Master of Public Policy
Capstone Project

More Than One Option: An Integrated Approach to Reduce Diesel Reliance – Introducing Forest Biomass Energy in Old Crow, Yukon, a Pilot Project

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Capstone Approval Page

The undersigned, being the Capstone Project Supervisor, declares that

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List of Acronyms

CBA	cost-benefit analysis
CHP	combined heat and power
CO_2	carbon dioxide
GHG	greenhouse gas
kg	kilogram
kg/h	kilogram per hour
km	kilometre
kW	kilowatt
kW/h	kilowatt per hour
kWh	kilowatt-hour
kWth	kilowatt of thermal power
m^3	cubic metre
NOx	nitrous oxide
NPV	net present value
$PM_{2.5}$	fine particulate matter
SC-GHG	social cost of greenhouse gas
SCC	Social cost of carbon
VOC	volatile organic compound
VSL	value of statistical life

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Abstract

This paper aims to implement an integrated approach to renewable energy solutions for remote Indigenous communities in Canada, focusing on forest biomass as a sustainable alternative. Indigenous communities, disproportionately affected by climate change due to historical displacement and colonial relocation, are actively seeking alternatives to fossil fuels amidst Canada's goal of achieving net-zero emissions by 2050. However, existing climate regulations often overlook the unique challenges faced by these communities. A comprehensive cost-benefit analysis was conducted on the implementation of a woody biomass combined heat and power system to generate electricity in the Vuntut Gwitchin Nation, a remote community located in Old Crow, Yukon. The objective is to combine forest biomass-based energy with existing solar infrastructure to further reduce diesel reliance, improve community health, and address energy security. This research showcases the importance of a multi-pronged approach to renewable energy solutions for remote Indigenous communities and highlights the potential of biomass integration to achieve sustainable energy goals in Canada. It also suggests the need for inclusive climate policies and government support to ensure remote Indigenous communities have equitable access to clean energy transitions.

1. Introduction

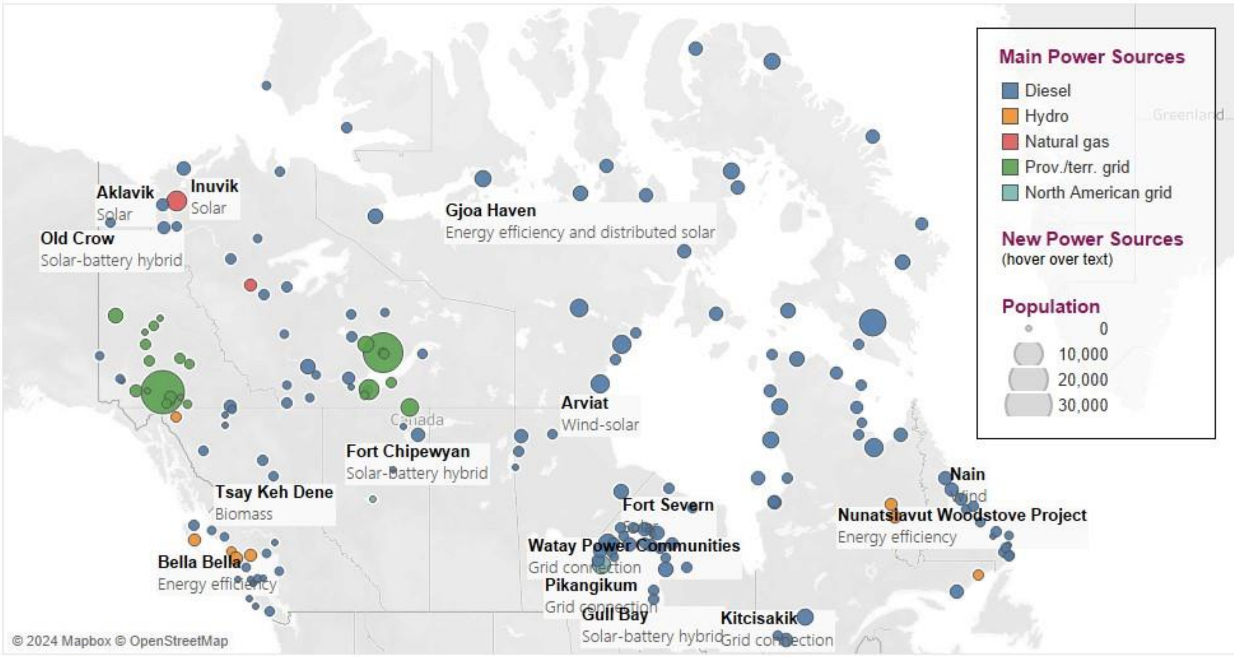
In Canada, the narrative of energy access and climate change intertwines profoundly, especially in the context of nearly 280 remote communities. These communities are widely distributed across the country and are not connected to the North American electricity grid or natural gas infrastructure. Year-round road access is only available in some of these communities, and over half can only be reached by air (Canada Energy Regulator 2018). Approximately 178 of these communities are Indigenous, and they rely exclusively on fossil fuel to generate electricity (Canada Energy Regulator 2023) while facing the adverse impacts of climate change.

Indigenous communities in Canada are exceptionally vulnerable to the impacts of climate change because they tend to live in northern remote regions undergoing rapid climate change and because they have traditionally relied on the environment and its natural resources. The direct and indirect impacts of climate change on the health and well-being of Indigenous peoples are interconnected and far-reaching. According to the National Collaborating Centre for Indigenous Health, climate-related concerns in Northern Canada include increased "drought, wildfire, and flooding events; instability of and melting of permafrost and changes to sea ice extent and thickness; and decreased availability and quality of traditional food sources" (National Collaborating Centre for Indigenous Health 2022, 7). Natural hazards, along with erratic and extreme weather events caused by climate change, have the potential to damage or disrupt the already limited infrastructure, such as ice roads, limiting access to health systems and supplies. These changes will exacerbate the health and socio-economic inequities already experienced by the Indigenous peoples, including diseases associated with a warming climate, as well as financial hardship and food insecurity (National Collaborating Centre for Indigenous Health 2022). In July

2019, First Nations leaders at the Assembly of First Nations, the National political organization of First Nations and their on-reserve and off-reserve citizens, declared a First Nations Climate Emergency, and began exploring ways to decarbonize from within to combat climate change (Climate Atlas of Canada, n.d.).

