of electrolysis primarily requires water as its feedstock. The source of water can be either freshwater bodies like rivers and lakes or seawater, depending on the availability in the local area. The production of electrolytic hydrogen requires desalinated and distilled water to reduce equipment damage. The water used for hydrogen production through electrolysis can be broadly classified into two types:

- **Feedstock Water** is the water that undergoes electrolysis to produce hydrogen. This is the water (H_2O) that gets split into hydrogen (H_2) and oxygen (O_2) during the electrolysis process. About 9 litres (L) of water is typically required to produce 1 kilogram (kg) of hydrogen via electrolysis.[27]

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[25] While pink hydrogen could play a future role, its viability depends on a nuclear buildout in British Columbia or Alberta, making it a subject for future consideration. Thermochemical reduction of renewable feedstock such as biomass, hydrogen production using nuclear energy, and methane pyrolysis with carbon capture, are other potential pathways for low-carbon hydrogen production.
[26] Accounting for life cycle emissions from manufacturing renewable technologies such as solar, wind and storage.
[27] Hydrogen Reality Check: Distilling Green Hydrogen's Water Consumption - RMI

- **Process Water** is used in the cooling systems and other equipment associated with the electrolyzer. The amount of process water used can vary based on the specific design and technology of the electrolyzer.[28] Approximately 10-20 L/kg of water is typically required for water purification and cooling.

Electrolytic hydrogen production requires pre-treated water to ensure high efficiency and minimal organic carbon. Poor water quality can affect the process and electrolyser lifetime.

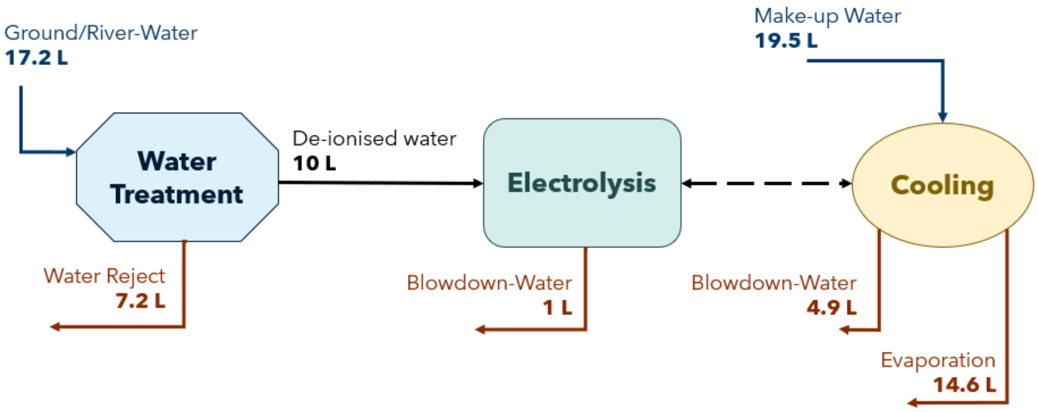

Figure 3: Schematic of Water Usage in Electrolytic Hydrogen Production

2. Electrolyzer

An electrolyzer's primary function is to break down water into hydrogen and oxygen by facilitating electrochemical reactions. A typical electrolyzer consists of two electrodes- an anode and a cathode- separated by an electrolyte. Two types of electrolyzers could be applicable to remote communities.[29]

- **Alkaline Electrolyzers** have been used in various industries for several decades due to their efficiency. They utilize an alkaline electrolyte solution, commonly potassium hydroxide (KOH).
- **Proton Exchange Membrane (PEM) Electrolyzers** utilize a solid polymer electrolyte membrane that selectively allows protons to pass through.

The following table provides a comparison between the two types of electrolyzers and their applicability in remote communities.

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[28] Among the different types of electrolyzers, PEM electrolysis has the lowest water consumption intensity, using approximately 17.5 litres of water per kilogram of hydrogen. Alkaline electrolysis follows PEM electrolysis, with a water consumption intensity of 22.3 litres per kilogram of hydrogen Water for hydrogen production

[29] There is a third type of electrolyzers, which are solid oxide electrolyzers. These types operate at high temperatures and use a solid ceramic electrolyte. They are suitable for high-temperature heat integration and have potential applications in industrial processes.

Table 2. Comparing the applicability of electrolyzers for remote communities.[30]

	Proton Exchange Membrane Electrolyzer	Alkaline Electrolyzer
Technology Maturity	Next most mature technology with growing commercialization	Established and commercial technology
Load Following	Ability to follow load due to lower startup and system response times, lower minimum load requirements and greater load flexibility.	Needs more constant and stable power supply. Slower to respond to changes in load.
Operating Temperature and Pressure Requirements	Operate at higher temperatures (50-80°C, can go up to 120°C) and higher pressures, typically between 15 and 30 bar.	Typically operate at lower temperatures (generally around 40-60°C) and lower pressures, around 1-10 bar.
Size[31]	Generally small-scale applications and can handle variable loads. A 1 GW facility typically ranges from 8-13 hectares.	They are commonly used in larger-scale applications and need a stable continuous power supply. A 1 GW facility typically ranges from 10-17 hectares.
Purity of Hydrogen Produced	Produce high-purity hydrogen due to the selective permeability of the membrane.	May require additional purification steps to achieve high-purity hydrogen.
Affordability	Generally higher due to precious metal catalysts (e.g., platinum). Capital costs vary from $700-$1400/kW.	Lower costs, uses non-precious metals. Capital costs vary from $500-$1000/kW.

3. Ancillary Components

- **Hydrogen Compression:** After the production, hydrogen gas is required to be compressed for storage and transportation purposes. The compression system usually comprises compressors and associated infrastructure to pressurize and store hydrogen gas.
- **Oxygen Handling System:** The oxygen produced as a byproduct during electrolysis needs to be collected and handled.
- **Power Balancing:** Ancillary equipment in electrolyzer operations includes transformers, rectifiers, inverters, and filters to maintain power quality and balance.

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[30] Lazard's Levelized Cost of Hydrogen Analysis

[31] IRENA. Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5C climate goal.

Hydrogen from Carbon Capture and Storage

Hydrogen can be produced through various methods from fossil fuels, but the most common method is Steam Methane Reforming, an industrial process that converts natural gas (methane, CH_4) into hydrogen gas (H_2). It is the primary method for hydrogen production globally and accounts for a significant portion of the world's total hydrogen output.

However, Steam Methane Reforming is not a carbon-neutral process, as carbon dioxide is produced as a byproduct. The overall environmental impact depends on the implementation of carbon capture technologies. Hydrogen produced from fossil fuels that employ carbon capture and storage (CCS) is referred to as blue hydrogen.

The primary feedstock for this process is natural gas, primarily composed of methane (CH_4). Methane is a hydrocarbon that serves as the source of hydrogen in the reforming process. Given the infrastructure requirements to support high-temperature reactions and the need for constant methane and steam supply, this method of hydrogen production may not be ideal for remote communities. However, the hydrogen could be produced elsewhere and transported to remote communities.

Hydrogen production from fossil fuels with CCS is often seen as a **transitionary solution** to decarbonize certain end uses while renewable hydrogen technologies are further developed. It can play a **role in a broader strategy** that gradually shifts towards renewable hydrogen production methods.

Choice of Hydrogen Supply in Remote Communities

The key consideration we must make when selecting a hydrogen supply option in Remote Communities are summarized below.

Table 3. Key considerations for hydrogen supply

	Applicability	Scalability	Affordability	Decarbonization
Electrolytic Hydrogen (PEM)	Suitable for areas with variable renewable energy sources due to its rapid response to load changes. Suitable to hydrogen end uses with higher hydrogen purity requirements.	Well-suited for smaller, modular setups and scalable for various community sizes.	Higher initial capital cost	Hydrogen produced using surplus energy from renewables emits zero carbon while from grid electricity, the emissions intensity varies depending on the provincial energy mix.
Electrolytic Hydrogen (Alkaline)	More appropriate for locations with consistent and stable power availability. Hydrogen produced tends to have lower purity.	Larger system sizes may be more feasible for steady-state applications.	More cost-effective than PEMs and may align better with limited budgets.	
CCS Hydrogen	The transportation of hydrogen to remote communities depends on the existing infrastructure – roads or dedicated pipeline.	The scalability will depend on the transport infrastructure.	Transportation aside, hydrogen from SMR and CCS could be a cheaper low-carbon alternative to hydrogen produced from renewables.	Low carbon intensity. Carbon generated from steam reforming is captured and stored via CCS. However, the current capture rates are around 85% to 90%.

3.2 Hydrogen Storage and Distribution

The effective deployment of hydrogen architecture hinges on the efficient storage and transport of hydrogen. This section outlines the various hydrogen storage and transport options, evaluating their applicability, scalability, and affordability in the context of remote communities.

Hydrogen Storage

Each option's feasibility heavily depends on the local geological conditions and the availability of the necessary technical expertise and infrastructure for development and maintenance.

Hydrogen Gas Tanks: Hydrogen gas is stored at high pressures, typically in cylinders or tanks. This method is widely used because of its simplicity and the maturity of the technology. It requires strong, durable containers to withstand high pressure, and the energy density by volume is relatively low compared to other methods.

Liquid Hydrogen Tanks[32]: Liquefaction represents another method of storing hydrogen and is suitable for long-distance transport due to its high energy density, ambient storage pressure, high hydrogen purity (no contamination risks), and mature technology. However, there are critical obstacles to developing liquid hydrogen systems: an energy-intensive liquefaction process (~13.8 kWh/kgL H_2) and high hydrogen boil-off losses (liquid hydrogen evaporation during storage, 1–5% per day). Significant technology demonstrations and market development efforts are needed for liquid hydrogen to be commercially feasible.

