Toward Sustainable District Heating Solutions for Łíídlı̨ Kų́ę́ First Nation, Northwest Territory

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Introduction

This capstone research explores sustainable district heating solutions for the **Łíídlı̨ Kų́ę́ First Nation (LKFN) community in Fort Simpson, Northwest Territories.**

The main objective is to identify cost-effective clean energy options that align with the community's unique heating requirements and self-sufficiency goals.

The methodology incorporates examining and analyzing various heating technologies, integrating relevant data from previous studies, and implementing a systematic approach to ensure scalability, comparability, and reliability.

The research considers biomass and geothermal energy as alternatives to fossil fuel-based systems, evaluating their technical feasibility, economic viability, and environmental impact. This study seeks to develop a decision-making reference that empowers the LKFN to create an energy roadmap towards economic independence and sustainability by incorporating government policies, funding opportunities, and community engagement.

The approach includes:

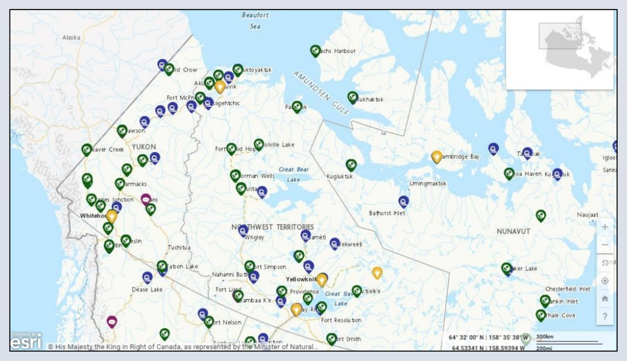
- Assessing community heating needs
- Conducting economic analysis of options
- Investigating government funding opportunities
- Evaluating environmental impacts
- Exploring local capacity-building and employment opportunities
- Reviewing regulatory frameworks

Background

The Canadian government supports renewable energy in northern communities to reduce fossil fuel reliance, with programs like Northern REACHE and CERRC investing millions in projects.

Over the past decade, Northern REACHE funded 140 projects with over $29 million, while the 2020 Strengthened Climate Plan added $300 million over five years. The 2021 federal budget allocated $40.4 million for hydroelectricity projects, and many are biomass projects.

This **climate action map** highlights funded projects. Challenges include the lack of a clear IPP policy, financial obstacles, and regulatory restrictions, necessitating increased community engagement and partnerships.



The **Canadian Bioheat Database** tracks bioheat projects nationwide, showing 646 systems with 481MWth installed capacity. In the Northwest Territories, there are 96 systems with 37MWth capacity.

Canadian Bioheat Database Overview			
646	481	266,167	349,371
Systems	Installed Capacity (MWth)	Estimated Biomass Demand (bdt/y)	Estimated Avoided CO2 Emissions (t/y)

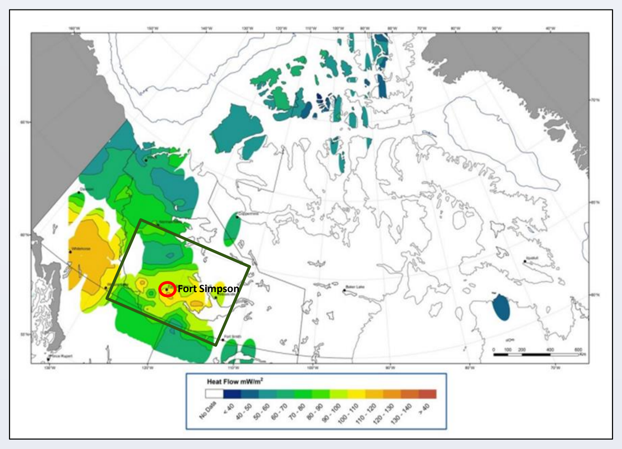
Fort Simpson has a central heat plan for community buildings, installed in 2012, with a 980-kWh system capacity.