Many of these remote Indigenous communities rely exclusively on diesel fuel to generate electricity locally and heat their homes, with only a few communities benefiting from access to hydroelectricity or natural gas. Diesel is an energy source that is unreliable and expensive due to transportation and storage costs worsened by the remoteness and harsh winters of these communities. Furthermore, burning diesel releases large amounts of carbon dioxide (CO_2), a greenhouse gas that is destructive to the environment, into the atmosphere (Cook 2019). The emissions from diesel generators can have adverse effects on the respiratory health of community members, and the reliance on diesel can limit economic opportunities and impact the overall well-being of the community. Some remote communities have peak electricity demand that is rapidly approaching or has already reached their generation capacity. Failure to expand the electricity supply would impede the ability of new residential, industrial, or commercial developments to obtain electricity, resulting in lost critical infrastructures and economic opportunities (Knowles 2016). Concerns about how to mitigate the adverse effects of climate change and negative social and health impacts from diesel emissions are among the most urgent issues facing Indigenous communities. Some of these communities have already begun decarbonization discussions and strategic planning to transition away from fossil fuels. Figure 1 below provides an overview of remote Indigenous communities and their current energy profile, some of which have already implemented renewable energy production.

Figure 1: Map of remote Indigenous and Northern communities in Canada and their primary source of electricity (Canada Energy Regulator 2023).



The Government of Canada has a suite of emissions reduction policies already proposed or implemented, such as Carbon Pricing, Fuel Charge, and the Clean Electricity Regulations. However, these regulations currently do not apply to remote communities reliant on diesel, reducing incentives to shift away from diesel (Canada 2018a; Canada 2023a). The exemption of remote communities from these regulations is restricting progress toward more environmentally friendly options. These regulatory exemptions, while preventing the imposition of additional financial burdens on remote communities already lacking access to clean energy, encourage the continued use of inefficient, emission-intensive generators, making it more challenging to transition to clean energy. As the Canadian government seeks to reduce greenhouse gas ("GHG") and reconcile its relationship with the Indigenous Peoples of Canada, promoting and supporting clean energy projects offers an opportunity to address energy poverty in northern Indigenous communities while simultaneously accomplishing decarbonization goals.

This paper examines the potential costs and benefits of integrating forest biomass energy generation with an existing solar power plant in the remote community of Old Crow, Yukon, in order to further reduce reliance on diesel, produce electricity consistently, and decrease GHG emissions and other harmful air pollutants. Old Crow was chosen for this pilot project because the community has expressed a desire to transition from diesel to renewable energy by installing solar panels in 2021. The solar panels met 25% of the community's energy demand, leaving the rest to diesel. Because the town of Old Crow has easy access to forest biomass, introducing bioenergy production may help satisfy the remaining energy demand sustainably, and provide a path to an integrated approach.

1.1 *The Vuntut Gwitchin First Nation and Current Energy Profile in Old Crow, Yukon*

The Vuntut Gwitchin First Nation sits at the heart of Old Crow, the most northwest habitation in Canada — roughly 130 kilometres (km) above the Arctic Circle. Located in a periglacial region, the community is next to the Porcupine River in the far northern part of the Yukon territory. Old Crow is the only Yukon community that cannot be reached by motor vehicle, requiring visitors to fly into Old Crow Airport. This remoteness contributes to a solid foundation of self-sustainability. Chief Dana Tizya-Tramm of the Vuntut Gwitchin First Nation said in an interview with the Washington Post on November 8, 2021, that climate change is among the most pressing threats facing his people. With the Arctic winters warming and less predictable caribou migration patterns, some community members may go years without a successful hunt. The spawning of certain salmon species has also decreased so much that fishing has been severely reduced or restricted in recent years. These climate-caused shifts can mean immediate hardship. With less meat and fish available, more people pay a premium for food at the only grocery store in town, where all the goods must first be transported by trucks from Winnipeg to Whitehorse, before being loaded onto an airplane to reach Old Crow. Diesel, however, is one of the most expensive goods in Old Crow. Since 1961, the town has generated its electricity from three massive generators powered by diesel flown in at approximately $30,000 per every 10,000 litres (Root 2021). In 2019, the Vuntut Gwitchin Nation became among the first Indigenous peoples in Canada to declare a climate emergency. That same year, they announced a target of reaching net-zero GHG emissions by 2030, and as they move toward the goal, the First Nation has been working to install one of the largest solar projects in the Arctic. In 2021, the Vuntut Gwitchin First Nation and Canadian Utilities Limited, an ATCO company, announced the completion of Canada's most northerly off-grid solar project “the Sree Vyàa”. The project replaced 189,000 litres (or 25%) of Old Crow’s diesel consumption annually, providing them with clean energy for years to come (ATCO 2021). The Vuntut Gwitchin First Nation also entered into an electricity purchase agreement with ATCO Yukon, selling excess electricity generated from the solar facility back to the grid for 25 years (ATCO, n.d.). Sree Vyàa is a key component to Old Crow's net-zero emissions goal by 2030 and is the largest solar energy project in a remote Yukon community. Since Old Crow turned on a 940-kilowatt (kW) solar panels and a 616-kW battery energy storage system in 2021, Sree Vyàa has reduced the community's reliance on diesel for electricity, while generating income that can be used toward future clean energy projects and other community initiatives (Canadian Northern Economic Development Agency 2022). While this demonstrates success in a power shift, solar energy is weather-dependent and intermittent, and the reliance on diesel to generate most of the electricity needed for the community remains. Alternatives to diesel need to be more reliable and cost-effective, not simply better for the environment.

