Renewable Energy Prefeasibility Assessment Results

A summary of viability of future development of various renewable energy sources in the communities of the Peter Ballantyne Cree Nation

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Executive Summary

This project came out of the Fulbright Arctic Initiative, connecting SaskPower and the Alaska Center for Energy and Power (ACEP), University of Alaska Fairbanks, and the School of Environment and Sustainability, University of Saskatchewan to identify opportunities to support PBCN's interest in pursuing renewable energy development. The primary purpose of this study is to determine which renewable energy resources are feasible for utilization in Peter Ballantyne Cree Nation (PBCN) communities, with regards to resource availability, technical feasibility, affordability, and long-term sustainability. Also considered are secondary benefits such as producing jobs, increasing local energy independence, and supporting the local economy. Specific technologies under consideration include: 1) ground, water and air-source heat pumps; 2) solar energy; 3) wind power, and 4) biomass (cordwood, wood chips, and wood pellets).

For each technology that appears feasible at this point, we recommend that SaskPower pursue more detailed resource assessments. Our recommendations utilize existing data for similar situations in Alaska, which we have selected as "comparable", to outline potential parallel situations in PBCN communities. Based on what we consider the strongest candidates for potential energy sources, we will outline recommendations for how to pursue quantification and fuller economic projections, where applicable. We outline here barriers the Alaskan communities have faced, as well as lessons learned from the Alaska projects, for the use of PBCN in their resource assessment and planning efforts.

Based on our initial assessments, the all of the following are strong candidates for renewable energy in the PBCN communities: solar thermal, solar photovoltaic, water- and ground-source heat pumps, and biomass. Wind is not at this point as economical or technology-ready as solar or biomass, but collection of wind data is suggested for future portfolio diversification. Air-source heat pumps do not appear to be a strong candidate.

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1.0 Introduction

This project came out of the Fulbright Arctic Initiative, connecting SaskPower and the Alaska Center for Energy and Power (ACEP), University of Alaska Fairbanks, and the School of Environment and Sustainability, University of Saskatchewan. Largely led by Native Alaskans, Alaska has considerable experience applicable to the challenges faced by Canadian Arctic and Sub-Arctic communities, particularly in community-level deployment of renewable energy projects—wind power, solar, biomass, and batteries. Alaska also has growing experience with new and retrofit energy conservation for homes and buildings that both retain heat more efficiently and mitigate moisture and molding issues. Northern Saskatchewan communities are not traditionally defined as “remote” because they are connected to the northern SaskPower transmission grid. Nevertheless, many of these communities remain economically remote because they do not have natural gas, which translates into higher business costs for Northern enterprises and higher financial costs for households in communities that are already economically disadvantaged, in comparison to the rest of the province.

Peter Ballantyne Cree Nation (PBCN) is an Asinīskāwiyiniwak First Nations band government, comprising seven communities: Amisk Lake, Deshambeault Lake, Kinoosao, Pelican Narrows, Sandy Bay, Southend, and Sturgeon Landing. Each of these communities is connected to the northern SaskPower transmission grid, with the exception of Kinoosao, which is powered by diesel generators. All of the communities heat buildings electrically, as there is no local access to natural gas. PBCN has expressed a high interest in exploring renewable energy options for member communities to address two key issues: on-going own source revenue streams, and heating costs for PBCN individual households and PBCN public buildings. Through investing in and incorporating more locally sourced renewable energy, PBCN is ultimately aiming to increase energy self-reliance, provide new opportunities for local jobs and economic development, and combat climate change.

To assess the viability of exploring the viability of renewables to address these two issues, SaskPower (Ranjith Narayanasamy, Tim Zukolkski, Greg Poelzer) traveled to Alaska on January 18 – 21, 2016, and met with Alaskan research centers (Cold Climate Housing Research Center, Alaska Hydrokinetic Energy Research Center), utilities (Golden Valley Electric Association, Alaska Energy Authority), and Native corporations (Alaska Village Electric Cooperative, Cook Inlet Regional Corporation, TDX Power). The project lead then traveled to Northern Saskatchewan on August 22 – 23, 2016, to survey and gather geographical and environmental data from communities in PBCN.

Following, ACEP undertook to evaluate resource potential and propose methods for detailed resource assessment, as well as offer technical expertise regarding development of renewable energy systems in northern Saskatchewan for communities inhabited by members of PBCN. The overarching goal of the project was to produce a set of high-level social, economic, and technical guidelines, as well as recommendations on how to conduct feasibility studies on renewable energy options for PBCN and Northern Saskatchewan to inform and assist decision-making.

This report provides a summary review of the findings, including high-level assessments of:

- Resource and market potential for each technology in the study area.
- Current and projected estimated technology performance, including efficiency, economic life, availability, capacity factor, etc.

