NORTHLANDS DËNESŲŁINÉ FIRST NATION RENEWABLE ENERGY FEASIBILITY STUDY

A Plan to End Diesel Dependency in Northlands Dënesułiné First Nation

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created for

Northlands
Dënesųłiné
First Nation

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EXECUTIVE SUMMARY

Northlands Dënesułiné is a remote First Nation in north-western Manitoba, located on the north shore of Lac Brochet. Because of the energy systems currently in place, Northlands is forced to rely on diesel fuel for both heat and electricity.

This is not sustainable.

The cost of buying and trucking in this diesel drains millions of dollars from Northlands every year. The winter road to Northlands is only open 6 to 8 weeks a year and, with global warming, is becoming increasingly unreliable. The diesel leaks and contaminates soil and groundwater, threatening the drinking water and the fish in Lac Brochet. Fumes that come from the diesel-contaminated soil around and under buildings, infiltrate homes and community buildings. These fumes exacerbate health problems and reduce the quality of life of community members. Cleaning up these contaminated sites costs millions of dollars more.

This renewable energy feasibility study details a comprehensive plan and approach to replace the diesel systems in Northlands with a locally owned and operated, integrated renewable energy systems. The systems would address heat and electrical needs both now and for at least the next 15 years. This plan includes:

- Community members harvesting dead trees left standing after forest fires near their community
- Two parallel organic Rankine cycle systems, operating in combined heat and power mode, with one serving as the primary energy source and the other serving as the backup
- A solar photovoltaic array
- Electric battery storage
- A micro-grid controller
- Community-wide energy efficiency improvements for heat and electricity
- Training so that local people are employed to operate, maintain, and manage these systems

The technologies recommended are already commercially available, with proven track records in harsh climates. When fully implemented, the energy systems recommended will enable Northlands Dënesułiné to meet its energy needs without reliance on diesel fuel for either heat or electricity. The capital costs will be equal to, or less than, the costs that will otherwise be incurred to replace the ageing diesel-electric and diesel furnace systems with modern diesel-based systems. The operating costs will also be equal to or less than the operating costs of the current diesel systems.

The benefits of this plan, compared to the *status quo* of continued diesel dependency include:

- Significantly reduced greenhouse gas emissions
- Increased resilience in the face of climate change
- Greatly reduced risk to groundwater, soil, drinking water, food staples, and the beautiful, unspoilt natural world that surrounds Northlands
- Elimination of diesel contamination and fumes in homes, schools, medical centres and other buildings where people work, learn, and play
- Improved health and quality of life of community members
- Approximately 20 permanent, sustainable, local jobs for Northlands members

Northlands has demonstrated its commitment to achieving energy sovereignty with local, renewable energy. This feasibility study lays out a detailed, practical plan to turn that commitment into reality by integrating the following components:

Bio-energy combined heat and power system: Two independently operating biomass systems each consisting of a wood chip fuel delivery system, biomass combuster, hot oil storage tank, an organic Rankine cycle, and heat exchangers. These will produce in electricity: 965 $\mathrm{kW_{net}}$; and in thermal heat: 2,700 $\mathrm{kW_{th}}$.

Solar energy using bi-facial photo-voltaic panels: At full capacity these panels generate 680 $\mathrm{kW_p}$ (282 kW already installed) of electricity.

Renewable energy storage: Batteries enable energy supply to exactly match energy demand, to bridge power interruptions, and to improve overall power quality.

Micro-grid controller: An Energy Management System (EMS) which interacts with the controls of the biomass system, solar photovoltaic system, and the Battery Management System (BMS) to provide system reliability and stability.

District energy: Underground insulated pipes laid throughout the community to heat buildings using existing heating systems or new in-floor heating, supply domestic hot water, heat trace sewage and water lines, dry clothes, and address future heat loads.

Wood stoves: Modern wood stoves to provide backup heat in homes.

If this plan is enacted, Northlands Dënesułiné First Nation will become a leader in Canada's drive to achieve net-zero emissions.

1 A PLAN TO END DIESEL DEPENDENCY

Three communities in northern Manitoba—Barren Lands First Nation (BLFN, located in Brochet on Reindeer Lake), Northlands DënesułinéFirst Nation (NDFN, located on Lac Brochet), and Sayisi Dene First Nation (SDFN, located on Tadoule Lake)—are determined to end their dependency on diesel fuel. This study lays out a roadmap to achieving this goal.

If these communities achieve this goal, they will be leaders in Canada in the drive to become net-zero emission communities.

Currently, these three First Nations communities pay to have diesel fuel trucked in over winter roads. These roads are now only open 6 to 8 weeks a year and, with climate change, are becoming increasingly unreliable. Each community requires between 1 and 2 million litres of diesel a year—about half to generate electricity and half to address their heating requirements.

Each community is currently home to an off-grid diesel generating system, owned and operated by Manitoba Hydro. Each community's system generates electricity for the local community, with all costs of operation, maintenance and capital charged back to the community and the federal government. Heat is generated using diesel furnaces located in each residential and commercial building.

Electricity and heat derived from diesel fuel are expensive. Critical community issues resulting from the use of diesel fuel to address their energy needs include:

- No local ownership of local energy systems.
- Millions of dollars leave each community every year to pay for the fuel, the shipping costs, and for operations, maintenance and capital for both the electrical and heating systems.
- Virtually no local jobs are created from diesel-based energy production.
- GreenHouse Gases (GHGs) are emitted from extracting, refining, transporting, and burning diesel fuel.
- Every house and building in each community has a diesel tank beside it which is attached through piping to a diesel furnace. Each community has more than 150 of these systems, totalling more than 700 between the three communities. The tanks, lines and furnaces are all prone to leaking. Most were installed more than 20 years ago, are approaching their end of life, and are in urgent need of replacement. Each one of these systems poses an environmental hazard.
- When diesel leaks into the sandy soil, it plumes down and outward, extensively contaminating soil and groundwater around and under homes and buildings, releasing fumes into occupied spaces.

- Unless all contamination from the soil and groundwater is removed—an expensive process—diesel fumes are released for years, even after the sources of the leaks are identified and repaired.
- Contaminated groundwater can migrate to the lakes beside each community. This threatens each community's drinking water supply. It also threatens the traditional food supply of fish, on which many community members depend.
- The diesel-electric generating systems are ageing. If they continue to be used, they will require extensive, expensive replacements and upgrades. Even if this money was to be spent, it would only address electricity needs, leaving the community still having to address their heating needs.

These communities have quite a bit in common with more than 200 other communities in Canada who are currently dependent on diesel for heat and electricity. Their energy is expensive and unreliable; their GHG emissions per person are high, and they experience diesel contamination of their homes, soil, lakes and rivers.

