Analysis of the Policy Options to Adopt Hydrogen for Electricity Generation in Nunavut Remote Communities

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Abstract

In order to reach net-zero carbon targets by 2050, the Canadian federal government released the Hydrogen Strategy to accelerate the adoption of hydrogen as it is a zero-emission fuel source when produced through electrolysis from renewable energy. One of the potential applications of hydrogen is to replace diesel-fired generators in remote communities through renewable-hydrogen coupled projects. As remote communities are not connected with the main North America electricity grid, these communities rely on an independent micro-grid that is powered exclusively by diesel-fired generators with no available back-up systems. The objective of this study is to investigate the potential hydrogen economy in Nunavut and the overview of Nunavut's tentative Independent Power Producer (IPP) program. For this purpose, a comparative analysis was conducted over different IPPs in place in Alaska and selected Canadian jurisdictions.

The results of this study show that the central challenge to renewable projects is creating viable business cases to secure project financing. The comparison of different IPP policies for remote communities conducted in this study shows that this challenge can be overcome through Indigenous ownership, continuous Indigenous consultation and engagement, incorporating Power Purchase Agreement (PPA) rates that reflect the true cost of avoiding diesel as well as long-term PPAs. As the Government of Nunavut has not developed an IPP policy, the results of the study can provide a guideline for Nunavut's tentative IPP.

1.0 Introduction

Canada has adopted climate policies, including the Pan-Canadian Framework on Clean Growth and Climate Change to assist the nation in lowering their greenhouse gas emissions (GHG) by 30% below 2005 levels by 2030 [1]. Additionally, Canada has strengthened their long-term climate plan to reach net-zero emission goals by 2050 alongside Prime Minister Trudeau's pledge to "eliminate diesel from all Indigenous communities by 2030" [1, 2]. Consequently, clean energy projects need to be explored in further detail to stay aligned with Canada's climate policy goals.

Northern remote communities in Nunavut rely on diesel for electricity generation [3]. Although diesel has provided reliable energy for residents, it is associated with high operating costs and has contributed to harmful local air emission pollutants, such as nitrogen oxides and black carbon [3, 4]. Hydrogen is a sustainable and alternative clean fuel that has the potential to serve as a viable energy replacement in Nunavut. Specifically, using hydrogen to make power has zero emissions as water is the only byproduct. Therefore, the use of hydrogen can lower annual GHG emissions in Nunavut as well as provide the required energy capacity [5]. Moreover, the reduction in black carbon, or particulate matter, has the ability to reduce the acceleration of snow melting in the area [6].

In order to support the development of community-scale projects in Nunavut, Independent Power Producer (IPP) programs need to be implemented to allow communities to produce electricity from renewable energy sources [7]. Currently, these programs are in development and have not been released. If there are community-scale developments of hydrogen generation and electric power in Nunavut, what are the IPP options that the Government of Nunavut can explore to enable the uptake of these projects?

This paper explores Nunavut's current diesel-fired electricity generation to develop a comprehensive understanding of the challenges associated with providing electricity for remote communities. Afterwards, a description of a potential hydrogen economy in Nunavut and overview of Nunavut's tentative IPP program will be described. Subsequently, a comparative analysis of the different IPPs in place in Alaska and selected Canadian jurisdictions is discussed at length to inform the Government of Nunavut's approach to developing an IPP policy for the implementation of a community-owned clean energy electricity grid coupled with renewable hydrogen.

2.0 Background

Northern remote communities in Nunavut rely mainly on diesel fuel to supply their energy needs, however, diesel consumption has been associated with economic, social, and environmental challenges [8]. As renewable energy is intermittent, there needs to be a source of power that can provide grid stability and available storage options for times of variability. Hydrogen can be converted to electricity in fuel cells and in times of excess renewable energy, hydrogen can be created through electrolysis and stored.

2.1 Diesel Reliance in Remote Northern Nunavut Communities

As the 25 communities in Nunavut are not connected with the main North American electricity grid, remote communities rely on an independent micro-grid that is powered exclusively by diesel-fired generators with no available back-up systems [3, 9–11]. Therefore, any mechanical problems or a disruption in diesel delivery could have dire consequences for residents. Community members reluctantly accept diesel as it is attributed to survival in harsh northern climates and there is a lack of reliable alternatives [12]. Indigenous perspectives for the development of renewable energy are driven by knowledge of natural resources, as they perceive renewable energy (e.g., wind and solar) as having strong and consistent potential, and support the development of renewable energy projects as it enables communities to gain autonomy and lead to a path of reconciliation [8, 13].

2.2 The Challenges of Diesel-Use

For many communities, diesel is flown in or delivered via barge once a year and stored in large tanks. This results in higher energy costs in Nunavut in comparison to the rest of Canada due to the limited seasonal delivery window, the inefficiencies of aging diesel-fired generators and the accompanying additional costs to store large volumes of diesel [14]. The electricity rate for households in Nunavut's communities is between \$0.59 to \$1.16 CAD/kWh and subsidized to an average electricity cost of \$0.32 CAD/kWh by the Government of Nunavut (Figure 1), which is still significantly above the Canadian average (\$0.18 CAD/kWh) [15-17].