Geological Storage: Offers large-scale storage and is generally considered safe and economical for massive volumes of gaseous hydrogen, but its feasibility is geographically limited. The options include:

- **Salt Caverns:** Utilizes underground salt formations to store large volumes of hydrogen. Salt caverns are created by dissolving the salt with water and then pumping the brine out, leaving a cavern.
- **Hard Rock Caverns:** Similar to salt caverns but carved out of solid rock formations. They can store hydrogen under high pressure.
- **Aquifer Storage:** Involves using natural underground reservoirs, typically depleted gas or oil fields, or water-bearing strata (aquifers) to store hydrogen.

Choice of Hydrogen Storage in Remote Communities

The table below summarizes the different hydrogen storage options along with their applicability, scalability, and affordability, specifically for remote communities in BC:

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[32] Hydrogen liquefaction and storage: Recent progress and perspectives - ScienceDirect

Table 4. Key considerations for hydrogen storage

Storage Method	Applicability	Scalability	Affordability
Hydrogen Tanks	High safety with proper tank materials and maintenance. Space-efficient for smaller volumes.	Easily scalable with additional tanks, suitable for small to medium volumes.	Moderate initial cost, low operational cost.
Geological Storage	Suitable for large-scale, long-term storage. Safety depends on geological stability.	High volume storage potential, but dependent on suitable geological formations. Limited scalability outside suitable locations.	High initial cost, low operational cost if suitable formation exists.

Hydrogen Distribution

Establishing a functional hydrogen ecosystem requires the delivery of hydrogen from its production site to the point of end-use. Hydrogen transportation entails either pressurizing it for delivery as a compressed gas or liquefying it.

Gaseous Hydrogen: The primary methods for delivering gaseous hydrogen are via trucks or pipelines. Compression is necessary since gaseous hydrogen is usually generated at relatively low pressures. Notably hydrogen gas is less compactable to liquid fuel, making it less efficient for transporting large volumes of fuel.[33]

Liquid Hydrogen: When high-volume transport is required in the absence of pipelines, hydrogen is typically delivered as a liquid. Hydrogen must undergo a cooling process to reach cryogenic temperatures to achieve liquefaction.[33]

Hydrogen Blending: Transporting gaseous hydrogen via existing pipelines can be an option for delivering large volumes of hydrogen. However, repurposing pipelines is complicated. Long-distance transmission pipes are typically carbon steel (where embrittlement is an issue), while local distribution pipes are typically polyethylene (where embrittlement is not an issue).[34] Communities may be able to blend hydrogen into existing pipeline networks to transport/receive hydrogen. In this scenario, downstream technologies are required to extract hydrogen from the natural gas blend.

Choice of Hydrogen Distribution in Remote Communities

Here's a table summarizing the different hydrogen transport options along with their applicability, scalability, and affordability, specifically for remote communities in Canada:

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[33] Office of Energy Efficiency and Renewable Energy. Accessed February 2024. https://www.energy.gov/eere/fuelcells/hydrogen-delivery.

[34] The Transition Accelerator. 2021. Techno-Economics of Hydrogen Pipelines: Technical Brief.

Table 5. Key considerations for hydrogen transport

Transport Method	Applicability	Scalability	Affordability
Pipelines	High safety if properly maintained. It is best for short to medium distances due to the potential for hydrogen embrittlement in steel pipes.	High infrastructure cost, but efficient for large volumes once established.	High initial cost, low operational cost.
Tube Trailers	Relatively safe with proper handling. Suitable for short to medium distances.	Modular and flexible, lower initial cost but less efficient for very large volumes.	Moderate, depends on distance and volume.
Marine Transport	Safety depends on vessel design and operation standards. Suitable for long distances.	High infrastructure cost for production and port facilities, high volume transport.	High, especially for specialized vessels.

For remote communities in Canada, the choice would depend on factors like the proximity to hydrogen production sites, infrastructure availability, volume requirements, and the community's budget for initial setup and ongoing operations. Affordability also needs to consider long-term operational costs, not just initial setup.

3.3 Hydrogen Demand

Hydrogen is emerging as a versatile and clean energy carrier, and its use in remote communities in Canada is gaining interest due to its potential to address energy access, reliability, and sustainability concerns. In this section, we will explore the role of hydrogen in decarbonizing the heating and power generation end uses.[35]

Transportation: Hydrogen could be used as a fuel for light-, medium-, and heavy-duty vehicles in the form of hydrogen fuel cells. Hydrogen fueling stations (similar to traditional gas stations) are required to support fuel cell vehicles.

Heating: Hydrogen can be used as a fuel for heating buildings. It can be mixed with natural gas and used in conventional gas boilers or burned in a pure hydrogen boiler.

Power Generation: Fuel cells using hydrogen can provide reliable, clean electricity generation, while hydrogen can be stored and used for power generation to provide backup during outages or peak demand times.

Transportation

Battery electric vehicles (BEVs) are currently viewed as the primary pathway to light- and medium-duty vehicle decarbonization. However, unmanaged EV charging can result in peak load growth and the need for large investments in additional grid infrastructure. Hydrogen-fueled vehicles could complement BEVs for decarbonizing transportation by alleviating pressure on the electric grid, diversifying fuel sources, and increasing fuel options.[36]

Light-Duty Vehicles: These vehicles convert hydrogen gas into electricity through a fuel cell, which powers an electric motor. The main advantages include fast refuelling times (comparable to conventional gasoline or diesel vehicles), longer range, and zero tailpipe emissions, with water vapour being the only byproduct. However, when compared to BEVs:

- **Lower Efficiency:** Hydrogen fuel cells are less energy-efficient overall. This includes the energy required to produce, compress, transport, and convert hydrogen into

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[35] Hydrogen can be used in the production of chemicals and for industrial processes. However, in remote communities, industrial applications will be limited, so the study focuses exclusively on the role of hydrogen in heating and power generation.

[36] Rebates for FCEV purchases for BC residents are available through the CleanBC Go Electric program and the federal iZEV and iMHZEV programs for light-, medium-, and heavy-duty vehicles.

electricity within the vehicle. Overall, the well-to-wheel[37] efficiency of BEVs typically ranges from 60% to 70%, making them more efficient than hydrogen fuel cell electric vehicles (FCEVs). This higher efficiency is largely due to the direct use of electricity to power the vehicle, avoiding the energy losses associated with hydrogen production, distribution, and conversion.

- **Higher Costs:** FCEVs and the hydrogen fuel are more expensive due to the high costs of vehicle production, fuel cell technology, and hydrogen production and distribution.
- **Lack of Infrastructure:** Require a network of hydrogen production facilities, transportation (pipelines or truck delivery), and refuelling stations. The current infrastructure for hydrogen is limited, with only five refuelling stations in the province: three located in Vancouver, one in Victoria, and another in Kelowna.[38]

Medium-Duty Vehicles: In the medium-duty sector, hydrogen fuel cells are particularly suited for delivery vans, smaller trucks, and buses. Hydrogen fuel cells can provide a longer range and offer higher payload capacities than comparable battery electric vehicles. However, similar to light-duty vehicles, the key challenges of high operational costs, lower overall well-to-wheel efficiency and lack of infrastructure will continue to challenge the deployment of hydrogen fuel cells for the medium-duty segment.

Heavy-Duty Vehicles: FCEVs are most promising in the long-haul trucking sector for freight transportation, with significant potential to reduce diesel consumption. However, this use case is not commonly observed in remote communities.

The lack of necessary infrastructure to support hydrogen fuel cells, limited economies of scale, and lower well-to-wheel efficiencies will likely impede the deployment of hydrogen as a transportation end-use in these communities.

Heating

Hydrogen boilers operate using hydrogen gas as fuel to produce heat for space heating and hot water, similar to natural gas boilers. The combustion efficiency of a hydrogen boiler is around 95% because almost all the energy content of the hydrogen fuel is converted into heat[39]. However, the overall efficiency can be significantly lower when considering the "well-to-burner" efficiency, which includes the energy lost during hydrogen production, transportation, and conversion into heat.

One issue with hydrogen boilers is that they require a dedicated supply of hydrogen. Hydrogen blending in existing natural gas networks is a means of gradually integrating hydrogen into the energy supply without the immediate need for dedicated hydrogen infrastructure or the complete overhaul of existing appliances and pipelines.

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[37] The "well-to-wheel" efficiency of a vehicle refers to the energy efficiency of the entire fuel pathway, from the primary energy source ("well") to the vehicle's wheels. This measure considers the production, processing, distribution, and conversion of energy into motion.

[38] Natural Resources Canada. Accessed February 2024. Electric Charging and Alternative Fuelling Stations Locator.

[39] Hydrogen Technologies LLC. "Dynamic Combustion Chamber". 2023

Several ongoing projects and pilot programs, such as the ATCO Fort Saskatchewan hydrogen blending project in Alberta, Canada, are assessing the feasibility and implications of hydrogen blending.[40] The ATCO project aims to demonstrate how hydrogen can be blended into the existing natural gas infrastructure, providing valuable insights into the technical, economic, and safety aspects of hydrogen blending. The ATCO initiative is not in a remote community but is an illustrative case of how hydrogen blending can be implemented in community settings, offering a glimpse into the potential for broader application.

Hydrogen can be efficiently distributed through H2 dedicated pipelines within a remote community. However, it is important to consider the compatibility of the existing infrastructure, considering factors such as material composition and age. When introducing hydrogen into a community, it's important to consider some key factors.

- **Combustion Characteristics:** Hydrogen has different combustion characteristics than natural gas, including a higher flame speed and a broader flammability range. These differences may require adjustments in combustion equipment and safety measures. Further, appliances and equipment at end-user facilities, such as heaters and stoves, may need to be compatible with hydrogen-blended natural gas.
- **Infrastructure Upgrades:** While low to moderate levels of hydrogen blending can typically be accommodated within existing natural gas pipelines, significant retrofits and investments are needed to accommodate high concentrations of hydrogen in pipelines. Remote communities generally lack pipeline infrastructure, and introducing hydrogen would require a significant buildout of hydrogen-compatible pipelines to support heating loads.