Capacity (KWth)	Facility	Primary Biomass Fuel	Installation Year	Capacity (mmBTU)	Capacity Specific Value (KWth)	Estimated Biomass Demand (bdt/y)
50-150	Nahanni Inn	Wood Pellets	2021	0.38	110	60.1
50-150	PR Contracting	Wood Pellets	2017	0.38	110	60.1
501-1,000	District Heating Plant - Schools and Arena	Wood Pellets	2012	3.34	980	542.8

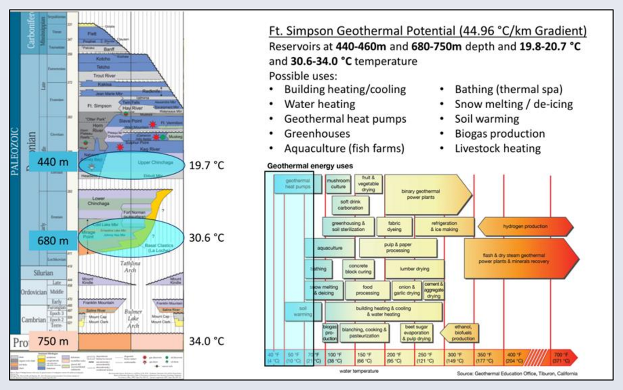
Stantec's study **(Van Driel, 2015)** explored biomass combined heat and power options for Fort Simpson, finding Organic Rankin Cycle as an efficient technology. The study identified **sufficient local feedstock within a 150 km** radius but noted challenges in access and transportation.

Background

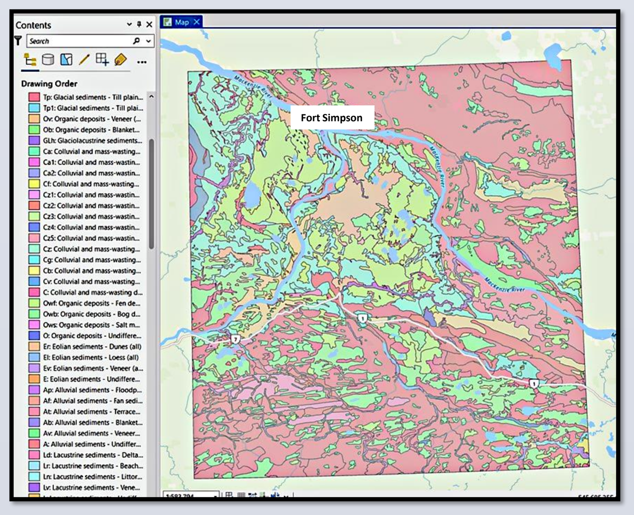
Canada's geothermal energy potential is diverse, ranging from geo-exchange systems to deep-enhanced geothermal systems (EGS). The country's only active commercial geothermal power plant is the Swan Hills Geothermal Power Project in Alberta, commissioned in January 2023. Several geothermal projects are underway across Canada, including Deep Corp.'s power facility in Saskatchewan and Eavor Technologies' closed-loop systems. E2E Energy Solutions repurposes oil and gas assets for geothermal energy in Rainbow Lake, Alberta. Research on geothermal potential is ongoing, focusing on dormant volcanoes in British Columbia and heat pump systems for building applications. The adoption of geo-exchange systems is growing, with over 100,000 residential and commercial systems estimated in Ontario alone.



Regarding Fort Simpson's geothermal potential, the **heat flow map in northern Canada** shows the region has a heat flow of approximately 100 -120 mW/m² **(Majorowicz et al., 2012)** showing a moderate geothermal potential. **Hickson et al. (2023)** studied the Dehcho area, focusing on bottom-hole temperatures from wells. They found that these temperatures generally underestimated the actual temperature gradients. The region near Fort Simpson has a shale overburden and a low potential for high porosity and permeability formations. The sedimentary section is thin, with a **bottom-hole temperature of 34°C** at the Precambrian unconformity. Due to these conditions, an enhanced geothermal system (EGS) or hybrid geothermal system was recommended for geothermal heat exploitation.