1.2 *Canada's Climate Commitment and Renewable Energy Programs in Remote Communities*

The Canadian Net-Zero Emissions Accountability Act, which became law on June 29, 2021, enshrines in legislation Canada's commitment to achieve net-zero emissions by 2050 (Canada 2022a). To combat climate change without imposing substantial financial burdens through regulations on remote communities, the Government of Canada introduced incentives such as the Clean Fuels Fund to support the development of domestic renewable fuel production capacity, establish biomass supply chains for feedstock, and develop enabling codes and standards (Canada 2022b). In addition, The Clean Energy for Rural and Remote Communities (CERRC) program provides funding for renewable energy and capacity-building projects in Indigenous, rural, and remote communities across Canada. Launched in 2018, the CERRC program was allocated $220 million over 8 years to reduce diesel reliance for heat and electricity in Indigenous and remote communities. On April 25, 2022, an additional $300 million in funding was announced to further support clean energy project development in these communities (Natural Resources Canada 2022). In 2019, the Canadian government launched the Off-Diesel Initiative for Remote Indigenous Communities. Approximately $20 million was allocated for research and development for Indigenous-led renewable energy projects to expand electricity production (Natural Resources Canada 2019). These government-supported funding programs could substantially accelerate the search for and implementation of suitable energy transition pathways in remote Indigenous communities.

1.3 *Canada's Biomass Advantage and Renewable Energy Landscape*

The current Canadian renewable energy landscape is dominated by hydro, wind, and solar energy as they have been around longer and/or more accessible. Bioenergy, or energy created from biogas and biomass, holds a lesser market share (Environmental Journal 2023). Biomass and geothermal together accounted for only 1% of Canada's electricity supply while wind and solar combined accounted for just over 5%, and hydroelectricity at 60% in 2019 (Canada Energy Regulator 2019). Biomass's distinct advantages over wind and solar energy are its reliability and fuel storage capacity. In other words, electricity is made even when the sun does not shine and the wind does not blow. Canada owns 347 million hectares of forest, and the total volume of wood in Canada's forests is estimated at 47 billion cubic metres (m^3) as of 2016, and 94% of this estimate is on public lands. This vast and underutilized resource can be harnessed for energy production. Despite the abundance of forest-based biomass, bioenergy generation in Canada is used primarily in industrial sectors (IEA Bioenergy 2021). In 2018, The Forest Bioeconomy Framework for Canada was adopted by the Canadian Council of Forest Ministers, a consortium of provincial, territorial, and federal forestry Ministers. The Framework seeks to increase the use of forest biomass throughout the economy, and one of its key priorities was to engage with Indigenous peoples to create green infrastructures and clean technology initiatives (Canadian Council of Forest Ministers 2017). Even though wind and solar energy are the fastest-growing renewable energy sources, Canada has considerable bioenergy potential and the world's highest amount of biomass per capita. With a sustainably developed forestry sector, Canada is ideally positioned for a much higher contribution from bioenergy towards its total energy supply while delivering clean and locally produced heat and electricity in remote Indigenous communities (Menghwani et al. 2023).

2. Background

2.1 *Woody Biomass for Heat and Power*

As stated above, forest biomass is among the most available renewable energy sources in Canada. Plants and trees produce this non-fossilized and biologically degradable substance. There are various types of plant-based biomass feedstocks available in Canada, including forest biomass and dedicated crops (Bagherian et al. 2021). This report focuses on using the abundant and easily accessible forest biomass in Northern Canada as feedstock for bioenergy generation. Forest biomass includes all parts of the tree (i.e. the trunk, the branches, the needles or leaves, the flowers and fruits, and even the roots). Woody biomass can be converted into solid, liquid, or gaseous forms called biofuel that can then be burned for heat or used to produce electricity. Trees are useful for energy production because they capture carbon dioxide from the atmosphere and convert solar energy into biomass via photosynthesis. Forest biomass is a renewable fuel for energy generation. As long as the forest biomass is sourced from a sustainably managed forest and is replenished over time through regeneration, the GHG emissions from the bioenergy production can be deemed to largely offset fossil fuel emissions. This is because carbon is absorbed by trees, which then undergoes decomposition and releases carbon that is re-absorbed by renewed forest growth. Converting biomass to energy efficiently captures carbon energy. Although this conversion releases some carbon dioxide and other GHGs into the atmosphere, it also replaces the usage of fossil fuels and their associated carbon emissions. Therefore, using forest biomass provides energy, concurrently, the forest continues to grow and capture the carbon dioxide emitted by this energy production (Natural Resources Canada 2020).

2.2 *Environmental Harm and Health Risks of Diesel Exhaust from Diesel Generators*

The combustion of diesel fuel produces diesel exhaust. The exhaust is a complex mixture of gases, vapours, and particulate substances. Diesel exhaust contains over 40 hazardous air contaminants, many of which are recognized or suspected as carcinogenic, including formaldehyde, benzene, and arsenic, which pose risks to human health. It also contains other harmful environmental pollutants, notably nitrogen oxide, which is now the single most important ozone-depleting emission (Awofeso 2011). "Short-term exposure to diesel exhaust can cause coughing and irritation of the eyes, nose, throat, and respiratory tract. Breathing in diesel exhaust can cause lung irritation and/or an allergic reaction, causing asthma (wheezing and difficulty breathing) or making pre-existing asthma worse. Other symptoms may include feeling lightheaded, headache, or nausea. Long-term exposure may lead to serious health effects. The International Agency for Research on Cancer, which is part of the World Health Organization, classified diesel engine exhaust as carcinogenic to humans, determining that exposure to diesel exhaust emissions increases the risk for lung cancer and possibly bladder cancer" (Canadian Centre of Occupational Health and Safety 2021). Diesel exhaust from generators is environmentally harmful, emitting large quantities of GHG (about 460 tonnes CO2e per GWh generated[1]) as well as particulate matter emissions, all of which impact the climate, local air quality, and human health. This is

[1] Greenhouse gas emissions calculator, United States Environmental Protection Agency. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

especially problematic in communities relying on diesel generators to produce electricity and heat, as people often live close to where the emissions are produced.