The figure below demonstrates that while hydrogen boilers offer a low-carbon alternative to natural gas boilers, heat pumps are a more efficient solution for heating buildings. This is because heat pumps transfer heat from the environment into buildings. While hydrogen has the potential to decarbonize residential heating in remote communities, it faces various economic, technical, and logistical challenges. A comprehensive approach is necessary to realize the potential of hydrogen heating in these areas. This includes community engagement, support from higher government levels, and the use of local renewable energy resources.

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[40] ATCO Fort Saskatchewan Hydrogen Blending. Accessed February 2024. https://gas.atco.com/en-ca/community/projects/fort-saskatchewan-hydrogen-blending-project.html

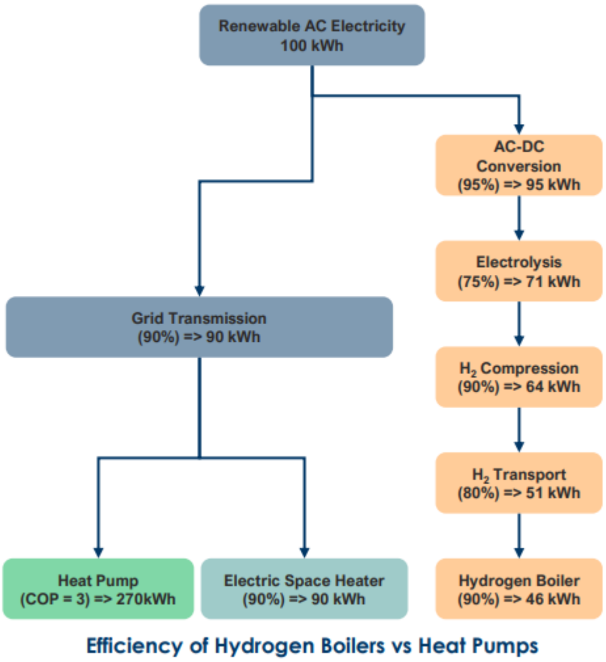

Figure 4. Efficiency of hydrogen boilers vs. heat pumps for heating[41]

Power Generation

Hydrogen can serve various end uses for power generation and storage in remote communities, offering energy solutions tailored to specific needs and challenges. Here are different end uses of hydrogen, along with key considerations:

Hydrogen fuel cells are a clean and efficient way to generate electricity, which makes them ideal for various applications, including powering remote communities. However, there are several crucial factors to consider when using them:

- **Purity and Storage:** High-purity hydrogen is necessary for fuel cells to operate effectively, and storage systems must maintain hydrogen purity to optimize fuel cell performance.
- **Fuel Cell Technology:** The choice of fuel cell technology, such as PEM or solid oxide fuel cells, depends on factors such as efficiency, scalability, and operating conditions. Choosing the right technology is essential for the specific application.
- **Infrastructure:** Deploying fuel cell systems requires developing infrastructure for hydrogen storage, distribution, and maintenance. It's necessary to have adequate infrastructure to ensure reliable hydrogen-based power generation.
- **Cost:** It's important to note that initial investment in fuel cell systems can be relatively high. A thorough cost-effectiveness assessment should be conducted to determine the viability of using fuel cells compared to alternative power generation methods.

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[41] The Coefficient of Performance (COP) indicates the efficiency of a technology by measuring the ratio of useful output energy to the input energy required. Higher COPs equate to greater efficiency. Heat pumps typically have COPs well over 1; meaning more thermal energy is produced than the amount of electricity used to operate it.

Hydrogen gas turbines are versatile and efficient devices[42] that can be used for power generation in remote communities. Natural gas turbines can be adapted to run on hydrogen, a clean and renewable energy source. However, some key considerations need to be considered when using hydrogen as a fuel for gas turbines:

- **Hydrogen Purity and Quality:** Maintaining the purity and quality of hydrogen is crucial to ensure efficient combustion and turbine performance. The method of hydrogen production and storage conditions must be considered to ensure the desired hydrogen quality.
- **Turbine Retrofitting and Modifications:** Retrofitting existing gas turbines or designing new ones to run on hydrogen may require combustion, fuel delivery, and turbine component modifications. Evaluating the cost and feasibility of retrofitting or designing hydrogen-compatible turbines is essential.

Hydrogen-based energy solutions can play a vital role in providing clean and reliable power generation and storage in remote communities by addressing these considerations.

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[42] Blending up to 100% technically feasible, under demonstration and being promised by several manufacturers (e.g. General Electric). CAPEX costs of H_2 Combustion Turbines will likely be in line with those for traditional natural gas combustion turbines.

4. Enabling Conditions of a Hydrogen Ecosystem

Beyond the technical and economic feasibility of different decarbonization solutions in remote communities, there are a set of enabling conditions that influences community-level ability to support the development and integration of new energy systems. Since energy supply in remote communities is strongly linked to various technical, social, economic, and health factors, these enabling conditions govern the viability of energy projects based on how they positively or negatively impact these factors.

The degree to which each condition influences the feasibility of an energy system varies and is project dependent however, they can be measured based on how they affect the applicability, scalability, affordability, and reliability of a given technology. For instance, a community situated in an arctic climate might encounter fewer technological choices or need to incorporate extra cold-weather measures. While this scenario could lead to higher capital and operating expenditures, resulting in an elevated Levelized Cost of Energy (LCOE), it does not prevent the community from effectively integrating the system.

In this section we discuss six key enabling conditions that exist in remote communities within BC and how they limit or influence viability of a hydrogen ecosystem. While there are other considerations (e.g., social, political, regulatory), these are highly project- and community-dependent and should be explored on a case-by-case basis.

Figure 5. Six key enabling conditions of a hydrogen ecosystem.

Table 6. Enabling conditions of remote communities and their influence on the viability of a hydrogen ecosystem.

Enabling Condition	Influence
Accessibility	• The economic feasibility of hydrogen projects is closely linked with road accessibility. Communities that lack adequate road access face **challenges in implementing hydrogen systems**, as the cost of transporting hydrogen, building infrastructure, and obtaining replacement parts are all affected by the road conditions. • Insufficient road access can further **delay the deployment of personnel**, making it harder to overcome operational challenges and achieve successful hydrogen projects. This can be mitigated by building local capacity and skillsets through training and knowledge sharing however, may take time to fully develop specialized skills necessary to operate and troubleshoot infrastructure.
Community Size	• **Economies of Scale:** Small communities struggle to achieve economies of scale, limiting the scale of the hydrogen ecosystem. Collaborative ventures with neighboring communities can help small communities achieve economies of scale. Isolated microgrids serving multiple communities generate economies of scale for some remote communities, but present challenges for similar collaborative ventures aimed at serving larger populations. • **Access to Funding:** Further, the initial investment required for hydrogen infrastructure in small communities may be high, and human capital and access to funding may be limited. In contrast, larger communities have better access to expertise and resources, and greater financial support.
Energy Infrastructure and Consumption	• **Leading indicator of operational expertise:** The presence of pre-existing renewable energy infrastructure demonstrates operational expertise and integration capabilities and serves as a foundation for potential local hydrogen production from co-located renewables. • **Decarbonization potential of the communities:** Many remote communities rely on diesel generators or a mix through renewable sources and transmission, to power their heating and electricity needs. Thus, hydrogen's scalability and decarbonization potential hinges on the emissions reduction potential and level of diesel dependency within communities.
Energy Service Provider	• **Enhances Project Viability:** Multiple service providers with varied ownership structures and business models can influence the approach to ensuring reliability, risk management, and integration with existing energy systems, thereby enabling more tailored and community-specific energy solutions. • **Leverages on-ground experience:** The type of service provider, particularly in the context of IPPs and utilities, affects the distribution of responsibilities for safety, reliability, and operational management of energy systems.
Climate	• **Diverse Climate Conditions:** The varied climate zones in BC, ranging from mild to arctic conditions, necessitate energy systems, including hydrogen technologies, that are adaptable and resilient. This diversity impacts technical, logistical, and operational considerations, as infrastructure must be designed to withstand the unique challenges of each climate zone, especially in remote and harsh climates.

	• **Climate as a Proxy for Energy Demand:** In colder regions, particularly those classified within climate zones 7A, 7B, and 8, there is a higher heating demand. Climate is a critical proxy for this demand, influencing the design and implementation of energy systems. • **Technical and Logistical Considerations for Hydrogen Systems:** Hydrogen technologies, like fuel cells and electrolyzers run at high temperatures, and additional infrastructure may be necessary for cold climates. This emphasizes the need for climate-adapted strategies to maximize the efficiency and effectiveness of hydrogen systems in diverse environmental conditions.[43]
Resource Availability	• **Water Supply:** Limited freshwater resources can restrict the selection and viability of electrolyzer technologies, making water access a pivotal factor in the deployment and efficiency of hydrogen production systems. • **Renewable Energy Access:** The ability to generate electricity on-site, particularly from hydro, wind, and solar, is fundamental for producing hydrogen from co-located renewables. • **Geological Considerations:** For successful hydrogen production facilities and renewable energy systems, it is essential to have access to adequate land and natural storage options such as salt caverns.
Other Considerations	• **Indigenous vs Non-Indigenous:** Indigenous communities often have distinct cultural, social, and governance structures that shape their perspectives and priorities regarding energy projects. Indigenous communities may prioritize energy sovereignty or majority community ownership, sustainable development, and cultural preservation versus non-Indigenous or commercial communities. • **Climate Action Plans:** A pre-existing climate action plan demonstrates a community's commitment to sustainability and decarbonization efforts. Incorporating hydrogen projects into existing climate action plans provides a strategic framework for achieving emissions reduction targets and transitioning to cleaner energy sources. • **Socio-demographics:** Socio-demographic factors, including education levels and community engagement, influence the acceptance and adoption of hydrogen projects. Understanding the unique socio-cultural dynamics of remote communities is essential for tailoring hydrogen projects to local needs and priorities. • **Proximity to Other Jurisdictions:** Proximity to other provinces, such as Alberta, may present opportunities for interprovincial transport of hydrogen produced from fossil fuels with carbon capture. Proximity to other remote communities creates opportunities for interconnection and expansion of future hydrogen systems. Collaborative efforts, such as shared infrastructure, joint projects, and regional partnerships, enhance economies of scale, optimize resource utilization, and improve hydrogen initiatives' overall feasibility and sustainability.