The threat of diesel spills occurring during delivery or storage is a major concern for residents in remote communities since they rely heavily on natural resources (e.g., land, water, wildlife) for basic living needs [16]. Two of the major fuel spills happened on Brevoort Island where about 150,000 liters of oil spilled from a broken fuel line in 2007, and in Resolute where about 87,000 litres of gasoline spilled out of the tank farm partly due to holes in the berm liner, in 2011 [17]. Although the trend for diesel spills (Figure 2) has been declining, there are still occurrences that affect communities. For example, on March 15, 2018 in Grise Fiord, approximately 4,000 liters of diesel spilled out from the power plant's tanks due to a faulty automated valve and loose plug [18]. Additionally, in March 2021, a fuel spill occurred at a tank farm in Baker Lake, which has contaminated the community's fresh water supply [19]. The incident is believed to have taken place on March 5, 2021 but was not discovered until March 29, 2021. These occurrences have emphasized the importance of reducing the possibility of fossil-fuel spills, especially in remote locations, due to the severe impacts on the environment and health of residents.

2.3 Renewable Energy Projects and Energy Storage

Renewable energy sources (e.g., wind and solar) have the potential to reduce the cost of electricity and increase energy security for remote communities. Recent feasibility studies show that a community-scale wind farm can be considered as an alternative energy source for some of Nunavut's communities (i.e., Iqaluit and Rankin Inlet) [20, 21]. In the last decade, the cost of renewable projects have dropped by 60% and are expected to drop even further. Thus, implementing renewables has become a viable option. One challenge with remote installations is the cost of large-scale projects, which will be higher than installations in southern latitudes, because equipment and personnel must be transported on-site during short weather windows. Another challenge with renewable energy is the supply and demand imbalances. This can be overcome using energy storage options that can generate power through rapid swings in variability (e.g., grid stabilization) and over long periods of time (i.e., days or weeks). Although batteries provide short-term energy storage with demand flexibility, alternatively, there needs to be a long-term storage option. Additionally, remote communities need a clean energy source that can be easily stored and locally produced in order to reduce diesel reliance to attain energy security. Hydrogen is able to discharge power over both short and long time periods, which makes it a viable low-carbon energy alternative [22]. By utilizing a wind-hydrogen energy system, a community would benefit from clean and affordable energy that can be relied upon when there is limited wind resources [23]. If the renewable projects are undertaken, existing diesel generators should not be retired as they provide reliable back-up power in case of any disruptions to the wind-hydrogen system.

2.4 Indigenous Perspective Towards Renewables

There is a high level of support from Indigenous communities for renewable projects due to the desire to make use of local resources, which are ingrained in much of the Indigenous and Inuit culture [8]. While there are many differing views on renewable energy projects, one study found that most perceptions are based on the association with previous projects, which include community familiarity and understanding, relationship with culture and sustenance, knowledge of local resources, and security of energy [8]. As there have been several failed wind projects in the past, some community members may show concern towards utilizing renewable projects, yet other members may support them as they understand the benefits that can be gained for the community, especially when they are owned by the community. Community familiarity and understanding are vital for the support of projects. Since wind and solar energy are quantifiable and relatable (i.e., an individual's relationship with nature), there is more support for these technologies. However, there is also an understanding that these resources are variable and therefore cannot be relied on all the time. In order to reduce diesel, community members are able to grasp the idea that there needs to be a storage system to harness energy and store it. Yet, this study also indicated that community members resisted emerging technologies as they did not fully understand them [8]. Integrating a battery storage system might have more acceptance, but because of its limited ability to store energy, it is not the best option [22]. Whereas hydrogen can be stored and used to power communities for long-time periods. Considering hydrogen is a new technology, there would need to be community wide education and discussion on its benefits to successfully integrate this technology within the culture of the community.

3.0 Hydrogen Overview

In December of 2020, the Government of Canada released the Hydrogen Strategy, a framework for the accelerated adoption of hydrogen as a key component of the net-zero carbon targets by 2050. This strategy includes 32 recommendations, under eight pillars, and involves switching from conventional fuel-like diesel to zero-emissions energy source, such as wind power, to achieve hydrogen adoption and development in Canada [24]. This roadmap can be applied to remote communities as the federal government looks to reduce diesel by 2030. Additionally, the strategy shows that hydrogen can create jobs, grow the economy, and protect the environment.