Additional emissions are also generated when fuel is transported, and these emissions can be high due to the long distances involved. A domestic flight emits 246 grams of GHG per km.[2] In the case of Old Crow, the frequency of diesel fuel deliveries to Old Crow via air transport can vary depending on several factors, including weather conditions, community demand, and logistical considerations. Generally, diesel fuel is flown into Old Crow multiple times per year to ensure an adequate supply for electricity generation and heating throughout the year. Assuming at least five diesel deliveries via air per year, approximately 1,956 kilograms (kg) of GHG are emitted from transporting diesel every year.[3]

Communities powered by diesel also bear the environmental risk inherent in the transportation and storage of fuel. Because access to many of these communities is limited, diesel fuel must be stored locally and in high volumes to ensure a secure supply. This increases the risk of spillage in or near remote communities (Knowles 2016). In 2014, Air North accidentally spilled an estimated 1,100 litres of diesel at the Old Crow airport when the storage tank overflowed into a ditch line connected to the Porcupine River (fish-bearing waters). Diesel spillage has the potential to contaminate water, air, and soil, threatening biodiversity and fish and wildlife habitats. Spillage such as the Air North incident can significantly limit community access to clean drinking water

[2] Our World in Data. Which form of transport has the smallest carbon footprint? (https://ourworldindata.org/travel-carbon-footprint)
[3] The distance between Whitehorse to Old Crow is 1,590 km roundtrip (Old Crow supplies are mostly flown in from Whitehorse).

and restrict fish harvests. Although spills are not common occurrences, they can be highly damaging to the community.

2.3 *Recent Major Bioenergy Development in Remote Communities*

The goal of this report is to assess whether to introduce biomass technology as a source of electricity in the town of Old Crow, Yukon. A similar remote Indigenous community – the Kwadacha First Nation - has already successfully implemented biomass technology to generate electricity and heat. The Kwadacha First Nation is located in Fort Ware, British Columbia, approximately 570 km north of Prince George. The community, with an estimated population of 242 and approximately 119 residences (Statistics Canada 2021a), has historically relied on trucked-in diesel and propane for electricity and heat. Since 2017, Kwadacha First Nation has been operating Canada's first off-grid biomass combined heat and power (Biomass CHP or CHP) system. The Biomass CHP plant consists of three linked CHP generators, each producing up to 45 kW of electricity and 100 kWth of heat in the form of hot water. The CHP facility is powered by wood chips produced locally and mostly from pine beetle-killed timber. The chips undergo gasification to generate biogas, which is then cooled and filtered before entering the combustion engine generators. The chips are sourced from the sawmill on the First Nation reserve, resulting in minimal additional production costs. The community has access to plenty of standing dead pine in the surrounding area, about four million m^3 of which are located within 30 km of Fort Ware, providing them with a 400-year supply.[4] The Biomass CHP system is estimated to replace 20 to 25% of diesel-based electricity demand and generates heat for local facilities such as greenhouses.

[4] A timber supply analysis was conducted by the Kwadacha First Nation. https://www.canadianbiomassmagazine.ca/green-gas-kwadacha-nation-installs-wood-gasification-system-6699/.

In addition to providing the community with renewable heat and electricity, the Biomass CHP plant has provided five full-time jobs for plant operations (IEA Bioenergy 2021). The Kwadacha First Nation developed this project under the leadership of Chief Donny Van Somer, who also successfully negotiated a 2-year electricity purchasing agreement with BC Hydro to sell excess power produced by the CHP plant to the grid (Frederick 2018). The Kwadacha First Nation believes the success of this project will benefit more than just their community and will serve as an example for other rural communities looking to lessen their dependence on fossil fuels. Due to the similarities between the two First Nations, the same biomass technology implemented in the Kwadacha First Nation is considered and evaluated in this report for the Old Crow community.

2.4 *Woody Biomass Availability and Access Assessment*

The efficiency and sustainability of the biomass supply chain play a crucial role in the operational and economic feasibility of a biomass facility and can impact the success of a project (Helal et al. 2023). In 2017, the Yukon government undertook partnerships with Yukon First Nations on five biomass projects with funding from the Government of Canada. The objective was to evaluate the viability of biomass electricity generation and to stimulate economic development related to forestry within these communities. The Yukon government and First Nations governments completed five projects in March 2017, which included a four-year research project on examining the potential of using willow as biomass fuel to heat commercial buildings in Old Crow (Yukon 2018). Based on the Yukon Biomass Life Cycle Analysis, the annual allowable cut[5] in Old Crow is 2,000 m^3 of coniferous trees and 1,000 m^3 of deciduous trees, with an estimated annual available

[5] The amount of timber that is permitted to be cut annually from a particular area to maintain sustainability.

dry mass biomass volume of 1,119 tonnes (Morris et al. 2020). The Yukon Government also has a FireSmart operation near Old Crow that removes deadfall and other forest fire-causing biomass, which can be utilized as additional supply.

3. Methodology

3.1 *Assessing the Public Interest in Biogas by Conducting a Cost-Benefit Analysis*

The *Impact Assessment Act* uses the definition of public interest inclusive of factors examining the positive and adverse effects of the project on environmental, health, social, and economic conditions (Canada 2019). This paper does not include a formal consultation with the Vuntut Gwitchin Nation. The decarbonization initiatives currently being discovered or implemented in Old Crow were sourced from publicly available information. Section 35 of the *Constitution Act* recognizes and affirms existing Aboriginal and treaty rights. It is imperative to establish and execute an engagement and collaboration process in order to uphold the principles of sovereignty and self-governance of the Vuntut Gwitchin Nation.