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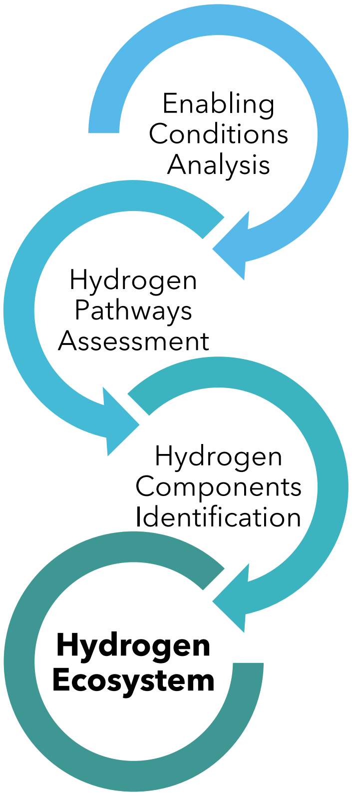
[43] Horacio R. Corti, Polymer electrolytes for low and high temperature PEM electrolyzers, Current Opinion in Electrochemistry, Volume 36, 2022, 101109, ISSN 2451-9103, https://doi.org/10.1016/j.coelec.2022.101109.

5. Potential Role of Hydrogen in Remote Communities

Recognizing that the feasibility for hydrogen will largely depend on community-specific consideration, we outline a framework that can be used for conducting preliminary assessments of the potential role of hydrogen in remote communities:



- **Enabling Conditions Analysis:** The first step is to analyze the enabling conditions that characterize the remote communities. This involves understanding the six factors discussed in Section 4 (climate, community size, energy infrastructure, service provider, accessibility, resource availability) as well as consideration of other factors that may influence the community's ability to support hydrogen. It is important to understand the interplay between these conditions and how some of them may be more or less restrictive in the context of the scale and type of hydrogen system. These conditions provide insights into the unique challenges and opportunities for hydrogen integration to guide the following pathway assessment.
- **Pathway Assessment:** Once the conditions that exist in a community are well understood, the next step is to evaluate different hydrogen pathways to determine the most suitable options for the selected communities. This assessment includes examining various production methods, such as electrolysis using renewable energy sources or importing hydrogen from other jurisdictions. Consider how the enabling conditions affect the applicability of various hydrogen technologies, scalability of hydrogen systems and their overall decarbonization potential, affordability of developing, operating, and maintaining a hydrogen system and, the operational reliability of a hydrogen ecosystem in community-specific conditions.
- **Technology and Component Identification:** Identify the specific technologies and components necessary to support the selected hydrogen pathway. This includes evaluating electrolyzers, storage systems (such as tanks or underground caverns), transportation infrastructure, and distribution networks. Assess the technical feasibility, reliability, and compatibility of these technologies with the community's existing infrastructure and energy requirements.

To explore the role of hydrogen in remote and end-of-line communities, we developed three high-level, illustrative case studies that represent different community archetypes. The case studies showcase examples of how hydrogen can potentially play a role in transition remote communities towards decarbonized energy systems, with consideration of their unique characteristics and context.

Community 1: End of Line

Community 1 is a large end-of-line remote community located in the central Valley region of British Columbia and is surrounded by the Rocky and Cariboo Mountains. There are oil reservoirs that have been previously used for hydrocarbon extraction and are now empty and proven to be capable of containing gases.

Climate Type	This climate has warm to hot summers and cold, snowy winters, with temperatures dropping below minus 18°C.
Population	The population is greater than 500 people.
Accessibility	Located on a major highway connected to the Trans-Canada Highway system, which is maintained year-round. Winter conditions, including snow and ice, can lead to challenging driving.
Generation Resource	BC Hydro manages the grid in this community. Isolated diesel backup power solutions are critical to ensure uninterrupted electricity supply due to the community's remote location and potentially extreme weather conditions, especially during winter.
Water Availability	**Quantity**: The region experiences seasonal variations in water flow, with higher levels in the spring and early summer due to snowmelt and potentially lower levels in late summer and early fall. Potential sources are rivers, streams and groundwater. **Quality**: Water from rivers and streams potentially contains dissolved minerals, organic matter, and pollutants from agricultural runoff. Water treatment would be necessary if the water is used for hydrogen production.
Renewable Potential	**Wind:** The community's varied topography may suit wind energy generation but building a transmission/interconnection could be challenging. **Solar:** Despite the high latitude of the community, there is potential for solar energy production, especially during the long summer daylight hours. **Hydro:** Rivers and streams in the region offer opportunities for small hydroelectric projects. Topography and water flow rates are conducive to run-of-river systems, generating electricity without large dams and minimizing impact.

Evaluation

Production Options				
	Applicability	***Scalability***	***Affordability***	***Assessment***
Electrolytic Hydrogen	*High*	*Moderate*	*Moderate*	**Potential option:** Continuous grid supply supports low-cost electrolytic hydrogen.
Hydrogen from Fossil Fuels w/ Carbon Capture	*High*	*Moderate*	*High*[44]	**Potential option:** To supply initial hydrogen demand. Year-round accessibility makes it ideal for transporting hydrogen.

Storage Options				
	Applicability	**Scalability**	**Affordability**	***Assessment***
H2 Tanks	*Low*	*Moderate*	*Low*	**Not Recommended:** Storage quantities may not support power generation applications.
Depleted Oil Wells	*High*	*Low*	*Moderate*	**Potential option:** High volume storage potential. The presence of existing oil wells offers the potential to reduce costs significantly.

End Uses				
	Applicability	**Affordability**	**Reliability**	***Assessment***
Transport	*Low*	*Low*	*Low*	**Not Recommended:** Electric Vehicles offer greater efficiency,
Heating	*Low*	*Low*	*Low*	**Not Recommended:** Heat pumps offer greater heating efficiency.
Power Generation	*High*	*High*	*High*	**Potential option:** Hydrogen turbines/ fuel cells can be used to offset the remaining fossil fuel consumption from backup diesel generators.

Low: *components not well suited to the unique conditions and challenges associated with the given community.*
Moderate: *components that have potential to meet the conditions of the community with specific project design considerations or modifications.*
High: *components with a high likelihood of successful operation in the conditions of the given community with minimal modification or reinforcement.*

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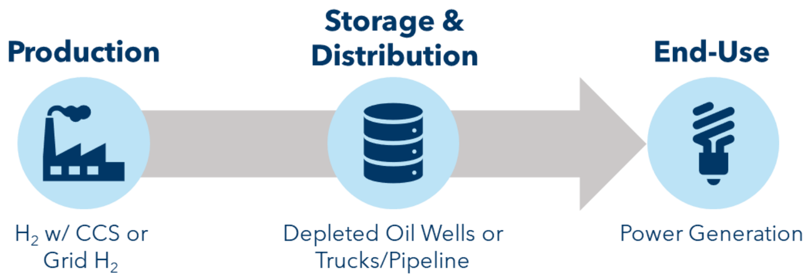
[44] Depending on the cost and feasibility of transporting hydrogen produced elsewhere.

Potential Hydrogen Ecosystem



Key Considerations

- **Evaluate Alternative Solutions**: Assess the economic competitiveness of using renewables coupled with long-duration energy storage solutions against hydrogen solutions.
- **Supply Constraints**: Hydrogen from fossil fuels with carbon capture is not yet an established production process. Key considerations need to be made on the availability and supply.

Community 2: Non-Integrated Area (multi-community)

Community 2 is a large NIA multi-community microgrid located in the coastal valley region of British Columbia. Geological studies indicate the presence of large saline aquifers, that could potentially hold significant amount of gaseous storage.

Climate Type	Its proximity to the Pacific Ocean influences this climate, resulting in mild, wet winters and cool, relatively dry summers.
Population	The population is greater than 500 people.
Accessibility	Seasonal accessibility through road. Location at the port offers accessibility by ferries.
Generation Resource	Run-of-river hydro with diesel backup, with 60% supplied from hydro and 40% supplied by diesel.
Water Availability	**Quantity**: The region is located in a high precipitation zone with substantial rainfall and surface water resources. **Quality**: Natural filtration provided by its dense forests and mountainous terrain reduces the number of dissolved salts and organic matter. Water treatment will still be needed prior to electrolysis.
Renewable Potential	**Wind:** The wind speeds are inconsistent enough to support large-scale wind farms. Topography lends to localized wind production. **Solar:** Despite the high latitude of the community, there is potential for solar energy production, especially during the long summer daylight hours. **Hydro:** Abundant rainfall and significant river systems offer strong hydro potential.

Evaluation

Production Options				
	Applicability	**Scalability**	**Affordability**	***Assessment***
Electrolytic Hydrogen	*High*	*Moderate*	*High*	**Potential option:** Hydro dams offer a continuous supply of power. Alkaline Electrolyzers could potentially reduce costs.
Hydrogen from Fossil Fuels w/ Carbon Capture	*Moderate*	*Moderate*	*High*	**Potential option:** To supply initial hydrogen demand. Seasonal access limits the potential of hydrogen being trucked in. Marine access offers potential transport through ferries[45].