Royer[1] provides a partial overview of these communities' energy situations. Unfortunately, this report focuses only on electricity and omits a discussion of diesel-based heat. However, Royer's report does provide the most comprehensive overview of Canadian diesel-dependent communities currently published. Equally important, it lays out a strong case for why diesel fuel can and should be replaced by renewable energy in these remote communities. The fact that this report is now 10 years old, and is in turn based on a report first compiled 35 years ago—in 1985—makes it clear that diesel dependency in remote communities is a long-standing and well-studied problem.

Fortunately, in recent years, a growing number of First Nations have begun to move from studying this problem to addressing it. Over the past five years, the three communities focused on in this study have taken the following steps steps to move away from diesel dependency:

- In 2016, after extensive community consultation, Sayisi Dene First Nation adopted a Comprehensive Community Plan[2] which included, as part of a drive towards self-sufficiency, that the community produce all of their own electricity.
- Also in 2016, again after community consultation, Northlands DënesułinéFirst Nation adopted a Sustainability Plan.[3] This plan also focused on self-sufficiency, with a diesel transition strategy.
- In 2017, all three communities participated with Aki Energy and their subcontractors in

[1]Jimmy Royer (Aug. 2011). *Status of Remote/Off-Grid communities in Canada*. Goverment of Canada, NRCan.

[2]Sayisi Dene Chief and Council (2016). *Sayisi Dene First Nation Comprehensive Community Plan*. Sayisi Dene First Nation.

[3]Northlands Dënesułiné Chief and Council (2016). *Northlands Dënesułiné First Nation Sustainability Plan*. Northlands Dënesułiné First Nation.

developing Community Energy Plans (CEP).[4] These included preliminary analyses of practical ways to end diesel dependency and implement Demand-Side Management.

- From 2016 to 2020, Northlands Dënesułiné First Nation worked with Aki Energy, Boke Consulting and Soft White60 to design an integrated renewable energy system—a biomass-based district energy system to provide approximately one third of the heat in the community, a lake-based geothermal system currently heating five buildings and capable of heating five more, and a 282 kW solar PV array. NDL Construction and their subcontractors worked with Northlands and the design team to implement the design. The geothermal system came online in October 2018, the biomass system came online in February 2019, and the solar array came online in September 2020. All three systems continue to function as designed and, as planned, are locally owned and operated.
- In 2019, crews in all three communities were trained and certified in safe chainsaw operation and in workplace safety.

Members of all three First Nations see great value in the job creation, self-reliance, environmental protection, and local economic benefits that these renewable energy systems have created. Members of Barren Lands and Sayisi Dene First Nations are eager to replicate and expand on what has been done in Northlands. Members of Northlands are keen to augment the renewable energy systems that have already been put in place. The evidence so far is clear:

- Community members are committed to ending diesel dependency and creating their own renewable energy.
- Sustainable local resources are available to achieve this goal.
- Local people are more than capable of operating these renewable energy systems.

For each community, the objectives of this study are to:

1. perform a detailed accounting of electricity and heat loads, and then estimate 2035 loads by applying Demand-Side-Management (DSM), implementing peak shavings, and avoiding using electricity to address any heat load;
2. determine if the data supports extending the approaches used in Northlands to Barren Lands and Sayisi Dene, and expanding the systems already installed in Northlands; and
3. Select, integrate and optimize the size of commercially-proven, reliable renewable energy components to demonstrate how they can fully meet the goal of ending diesel dependency.

[4] Demand Side Energy and PrarieHouse (2017). *Community energy planning for Manitoba off-grid First Nations*. Aki Energy.

The outcome of this study shows how the three communities can immediately transition to meet their 2035 heat and electricity loads reliably, using proven renewable energy technologies at a much lower cost. Furthermore, this study explains how components will be controlled to achieve the reliability and redundancy needed in a remote community with weather extremes, using renewable energy as both primary and backup energy sources.

1.1 Defining the goal of ending diesel dependency

The long-term solution to the energy crisis facing our world is to eliminate fossil fuel use altogether. While that is also the eventual goal of Northlands Dënesułiné, this study does not propose leaping to that ultimate outcome in a single step. Instead, Northlands Dënesułiné—and this study—set a goal of ending diesel dependency. Achieving that goal will make Northlands Dënesułiné a leader in renewable energy in Canada.

Northlands Dënesułiné—and this study—define the goal of "ending diesel dependency" as:

1. Producing sufficient heat and electricity from renewable sources to meet all local community energy needs.
2. Eliminating the use of diesel to heat homes and smaller buildings.
3. Where larger diesel heating systems are present, and are not in need of immediate replacement (such as in schools or medical centres), leaving those systems in place, but using them only as emergency backup to the renewable energy heating systems.
4. Transforming the current diesel-electric generating systems from the primary source of electricity to an emergency back-up electricity source.
5. Leaving current, small, emergency diesel-electric backup generators in place. These are attached to critical infrastructure such as water treatment plants, schools, and medical centres. They are currently used for emergency electricity backup when the current diesel-electric generating system experiences an outage.
6. Beginning to introduce electric vehicles and motors, as feasible and accepted by community members.

This means that Northlands Dënesułiné would continue to use diesel for local heavy equipment and to truck in supplies, when needed. Gasoline would also be used for boat motors and personal vehicles, until replacement electric vehicles and motors are commercially available and suitable for use in Northlands Dënesułiné. It also means that flights in and out of the community would remain dependent on aviation fuel.

1.2 Principles for ending diesel dependency

The approach detailed in this study uses the following principles:

- Address energy loads using local, renewable energy sources
- Only use established, commercially-available technologies
- Use the fewest technologies required to achieve the goal of ending diesel dependency
- Only use technologies suitable for very cold climates
- Only use technologies that can be operated and maintained—and, when possible, repaired—by local community members
- Reduce energy consumption demand
- Improve energy efficiency
- Decrease peak loads
- Achieve resiliency through renewable energy system redundancy
- Plan for energy demand growth

These principles were developed through the Community Energy Plan (CEP) processes mentioned earlier,[5] and are further refined and detailed in this study.

1.3 Technologies required to end diesel dependency

Based on the analysis detailed in this report, five of technologies are required in Northlands Dënesułiné to achieve the goal of ending diesel dependency:

1. A Combined Heat and Power (CHP)[6] biomass-based system to produce both heat and electricity. The fuel for this system will be the tree trunks left standing after forest fires in the areas around Lac Brochet.
2. Solar photovoltaic (PV) arrays
3. Electricity battery storage
4. Underground district energy loops providing heat to each building
5. A microgrid controller in each community to integrate these systems

[5] Demand Side Energy and PrarieHouse, *Community energy planning for Manitoba off-grid First Nations*.
[6] In keeping with industry practice, the terms "power" and "electricity" are used interchangeably in this study.