Traditional cost-benefit analysis (CBA) in economics assesses the positive and negative effects of a project based on the values people place on its impact (i.e. what individuals are willing to pay for the positive effects or what must be rewarded to compensate for the negative impacts). CBA tackles the public interest question by assigning monetary values to social and environmental impacts, and by determining whether the total price people are prepared to pay for the project's outputs and the positive outcomes surpasses the amount they would have to be reimbursed to offset the costs of the inputs and negative outcomes. The fundamental basis for a CBA is rational choice, which means that a rational person will evaluate the costs and benefits of any proposed activity and will only choose to act if the benefits exceed the costs (Clinch 2004).

Although CBA is an essential and extensively used methodology, it has some limitations. Not all consequences can be properly captured in monetary terms. Economic indicators of success or failure may overlook elements such as the social values gained through Indigenous reconciliation by addressing the energy inequity, and the potential impact on local economic prosperity, such as increased infrastructure capacity. Costs, as defined in monetary terms, may also fail to capture factors such as the potential impacts of forestry and construction on wildlife habitat. These elements will be discussed later in the report. For simplicity and clarity, this paper adopts the traditional CBA approach to evaluate the overall benefits and costs of implementing a CHP Plant to reduce diesel use in Old Crow, as well as the overall social benefits gained globally from GHG reductions. The primary evaluation of the project is done via Net Present Value (NPV). NPV compares the present value of benefits and the present value of costs over the project's lifetime. All projects with a positive NPV provide a net economic benefit, thus, they contribute to the recommendation that a project proceed.

$$NPV = -K_0 + \sum_{t=1}^{N} \frac{Benefits_t - Costs_t}{(1+r)^t}$$

NPV = Net present value
K^0 = capital costs
r = discount rate
t = year
N = total number of years

3.2 *Key Assumptions*

The purpose of this CBA is to assess the potential economic and environmental benefits of installing a Biomass CHP to generate heat and power in the Old Crow community, thereby reducing diesel dependence. There are approximately 116 occupied dwellings in Old Crow with a population of 236 (Statistics Canada 2021b), similar to the Kwadacha First Nation, which has 119 homes and a population of 242. Despite Old Crow's more northern and remote location, both communities have historically depended on diesel fuel for electricity generation and have access to forested areas. Based on the similarities, it is assumed that implementing an equivalent CHP system with comparable costs and benefits would be suitable for Old Crow. This analysis examines the potential positive and negative impacts of installing a CHP system in Old Crow. All calculations are in today's dollars. Two scenarios are evaluated and compared in order to examine the potential impacts of installing a CHP system:

1. Status Quo Scenario – No Biomass CHP installation
2. Biomass CHP Scenario – Implement the same Biomass CHP system adopted by the Kwadacha First Nation

3.2.1 *Status Quo Scenario*

In the Status Quo Scenario, Old Crow residents continue to rely on diesel fuel to generate 75% of their heat and power. No other renewable energy options are explored or implemented. The community does not incur additional costs other than current power demand and supply. The community also does not receive the potential health and environmental benefits generated from the Biomass CHP scenario.

3.2.2 *Biomass CHP Scenario*

In the Biomass CHP Scenario, the CHP system adopted by the Kwadacha First Nation will be installed in Old Crow. This Analysis assumes that there would be identical initial capital expenditures, including the purchase of the product, transportation and installation expenses, as well as comparable operational requirements, such as labour and the quantity of wood chips required. Table 1 below illustrates the potential costs and benefits of the Biomass CHP Scenario.

Table 1: Costs and Benefits of Biomass CHP Scenario.

Costs	
Capital costs (K^0)	• Capital costs (purchase of the three linked CHP units, transportation, construction of facility to house the CHP plant)
Feedstock costs	• Woodchip supply • Delivered costs of woodchips (harvest costs, slashing/bucking, and haulage)
Operational costs	• Labour
Benefits	
Health Impacts	
Reduced deaths	• Anticipated decrease in number of deaths associated with air pollutants emitted by diesel generators
Reduced sick days and hospital visits	• Reduced number of sick days associated with respiratory illness caused by air pollutants released from diesel generators • Reduced hospital and emergency room visits related to inhalation of air pollutants
Economic Impacts	
Reduced transportation costs	• Savings from reduced trips to fly diesel fuel to Old Crow
Reduced diesel fuel costs	• Savings from reduced diesel purchase, which increases monetary capacity for new infrastructures such as medical facilities or schools.
Social Impacts	
Upholding UNDRIP	• Advancing reconciliation effort by addressing clean energy inequity

Improve local prosperity	• Job creation (construction and operational demand)
Global Impact	
Reduced GHG emissions globally	• Decreased global social costs of carbon as a result of reduced diesel fuel consumption and associated GHG emissions

i) *Spanner Re2 GmbH Combined Heat and Power Wood Gasification System*

The Spanner Group develops and markets biomass CHP systems. The model currently in operation in the Kwadacha First Nation is produced by the Spanner Group and consists of three linked HKA35 units. Spanner's technology utilizes modular, pre-assembled units that can be linked up to provide additional power. CHP system operators are not required to have technical expertise and their primary responsibilities include monitoring proper feedstock properties and doing basic cleaning, which is normally done once a week for around two hours. Each CHP unit generates electric power between 30 and 45 kW and a total heat power of 70 to 120 kWth. Wood chip consumption is between 30 and 45 kilograms per hour (kg/h) equaling consumption of approximately 1 kg/h of wood chips per kW electric output (Preto 2014). The CHP system's average running time per year is 8,500 operating hours.[6] The required feedstock for the three linked units is, therefore, 1,147.5 m^3 if the CHP plant runs at full capacity of 45 kW/h for 8,500 hours.[7] According to the assessment of woody biomass availability for Old Crow above, the annual total allowable cut is 3,000 m^3 which means there is more than adequate supply of feedstock to sustain the proposed CHP plant.

[6] Information on a HKA35 CHP unit is obtained from producer website (https://www.holz-kraft.com/en/products/hka-35-45-49.html).