The shallow **surficial map of the area indicates that Fort Simpson** is situated on alluvial deposits, primarily consisting of sand and gravel (Geological Survey of Canada, 2014) showing some potential for **Ground Source Heat Pumps (GSHP) heating**. Northern communities using GSHP must be carefully designed to balance heat flow or risk taking too much heat out of the subsurface in a heat-dominated energy system. (R. Shor, personal communication, May 24, 2024) and a subject for further study and validation. While the geothermal potential in Fort Simpson may not be as high as in some other regions of Canada, shallow geothermal systems could still be viable for heating and cooling applications. However, site-specific studies would be necessary to determine the exact potential and feasibility of geothermal energy in the area.

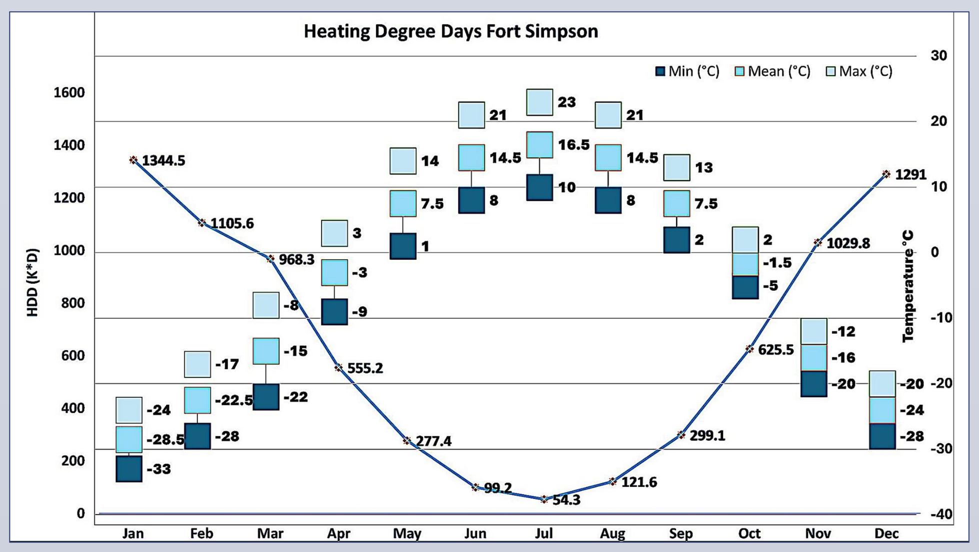


Methodology

The methodology for evaluating Fort Simpson's heating needs focused on district heating systems using diesel, biomass, and geothermal energy.

Heating degree days (HDD) were analyzed using the Climate Atlas of Canada to calculate the **Levelized Cost of Heating (LCOH)**.

Environmental impacts were assessed by comparing greenhouse gas emissions in these systems. Economic analysis calculated LCOH, considering investment, operational costs, and subsidies. A SWOT analysis was conducted to support decision-making, evaluating factors such as project delays, scalability, and future adaptability. This framework identified key challenges and opportunities for different heating options, providing a structured approach to inform the community's energy choices.



Results

Green House Gas Emissions

From the 2018 energy profile, the Arctic Energy Alliance constructed (AEA, 2018), the "current" state shows that 26 % is used for heating. An estimated annual heating load is 72 TJ for a town like Fort Simpson where heat is a requirement for 75% of the year (9 months or 6,570 hours and based on the HDD model)

The associated greenhouse gas (GHG) emissions for a diesel heat plant using the project GHG emission guidebook (ICLEI Canada, 2020) and using the heating value of diesel fuel = 38.6 MJ/L, the emission factor for diesel combustion = 0.002757 tonnes CO2e/L.

According to Climatiq (2021), wood pellets, including biogenic CO2 factors, have an emission factor (AR4 methodology) of 0.3494 kg CO2e/kWh and energy content for wood pellets around 4.8 kWh/kg. The amount of wood pellet fuel required is determined by using an average heating value of around 8,200 BTU/lb or 19.1 MJ/k

Full-life cycle geothermal system applications still present GHG emissions due to drilling and electrical requirements for heat pumps. A rough estimate using plant cycle emissions, which include construction and drilling, is around 10 gCO2e/kWh over a 50-year project lifetime (Fridriksson et al., 2017) and a global average of 122 gCO2e/kWh for plant operations.