Table 1: Main equipment required to end diesel dependency

First Nation	ORC CHP* net electricity	ORC CHP* heat in CHP mode	Solar Array	Batteries	Backup Diesel Gen. biomass plant	Backup Diesel Gen. MH plant	wood furnace or wood stove***	district energy loop trunk line****	micro-grid controller
Barren Lands	689 kWe net	1,900 kWth	550 kW	2 MWh	200 kW	425 kW	189	12,237 ft	1
Northlands Dënesųłiné	965 kWe net	2,700 kWth	680 kW**	4 MWh	250 kW	855 kW	316	9,362 ft	1
Sayisi Dene	689 kWe net	1,900 kWth	550 kW	2 MWh	200 kW	425 kW	143	11,913 ft	1

*Organic Rankine Cycle Combined Heat & Power systems - 2 in each community
**282 kW of solar array already installed in Northlands; 398 kW more recommended
***1 installed in each home, only if homeowners want a wood furnace or wood stove in their home
****Distance is length of line run. Actual pipe length is 2 times this number: 1 line for send and 1 line for return

Commercially-proven technologies are available for each of these technologies.

1.3.1 CHP SYSTEM

The heart of the system producing heat and the majority of the electricity are a pair of matched Organic Rankine Cycle (ORC) Combined Heat and Power (CHP) units. Each ORC is sized to that it will be able to supply the community's maximum required electricity and heat. At any one time, one is operating and one serves as backup. Figure 1 on page 6 gives a sense of the scale of the required units; each one is pre-assembled and fits on a single shipping-container-sized skid.[7]

In addition to the two ORCs, two biomass combusters and a walking floor system are required. Section 1 on page 1 provides details on why this CHP technology is recommended for these communities. Section 12.1 on page 131 and Section 14 on page 204 provide further details on this equipment.

Figure 1: One MWe Organic Rankine Cycle unit.

[7] Peter Cherry, Michael Conte, and Ilaria Peretti (Feb. 2020). *Biomass Powered ORC Turbine at Dalhousie University*. Accessed 2020. International District Energy Association. URL: https://www.districtenergy.org/viewdocument/biomass-powered-orc-turbine-at-dalh.

1.3.2 SOLAR PV ARRAY

This study recommends installing a bifacial solar array in each community. The electricity generated by the array will supplement the electricity provided by the CHP system, reducing the demand on that system. This will help to extend its operating life and reduce wood fuel consumption, especially in summer. It will also be used to replenish the electricity battery bank. Figure 2 on page 7 is a view of the current solar array in Northlands.

Figure 2: A view of the current solar array in Northlands Dënesułiné First Nation

The recommended size of the solar PV array for Northlands is based on the Homer optimization analysis in Section 13 on page 152.

Section 14.2 on page 229 provides details on what equipment is recommended for the solar arrays, and how those recommendations were derived.

1.3.3 ENERGY MANAGEMENT SYSTEM AND ELECTRICITY BATTERY STORAGE BANK

This study also recommends installing an electric battery storage bank, and an Energy Management System (EMS) as part of the renewable energy system in Northlands.

The batteries and the Energy Management System (EMS) would each be contained in their own shipping container.

Figure 3 on page 9 illustrates a battery bank (with its controls) in one shipping container, and an EMS in an adjacent container.[8] The recommended capacity of the battery storage is based on the the Homer optimization analysis that is found in Section 13 on page 152.

[8] Aspin Kemp & Associates (2018). *Pooles Corner Smart Microgrid*. URL: https://www.aka-group.com/green-energy/microgrid/.

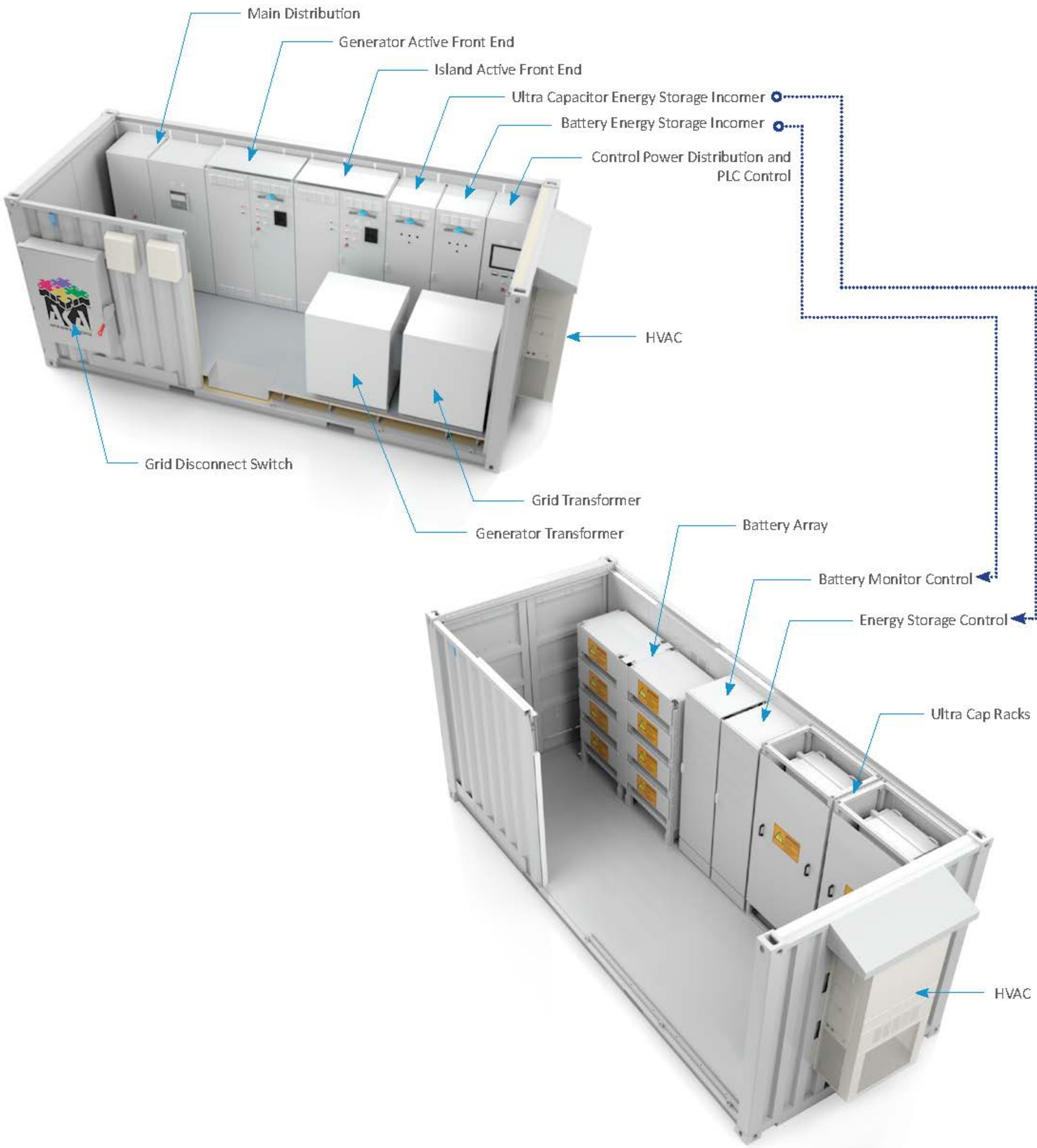

Figure 3: Drawing, with annotations, of an Energy Management System (top left) and a battery storage bank with its controls (bottom right).