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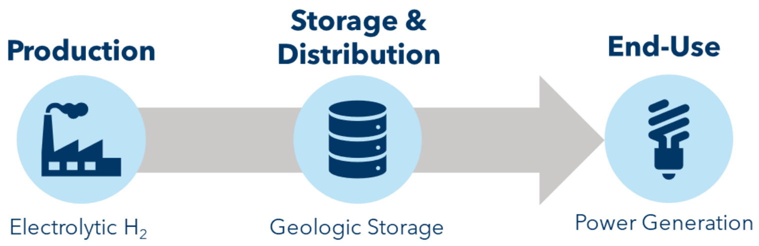
[45] This was successfully demonstrated in the Building Innovative Green Hydrogen system in Isolated Territory (BIG HIT) project in Scotland. See case study 4 in appendix A.

Storage Options				
	Applicability	**Scalability**	**Affordability**	***Assessment***
H2 Tanks	*Low*	*Moderate*	*Low*	**Strong Potential option:** For the initial phase of H2 ecosystem buildout.
Saline Aquifers	*High*	*Low*	*Low*	**Good Potential:** Long-term option

End Uses				
	Applicability	**Affordability**	**Reliability**	***Assessment***
Transport	*Low*	*Low*	*Low*	**Not Recommended:** Electric Vehicles offer greater efficiency.
Heating	*Low*	*Low*	*Low*	**Not Recommended:** Heat pumps offer greater heating efficiency.
Power Generation	*High*	*High*	*High*	**Potential option:** Hydrogen turbines/ fuel cells can be used to offset the remaining fossil fuel consumption from backup diesel generators.

Potential Hydrogen Ecosystem



Key Considerations

- **Hydrogen Storage Feasibility:** Land availability of hydrogen tanks should be considered. Any geological site for storage must be assessed for its stability, reliability, and safety, including ability to store and inject the required volumes of gas while avoiding leakage.
- **Electricity Supply for Transport:** A feasibility assessment of local microgrid capacity, ability to meet needs and manage BEV charging requirements may be needed to understand the ability for the community to support additional load growth from BEVs, potential infrastructure upgrades and associated costs.
- **Local Water Considerations**: Intentional siting of electrolytic hydrogen project locations is critical to avoid water system strain. Assess local water availability, competing uses, and rights. This ensures compliance with water policies and water needs are met.

Community 3: Non-Integrated Area (single-community)

Community 3 is a NIA, single-community microgrid located northwestern British Columbia. There are reservoirs that have been previously used for hydrocarbon extraction and are now empty. They have the advantage of being well-characterized geologically and proven to be capable of containing gases.

Climate Type	This subarctic climate is characterized by long, cold winters and short, mild to warm summers.
Population	The population is between 200 and 500 people.
Accessibility	Moderate accessibility, seasonal road access.
Generation Resource	Isolated diesel generation provides 100% of the power requirements.
Water Availability	**Quantity**: The region has an abundant water supply through rivers and streams. **Quality**: Water from rivers and streams potentially contains dissolved minerals and organic matter. Water treatment would be necessary if the water is used for hydrogen production.
Renewable Potential	**Wind:** Strong wind potential in the community, **Solar:** Despite the high latitude of the community, there is potential for solar energy production, especially during the long summer daylight hours. **Hydro:** Rivers and streams in the region offer opportunities for small but limited hydroelectric projects.

Evaluation

Production Options				
	Applicability	**Scalability**	**Affordability**	***Assessment***
Electrolytic Hydrogen	*High*	*Moderate*	*High*	**Recommended:** Strong wind resource supports hydrogen production.
Hydrogen from Fossil Fuels w/ Carbon Capture	*Low*	*Low*	*High*	**Not Recommended:** Low transport access will limit hydrogen production.

Storage Options

	Applicability	Scalability	Affordability	*Assessment*
H2 Tanks	*High*	*Moderate*	*Moderate*	**Recommended:** Lack of natural large scale storage facilities lends itself to H2 tanks being the most viable option.
Depleted Oil Wells	*Low*	*Low*	*Low*	**Potential option:** High volume storage potential. The presence of existing oil wells offers the potential to reduce costs significantly.

End Uses

	Applicability	Affordability	Reliability	*Assessment*
Transport	*Low*	*Low*	*Low*	**Not Recommended:** Electric Vehicles offer greater efficiency.
Heating	*Moderate*	*Moderate*	*Moderate*	**Potential option:** Although heat pumps offer greater heating efficiency, hydrogen heating can be used to provide reliable back up heating option.
Power Generation	*Moderate*	*Moderate*	*Moderate*	**Potential option:** Hydrogen turbines/ fuel cells can be used to offset the remaining fossil fuel consumption from backup diesel generators.

Potential Hydrogen Ecosystem

Key Considerations

- **Evaluate Alternative Solutions**: Assess the economic competitiveness of using renewables coupled with long duration energy storage solution against hydrogen solutions.
- **Electricity Supply for Transport:** A feasibility assessment of local microgrid capacity, ability to meet needs and manage BEV charging requirements may be needed to understand the ability for the community to support additional load growth from BEVs, potential infrastructure upgrades and associated costs.
- **Intermittency of Wind Resource:** A wind resource assessment will be required to determine the availability of wind power for electrolytic hydrogen production. The community will need a suitable form of backup energy generation for when hydrogen

storage reserves are depleted. A select few diesel generators (capacity determined during feasibility analysis) could be maintained for this purpose.

- **Regulatory Barriers:** Ownership of and access to depleted oil wells, as well as safety parameters and regulations must be adhered to. For example, integrity of oil wells and potential for leaks must be investigated. However, a similar process has proven successful for the Tu Deh-Kah Geothermal Project being developed on the depleted gas wells on the Clarke Lake gas field.[46]
- **Local Water Considerations**: Intentional siting of electrolytic hydrogen project locations is critical to avoid water system strain. Assess local water availability, competing uses, and rights. This ensures compliance with water policies and water needs are met.

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[46] Daily Commercial News. Fort Nelson First Nation developing geothermal energy on site of depleted gas wells. Accessed February 2024.

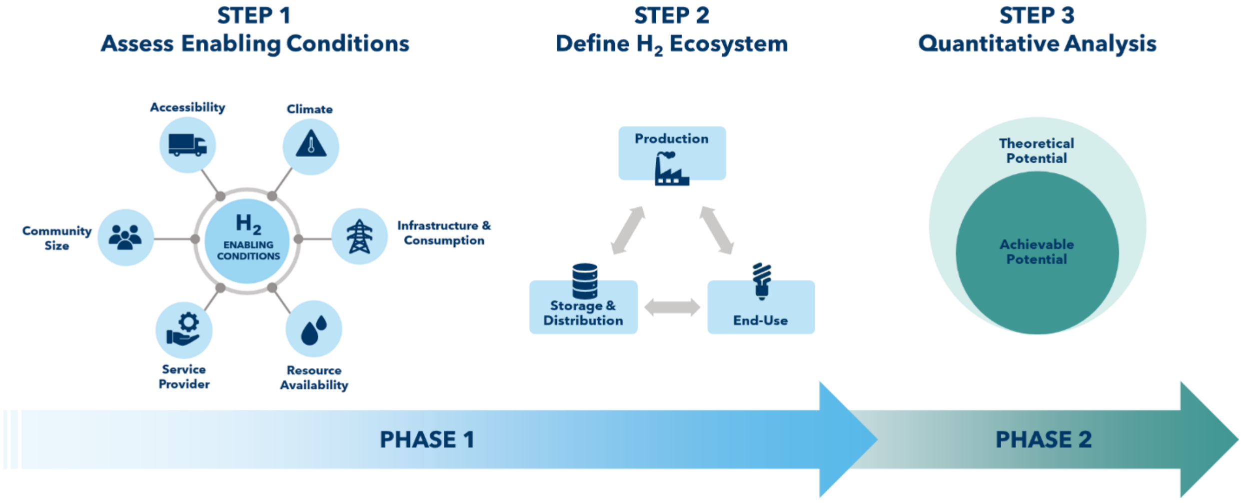
6. Next Steps

Remote communities in Canada are diverse in terms of culture, geography, and environment, each with unique energy needs and resource availability. Traditional methods of decarbonizing these communities face various technical, economic, and social challenges. Therefore, it is crucial to understand the context surrounding these communities, which includes environmental, economic, and social factors, in order to design and implement clean energy solutions that are customized to meet their specific needs and capabilities.

Hydrogen is a promising clean energy solution due to its scalability, versatility, and reliability, all of which are essential characteristics for isolated energy systems. To ascertain the applicability of hydrogen in remote communities, it's imperative to comprehend the fundamental requirements of a hydrogen ecosystem. Once the components and operating requirements of hydrogen ecosystems are well understood, a framework can be applied to assess their suitability.

1. The first step involves identifying the enabling conditions for each community. This is essential for evaluating the feasibility of different hydrogen technologies and determining which conditions are permissive or prohibitive.
2. The second step is to define the hydrogen pathway(s) most suitable for the community based on the enabling conditions and how they fulfil the minimum requirements for operating different hydrogen components. Project proponents should consider various production, storage and distribution pathways and their ability to meet a community's energy demand needs or use cases.