[7] Three CHP units running at full capacity of 45 kW/h for 8,500 hours would require 1,147,500 kg of woodchips, which is equivalent to 1,147.5 m^3.

ii) *Timing Assumptions*

This CBA assumes that the construction of the facility and the installation of the CHP plant can be completed the same year that it is proposed (in 2024), with the plant becoming operational on January 1, 2025. This CBA also anticipates that the CHP plant will have a lifespan and discounting period of ten years (2025 to 2034) to allow enough time to assess the costs and benefits, as most CHP systems offer a six-to-twelve-year warranty.

iii) *Discounting and Inflation*

This CBA discounts all monetized values using a 3% rate, which is consistent with the Treasury Board of Canada Secretariat's recommendation when computing the impacts on environmental goods and services (Canada 2023a). This report will also discuss non-monetized items in qualitative terms. The inflation rate of 2% is used in this CBA, which is consistent with the Bank of Canada's target inflation rate.

3.2.3 *Costs*

Capital Costs

The full capital cost will depend on such factors as the manufacturer, equipment transportation and installation costs. The Kwadacha First Nation completed the CHP plant project in 2018, at a total cost of approximately $4 million[8]. This same cost for the community of Old Crow would be approximately $4.76 million in 2024. This estimate includes the required equipment, buildings,

[8] Community Energy Association case studies – Kwadacha First Nation Off-Grid Utility Standard Biomass Gasification-To-Electricity Project. (https://closingtheloop.ca/case-study/off-grid-utility-standard-biomass-gasification-to-electricity-project).

transportation, additional machinery such as woodchip producer and drying technology, and development costs.

Feedstock Costs

There is an abundance of wood chips accessible to the community. The annual allowable cut exceeds the feedstock requirements. As a result, the supply of woodchips is deemed free. Woody biomass production costs consist of harvest and transport costs. The delivered costs of biomass, including harvest costs, slashing/bucking, and haulage, is estimated at $67.53/m^3 of timber (PBrand Bioenergy Consulting 2009). Assuming the CHP plant runs at a capacity of 35 kW/h for an average of 8,500 hours per year, it would require 892,500 kg of woodchips, which is equivalent to 892.5 m^3. At $67.53/m^3 the feedstock cost is $60,271 per year. The resulting cost of feedstock is $560,237 in present value terms at a discount rate of 3% over the 10-year period.

Labour Requirement Costs

According to the Spanner Group, minimal mechanical knowledge is required to operate and maintain the CHP Plant. Based on information obtained from the Economic Research Institute, the average pay for a mechanic in Yukon is $28 per hour.[9] The Kwadacha First Nation employs five people to operate their CHP facilities. Assuming the same labour requirements for Old Crow's CHP facility and that each employee works in shifts to fulfill the average operational time of 8,500 hours annually, labor costs are estimated to be $245,280 per year. Therefore, the cost of labour is $2.28 million in present value terms at a discount rate of 3% over the 10-year period.

[9] ERI Economic Research Institute estimates an hourly rate of $28 for a mechanic working in Yukon (https://www.erieri.com/salary/job/automotive-mechanic/canada/yukon-territory/whitehorse).

3.2.4 *Benefits*

The CHP plant, consisting of three units each producing 35 kW per hour for an average of 8,500 hours, is expected to produce 892,500 kWh of electricity annually. Diesel generators typically use 0.4 litre of diesel to produce 1 kWh[10]. Therefore, the CHP plant would replace approximately 357,000 litres of diesel required to generate the same amount of electricity.

Health benefits

Diesel generators produce particulate matter ($PM_{2.5}$), volatile organic compounds (VOCs), and nitrous oxide (NOx), among other harmful pollutants that create smog and worsen respiratory illnesses. Long-term exposure to $PM_{2.5}$ has been linked to premature death, especially in those with chronic heart or lung diseases, as well as reduced lung function growth in children. Environmentally, $PM_{2.5}$ has also been linked to reduced visibility by altering how light is absorbed and scattered in the atmosphere (California Air Resources Board, n.d.). VOCs serve as a precursor pollutant to the secondary formation of $PM_{2.5}$. VOCs also mix with NOx in the atmosphere to produce ground-level ozone, which is a component that creates smog. Both ozone and $PM_{2.5}$ have been proven to have adverse effects on human health and the environment (Canada 2013). Health Canada states, "Diesel emissions are also associated with significant numbers of acute respiratory symptom days, restricted activity days, asthma symptom days, hospital admissions, emergency room visits, child acute bronchitis episodes, and adult chronic bronchitis cases across Canada" (Canada, 2023c). By eliminating 357,000 litres of diesel (or 357 m^3), 1.82 tonnes of $PM_{2.5}$,

[10] Energy Education (https://energyeducation.ca/encyclopedia/Diesel_generator).

2.11 tonnes of VOCs, and 25.85 tonnes of NOx would also be eliminated from the air in Old Crow (see Table 2 below).

Tale 2: Total harmful air pollutants removed by displacing 357 m^3 of diesel in Old Crow[11]:

Substance Name	Emission Factor (kg/m^3)	Total Release (tonnes)
$PM_{2.5}$	5.089	1.82
VOCs	5.910	2.110
NOx	72.396	25.85

Anticipated deaths avoided is an indicator of the effectiveness of health promotion and disease prevention policies. It calculates the number of fatalities for every 100,000 people that could have been averted through better treatment and/or prevention measures (Canadian Institute for Health Information, n.d.). In order to estimate the health benefits resulting from reduced air pollutants from diesel, this report calculates the monetary value of deaths that may be avoided in Old Crow using the formula below, obtained from the Health Effects Institute (Krewski et al. 2009). $PM_{2.5}$, as stated above, is associated with premature deaths. Per Yukon Community Statistics, there were two deaths in Old Crow, Yukon in 2022[12]. The population in Old Crow is 236. Therefore, the mortality rate in Old Crow is 847 (per 100,000 people).

$$\text{Deaths } = [e^{\ln{(1.06/10)} * \text{PM2.5}} - 1] * \text{Total Population} * \text{Mortality Rate}/100000$$

[11] Diesel Fuel Generator Fuel Usage and Emissions Calculator, Natural Resources Canada. (https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/report/tools-calculating-emissions/diesel-fuel-generator-fuel-usage.html).