1.4 Recommended locations of renewable energy technologies

The following maps[9] show where this study recommends locating the biomass building and the log yard, as well as a recommended solar array location for each community. The biomass building might more properly be called the "renewable energy building" because, in addition to housing the walking floor, combusters, ORCs and buffer tanks associated with biomass, it also houses the pump system for the district energy loops sending heat to each building in the community, and the Energy Management System. Battery storage should also be located immediately adjacent to this building.

[9] All satellite images and maps shown are reproduced at a larger scale in Appendix B on page 305. Full-sized versions—24 x 36 inches—are available, with permission of Northlands Dënesułiné, from this study's authors on request.

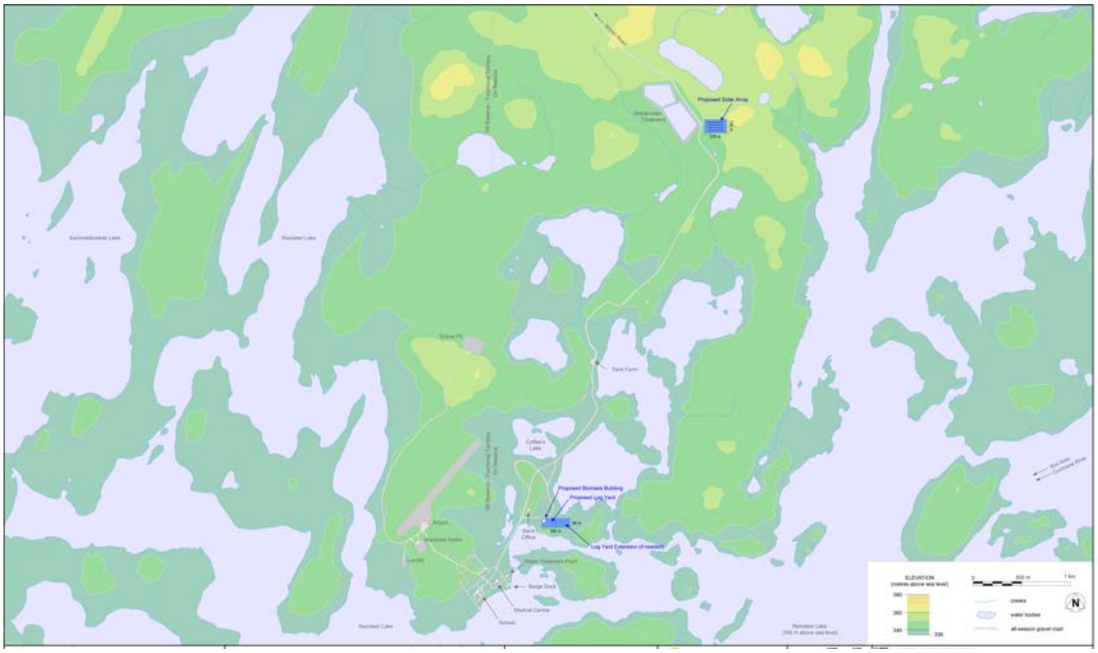

Figure 4: Recommended renewable energy systems locations - Barren Lands First Nation

Figure 5: Existing and recommended additional renewable energy systems locations - Northlands Dënesułiné First Nation

Figure 6: Recommended renewable energy systems locations - Sayisi Dene First Nation

1.5 Costs

Implementing these technologies will cost less than estimates for refurbishing and extending the life of the current diesel systems.

Table 2: Class 4 budget estimate of recommended renewable energy system components, in millions

	First Nation		
item	*Barren Lands*	*Northlands*	*Sayisi*
2 biomass and ORC systems	$17.5	$20.5	$17.5
Solar PV array	$2.7	$1.9	$2.2
Containerized battery system, Battery Management System, and Energy Management System	$2.2	$3.5	$2.2
District energy systems, up to building	$4.1	$3.5	$4.6
Wood stoves for houses	$0.4	$0.6	$0.5
totals:	***$26.9***	***$30.0***	***$27.0***

This is a Class 4 feasibility study budget estimate. Details of how this budget was derived are given in Section 15 on page 249.

1.6 Benefits

Important benefits will flow if the recommendations of this study are implemented. Northlands Dënesułiné will:

- Reduce the high cost of operating and maintaining the current diesel-electric systems—approximately $5 million per community, per year.
- Reduce the high cost of replacing the current diesel-electric systems as they age out. Quoted prices range from $40,000 to $80,000 per kW installed for diesel-electric systems.
- Address both heat and electricity needs in an integrated fashion.
- Create an estimated 60 permanent seasonal and full-time local jobs amongst the three communities.
- Increase training in transferable job skills.
- Strengthen connections between skills learned in high school and job opportunities.
- Improve the health of community members by reducing diesel fumes in homes and occupied buildings, and by offering jobs that will improve physical fitness.
- Keep millions of dollars currently spent on trucked-in diesel in Northlands Dënesułiné.
- Eliminate diesel contamination in homes and community buildings.
- Avoid the high cost of diesel contamination remediation.
- Eliminate the risk of contamination to drinking water and food supplies from diesel spills.
- Eliminate budget problems caused by fluctuations in fossil fuel prices.
- Eliminate the risk not being able to truck diesel in on a winter road system that is becoming increasingly unreliable due to climate change.
- Drastically cut greenhouse gas emissions.
- Build community ownership and local control of energy systems.

1.7 Study decision-making framework

This study uses an overall decision-making framework the authors have named THE-RED-CUP:

THE: Every community has three broad types of energy demands:[10]

- **T**ransportation
- **H**eat and cooling, and
- **E**lectricity

This study does not propose a wholesale replacement of fossil fuel vehicles with electric vehicles in Northlands Dënesułiné. Instead, it expects that some community members will choose electric vehicles, as the technology matures and prices come down. As a result, there is no comprehensive review of transportation energy needs in this study. However, the results of this study's modelling indicate that, so long as electric motors for vehicles are charged at night, the renewable energy systems recommended will be able to meet the electricity demands that will result from the natural, gradual adoption of electric vehicles over the next 15 years.