3.1 Hydrogen Economy in Remote Northern Communities

"The hydrogen economy is a proposed system where hydrogen is produced and used extensively as the primary energy carrier" [5]. For remote communities, hydrogen has the ability to replace diesel consumption for electricity generation, heating and transportation. Hydrogen can be produced through electrolysis, where electricity is used to split water into hydrogen and oxygen molecules. Some regions have an abundance of wind energy, which can supply not only the needs of the community, but also the production of hydrogen. This hydrogen can be used in a fuel-cell, in which hydrogen and oxygen are recombined to produce water and electricity. Not only can hydrogen generate grid-stabilization energy for times when the wind is variable, but it can also be stored in vessels (i.e., tanks) and utilized for longer periods of time when wind energy is below the energy demands of the community. Additionally, hydrogen can be used for residential heating, similar to natural gas. While this would require modifications to the current heating system, which relies on fuel-oil, it is currently feasible. Lastly, as internal combustion engines are phased out of production, fuel-cell vehicles are the logical choice for northern climates as they are more efficient in cold weather than battery vehicles [25]. In conclusion, hydrogen is a sustainable and versatile energy carrier that benefits the economy and environment. Moreover, it can play an important part in decarbonization of energy systems in remote northern communities [5, 24, 26].

4.0 The Role of IPP Agreement Policies to Enable Hydrogen Power in Nunavut

A Power Purchase Agreement (PPA) is a contract between electricity producers/sellers (i.e., IPP) and buyers (i.e., utilities) that defines the revenue/rate of the generating project, which is a key component to the economics of the project. If both the duration and rate of the PPA are higher, this will lead to a successful implementation of the project. For remote communities, this rate is not fully understood as it is complicated to calculate the results. Many utilities use the marginal cost and avoided cost of diesel to determine the rate of the PPA. The marginal cost encompasses the commodity price of diesel, the cost of transportation, the taxes associated with handling and distribution, and the generation of the electricity. This marginal cost can vary over time due to commodity prices and the efficiency of aging diesel generators. The avoided cost of diesel includes the marginal cost, and the cost of service, which includes the costs associated with the operation, maintenance, and servicing of machinery and buildings; storage facilities for the fuel; amortization of capital costs and staff to operate the facility [27]. If a renewable system was able to completely replace a diesel system, the avoided costs could be the financial metric used to finance a clean energy system. If the renewable system was able to produce electricity at costs lower than a new diesel system, both the community and the provincial/territorial government would benefit from the lower rates. While many provinces and territories have energy strategies to reduce diesel reliance by developing clean energy projects, policies that have strong Indigenous engagement can allow communities to participate and take ownership in energy projects. Community-ownership can have positive effects that create local jobs, provide economic opportunities, energy independence, and a pathway towards self-governance.

5.0 Jurisdiction Comparison of IPP Policies for Remote Communities

Each of the three Canadian territories, Nunavut, Yukon, and Northwest Territories (NWT), have developed energy strategies to encourage renewable energy generation, but all three differ in scope and implementation [28]. These differences are related to how each of these territories produce and distribute power. For instance, 25 communities in the Yukon and NWT are connected to regional hydro-electricity grids in comparison to 34 communities that rely on micro-hydro electricity. The remainder of northern communities rely on fossil fuels, therefore, each territory will have a different approach to reduce diesel power generation. These strategies, coupled with initiatives, such as the Alaska Renewable Energy Fund, NWT Community Renewable Energy Program and the Yukon's Innovative Renewable Energy Initiative, are catalysts to commence renewable energy projects, drive economic growth and develop local capabilities [29]. Since these projects may not always reduce the cost to electricity rates from the incumbent diesel-fired generation, IPP policies can ensure the successful implementation of community-scale renewable projects. The following section is a comparative study of the current strategies, initiatives and IPP policies that are currently in place in selected communities.

5.1 Nunavut CIPP and IPP Overview

In 2007, the Government of Nunavut released the Ikummatiit Energy Strategy with the goal of reducing their dependency on diesel fuel consumption. This strategy specifically focused on developing an affordable, sustainable, and environmentally responsible renewable energy system. Additionally, the Qulliq Energy Corporation (QEC), the Government of Nunavut owned electricity service provider, recently included hydrogen fuel cells as energy alternatives to diesel power [30].

In March 2021, QEC released a Commercial and Institutional Power Producer (CIPP) program and currently has an IPP program in development. The purpose of the IPP is to foster clean energy developments to reduce reliance on diesel-fuel, decrease carbon emissions while helping Nunavut promote self-reliance. QEC expects that the IPP program will pay up to the avoided cost of diesel so that there is no rate increase for customers [7].

The CIPP program allows for small-scale producers to generate power on-site and sell electricity to QEC. In order to reduce the risk of customer rate increases, QEC will purchase the electricity generated at the strike price, which is set at $0.2476 CAD/kWh multiplied by the amount of energy produced (but only up to contracted capacity). One disadvantage for the CIPPs is that the Renewable Attributes (REC) must be assigned and transferred to QEC. Therefore these businesses and institutions are not able to generate revenue from carbon credits provided by federal government programs.