[12] Yukon Community Statistics. https://community-statistics.service.yukon.ca/datasets/d269343d35864609804d00f6cf3aea83/explore.

Replacing diesel with biomass is expected to reduce the risks of premature death. The benefits of these risk reductions are typically measured by the value of statistical life (VSL). VSL is refers to the additional monetary amount an individual is ready to pay for reduction in risk of dying. Therefore, VSL represents the valuation of the anticipated reduction in mortality risk (Canada 2018b). According to Health Canada, the average VSL is $9.2 million.[13]

Table 3: Avoided deaths by displacing 357,000 litres of diesel:

$PM_{2.5}$ removed / year	1.82 tonnes
Population	236
Mortality rate	847 / 100,000
Deaths / year	0.0213
Monetary benefits of avoided deaths / year	$196,063

Table 3 above shows the avoided deaths associated with reduced exposure to diesel emissions in the Biomass CHP scenario, which is valued at $196,063 per year. The benefit is $1.82 million over the 10-year period, in present value terms at a discount rate of 3%.

Reduced transportation costs of diesel

The feedstocks required for the CHP system to produce heat and electricity are sourced and produced locally with minimal transportation requirement, while diesel fuel is flown-in and costs approximately $3.64 per litre.[14] The annual savings resulting from replacing 357,000 litres of diesel amounts to $1,299,480. The transportation cost saved $12.08 million, in present value

[13] Canada's Cost-Benefit Analysis Guide for Regulatory Proposals. Canada's Cost-Benefit Analysis Guide for Regulatory Proposals - Canada.ca.

[14] It costs $11 USD per gallon to fly diesel to Old Crow in 2021, which is approximately $3.64 CAD per litre. https://www.washingtonpost.com/climate-solutions/interactive/2021/climate-change-chief-dana-tizya-tramm/.

terms at discount rate of 3% over the 10-year period. The anticipated costs saved from reduced transportation could potentially be higher as fuel prices have increased on a year-over-year basis.

Savings from Reduced Diesel Consumption

The average costs per litre of diesel in Yukon, as of December 2023, is $1.80 per litre[15]. The savings from reduced consumption of 357,000 litres of diesel is $642,600 annually. The fuel savings, in present value terms at 3% discount rate over a 10-year period, is $5.97 million.

3.3 *Net Benefits to Old Crow, Yukon*

At 3% discount rate, the project is estimated to have incremental costs of $2.84 million and incremental benefits of $19.87 million. The net benefit, after accounting for the initial capital costs of $4.76 million, is $12.27 million, in present value terms over the 10-year period.

A sensitivity test was also conducted by increasing initial capital costs by 50% and 100% since all materials and equipment must be flown into Old Crow, which may increase transportation costs. The resulting net benefit is $9.89 million and $7.51 million, respectively, in present value terms. Thus, the analysis concludes that the Biomass CHP Scenario would be a welfare- improving measure for reducing diesel dependence in Old Crow, Yukon. Table 4 below summarizes the costs, benefits, and net benefits to the Old Crow community over the 10-yer period.

[15] Statistics Canada. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810000101.

Table 4: Summary of monetized benefits, costs, and net benefits from 2025 to 2034 (millions of dollars)

Initial capital costs	**$4.76**
Monetized Benefit/Costs	**Discounted (3%)**
Benefits	
1. Prevented deaths	$1.82
2. Transportation	$12.08
3. Diesel fuel savings	$5.97
Total benefits	$19.87
Costs	
1. Feedstock	($0.56)
2. Labour	($2.28)
Total costs	($2.84)
Net Benefits	**$12.27**
Net Benefits (50% increase in initial capital costs)	**$9.89**
Net Benefits *(100% increase in initial capital costs)*	**$7.51**

3.4 *GHG Reduction Assessment and Avoided Damages Globally*

As with any renewable energy, climate impacts are an important consideration. A GHG assessment was carried out in Table 4 below and found that a Biomass CHP system would result in GHG emissions reductions when compared to the status quo scenario. This assessment uses the Environment and Climate Change Canada's official schedule of social cost of greenhouse gas (SC-GHG) values, commonly known as social cost of carbon (SCC). Each SC-GHG value is a measure of the incremental additional damages that are expected from an additional tonne of GHG emissions (or conversely, the avoided damages from a decrease in emissions). The SC-GHG values are discounted at a lower discount rate (around 2% instead of the previously used 3%) as a comprehensive assessment of climate impact on society globally using an intergenerational lens is lengthy and complex. A lower discount rate is, therefore, appropriate to account for intertemporal trade-offs over extended time periods (Canada 2023d). The amount of CO_2 produced per litre of fuel consumed by the diesel generator depends upon the features of the diesel generator and the properties of the fuel, and it usually falls in the range of 2.4 to 2.8kg per litre (Jakhrani et al. 2012). This assessment assumes an average of 2.6kg of CO_2 is emitted per litre of diesel. Since 357,000 litres of diesel are displaced by the CHP plant every year, the discounted values of avoided damages per year over a 10-year operational period are listed in Table 5.

Table 5: Social benefits from reduction in diesel emissions from 2025 to 2034 (discounted at 2%)

Year	Annual CO_2 Reduction (kg)	SCC ($/tonne)	Annual Societal Benefit
2025	928,200	271	$ 251,542.20
2026	928,200	275	$ 255,255.00
2027	928,200	280	$ 259,896.00
2028	928,200	285	$ 264,537.00
2029	928,200	289	$ 268,249.80
2030	928,200	294	$ 272,890.80
2031	928,200	299	$ 277,531.80
2032	928,200	303	$ 281,244.60
2033	928,200	308	$ 285,885.60
2034	928,200	313	$ 290,526.60

The Biomass CHP Scenario is anticipated to reduce 9,280 tonnes of CO2 cumulatively between 2025 and 2034. In present value terms, the project is estimated to have a monetary benefit (or avoided damages) of $2.7 million globally over the 10-year period. The combined net benefit, including net benefits local to Old Crow and the net benefits globally, is therefore $14.97 million (or $12.59 million if capital costs increase by 50% and $10.21 million if capital costs increase by 100%).