RED: Energy demands can be met with renewable energy and diesel dependency can be ended by taking three integrated actions:

- increase use of **R**enewables
- increase energy **E**fficiency, and
- reduce energy **D**emand

The recommendations of this study include an emphasis on peak load reductions because constraining and reducing peak loads significantly lowers the cost of achieving an end to diesel dependency because systems must be sized to meet the highest peak load expected in the next 15 years.

CUP: It is useful to focus each of these three actions on three levels of analysis:

- the actions the **C**ommunity as a whole can take
- the actions the power **U**tility can take, and
- the actions individual **P**eople and households can take

This study found that:

[10]There is obviously some overlap between these types of demand—when electricity is used to heat or cool a building, for example, or if a vehicle uses electricity for propulsion. In this study, electricity used for heating, cooling or charging electric vehicles are classified as electrical demand.

- Any comprehensive solution to ending diesel dependency must consider **H**eating and **E**lectricity together. Solutions which address one or the other in isolation were found to be less efficient and cost-effective than those which addressed them together.
- Actions to increase **R**enewables, increase **E**fficiency and reduce **D**emand need to be planned together. Focusing on only one or two of these actions does not achieve the goal of ending diesel dependency.
- Similarly, actions which focus only on the **C**ommunity, **U**tility, or **P**eople level will be piecemeal and ineffective. For example, because not all users within a community pay the same rate for electricity, it can be tempting to focus on the most "expensive" electricity first. Differential pricing tends to prioritize reducing the most expensive consumption first, rather than the most diesel-intensive. As a result, it does not result in the maximum reduction of diesel use at the lowest cost. This study treats all uses of electricity equally.

Considering all these factors together is not a simple process. It is, however, the only way to achieve a practical, comprehensive and robust solution for ending diesel dependency.

1.8 Reliability, redundancy, and robustness

Diesel plants operated by Manitoba Hydro in the three communities have an N-2 redundancy. N-2 redundancy (read as "N minus two") means that community electricity peak loads can still be met even if the two largest-capacity diesel generators in the Manitoba Hydro plant are off line. This approach should provide high system reliability. However, the points of failure in the community's electrical supply have not, at least in recent years, been caused primarily by failures in the diesel generators themselves. There have been electrical power interruptions, but they have usually been as a result of a failure in some other part of the existing electrical systems, such as controls, power lines and transformers.

The recommendations in this study meet or exceed the standard of N-2 redundancy, but achieve this standard through renewable energy, with the diesel-electric generators acting as emergency backup. The renewable power systems recommended in this study achieve N-1 redundancy, meaning that:

- A single baseload renewable energy unit (an ORC) is sized to meet the projected total peak load energy demand of a community (both heat and electricity) up to at least 2035.
- An additional baseload renewable energy unit—also an ORC, identical to the first—is always on standby.
- If the first unit goes down for any reason, the second will come on line in no more than 20 minutes.

- The battery system will sustain electrical power during the transition from one baseload unit to the other. (The batteries will also help with peak load shaving, smoothing of solar photovolatic output, and electrical power quality.)
- The buffer tanks built into the district energy loops will sustain heat supply during the transition.
- A diesel generator is attached to both baseload renewable energy units as an emergency electrical backup.
- The current Manitoba Hydro diesel generating system will remain in place, should both renewable energy units fail for any reason. Because they would be used only as a standby system, the life of the diesel generators would be extended. Depending on how many generators remain operational in Manitoba Hydro's plant, this will enable at least N-2 redundancy, without requiring rebuilds of the diesel generators. If the Manitoba Hydro plant were to be shut down completely, backup diesel generators could be added to the energy system proposed here to achieve the same N-2 level of redundancy.
- Each home would have a certified modern wood stove or wood furnace, which would heat the home should both renewable energy units fail for any reason. These units would be serviced and WETT-certified annually.
- The efficiency of all buildings in the community must be improved, to moderate growth in energy demand and constrain peak load growth.

Taken together, the systems being recommended in this study will be more reliable than the current, diesel-dependent systems. In particular, the current heating systems have no redundancy at all. Currently, if a diesel furnace system fails in winter, the home or building it is in quickly becomes uninhabitable. Depending on the outside temperature, if it cannot be repaired or replaced within a day or two, water pipes burst, and other components in the home become damaged. The systems being proposed in this study add at least two levels of redundancy for heat.

The solar photovoltaic array provides intermittent—rather than dispatchable—electricity. It therefore is not credited as providing redundancy for this system. Instead, it will reduce the total annual demand on the baseload ORCs, extending their operating lives. The solar array also results in less wood being consumed in the central system.

1.9 Training required to end diesel dependency

To ensure these systems operate in a long-term, sustainable manner, training will be required for local people to:

- Operate and maintain these renewable energy systems
- Safely harvest and transport wood

- Implement energy efficiency improvements
- Maintain the ageing diesel furnaces, until they are replaced
- Manage the waste-oil burner
- Develop, implement and verify demand-side management programs for both electricity and heat

This training can, and should, be done within each community. Community-based training is strongly preferred over sending community members away for training. Once transportation, accommodation and food costs are factored in, the cost of training in-community is less than going out for training. As well, the skills learned can be directly applied in the actual work situation. And, perhaps most important, training locally does not disrupt family life.

In addition to providing the opportunity for training adults for the new jobs renewable energy creates, this training can be integrated in the high school curriculum, so that students will have local jobs when they graduate.

1.10 Role of CHP technology in this design

Combined Heat and Power (CHP) technologies are particularly promising for remote, non-grid-tied communities seeking to achieve 100% renewable energy, because they can produce dispatachable power able to match heat and power demands, in most instances using renewable biomass that can be sourced locally.

The CHP system is the core of the design recommended in this study, providing dispatchable heat and electricity. Because choosing the appropriate CHP system is be crucial to the success of this design, significant analysis and research went into this choice.

1.10.1 CHP TECHNOLOGIES REVIEWED

Six CHP technologies were reviewed in this study:

- gasifier
- pyrolysis
- Hybrid Brayton Cycle
- steam
- ORC
- diesel

These technologies each have particular strengths and weaknesses. The challenge is choose the technology that best matches the situation and energy needs of Northlands Dënesułiné.