5.2 Yukon Policy Overview

Yukon is the only territory in Canada with a formal IPP policy [31]. This policy establishes IPP targets of 10% of the territory's electricity demand, and at least 50% of all IPP projects incorporate some share of First Nation ownership. In 2009, the Government of Yukon released its Energy Strategy, which was updated in 2018, with a focus on promoting energy security by supporting renewable energy projects through IPP policies. The IPP policy, called the Standing Offer Program, was introduced in October 2015 and supports large-scale power producers. The

Yukon Utilities Board governs the PPA rate and is intended to be based on the avoided cost of diesel; however, as these avoided costs are variable with no consistent rate among the communities, the marginal cost tends to be closer to the rate negotiated. Overall, more projects in the Yukon have had successful implementation when the PPA rates were negotiated to be 10% to 20% higher than the marginal cost [32, 33].

Additionally, through the Innovative Renewable Energy Initiative, the Government of Yukon has supported the development of IPPs, including the Vuntut Gwitchin First Nation's solar project in Old Crow and the Kluane First Nations wind project in Destruction Bay.

5.3 Northwest Territories Policy Overview

The Government of the Northwest Territories (GNWT) does not have a formal IPP policy and any project proposals must be negotiated with the provincial government as well as the Utility [34]. In 2018, the 2030 Energy Strategy proposed that all new renewable power projects must be largely-owned by the community or Indigenous organizations. The GNWT continues to support developments by providing technical and financial programs [34]. Since community-based renewable energy projects are expensive, the GNWT may choose to subsidize the potential increase in electricity rates so there are accompanying benefits for the consumers, but no profits will be allowed for the project. This policy limits the business case for community-owned projects and restricts the number of projects that have been implemented. Moreover, the Northwest Territories Power Corporation (NTPC) has a Net-Metering Program that encourages alternative energy generation. However, since high penetration rates of renewable energy can cause grid instability, the NTPC and other utilities have capped renewable energy generation at 20% since current electricity systems cannot absorb large load swings [34]. The NTPC recognizes that the combination of variable speed generators, grid controls and storage systems could be solutions to these imbalances. This program allows for small-scale residential and industrial customers to integrate renewable energy into the existing grid and gain credits that can be used during winter months when they are most needed [35].

While there is no clear policy in place, the first IPP in all of the northern territories was a 35 kW solar project in the Indigenous community of Lutsel K'e, located to the east of Yellowknife. Released in 2016, this project was awarded a PPA 5% greater than the marginal cost of diesel [36]. Furthermore, this community-owned project has created a green fund for future initiatives from the savings that they have garnered from the project [36]. To date, there has been no additional community-owned projects.

5.4 Alaska Policy Overview

Similar to Canadian northern remote communities, diesel generators are the main source of electricity in Alaska's remote communities [37]. This results in higher costs of electricity, which tend to be three to five times the cost of electricity in urban areas [38, 39]. In alignment with global climate policy goals to reduce their emissions, Alaska had instilled a non-binding goal to produce 50% of their electricity generation from renewables by 2025 [37, 38]. Consequently, the Alaska Independent Power Producers Association (AIPPA) was formed to assist Alaska in achieving this target "by utilizing private know how and private capital to invest and develop Alaska's energy resources for Alaskans now and for years to come" [39]. Ultimately, this would allow renewable projects to operate and sell power at or below the market rate, which would minimize the need for government interventions and subsidies (e.g., Power Cost Equalization payments) [39].

Currently, AIPPA members consist of Arctic Energy, Delta Wind Farm, STG Incorporated, Juneau Hydropower, Fishhook Renewable Energy, LLC, CIRI, and the Alyeska Resort [39]. These members represent private enterprises who can develop renewable energy projects where the contract price is fixed for up to 40 years [39]. Furthermore, utilities and municipalities are permitted to enter IPP long-term contracts, which will "eliminate price uncertainty for its ratepayers with the financing risk left to the independent producer" [39]. These projects must be approved by the Regulatory Commission of Alaska to sell power, otherwise it cannot proceed [40–42].

5.5 British Columbia Policy Overview

Since 1980, British Columbia (BC) Hydro has been acquiring power from IPPs and has been the leading jurisdiction for reducing diesel in remote communities by establishing strong climate and energy policies. The 2019 BC Energy Plan aims to reduce diesel use to 80% by 2030 for the largest 12 remote communities served by BC Hydro, and the 10 remote communities that act as independent power authorities whom own diesel generation stations [43]. In 2008, BC Hydro implemented the Standing Offer Program (SOP) and the Micro-Standing Offer Program (Micro-SOP) to enable small-scale clean energy projects between 100 kW to 1 MW, especially for projects developed by First Nations and communities [44]. Similar to other IPP agreements, this program is designed to shift the risk to the power producer and not the ratepayers. The PPA rates are typically for the marginal cost of diesel, but because the IPP contracts are typically confidential, there is no measure as to whether the rate actually avoids the displaced cost of diesel. In 2018, the program was put on hold during a review process and suspended indefinitely the following year in order to reduce overall costs and maintain low power rates. Overall, this will reduce the amount of future energy projects from IPPs in BC, especially from remote communities pursuing diesel-reduction projects.