Heating 100%	Diesel	Biofuel	Geothermal
Cost of Supply for Energy Per year $ (CAD)	2. 29 M	1.18 M	1.40 M
GHG emissions (tonnes)	6,415	7,463	3,122

Levelized Cost of Heating

Three district heating options were compared: diesel/oil, biomass, and geothermal systems. The levelized cost of heat (LCOH) was calculated for each option over a 50-year project lifetime using the NREL LCOE Calculator. The analysis considered capital costs, energy output, operational expenses, discount rates, and energy degradation. The impact of government grants and subsidies on project economics impacted LCOH calculations.

LCOH = (Present Value of Total Costs) / (Present Value of Total Energy Production)

Heating 100%	Diesel	Biomass	Geothermal
Plant Size MWth	3.8	3.1	3.8
LCOH cents/kWth	56.92	13.72	19.08

The analysis covered energy consumption, emissions, operational costs, and opportunities for sustainable alternatives. The diesel case was modelled with unsubsidized fuel costs and a fully loaded carbon tax levee as the other 2 systems are not subsidized. Heat energy and fuel needs were estimated, along with capital and operational costs. The geothermal case used Dr. Hickson's findings to model heat output for a geothermal district heating system.

Heat Output

$$Q = m \times Cp \times \Delta T$$

- *Where:*
- *Q = Heat output (watts)*
- *m = Mass flow rate of the heat transfer fluid (kg/s)*
- *Cp = Specific heat capacity of the heat transfer fluid (J/kg·K)*
- *ΔT = Temperature difference between inlet and outlet (°C)*

Net Present Value (NPV) and Internal Rate of Return (IRR)

NPV and IRR are common metrics for evaluating geothermal projects, but they have limitations. NPV uses discounted cash flows and fixed assumptions, potentially yielding negative results for long-term projects. IRR represents the expected rate of return but may not capture the full project lifespan.

Real Options Analysis (ROA) and Monte Carlo simulations offer more nuanced approaches for geothermal project valuation. ROA considers manageable risks and future options, while Monte Carlo simulations provide probability ranges for project outcomes. These methods better account for the unique characteristics and uncertainties of geothermal investments

Improved resource assessment techniques are crucial for enhancing project valuation accuracy. Quantifying heat as a resource supports investor decision-making for geo-exchange and hybrid systems. Integrating oil and gas exploration methodologies with geothermal-specific data can help establish more precise thermal resource models and productivity timelines.

Conclusions

The study compared diesel, biomass, and geothermal energy options for district heating in Fort Simpson, NWT. Key findings from Table 8 show:

- **Diesel has the lowest levelized cost of heating (LCOH) at $0.21/kWh**, but this is heavily subsidized. The true cost is much higher at $057/kWh
- **Biomass has a lower LCOH at $0.14/kWh** but does not offer significant greenhouse gas (GHG) emission reductions or energy independence.
- **Geothermal has the highest LCOH at $0.19/kWh** but provides the most GHG reductions and long-term energy independence.

The comparison highlights the need to consider factors beyond just cost, including subsidies, carbon taxes, and long-term sustainability. Biomass is a preferred option in northern communities due to existing infrastructure and local resource availability. Geothermal, while promising, faces barriers of high initial costs and a lack of supportive policies.