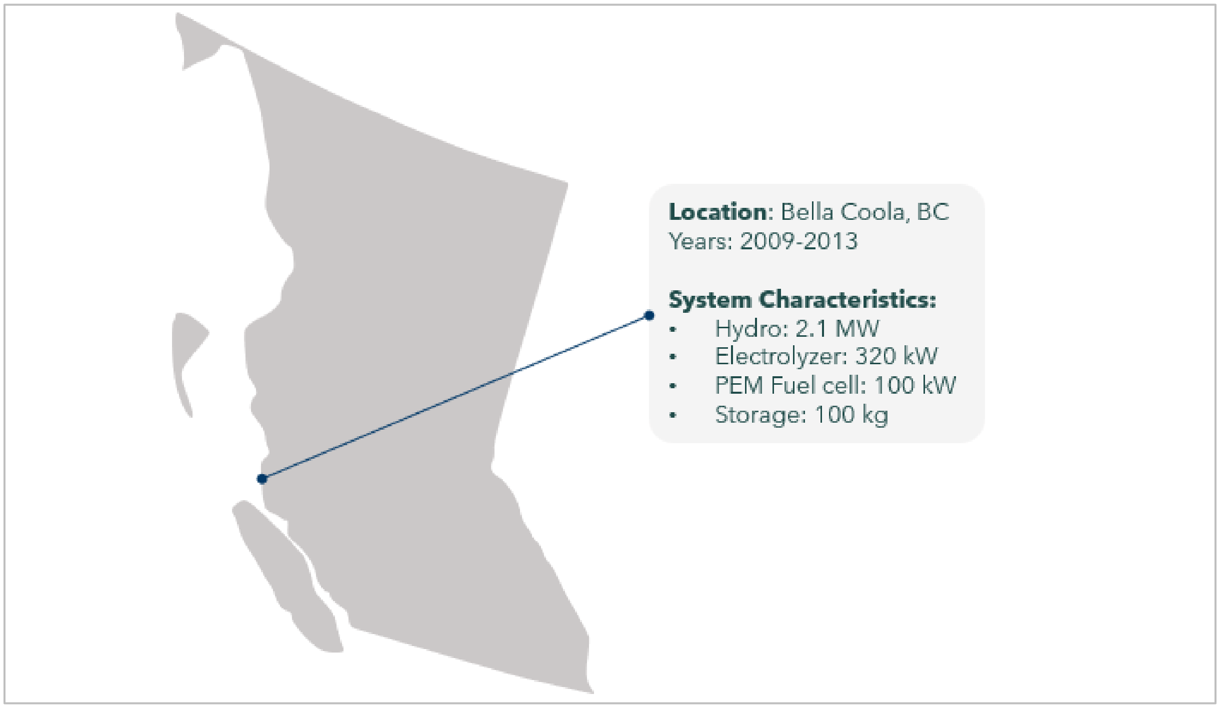
Defining the most suitable hydrogen pathways based on community-specific conditions establishes a qualitative framework, akin to a pre-feasibility assessment, that can be applied across the diverse remote community classifications within the province. Moving forward, the next phase includes conducting a detailed quantitative analysis to validate the outcomes of the preliminary suitability assessment. This would offer insights into the technical and financial feasibility of specific hydrogen pathways, validating or disproving previously identified theoretical role of hydrogen.



Assessing the feasibility of hydrogen as a decarbonization solution requires a comprehensive evaluation of the costs and benefits of implementing hydrogen systems versus other available decarbonization solutions. Adopting a holistic approach enhances informed decision-making, uncovers the realistic potential of hydrogen, and delineates its role in offering a sustainable solution for the intricate challenges of decarbonization in remote communities.

Appendix A: Hydrogen Case Studies

Case Study 1: Hydrogen Assisted Renewable Power (HARP)



Location: Bella Coola, BC
Years: 2009-2013

System Characteristics:
- Hydro: 2.1 MW
- Electrolyzer: 320 kW
- PEM Fuel cell: 100 kW
- Storage: 100 kg

Objective: The HARP project was a small demonstration that combined hydrogen production via electrolysis, hydrogen storage, and fuel cells. Renewable energy from the Clayton Falls hydro station was used to power an electrolyzer to create hydrogen, which was then compressed and stored. The project used a microgrid control system to balance the electrical load between the renewable energy source, diesel generation, and the power provided by the fuel cells.

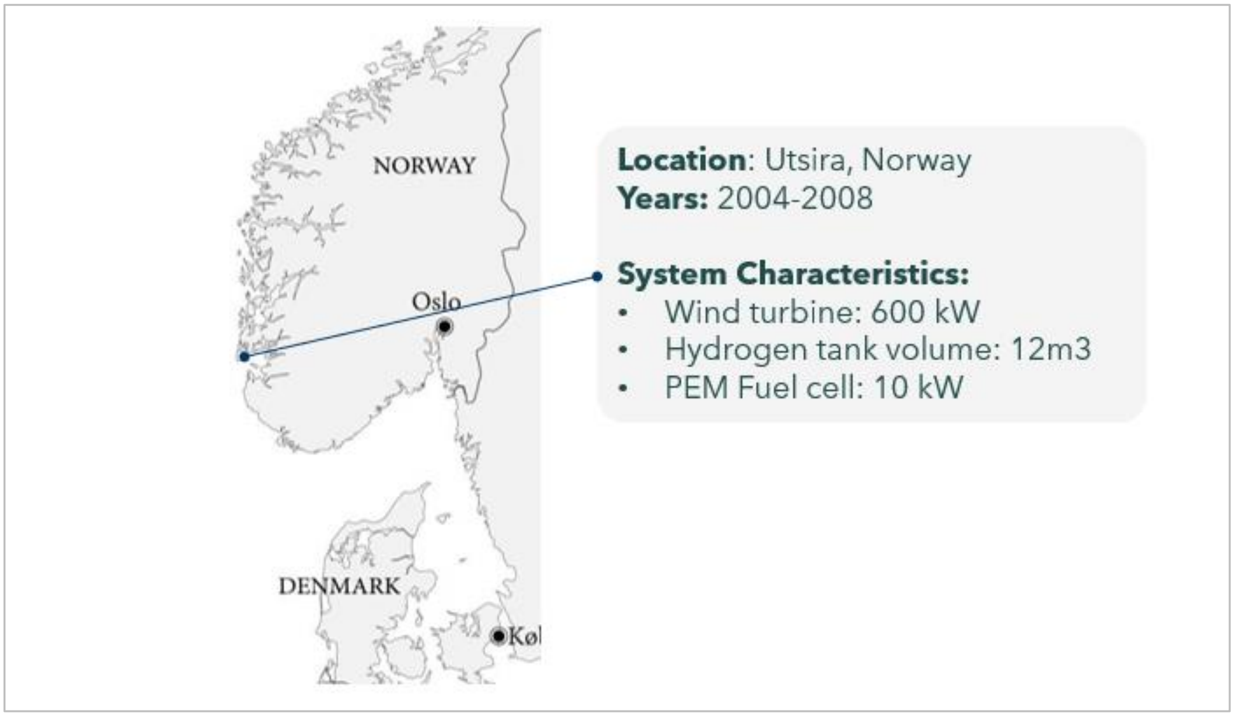
Lessons Learned

Reliability challenges: The initial equipment and spare parts purchase had issues. 100 kW fuel cells were unavailable, so 100x 1 kW fuel cells were used. This created a system with 100 modules, increasing the number of failure points and affecting reliability.

Low System Efficiency: The project incurred high costs associated with the fuel cell and electrolyzer equipment, and the 3-step process for generating electricity (hydroelectricity > electrolysis > fuel cell) was very expensive, with a system efficiency of only ~35%.

Success	**Diesel Reduction:** The project reduced diesel consumption by 10%, exceeding the initial project targets. Demonstrated the value of hydrogen for multiple end-uses by incorporating a hydrogen-fueled truck. **Community Support:** Successfully generated community support for the project and the potential of hydrogen. Engaging the local people involved in the project is key to project success as they are responsible for operating the equipment.

Case Study 2: Wind-Hydrogen System in Utsira Norway



Location: Utsira, Norway
Years: 2004-2008

System Characteristics:
- Wind turbine: 600 kW
- Hydrogen tank volume: 12m3
- PEM Fuel cell: 10 kW

Objective: The Utsira project was chosen as the world's first combined wind and hydrogen power plant. The island has a population of 200 people and faces harsh weather conditions that disrupt the transportation of goods, including the delivery of fossil fuels. The project aimed to demonstrate the production of hydrogen from wind energy in a remote northern environment.

Lessons Learned	• It was very difficult to transport the largest components out to the site with the harsh climate and environment, including high winds, strong waves, salty air, and temperatures below freezing.[47] • Developers needed to select equipment with a high degree of fail-safe and remote operation. However, remote resetting for all of the components was not possible to achieve from the start of the project, due to limitations in the available technology.

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[47] (Ulleberg et al., 2010).

	• Often equipment manufacturers have proprietary control systems. Regardless, communication and interfaces between components should be standardized. • The plant itself faced significant technical and reliability issues. Notably, a durability of less than 100 hours was reported for the fuel cells and the hydrogen engines lasted only 3 years before the pistons were damaged.[48] • Like diesel generators, it is important to install an electrolyzer with quick response capabilities. Ideally, the electrolyzer is capable of continuous operation with the ability to scale operation down to only a few percent of its rated capacity. However, availability of commercial electrolyzers that allow for scaled operation to 25–50% of their rated capacity is limited. • The fuel cell system had to comply with strict requirements for an autonomous power system and tough climatic conditions and it was extremely difficult to find a fuel cell stack supplier who would assume responsibility for overall fuel cell system integration.
Successes	• Remote operation is a necessity for safe operation and systems need to be designed for self-testing and automatic remote resetting of individual components after shutdowns was put in place. While improvements can be made, it was demonstrated that an autonomous system is viable to supply remote area communities with wind power using hydrogen as the energy storage medium. • The hydrogen engine generator was a diesel engine genset rebuilt for hydrogen. The rated power capacity (55 kW) was sufficient to supply the customers without relying on the fuel cell. The hydrogen genset was designed for black start and parallel operation with the fuel cell. It also provides voltage control and inertia to the autonomous system.