6.0 Discussion and Recommendations

The jurisdictional comparisons of IPP policies for remote communities conducted in this study shows that the central challenge to renewable projects is creating viable business cases to secure project financing. As previously mentioned, the collective advantages include majority owned Indigenous ownership, continuous Indigenous consultation and engagement, incorporating PPA rates that reflect the true cost of avoiding diesel as well as allowed long-term PPAs. Moreover, by outlining prices and escalation in the PPAs, a predictable cash flow can be determined throughout the entirety of the contract, which makes these kinds of projects favourable for financing arrangements.

In some jurisdictions, proponents voiced frustration over the process of implementing clean energy projects due to a lack of clear IPP policies with no public details on the actual cost of diesel generation. There is also concern whether privatization of government-owned electricity systems could lead to higher prices in order for proponents to cover the actual cost of energy generation.

6.1 Recommendations

Going forward, the Government of Nunavut should update their published Ikummatiit Energy Strategy to include hydrogen as an alternative energy option [45]. By incorporating hydrogen into their energy strategy, the Government of Nunavut officially recognizes hydrogen as an appropriate pathway to decarbonizing their electricity. Moreover, the territorial government should look to release their highly anticipated IPP program in order to promote the development of community-scale projects. PPAs should be based on the avoided costs of diesel since there are accompanying benefits when diesel generators are inactive for extended periods of time. To promote higher levels of implementation, the Government of Nunavut should provide financial support either through partnerships or subsidies to improve business cases for clean energy projects. This would allow the communities to generate revenue for technical training in operating and maintaining clean energy projects. As these projects tend to be more technically diverse, the PPAs should have stipulations built in where the Utility will provide technical expertise until the community can handle the daily functions themselves. As the Government of Nunavut heavily subsidizes diesel electricity generation, the savings in electricity subsidies should be redirected to other social programs such as education, healthcare and housing.

Since 85.9% of Nunavut's population has identified as Indigenous, honest and transparent consultation and engagement must be continuously upheld as alternative energy options (e.g., hydrogen) are explored in further detail [46]. This will ensure that Indigenous peoples are able to express their concerns and thoughts in a fair and equitable manner. Additionally, since QEC has announced that their upcoming IPP program will allow municipalities and Inuit organizations to own and operate community-scale renewable energy systems, these IPPs should be structured so that Inuit communities have majority ownership and fair PPA rates are given to make a viable business case for the projects [7]. The policy should also be clear on the level of private investments to ensure that electricity rates cannot be increased without consent of the community. Ultimately, these adjustments would collectively incentivize community-scale hydrogen energy projects.

7.0 Conclusions

As Nunavut looks to renewable energy sources to reduce the reliance on diesel and decrease GHG emissions, hydrogen should be considered as a viable alternative fuel as it can provide grid stabilization and long-term power to balance the variability in renewable energy systems. This is in accordance with the published Hydrogen Strategy for Canada, which outlines potential production pathways alongside economic, environmental and social opportunities.

Currently, Nunavut does not have a published IPP policy to encourage the investment of community-scale renewable energy projects. In order to support the development of hydrogen projects for electricity generation, there should be a clear PPA policy in place. Clearly defined long-term PPAs and rates that are competitive against incumbent diesel electricity should be made accessible to proponents to move projects ahead quickly. Indigenous-ownership is essential for communities to adopt community-scale renewable power generation projects as this can also lead to local jobs, economic opportunities, energy independence and a pathway to self-governance.

In order to reach decarbonization goals, hydrogen plays an important role in the electricity energy mix. Remote communities need accessibility to reliable and locally-produced energy sources in order to attain energy security. Hydrogen has the potential to not only reduce high energy costs, but provide environmental and social benefits. Additionally, since this is a new technology, local residents could participate in educational and training programs that would empower them to be valuable leaders in Canada’s hydrogen economy.

Abbreviation

Abbreviation	Definition
AIPPA	Alaska Independent Power Producers Association
BC	British Columbia
CIPP	Commercial and Institutional Power Producer
GHG	Greenhouse gas emissions
GNWT	The Government of the Northwest Territories
IPP	Independent Power Producer
NTPC	Northwest Territories Power Corporation
NWT	Northwest Territories
PPA	Power purchase agreement
QEC	Qulliq Energy Corporation
SOP	Standing Offer Program

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References

[1] Government of Canada, "Progress towards Canada's greenhouse gas emissions reduction target," *Government of Canada*, 03-Mar-2021. [Online]. Available: https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/progress-towards-canada-greenhouse-gas-emissions-reduction-target.html. [Accessed: 25-Apr-2021].

[2] Government of Canada, "Net-Zero Emissions by 2050," *Government of Canada*, 06-Apr-2021. [Online]. Available: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html. [Accessed: 25-Apr-2021].