	Diesel	Biomass	Geothermal
Heat Capacity Range	72TJ	72TJ	72TJ
Assumed Annual Heat Production	3.8 MW - 16,293,600 kWh /year	3.1 MW - 13,140,000 kWh/year	3 MW - 13,504,097 kWh/year
Capital Costs	Capital Cost $700/kWh	Capital Cost $1,500 per kWh	Capital Cost $8,230 per kW
Annual Fuel Consumption	2,326,531 L	4,450 tonnes	Est. 1,132,257 L * using Diesel power support heat pumps
Considerations of Capital investment	50 Year Life Cycle 7 % Interest	50 Year Life Cycle 7 % Interest	50 Year Life Cycle 7 % Interest - Cost of drilling 2 wells
Operation Costs			
*Fixed Operations Costs	Fixed O&M : $20/kWh*year or $.02/kWh	Fixed O&M: $60/kW-year or $.06/kWh	Fixed O&M costs $20/kWh*year or $.02/kWh
*Variable Operational Costs	Fuel Cost $1.9/L $.01/kWh	Fuel cost: $290 per tonne $.02/kWh	$.01/kWh
Considerations of Operational Costs	Plant maintenance Logistics and Fuel Cost	Plant Maintenance Logistics and Fuel Cost	Plant Maintenance
GHG Emissions	6,415 tonnes CO2e	7,463 tonnes CO2e	3,122 metric tons CO2e/year * using Diesel power support heat
Carbon Tax Considerations	Subject to Carbon Tax - Dependent on Government Policy	Subject to Carbon Tax - Dependent on Government Policy and Exclusion of Biogenic Gas Emissions	Subject to Carbon Tax - Dependent on Government Policy and Green Hybrid offsets
LCOH Subsidized	$0.21 /kWh or 21 cents/kWh	$ 0.1372/kWh or 13.72 cents/kWh * not subsidized	$ 0.1908/kWh or 19.08 cents/kWh * not subsidized
Total LCOH	$0.5692/kWh or 56.94 cents/kWh	$ 0.1372/kWh or 13.72 cents/kWh	$ 0.1908/kWh or 19.08 cents/kWh

Conclusions

The following Strengths, Weaknesses, Opportunities and Threats charts compare the three heating systems.

Strengths		
Diesel	Biomass	Geothermal
Reliable and well-established technology	Considered renewable energy	Post-installation – low operating costs
High energy density	If sustainably managed can be carbon-neutral	Minimal operational emissions
Fuel easily transported	Waste products such as forestry residue can be used	Consistent energy baseload can be used for heating
Fast start-up and response to demand changes	Local fuel sourcing options – forest management and wildfire mitigation	No (direct) fuel transportation or storage costs

Weaknesses		
Diesel	Biomass	Geothermal
High GHG emissions	Emissions and air quality issues	High capital costs for drilling and plant installation
Volatile and high prices especially in northern and remote communities	Fuel supply and storage logistics – e.g. Wood pellets from Alberta	Thermal gradient and conductivity in Fort Simpson support only heating.
Pollution and environmental issues	Regular maintenance required	Retrofitting buildings for geothermal systems is costly
Carbon taxes and regulatory actions	Not sustainable if fuel sources and boiler operations are not managed	Technology not broadly adopted in Canada
Regular maintenance required		Regulatory framework inconsistent across Canada, no framework or supporting IPP in NWT

Opportunities		
Diesel	Biomass	Geothermal
New models could improve efficiency	Advanced biofuel developments such as second (grasses) and third (algae) generations can improve the efficiency of the fuel stock	Drilling technology advancements to reduce costs and reach deeper thermal resources
Available where other sources may not be	Waste management integration for fuel stock	Integration with district heating system to provide reliable combined baseload
Potential integration with biofuels to reduce environmental impact	Local biomass, wood chip, forestry waste management – jobs for the local economy	Hybrid systems with other renewable sources show economic promise
	Active forestry management mitigating wildfires	

Threats		
Diesel	Biomass	Geothermal
Carbon tax and regulation increases could raise operation costs	Unsustainable biomass sources	Public perception and acceptance
Public and government pressure to transition to cleaner energy sources	Competition from other land use cases	Other renewable resources have shorter installation times and lower capital costs
Possible supply chain disruptions affect supply costs and system reliability	Persistent air quality issues	Regulatory and policy support is not moved or moved quickly enough to enable geothermal system development

This study emphasizes the importance of community engagement, capacity building, and aligning energy solutions with local values. It recommends exploring hybrid systems, leveraging government funding, and advocating for clear Independent Power Producer policies to facilitate a successful transition to renewable energy in Fort Simpson

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