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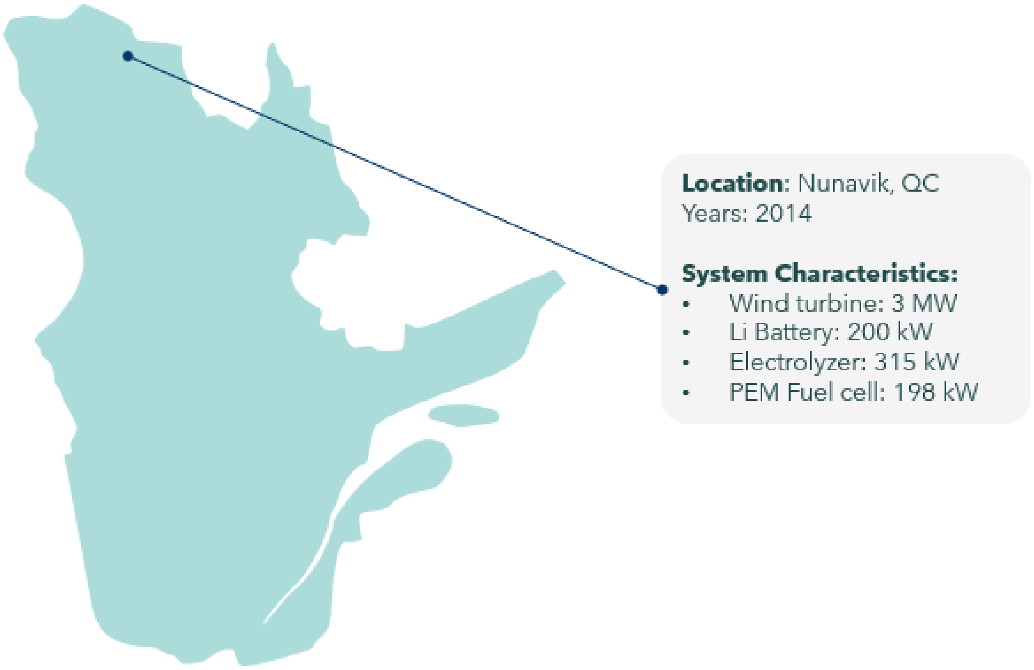
[48] (Widera et al., 2021)

Case Study 3: Glencore Raglan Mine



Location: Nunavik, QC
Years: 2014

System Characteristics:
- Wind turbine: 3 MW
- Li Battery: 200 kW
- Electrolyzer: 315 kW
- PEM Fuel cell: 198 kW

Objective: This initiative combines wind power with a hydrogen energy storage system and diesel generators. The project aims to reduce diesel consumption and GHG emissions, showcasing a model for sustainable energy in remote, harsh environments. While this is a commercial operation, due to the extreme environment of the mine's location, and to the sparse population spread out over large distances, the challenges faced by mining companies pursuing operations in the North are similar to those faced by re and unities.

Lessons Learned

- There were very few manufacturers producing arctic-grade technologies such as wind turbines and so selection was limited, acting as a constraint on design and budget.
- Extremely short summers (typically just one month) coupled with unpredictable weather patterns meant many obstacles and delays were encountered during construction (including a July snowfall). Additionally, the mine is not linked to roads and all wind turbine components had to be delivered by ship.[49]
- Wind turbines on their own typically have a penetration of 15-20%. To capture more of the available wind resource, the project had to develop and implement a three-tiered storage architecture, emphasizing the difficulties in reliably reducing diesel.
- Complex control systems were required to monitor the demand for wind power against natural variations in supply to economically dispatch the charge and discharge of the energy storage units to produce a smooth power output that enabled high (50%) wind power penetration.

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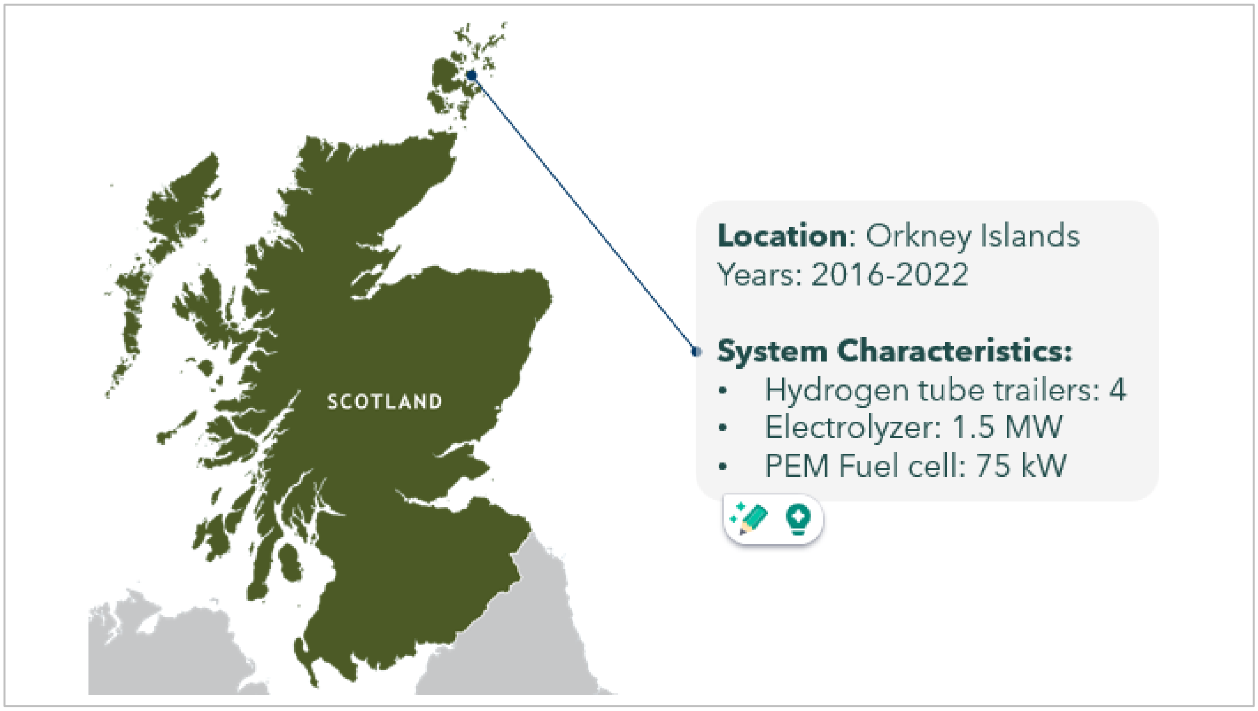
[49] https://energyandmines.com/wp-content/uploads/2014/08/Raglan.pdf

Successes	• Over the first three months, the system successfully demonstrated the interplay of multiple storage technologies in the smoothing of sudden wind energy resource loss, more reliably adapting to the dips and drops in wind power. • The turbine also achieved 97.3% availability since installation and the number of curtailments required to maintain grid stability when wind power generation exceeds the load incurred in conventional wind-diesel hybrid installations were minimized.[50] • Established a flagship reference site validating the technical feasibility and year-round operation of hybrid renewable-hydrogen-storage systems under extreme conditions.

Case Study 4: Building Innovative Green Hydrogen system in Isolated Territory (BIG HIT)



Location: Orkney Islands
Years: 2016-2022

System Characteristics:
- Hydrogen tube trailers: 4
- Electrolyzer: 1.5 MW
- PEM Fuel cell: 75 kW

Objective: BIG HIT is an initiative that leverages the archipelago's vast renewable resources - wind, wave, and tidal energy - to produce hydrogen. This hydrogen is generated through electrolysis using surplus renewable energy, distributed by truck and tube trailer, and is then used in various applications, including heating, transportation, and power generation. One of the key aspects of this project is the demonstration of a community-centric approach to energy self-sufficiency using hydrogen.

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[50] https://natural-resources.canada.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/glencore-raglan-mine-renewable-electricity-smart-grid-pilot-demonstration/16662

Lessons Learned:	- The main results from this work reinforce the idea that issues of scale and geography are critical parameters in relation to the costs of developing hydrogen infrastructure systems. - The equipment was subject to harsh, coastal saline environments and prone to corrosion issues. To maintain reliability, the system needed to be prepared for the environment at the expense of increased expenditures and maintenance. Ensuring the protection of equipment suitable for their operating environment will have a significant positive impact on future designs and on the reduction of maintenance costs. - The project demonstrated that the cost of using hydrogen for energy purposes is still higher than the cost of using fossil fuels. The project was not cost-competitive with conventional energy sources for mobility or electricity generation. - It was determined that the integration of hydrogen into the energy market would require more support from policy and government intervention. Additionally, considering the potential of net zero emissions from renewable sources by developing a method to quantify and value the environmental benefits of hydrogen would also narrow the economic gap between hydrogen and fossil fuel systems.
Successes	- A good example of how remote communities can harness local renewable energy resources to create a sustainable and self-sufficient energy ecosystem. - Successfully demonstrated the benefits of a hybrid, renewable-hydrogen energy system by minimizing curtailment and recovering “lost” energy from intermittent renewables. - The project demonstrated an integrated approach with multiple hydrogen production pathways, hydrogen transportation and storage, and different end-uses, including heat, power, and transport. - The project helped both project partners and regulatory bodies gain practical experience and valuable knowledge on the safe operation and procedures of transporting hydrogen-filled tube trailers on roads and ferries.