3.5 *Other Benefits*

Reducing diesel reliance in remote communities yields a myriad of qualitative benefits by significantly mitigating environmental and health risks. The decreased reliance on diesel reduces the risk of spillage and contamination, safeguarding local ecosystems and water sources. Moreover, the shift away from diesel power generation contributes to lowered healthcare costs by reducing respiratory illnesses and sick days associated with diesel emissions. Beyond the tangible health and environmental advantages, this energy transition plays a crucial role in fostering reconciliation by actively addressing energy inequity and empowering marginalized communities with sustainable energy solutions. The project also has the potential to lower utility costs in Old Crow, as the price of diesel become more expensive. Many remote Indigenous communities in Canada rely on utility companies for electricity, including Old Crow, which historically depended on ATCO Yukon and its diesel generators. The geographical and logistical constraints of remote communities (i.e. how difficult it is to bring in fuel and supplies) also have a major impact on energy prices. The utility companies operating in remote regions often use inefficient energy sources such as diesel and propane that must be transported from far away, resulting in expensive electricity for the communities. Incorporating renewable energy sources, such as nearby forest biomass, can be an affordable, secure, and sustainable alternative to improve this situation, which also helps Indigenous communities to become self-sufficient in energy requirements (Lovekin and Heerema 2019).

4. Limitations

4.1 *Carbon cycle neutrality considerations*

Further research is required to determine if harvesting local forests so frequently will be sustainable at this latitude in the long run and if such practices are compatible with the impacts of climate change on forest productivity. The risks linked to biomass fuel come from the perception that it is nearly carbon neutral as an energy source. According to this concept, forest biomass extracted and then replanted might be considered carbon neutral. Carbon cycle neutrality asserts that the same amount of carbon that was emitted to the atmosphere can be reabsorbed during the regrowth process (i.e. photosynthesis) after a given period of time. When biomass is burned, carbon is released back into the atmosphere, establishing a balance of absorbed and emitted carbon (Selivanov et al. 2023). However, there are challenges associated with the secondary processes in the biomass industry. Activities such as harvesting, processing, fuel transportation, and reforestation often rely on fossil fuels. Although biomass fuel is deemed "low carbon" when sustainably harvested, accurately quantifying emissions rates throughout the fuel's lifecycle remains a considerable challenge. The perception of biomass as "low carbon" is increasingly questioned due to a lack of consensus on accurate carbon emission quantification. The lifecycle carbon emission analysis can vary substantially depending on a variety of project-specific factors, production methods, distance of transport if applicable, and the analysis timeframe. Currently, there are many opinions on this matter. Although biomass fuel is commonly regarded as a renewable energy source with minimal carbon emissions, the evolving understanding of this matter may lead to a different consensus that could impact its perceived effectiveness in carbon emissions reduction (Morris et al. 2020). Suppose the Yukon or the

Canadian government adopts a more stringent approach to GHG emission rate for biomass in the future, in that case, it might potentially have a significant and immediate impact on the industry and the technologies accepted for use in decreasing GHG emissions. It is important to note that this report does not assess the carbon neutrality of the Biomass CHP Scenario in Old Crow as the science surrounding biomass carbon neutrality appears unclear.

4.2 *Wildlife habitat considerations*

The forest surrounding Old Crow is home to the Porcupine caribou herd. The people of Vuntut Gwitchin First Nation have traditionally depended on the Porcupine caribou herd for food and clothing. Each spring and autumn, the caribou pass through the lands of the Vuntut Gwitchin, travelling north to calve in the summer months and south of Old Crow during the frigid winter months. The Porcupine caribou herd migrates to the Arctic National Wildlife Refuge in Alaska to give birth to their young[16]. Climate change and the oil-drilling in the Arctic National Wildlife Refuge region have seriously threatened the Porcupine caribou population and changed its migratory habits. The Vuntut Gwitchin First Nation has been on the frontline lobbying against further oil and gas explorations in the region as it negatively impacts harvesting and cultural practices on their land. Constructing a facility to house the new CHP plant may lead to further habitat fragmentation. Road development and noise impacts may also add to the cumulative effects of already existing human activities and climate change on wildlife. As a result, collaboration between project developers, the community, and the government to protect wildlife is crucial. This can be achieved through planting trees, improving forest management,

[16] Caribou coordination, Old Crow – Home of the Vuntut Gwitchin. https://www.oldcrow.ca/caribou.htm.

minimizing losses from fires and invasive species, and appropriate infrastructure planning to reduce habitat disruption.

5. Conclusion

In summary, the CBA conducted in this report revealed more benefits than costs both locally and globally in the Biomass CHP scenario in Old Crow, Yukon, which has the potential to replace 357,000 litres of the diesel fuel to power the community. Moreover, this report highlights the versatility of renewable energy solutions for remote Indigenous communities, showcasing how a combination of solar and biomass technologies can further reduce reliance on diesel and accelerate the transition towards sustainability. Such initiatives not only contribute to Canada's energy transition objectives but also play a vital role in promoting reconciliation, self-determination, and self-sustainability among Indigenous Peoples. Additional governmental support through legislative frameworks and targeted funding programs are important in fostering the widespread adoption of more than one renewable energy technology in remote regions. By creating a conducive environment for investment and community involvement, policymakers can empower Indigenous communities to take ownership of their energy future while contributing to national emissions reduction targets. In conclusion, initiatives like the Biomass CHP project in Old Crow combined with the existing solar plant, exemplify the transformative potential of a multi-pronged approach in addressing energy inequity, improving community health, reducing GHG impacts, and advancing environmental sustainability. By embracing and promoting forest biomass as one of the renewable energy solutions in remote communities, Canada can pave the way towards a more inclusive and resilient energy future, ultimately working towards the shared goal of achieving net-zero emissions by 2050.

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