1.10.2 CRITERIA FOR COMPARISON

Seven go/no-go criteria were used to rule technologies "in" or "out". The first three focus on the fuel; the next two focus on the technology; the last two focus on the effect using the technology will have on Northlands Dënesułiné:

- **renewable fuel**:
  - Is the fuel source is renewable?
- **local fuel**:
  - Is the raw material needed to make fuel locally available?
  - Is the processing capability needed to convert raw material to fuel locally available?
- **fuel flexibility**:
  - Can the fuel form can vary without impairing operation?
  - Can the fuel moisture content can vary without impairing operation?
- **proven commercially**:
  - Does the technology have a proven track record of successful commercial installations?
  - Does that proven track record include units in the 1 MW range, which is the range needed for this installation?
  - For small-scale CHP systems, particularly in off-grid communities, the selection of a commercially-proven technology is crucial to ensure a high reliability factor. Lack of heat, even for only a few hours, can have a devastating effect in northern communities.
- **local operability**:
  - Can the system can be operated by local people without extensive certification?
  - Does the system require round-the-clock supervision?
- **effect on local jobs**:
  - Will installing the system create local, permanent jobs to operate it?
  - Will installing the system create local, permanent jobs to provide the fuel?

Table 3: Comparison of Combined Heat and Power (CHP) technologies on Go/No-go criteria

	Fuel			Technology		Effect	
						sustainable local jobs	
	renewable	*local*	*flexible*	*proven commercially*	*local operability*	*operating*	*harvesting*
gasifier	yes	possible	no	no	no	no	yes
pyrolysis	yes	yes	yes	no	no	no	yes
Hybrid Brayton Cycle	yes	yes	yes	no	yes	yes	yes
steam	yes	yes	yes	yes	no	no	yes
ORC	yes	yes	yes	yes	yes	yes	yes
diesel	no	no	no	yes	no	no	no

Four preference criteria were used to rank technologies as more and less preferred:

- **capital cost**
- **operating cost**
- **installation size**
- **efficiency of conversion to electricity**
  - There are many ways to measure efficiency. Following the approach taken by Tampier,[11] this study uses a "fuel-to-wire" measure of efficiency, calculating how much of the potential energy in the fuel actually becomes electricity available to the local microgrid.

Table 4: Comparison of Combined Heat and Power (CHP) technologies on preference criteria

	capital cost	*operating cost*	*installation size*	*efficiency of conversion to electricity*
gasifier	higher	higher	larger	<10%
pyrolysis	higher	higher	larger	<10%
Hybrid Brayton Cycle	mid-range	lower	larger	15%
steam	mid-range	mid-range	mid-range	<10%
ORC	mid-range	lower	mid-range	15%
diesel	lower	lower	smaller	35% - 50%

[11] M. Tampier et al. (2004). *Identifying environmentally preferable uses for biomass resources: Phase 2 report: life-cycle emission reduction benefits of selected feedstock-to-product threads*. Project sponsored by the National Resource Canada, the National Research Council, and the Commission for Environmental Cooperation. Accessed 2020. Envirochem Services Inc. URL: http://www3.cec.org/islandora/en/item/2130-identifying-environmentally-preferable-uses-biomass-resources-en.pdf.

1.10.3 HOW THESE TECHNOLOGIES FARE AGAINST THESE CRITERIA

Electricity generation using diesel turbines is a mature, proven technology. However, its drawbacks are well known (and touched on already in Section 1 on page 1). It is a non-renewable fuel that cannot be produced locally. And its use creates no local jobs.

A main difference between biomass and fossil fuels is the moisture content. Fossil fuels have low moisture content and the water vapour produced is from the combination of hydrogen and oxygen in the fuel and in the combustion air. The free water in the fuel represents additional unrecoverable energy. As a result, biomass systems will usually have lower overall energy efficiency than fossil fuel systems.

Two forms of non-fossil-fuel diesel are available. The first, biodiesel would still need to be trucked in, and would create no local jobs. Even more problematically, it has a "cloud point" of +10°C, which means it cannot be used when the air temperature is below that point. The second, "renewable diesel", does not have the cloud point problem of biodiesel,[12] but it also needs to be trucked in. There are also serious concerns about the environmental footprint of renewable diesel, especially when it is made from palm oil.[13]

Technologies for conversion of biomass to energy have been modelled and previously reported by Tampier[14] to NRCan.[15]

One of the crucial distinctions between these technologies is whether they use direct or indirect conversion technologies. In direct conversion, biomass gaseous products directly contact the turbine or piston. In indirect conversion technologies, biomass gaseous products transfer heat through a heat exchanger. ORC systems and HBC systems are both indirect conversion technologies. This distinction is critical for small-scale implementation of power cycles for isolated micro-grid applications where simplicity and reliability are key.[16] Direct conversion technologies have not achieved commercialization status for this use, or at this scale.

Gasifier and the pyrolysis technologies are direct conversion technologies. They have the advantage of being able to use existing generators and gas turbines available in the marketplace. How-

[12] Shelley Ernst (Mar. 2016). *What You Need to Know About Renewable Diesel*. Government Fleet. URL: https://www.government-fleet.com/156621/what-you-need-to-know-about-renewable-diesel.

[13] Ville Uusitalo et al. (Sept. 2014). "Carbon footprint of renewable diesel from palm oil, jatropha oil and rapeseed oil". In: *Renewable Energy* 69, pp. 103–113. DOI: 10.1016/j.renene.2014.03.020.

[14] Tampier et al., *Identifying environmentally preferable uses for biomass resources: Phase 2 report: life-cycle emission reduction benefits of selected feedstock-to-product threads*.

[15] In the Tampier report, a 50% moisture content ("green biomass") and 20.5 $\mathrm{MJ/BDkg_{fuel}}$ was selected. This higher moisture content was considered in the Tampier modelling even though the moisture content of fire-killed trees near the three communities studied in this report is 6%. Not all remote communities in Canada will have access to fire-kill wood or wood with such a low moisture content. Communities in high-rainfall ecozones (such as the west coast of Canada) who are currently dependent on diesel for heat and/or electricity may only have local access to a wood feedstock with significantly higher moisture content that in the three communities focused on here.

[16] Tampier et al., *Identifying environmentally preferable uses for biomass resources: Phase 2 report: life-cycle emission reduction benefits of selected feedstock-to-product threads*.

ever, they require precise standardization of fuel moisture content and fuel form. As a result, while they can be operated with commercial-grade wood pellets as a fuel source, they cannot be operated using wood chips as fuel, unless the chips have a highly standardized moisture content, size and shape. As a result demonstrations of gasification technologies have experienced many failures, which often remain unreported.

Biomass has been successfully used to drive steam turbines, but not at the relatively small scale (in the 1 MW range) appropriate for these communities. Small steam systems are not appropriate for small-scale CHP use, as small turbines must operate at a lower specific speed, which makes smaller steam systems much less efficient than larger ones. Steam turbine plants also require round-the-clock supervision by highly-trained and accredited operators.