[3] Canada Energy Regulator, "Market Snapshot: Overcoming the challenges of powering Canada's off-grid communities," *Canada Energy Regulator*, 29-Jan-2021. [Online]. Available: https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2018/market-snapshot-overcoming-challenges-powering-canadas-off-grid-communities.html. [Accessed: 24-Apr-2021].

[4] Z. Klimont *et al.*, "Global anthropogenic emissions of particulate matter including black carbon," *Atmos. Chem. Phys.*, vol. 17, no. 14, pp. 8681–8723, Jul. 2017.

[5] J. O. Abe, A. P. I. Popoola, E. Ajenifuja, and O. M. Popoola, "Hydrogen energy, economy and storage: Review and recommendation," *Int. J. Hydrogen Energy*, vol. 44, no. 29, pp. 15072–15086, 2019.

[6] S. Kang, Y. Zhang, Y. Qian, and H. Wang, "A review of black carbon in snow and ice

and its impact on the cryosphere," *Earth-Science Rev.*, vol. 210, p. 103346, Nov. 2020.

[7] Qulliq Energy Corporation, "Independent Power Producer Program," *Qulliq Energy Corporation*. [Online]. Available: https://www.qec.nu.ca/customer-care/generating-power/independent-power-producer-program. [Accessed: 24-Apr-2021].

[8] N. Mercer, A. Hudson, D. Martin, and P. Parker, "'That's Our Traditional Way as Indigenous Peoples': Towards a Conceptual Framework for Understanding Community Support of Sustainable Energies in NunatuKavut, Labrador," *Sustainability*, vol. 12, no. 15, p. 6050, Jul. 2020.

[9] Government of Nunavut, "Statistics Home," *Government of Nunavut*. [Online]. Available: https://www.gov.nu.ca/executive-and-intergovernmental-affairs/information/statistics-home. [Accessed: 24-Apr-2021].

[10] Canada Energy Regulator, "Provincial and Territorial Energy Profiles - Nunavut," *Canada Energy Regulator*, 17-Mar-2021. [Online]. Available: https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-nunavut.html. [Accessed: 24-Apr-2021].

[11] Conference Board of Canada, "Power Shift: Electricity for Canada's Remote Communities," *Conf. Board Canada*, no. September, pp. 1–65, 2016.

[12] N. C. Mcdonald and J. M. Pearce, "Community Voices: Perspectives on Renewable Energy in Nunavut," *Arctic*, vol. 66, no. 1, pp. 94–104, Mar. 2013.

[13] Dixon L. Byrne, "Exploring Renewable Energy Opportunties for," *University of Calgary*, Aug-2018. [Online]. Available: http://hdl.handle.net/1880/108742. [Accessed: 24-Apr-2021].

[14] Canada Energy Regulator, "Market Snapshot: Explaining the high cost of power in northern Canada," *Canada Energy Regulator*, 11-Feb-2021. [Online]. Available: https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2017/market-snapshot-explaining-high-cost-power-in-northern-canada.html. [Accessed: 24-Apr-2021].

[15] Rylan Urban, "Electricity Prices in Canada 2021," *Energyhub*, 11-Mar-2021. [Online]. Available: https://www.energyhub.org/electricity-prices/. [Accessed: 24-Apr-2021].

[16] Connie Vitello, "The future of energy in remote communities," *ReNew Canada*, 24-Jun-2020. [Online]. Available: https://www.renewcanada.net/feature/the-future-of-energy-in-remote-communities/. [Accessed: 24-Apr-2021].

[17] CBC News, "Nunavut fuel spills are down, but accidents still happen," *CBC News*, 16-Apr-2014. [Online]. Available: https://www.cbc.ca/news/canada/north/nunavut-fuel-spills-are-down-but-accidents-still-happen-1.2612118. [Accessed: 24-Apr-2021].

[18] ES&E Magazine, "Latest spill shows North still struggling to prevent and control oil events," *ES&E Magazine*, 09-Apr-2018. [Online]. Available: https://esemag.com/hazmat-remediation/latest-spill-shows-north-still-struggling-prevent-control-oil-events/. [Accessed: 24-Apr-2021].

[19] Nunatsiaq News, "Fuel spill poses risks to Baker Lake's water supply: Nunavut government," *Nunatsiaq News*, 23-Apr-2021. [Online]. Available: https://nunatsiaq.com/stories/article/fuel-spill-poses-risks-to-baker-lakes-water-supply-nunavut-government/. [Accessed: 25-Apr-2021].

[20] Tugliq Energie, "Iqaluit - Wind campaign measurement ," *Tugliq Energie*, 2017. [Online]. Available: https://tugliq.com/en/realisation/iqaluit/?fbclid=IwAR1SZ1xCeyr39tH1e6jp8Jkh3TFlRIjAovOyKjmNxV_aewDOestakwhbxM8. [Accessed: 24-Apr-2021].

[21] Natural Resources Canada, "Remote Communities Energy Database," *Government of*

Canada, 03-Aug-2018. [Online]. Available: https://atlas.gc.ca/rced-bdece/en/index.html. [Accessed: 24-Apr-2021].