Type of Electrolyzer	**Water withdrawal intensity (L/kg)**			**Water consumption intensity (L/kg)**		
	Average	**Max**	**Min**	**Average**	**Max**	**Min**
Alkaline	32.24	34.61	29.88	22.28	23.59	20.96
PEM	25.70	26.46	24.94	17.52	18.04	17.00

Appendix B: Community List

Community Name	Classification	Year-round road access?	Population	Main power source	Name of service provider	Fossil fuel generating capacity (kW)	Price of fuel at site ($/l)	NIA Name	Annual Diesel Consumption (L) 2019	Climate Zone
McBride	EOL	Yes	616	Transmission	BC Hydro				29759	6
Iskut First Nation	EOL	Yes	812	Transmission	BC Hydro				9225	7B
Takla Lake First Nation	EOL	Yes	891	Transmission	BC Hydro				170041	7A
Ocean Falls	NIA	No	203	Hydro	BC Hydro			Bella Bella	Unknown	5
Bella Bella	NIA	No	1019	Hydro	BC Hydro			Bella Bella	304774	5
Wagisla	NIA	No		Hydro	BC Hydro			Bella Bella	Unknown	5
Shearwater	NIA	No	50	Hydro	BC Hydro			Bella Bella	8259	5
Bella Coola	NIA	Yes	807	Hydro	BC Hydro			Bella Coola	1793122	5
Firvale	NIA			Hydro	BC Hydro			Bella Coola	36719	5
Hagensborg	NIA	Yes	256	Hydro	BC Hydro			Bella Coola	313337	5
Masset	NIA	No	793	Diesel	BC Hydro			Masset	1213471	5
Old Masset	NIA	No	555	Diesel	BC Hydro			Masset	3913717	5
Port Clements	NIA	No	555	Diesel	BC Hydro			Masset	1213471	5
Queen Charlotte	NIA	No	852	Hydro	BC Hydro			Sandspit	660195	5
Sandspit	NIA	No	296	Hydro	BC Hydro			Sandspit	229364	5
Skidegate Landing	NIA	No	837	Hydro	BC Hydro			Sandspit	648572	5
Tlell	NIA	No	539	Hydro	BC Hydro			Sandspit	470350	5
Anahim Lake	NIA	Yes	82	Diesel	BC Hydro	3050		Anahim	721175	6
Atlin	NIA	Yes	450	Hydro	BC Hydro	2600		Atlin	107619	7B
Dease Lake	NIA	Yes	335	Hydro	BC Hydro	2450		Dease Lake	1382	7B
Kwadacha	NIA	Yes	332	Diesel	BC Hydro	1835		Kwadacha	661491	7B
Good Hope Lake	NIA	Yes		Diesel	BC Hydro			Good Hope Lake	130286	8

Jade City	NIA	Yes	30	Diesel	BC Hydro			Good Hope Lake	82621	8
Kulkayu	NIA	No	68	Diesel	BC Hydro	1020		Hartley Bay	493631	5
Telegraph Creek	NIA	Yes	250	Diesel	BC Hydro	1800		Telegraph	633672	7A
Toad River Area	NIA	Yes	40	Diesel	BC Hydro	600		Toad River	283526	7B
Tsay Keh Dene	NIA	Yes	525	Diesel	BC Hydro	2410		Tsay Keh Dene	861390	7B
Uchucklesaht	NIA	No	5	Diesel	BC Hydro	519		Ehthlateese	79766	5
Da'naxda'xw First Nation	Remote	No	19	Diesel	Independent				100000	5
Quaee 7	Remote	No	90	Diesel	Independent				Unknown	5
Gwawaenuk	Remote	No	16	Diesel	Independent				230000	5
Hesquiaht	Remote	No	44	Diesel	Independent	150	0.41		231680	5
Klemtu	Remote	No	292	Hydro	Independent				1349040	5
Kwikwasut'inuxw Haxwa'mis	Remote	No	27	Diesel	Independent	225			135715	5
Kluskus	Remote	Yes	32	Diesel	Independent	20			125000	6
Liard First Nation	Remote	Yes	81	Diesel	BC Hydro/ YT Electrical	995			Unknown	8
Owikeno	Remote	No	90	Diesel	Independent	300	0.506		32400	5
Tlatlasikwala	Remote	No	30	Diesel	Independent	70			61600	5
Xeni Gwet'in First Nation	Remote	Yes	197	Diesel	Independent	78	0.99		129000	6
Sechelt Creek	Remote	No	45	Diesel	Independent	125	0.34		Unknown	5
Seymour Inlet	Remote	No	45	Diesel	Independent	125	0.36		Unknown	5
Sheemahantt Conservancy	Remote	No		Diesel	Independent	575	0.35		Unknown	5
Timfor	Remote	No	45	Diesel	Independent	125	0.34		Unknown	5
Knight Inlet	Remote	No		Diesel	Independent	125	0.344		Unknown	5
Narrows Inlet Logging Div	Remote	Yes	45	Diesel	Independent	125	0.34		Unknown	5
Quatam River	Remote	No		Diesel	Independent	125	0.34		Unknown	5
Scott Cove	Remote	No		Diesel	Independent	125	0.36		Unknown	5
Cleagh Creek	Remote	No		Diesel	Independent	125	0.357		Unknown	5
Drury Inlet	Remote	No		Diesel	Independent	125	0.36		Unknown	5
Machmell	Remote	No		Diesel	Independent	125	0.34		Unknown	5
Mooyah Bay	Remote	No		Diesel	Independent	125	0.34		Unknown	5
Moses Inlet	Remote	No		Diesel	Independent	100	0.35		Unknown	5

Phillips Arm	Remote	No		Diesel	Independent	125	0.34		Unknown	5
Pitt Lake	Remote	Yes		Diesel	Independent	125	0.34		Unknown	4
Gilford Island	Remote	No	30	Diesel	Independent	45	0.46		Unknown	5
Kingcome Inlet	Remote	No	91	Diesel	Independent	190	0.52		274000	5
Kitkatla	Remote	No	68	Diesel	Independent	850	0.46		Unknown	5
Queens Cove	Remote	No		Unknown	Unknown				Unknown	5
Nuchatlaht	Remote	No	20	Diesel	Unknown	8			Unknown	5
Tide Lake	Remote			Diesel	Unknown				Unknown	7A
Myra Falls	Remote	Yes		Diesel	Independent	2000			Unknown	5
Table Mountain Gold Project	Remote			Diesel	Independent	2100	0.33		Unknown	8
Big Bar	Remote	Yes		Diesel	Unknown		0.37		Unknown	6
Bob Quinn Lake	Remote	Yes		Diesel	Unknown	250			Unknown	7A
Boulder Bay	Remote			Diesel	Unknown	75			Unknown	4
Germansen Landing	Remote	Yes		Unknown	Unknown				Unknown	7B
Stave Lake	Remote	Yes		Diesel	Unknown	110			Unknown	4
Lasqueti Island	Remote	No	399	Diesel	Independent				Unknown	5
Savary Island	Remote	No	100	Unknown	Unknown				Unknown	5
Seymour Arm	Remote	No	102	Unknown	Unknown				Unknown	6
Eastgate	Remote	Yes		Diesel	Unknown	50	0.356		Unknown	5
Longworth	Remote	Yes		Unknown	Unknown				Unknown	7A
Lower Post	Remote	Yes	81	Diesel	ATCO Electric (YT)				Unknown	8
Penny	Remote	Yes		Unknown	Unknown				Unknown	7A
Dome Creek	Remote	Yes		Diesel	Unknown		0.44		Unknown	7A
Crescent Spur	Remote	Yes	24	Diesel	Unknown				Unknown	7A
Meziadin Lake	Remote	Yes	20	Diesel	Independent	500	0.43		Unknown	7A
Dease River 4	Remote	Yes	38	Diesel	Unknown				130286	8

2019 Data from NRCan Remote Community Energy Database and CleanBC Remote Community Energy Strategy (RCES)

Appendix C: Consumption Data

Consumption data was only readily available for NIA and EoL communities.

Name	Classification	# of Communities	Diesel Generation Capacity (kW)	Diesel Generation (MWh)	Diesel Consumption (L)	Renewable Generation (MWh)	Total Generation (MWh)	Annual Consumption (MWh)	Clean Energy Type	Combined Population Served	Climate Zone	Year-round road access?	% Diesel Generation (Diesel Generation /Annual Consumption)
Masset	NIA	3	10,250	24,470	6,539,995		24,470	24,555		1903	5	No	100%
Anahim	NIA	1	3,050	5,412	1,526,018		5,412	5,329		82	6	Yes	100%
Tsay Keh Dene	NIA	1	2,410	3,271	943,735		3,271	3,241		525	7B	Yes	100%
Telegraph Creek	NIA	1	1,800	2,324	687,346		2,324	2,024		250	7A	Yes	100%
Hartley Bay	NIA	1	1,020	1,875	551,828		1,875	1,895		68	5	No	100%
Good Hope Lake	NIA	2	765	894	325,864		894	898		30	8	Yes	100%
Toad River	NIA	1	600	729	271,674		729	716		40	7B	Yes	100%
Ehthlateese	NIA	1	219	184	117,386		184	160		5	5	No	100%
Sandspit	NIA	4	11,250	3,656	1,014,065	23,996	27,652	26,175	Hydro	2524	5	No	14%
Bella Coola	NIA	3	8,100	8,331	2,280,960	10,714	19,045	24,187	Hydro	1063	5	Yes	34%
Kwadacha	NIA	1	1,835	2,787	832,216		2,787	2,770		332	7B	Yes	100%
Bella Bella	NIA	4	4,900	279	83,194	13,802	14,082	14,068	Hydro	1272	5	No	2%
Dease Lake	NIA	1	2,450	16	2,505	6,120	6,135	5,943	Hydro	335	7B	Yes	0%
Atlin	NIA	1	2,600	48	32,400	5,879	5,927	5,618	Hydro	450	7B	Yes	1%
McBride	EOL	1	5,000 ^	98*	29,759 °			3,182	Transmission	616	6	Yes	3%
Iskut (Eddontenajon)	EOL	1	1,200 ^	30*	9,225 °			1,524	Transmission	812	7B	Yes	2%
Takla Lake	EOL	1	500 ^	561*	170,041			3,357	Transmission	891	7A	Yes	17%

2019 Data from CleanBC Remote Community Energy Strategy (RCES), ° 2018 Data from CleanBC Remote Community Energy Strategy (RCES), ^ 2022 Data from 2022/23 BC Hydro quick facts, * calculation using average diesel generation to diesel consumption ratio of 3.3.

“NO DISCLAIMERS” POLICY

This report was prepared by Dunsky Energy + Climate Advisors, an independent firm focused on the clean energy transition and committed to quality, integrity and unbiased analysis and counsel. Our findings and recommendations are based on the best information available at the time the work was conducted as well as our experts' professional judgment.
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