Although Hybrid Brayton Cycle technologies use indirect conversion, and therefore can accept a wide range of fuel moisture content and a variety of fuel forms, this study does not recommend them for remote use because they have not yet achieved commercialized status for uses similar to the use required in Northlands Dënesułiné, or at this scale.[17]

ORC technology is a mature, commercially-established technology. The most recent, published overview of installed ORC systems worldwide is Tartière *et al.*,[18] which reported that, as of the end of 2016, over 1,700 ORC units were installed at over 700 sites throughout the world, and that these units, together, had a total installed capacity of over 2,700 MW of electrical generation. Because it is an indirect conversion technology, ORC technology can use virtually any heat source as an input. It can use a wide variety of biomass fuel forms—everything from forestry slash and waste wood to pellets. It can also accept a very broad range of moisture content.

A useful, short overview of the ORC and its applications is "Organic rankine cycle; a technology worth replicating"[19] published by NRCan.

More detail on CHP systems can be found later in this study. Specifically:

- ORC systems: Section 12.1 on page 131
- Pyrolysis: Appendix A.1.2 on page 301
- Hybrid Brayton Cycle: Appendix A.1.3 on page 302

[17]The HBC is based on extending the application of a micro turbine and removing the combustion chamber altogether. It will be as reliable as an ORC system using 5 atmosphere air as the working fluid. The HBC was developed, in part, by the main author of this current study, Eric Bibeau.

[18]Thomas Tartière and Marco Astolfib (Sept. 2017). "A World Overview of the Organic Rankine Cycle Market". In: *Energy Procedia* 129, pp. 2–9. URL: https://www.sciencedirect.com/science/article/pii/S1876610217340286.

[19]Natural Resources Canada (2016). *Organic rankine cycle - a technology worth replicating*. Goverment of Canada, Canadian Forest Service, Investments in Forest Transformation Program (IFIT). URL: https://d1ied5g1xfgpx8.cloudfront.net/pdfs/38744.pdf.

1.10.4 CHP TECHNOLOGIES COMPARISON CONCLUSION

Currently, the ORC is the only CHP system which meets all the required criteria and is therefore recommended in this study.

1.11 Supplemental technologies required

Supplemental technologies are also required to achieve the goal of ending diesel dependency in Northlands Dënesułiné:

- Biomass harvesting and hauling equipment.
- Safe, modern, WETT-certified wood stoves or wood furnaces in each home, if wanted by the people living in that home.
- Installation, certification and operation of a waste-oil burner in each community.
- Energy retrofits of homes and buildings to improve the efficiency of both heat and electricity use. Among other initiatives, this will need to include blow-in insulation in attics, improved insulation in crawl spaces, and the replacement of any broken windows and doors.

1.12 Renewable energy technologies not required at this time

This study reviewed a number of technologies and concluded that they are not essential to achieve the goal of ending diesel dependency in Northlands Dënesułiné. While all of these would be viable sources of renewable energy in these communities, this study proposes using as few systems as possible to meet the goal of ending diesel dependency.

1.12.1 GEOTHERMAL

All three communities are too cold for ground-based horizontal geothermal loops. More heat will be extracted from the ground in the winter than will be replaced in the summer. This will cause the ground freeze and not thaw, resulting in failure of the geothermal system.

Vertical bore geothermal is technically feasible in Northlands Dënesułiné. However, boring the holes would require bringing in a large drill over the winter road, keeping it in the community for a year to bore the holes, and then shipping out on next year's winter road.

Lake-based geothermal heating and cooling is feasible for both Barren Lands and Sayisi, and the expansion of the existing lake-based geothermal system in Northlands is also possible. However, this study does not propose the addition of these systems at this time. Once the biomass heating system is fully functional and heating all buildings, adding geothermal, especially to more remote homes and buildings, may be appropriate. However, use of electricity for heat pumps is not recommended if reliable heating can be achieved through the biomass-based district energy system.

1.12.2 WIND TURBINES

Wind turbines are not recommended at this time. There is certainly sufficient wind in Northlands Dënesułiné to drive wind turbines, especially if they are located on the top of hills, in areas open to the dominant north-west winds. Like solar photovoltaics, wind power is non-dispatchable (meaning it is generated intermittently, rather than on demand). For the sake of system simplicity, this study recommends that only one form of non-dispatchable energy be installed in Northlands Dënesułiné at this stage. Solar photovoltaics are preferable to wind turbines in Northlands Dënesułiné for a number of reasons:

- Northlands Dënesułiné has an airport right beside it. Wind turbines need to be located far enough away from airports to ensure they present no hazard to flight. This is particularly important for Northlands Dënesułiné's an airport, which is used by smaller planes that often have to land in difficult flying conditions.
- Northlands has two hilly area that are well-exposed to north-west winds. One is located approximately 10 kilometres to the west of the community, near the winter road. The second is located south across the lake, 12 kilometres from the community. If wind turbines were installed on either of these hilly areas, power lines would have to be installed from there to the community. Constructing either of these lines would be expensive—a rough estimate being $1,000,000 per kilometre. This cost would, of course, be in addition to the cost of the turbines.
- Wind turbines of a size sufficient to provide community-scale electricity would require cranes for service and repair. Because the winter road is only open 6 to 8 weeks a year, a crane would have to be brought in one year, stay in the community until the next winter road season, and then be shipped out.
- Crane operation and wind turbine servicing will require outside specialists.

1.12.3 HYDRO

Hydro power—either micro or run-of-the-river—are not recommended for inclusion in this project. Northlands Dënesułiné has rapids approximately 10 km away from the community. As with wind turbines, installing power lines to bring the electricity back to the community would be expensive.

1.13 Smaller renewable energy technologies that could be added later

Smaller wind turbines, hydrokinetic turbines, and off-grid solar may be particularly suitable to meet the energy needs of isolated cabins and lodges that Northlands Dënesułiné wishes to establish. Other renewable technologies may also have important specialized uses.

1.13.1 SMALLER SOLAR

Smaller roof-top and ground-mount PV solar systems for residential and commercial buildings could be considered as part of demand-side management initiatives. They would also be appropriate for isolated cabins and lodges.

1.13.2 SMALLER WIND TURBINES

Smaller wind turbines—either horizontal or vertical axis–could also be appropriate for isolated cabins and lodges, particularly on north-facing lake slopes, where PV solar would be blocked by hills and trees.

1.13.3 HYDROKINETIC TURBINES

Small hydrokinetic turbines may be particularly suitable for isolated cabins and lodges, if they are situated beside fast-flowing water that is consistently at least 3 metres deep.

1.13.4 THERMOSYPHON

Passive thermosyphon cooling should be added in situations where discontinuous permafrost melting under buildings is a problem.

1.13.5 SOLAR THERMAL

Solar thermal systems—including solar walls—would be suitable for Northlands Dënesułiné and should be integrated into new larger buildings such as schools and medical centres. Solar walls are not covered in this study because it would be expensive to retrofit buildings not designed for this technology. However, solar walls should be considered for new buildings. Mapping building data included in this study now incorporates building orientation to facilitate future solar analysis.

1.14 Study structure

This study first provides an overview of the three communities.