[22] Hydrogen Council, "Hydrogen Council - An Introduction," *Hydrogen Council*. [Online]. Available: https://hydrogencouncil.com/en/. [Accessed: 24-Apr-2021].

[23] Fong, M., Jalilpour, S., Wallace, C., Wu, P. S., Zeinabady, D. "Investigating the Feasibility of Hydrogen to Reduce Diesel Reliance in Remote Communities. Poster presentation.," Calgary, Alberta, 2021.

[24] Natural Resource Canada, "Hydrogen Strategy for Canada," *Government of Canada*, 2020. [Online]. Available: https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf.

[25] M. Henning, A. Thomas, and A. Smyth, "An Analysis of the Association between Changes in Ambient Temperature, Fuel Economy, and Vehicle Range for Battery Electric and Fuel Cell Electric Buses," *Urban Publ.*, Nov. 2019.

[26] Hydrogen In Motion, "Products," *Hydrogen In Motion*. [Online]. Available: https://www.hydrogeninmotion.com/products/. [Accessed: 24-Apr-2021].

[27] D. Lovekin and D. Heerema, "The True Cost of Energy in Remote Communities: Understanding diesel electricity generation terms and economics 2 nd edition," *Pembina Institue*, Mar-2019. .

[28] Senate of Canada, "Powering Canada's Territories: Standing Senate Committee on Energy, the Environment and Natural Resources," *Senate of Canada*. [Online]. Available: https://sencanada.ca/content/sen/Committee/412/enev/rep/rep14jun15-e.pdf. [Accessed: 24-Apr-2021].

[29] WWF-Canada, "Fueling the Change in the Arctic," *WWF-Canada*. [Online]. Available: https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/energy-resources/WWF_-_Fueling_the_change_in_the_Arctic.pdf. [Accessed: 24-Apr-2021].

[30] Qulliq Energy Corporation, "Alternative Energy," *Qulliq Energy Corporation*. [Online]. Available: https://www.qec.nu.ca/power-nunavut/alternative-energy. [Accessed: 25-Apr-2021].

[31] Government of Yukon, "Department of Energy, Mines and Resources," *Government of Yukon*. [Online]. Available: https://yukon.ca/en/department-energy-mines-resources. [Accessed: 25-Apr-2021].

[32] Yukon Electrical Company Limited and Yukon Energy, "Rate Schedules," 01-Jul-2011. [Online]. Available: https://www.atcoelectricyukon.com/content/dam/web/electric-yukon/YECL YEC Rate Schedules 04-2021.pdf. [Accessed: 25-Apr-2021].

[33] Government of Yukon, "Add a solar system and sell your surplus energy," *Government of Yukon*. [Online]. Available: https://yukon.ca/en/micro-generation-program. [Accessed: 25-Apr-2021].

[34] Northwest Territories Power Corporation, "Adding Renewables to Electricity Grids," *Northwest Territories Power Corporation*, Feb-2018. [Online]. Available: www.ntpc.com. [Accessed: 25-Apr-2021].

[35] Northwest Territories Power Corporation, "Net Metering." [Online]. Available: https://www.ntpc.com/customer-service/net-billing. [Accessed: 25-Apr-2021].

[36] Renée Francoeur, "First Nation becomes NWT's first independent power producer ," *Electrical Business*, 22-Jun-2016. [Online]. Available: https://www.ebmag.com/first-nation-becomes-nwts-first-independent-power-producer-18750/. [Accessed: 25-Apr-2021].

[37] U.S. Energy Information Administration, "Alaska State Energy Profile," *U.S. Energy Information Administration*, 21-Jan-2021. [Online]. Available: https://www.eia.gov/state/print.php?sid=AK. [Accessed: 25-Apr-2021].

[38] U.S. Environmental Protection Agency, "Remote Areas of Alaska: Affordable and Reliable Options for Meeting Energy Needs and Reducing Emissions," *U.S. Environmental Protection Agency*, Sep-2020. .

[39] The Power of Alaska, "Independent Power: The Cost of Electricity from Alaska Independent Power Producers," *The Power of Alaska*, 2021. [Online]. Available: https://aippa.info/alaskas-potential/independent-power/. [Accessed: 25-Apr-2021].

[40] Regulatory Commission of Alaska, "Alaska Independent Power Producers Association," *Regulatory Commission of Alaska*. [Online]. Available: http://rca.alaska.gov/RCAWeb/Entity/EntityDetails.aspx?id=E78A933B-14CE-46D6-AA2A-1DA932556E7F. [Accessed: 25-Apr-2021].

[41] Renewable IPP, "Chugach Solar Farm-Frequently Asked Questions," *Renewable IPP*, 25-Feb-2021. [Online]. Available: www.renewableipp.com. [Accessed: 25-Apr-2021].

[42] Renewable IPP, "Houston Solar Farm - Frequently Asked Questions," 02-Jun-2020. [Online]. Available: www.renewableipp.com. [Accessed: 25-Apr-2021].