It then considers the communities in their ecological context and develops an estimate of the fire-kill available for harvest and use in the biomass systems recommended in this study.

It then reviews the climate of the communities, with a particular emphasis on:

- The heating requirements based on Heating Degree Days (HDD)
- Heat gain on buildings from solar energy
- Heat loss from wind

- Solar resources for solar PVs

A detailed Energy Inventory (EI) for each community investigates the heat and electricity required in Northlands Dënesułiné using 2016 as the base year. The EI builds and expands on previous Community Energy Plan research and recommendations.[20]

The study then predicts demand growth until 2035. Using the best data available at this time, the study estimates a load growth curve for electricity and heat in Northlands Dënesułiné, providing an estimated demand—an estimated EI—for the year 2035. This data included information from the Community Energy Plans mentioned earlier, the number of houses built and the population growth experienced in each community over the last decade, discussions with community leaders on projections for future growth, and Manitoba Hydro's demand projections.

The study then proceeds to simulate and match electricity and heat loads using a biomass-based Combined Heat and Power (CHP) system. As the simulations progress, micro-grid concepts are included to provide insight into the control strategy that forms the basis of the Energy Management System (EMS) micro-grid controller. A solar array and batteries are then added to the design and properly sized.

The specification of each component is detailed.

A budget estimate of each component is then provided.

Finally, the study recommends qualified suppliers for each of the key renewable energy technologies.

1.15 Data archiving

During this study, significant resources were spent on accessing limited data. Data files collected and developed for this study are archived with this report, as shown in Table 5 on page 26. This will allow the community, the locally-owned energy corporation, and other stakeholders improve assumptions, estimations, and deployment in future years, building on a base of knowledge.

[20] Demand Side Energy and PrarieHouse, *Community energy planning for Manitoba off-grid First Nations*.

Table 5: Archived datasets

File	Description
`FS3_weather.xlsx`	Weather data for the three communities and surrounding weather stations. Does not include weather service data subscribed by software packages like PVWATTS and HOMER. Produces dataset required for heat load calculations in `FS3_database.xlsx`
`FS3_database.xlsx`	Main database for this study
`FS3_report.tex`	This report
`*.jpg`	Original bitmap for PID's, controllers, diagrams. Original files can be obtained upon request.
Files used to model the system are proprietary and not archived.	

1.16 Assumptions & Estimates

Assumptions and estimates were required for this this study because some of the data of past and present energy consumption was either incomplete or unavailable. Estimates were, of course, also required for future projections.

Table 6 on page 27 shows the assumptions and estimates made, the values attributed to each parameter, and the variable name used. Parameters that are traceable are in green; yellow shows parameters that have a larger potential error margin; and, red indicates a value needs to be updated in future years when better information is obtained. As calculations are programmed using variables instead of the actual values in Excel, updating a parameter cascades throughout this study calculations and modelling. Ongoing community involvement is required to update these assumptions to allow for better prediction of loads in 2035, which will impact the numbers of modules and sizes of the integrated renewable energy system.

Table 6: Assumptions & estimates required for load calculations

Label	Value	Details
Power_factor	0.98	Power factor which is the difference from true power and billed power by hydro
Avg_line_loss	6.0%	Losses in the hydro lines
Avg_pipe_loss	0.08	heat loss in disctrict heat pipes
Heat_Num	0.75	Fraction of people having 1 kW heaters in their homes 2018
Heat_On	0.25	Fraction of time heaters are on
Heat_PEDD	5%	Fraction of homes with electric heaters post PEDD
WS_Num	0.2	Fraction of people using wood stoves often
WS_PEDD	0.6	Fraction of people after PEDD using wood stoves often
WS_Cords	0.5	Cords per house before and after PEDD per year
House_Heat	28,279	kWh/yr per house of heat (from house audit) x 0.85 factor as electricty is high
House_Power	13,667	kW/hr used per house
House_DHW	0.41	fraction of electrcity uised by DHW electric per house
Com_DHW	60	Equivalent commerical hot water tanks units
Eff_Ratio_Fur	1.02	1/Diesel furnace/(air handler+DH pipes+biomass boiler)
Eff_Ratio_DHW	0.72	1/Electric HWT/(DH pipes + biomass boiler + tank)
Eff_Ratio_WS	1.5	1/old stoves/new stoves
LG_Power	0.75%	Load growth per year electricity commercial before DSM
LG_Power_res	1.00%	Load growth per year electricity residential before DSM
LG_Heat	0.20%	Load growth per year heat commercial before DSM
LG_heat_res	0.05%	Load growth per year heat residential before DSM (no real reason to increase)
DHW_Use	5559	kWh/yr per house
DSM_Eres	0.20	DSM electricity target fraction reduction for old and new homes (dominated by heat tracing reductions and dryers)
DSM_Hres	0.20	DSM heat target fraction reduction for old and new homes (derived CEP2017)
DSM_Ecom	0.2	DSM electricity target fraction reduction for commercial (from Fleming)
DSM_Hcom	0.1	DSM heat target fraction reduction for commercial (from Fleming)
HRV_Fan	100	W of power all the time for Regencore
Swidth	0.762	Soffits sizes
Com_DHW_Elec	3.0%	Percent total electricity reduction for electric to biomass DHW (need info)
Bat_PS	0.0%	Percentage peak savings from battery use (From Homer) includes with PV
OpenADR_PS	5.0%	Peak saving initiatives not yet defined using OpenADR
Feeder_BO_PS	2.5%	Do not open all feeders after a black out (From Homer)
Pipe_Heat	5.0%	Electricity used for heating pipes for residential and commercial before PEDD
Pipe_Heat_Reduce	80.0%	ORC
CHP_PtoH	3.2	Energy available for heat
Solar_PV	311	MWh/yr solar PV at 400 kW
HDD_ref	16.0	Reference to start heating in Celsius
Wind_HDD	0.2	Impact of wind on overall heat loss
Solar_HDD	0.1	Impact of solar gain on overall heat loss
Pop_inc	0.2	Population increase per decade
Pop_age	1.00	Population aging per decade (yrs)
Pop_house	2.75	Target people per households
Green: documented value; Yellow: value needs verification; Red: estimated and needs updating		

Uncertainty in the assumptions that impact system sizing and number of modules (e.g. number of solar photovoltaic panels) include:

- The number of new houses and buildings that will be added in each community. With each new houses and buildings, the electrical and heating loads will increase.
- The effectiveness of demand-side management programs each community will implement, as this impacts the estimated 2035 load reductions.
- New loads for electric vehicles are not included in the 2035 load predictions. However, if electric vehicles are only charged at night, their introduction will have less impact on the energy system, other than to increase the yearly wood consumption.

Note: The graphs in this document were generated by the Excel model and by the Homer software as part of this study.