[43] Government of British Columbia, "Ministries and organizations," *Province of British Columbia*. [Online]. Available: https://www2.gov.bc.ca/gov/content/governments/organizational-structure/ministries-organizations. [Accessed: 25-Apr-2021].

[44] BC Hydro, "Micro-Standing Offer Program Rules ," *BC Hydro*, Mar-2016. .

[45] Government of Nunavut, "Ikummatiit: The Government of Nunavut Energy Strategy," *Government of Nunavut*, Sep-2007. [Online]. Available: https://gov.nu.ca/sites/default/files/ikummatiit_energy_strategy_english.pdf. [Accessed: 25-Apr-2021].

[46] Statistics Canada, "Focus on Geography Series, 2016 Census - Nunavut," *Statistics Canada*, 10-Apr-2019. [Online]. Available: https://www12.statcan.gc.ca/census-recensement/2016/as-sa/fogs-spg/Facts-PR-Eng.cfm?TOPIC=9&LANG=Eng&GK=PR&GC=62. [Accessed: 25-Apr-2021].

Figures

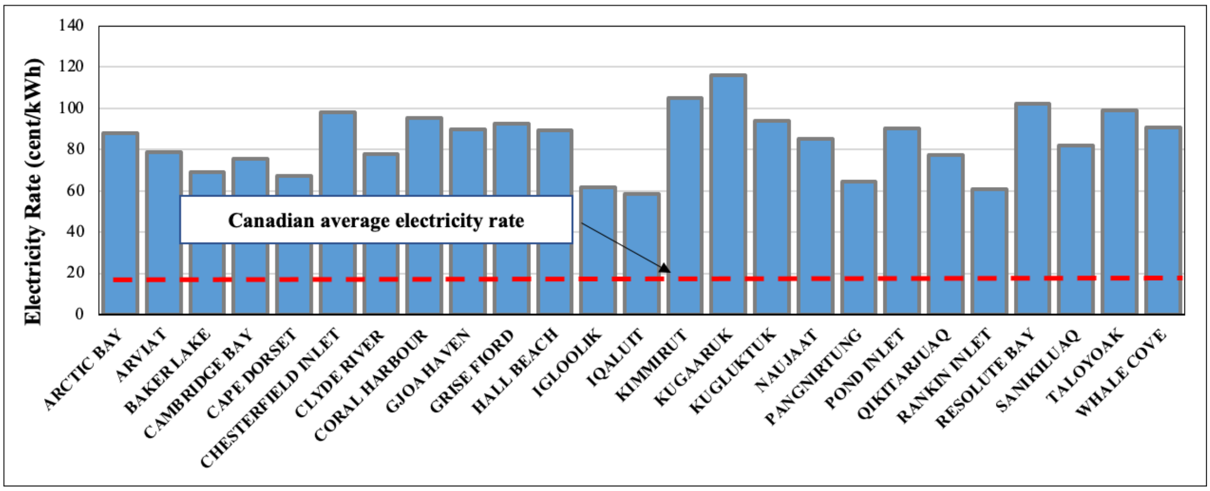

Figure 1. The comparison of electricity rate in Nunavut's communities with the Canadian average electricity price

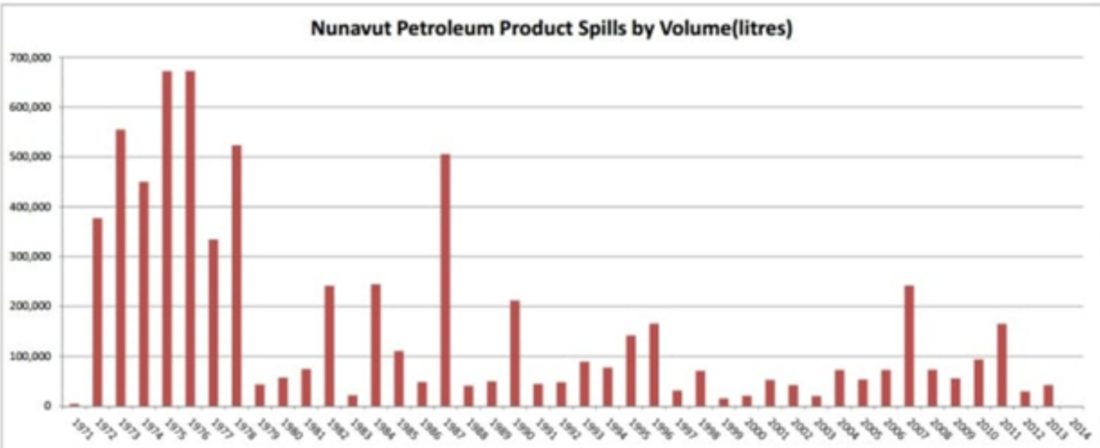

Figure 2. Petroleum product spills in Nunavut from 1971 to 2014 [17].