- Estimated cost of the technology, including installed cost/kW and O&M and R&R costs based on a similar assessment for remote areas, where available.
- Recommendations for how to pursue full detailed resource assessments, where recommended.

The remainder of this report is organized into the following sections:

- Section 2: Project Context
    - Context for this project
    - On what basis ACEP made projections
    - Assumptions made in this prefeasibility study
    - Some comments on efficiency measures
- Section 3: Technology Background and Feasibility Discussion
    - Pertinent background information for a basic technical understanding of the technologies under review, as they apply to Northern latitudes in general and the PBCN communities in particular:
        - Microgrids
        - Solar PV
        - Solar thermal
        - Wind
        - Ground source and lakewater heat pumps
        - Biomass heat alone, and Combined Heat and Power
    - Technology feasibility discussion and recommendations for full resource assessments of each, if indicated
- Section 4: Summary of Technical Findings and Recommendations
- A summary of findings from the project and recommended next steps concerning technology research, development, and application
- Section 5: Case Studies of Two Alaskan Utility Companies
    - History, and how their business model cam to be
    - Mechanisms of model
        - Cooperative vs. private ownership
        - Establishment of board

2.0 Project Context

The cost of power for the PBCN communities is subsidized and levelized by the Canadian government; thus they all share a common power cost, at present a flat monthly charge plus $0.12624/kWhr (CAD), even Kinoosao, which is an islanded diesel community 6.0. This differs from Alaska, where the cost of power varies between communities, even those that are connected to the state grid. Alaska's islanded diesel communities, to which diesel is flown or barged, have the highest and most volatile costs of power in the state, although residential power costs in off-grid villages are subsidized by the Power Cost Equalization program [2]. Therefore, the primary economic drivers in PBCN communities are energy security and independence, as well as job creation, rather than reducing generation costs in general. Moreover, all but one of the PBCN communities are connected to the provincial grid and enabled for net metering. Therefore, energy storage is not indicated by this study, and integration of small amounts of renewable generation will not be a controls challenge. The Saskatchewan grid has an average load of 4100 MW, with presently 25% renewable generation (20% conventional hydropower). PBCN's target is 2-3.5 MW renewable generation on PBCN lands..

The heating loads in PBCN communities are very high, comparable to those in Fairbanks and Interior Alaska. Heating in PBCN communities is almost exclusively via electricity. In Interior Alaska, electrical heating is almost unheard of. Most home heating is via oil and/or wood stoves. There is some wood stove usage in PBCN communities. Utility bills in PBCN communities average about $800-1000 CAD per month. The average household size in PBCN is 12 people per home.

It should be noted that the general recommendation of energy professionals with regards to reducing the cost of energy is to maximize efficiency first before investing in renewable generation. Indeed, efficiency measures are being undertaken in PBCN communities, and SaskPower has a progressive demand-side management team that assessed two PBCN communities in the past year. Although this study focuses on renewable energy generation and efficiency on the generation side, not the usage side, a brief discussion will be given on the possible involvement a utility may have in energy efficiency improvement.

2.1 The Communities of Peter Ballantyne Cree Nation

The Peter Ballantyne Cree Nation is comprised of seven communities, spanning 500 km as the crow flies. All are theoretically accessible from the highway system, but most of the access roads are gravel and can be rough. The local economies are heavily subsistence-based, with mining and tourism also present. Hunting, guiding, commercial fishing, and trapping are all available, and most of the communities offer a few services (gas, groceries, restaurant, boat rentals) for visitors. Recreational and cultural opportunities are suggested on the PBCN website.

Each community is situated on a large lake. They all have access to forest resources, although the quality of wood varies.

The PBCN communities are mapped in Figure 1:

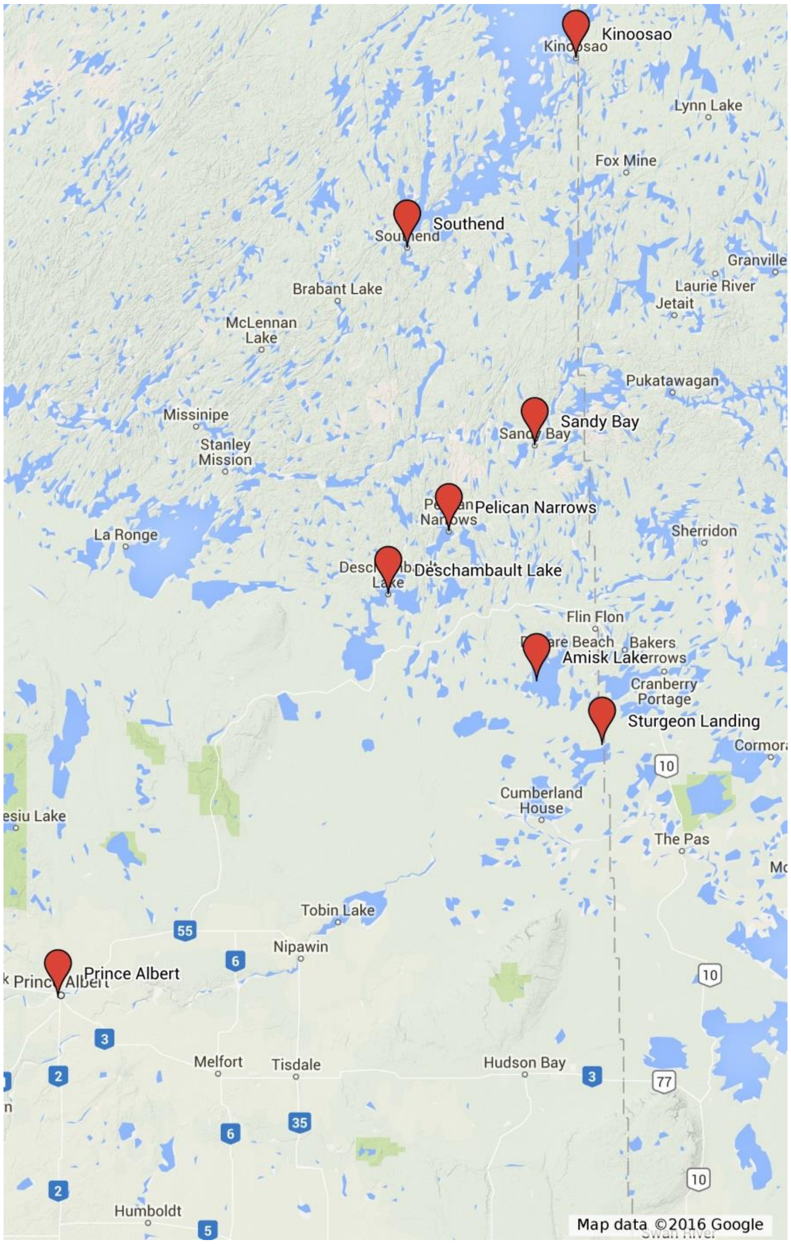


Figure 1. Peter Ballantyne Cree Nation Communities

The PBCN communities span from 53 to 57 degrees North latitude. The nearest advanced weather stations that follow approximately the same terrain as most of the PBCN communities are located at The Pas, Manitoba and Fort McMurray, Alberta. Solar data from The Pas and Fort McMurray are used for the solar portion of this study. Fairbanks, in comparison, is at 65 degrees North latitude. Table 1 shows comparison details.

Table 1. Geographic Comparison of PBCN Communities

PBCN Community	Population	Latitude, degrees N	Heating Degree Days, C° (F°)*
Amisk Lake	820	54.66	unknown
Deschambault Lake	821	54.91	unknown
Kinoosao	60	57.08	unknown
Pelican Narrows	2703	55.17	unknown
Sandy Bay	1233	55.53	unknown
Southend	904	56.33	unknown
Sturgeon Landing	37	54.28	unknown
Prince Albert administrative center	4400	53.19	unknown
Total PBCN	11,000		
Comparison Community			
Fairbanks North Star Borough, Alaska	100,000	64.84	7741 (13934)
Fort McMurray, Alberta	61,000	56.75	5621 (10117)
The Pas, Manitoba	5500	53.82	6915 (12447)

* Based on heating above 18.3°C

The primary targets for renewable generation in the PBCN communities are Sandy Bay, Southend, and Kinoosao. Sandy Bay is the site of Island Falls Hydroelectric Station, and its associated Dam. Southend has also been impacted due to the installation of the Whitesand regulatory dam, which controls flow from Reindeer Lake to control water flow to Island Falls. Kinoosao is the only PBCN community that is off-grid and dependent on diesel for power generation.

2.2 Assumptions Made for Resource Assessments

The assumptions made in this prefeasibility study, and their justifications, are as follows.

i. The solar resource in PBCN communities is similar to those in The Pas, Manitoba and Fort McMurray, Alberta. The Pas is similar in latitude to the more Southern of the PBCN communities; Fort McMurray is similar in latitude to the more Northern of them. Their climate is similar (inland prairie; warm, clear summers; extremely cold winters), and their amounts of cloud coverage are similar.
ii. Heating and cooling effects in PBCN communities are similar to those in Fairbanks, Alaska. In reality, heating degree days historically differ by approximately 30 percent. However, we are using this estimate, which is on the conservative side.
iii. Only small pockets of discontinuous permafrost are present on PBCN lands.

2.3 Notes on Efficiency

This study focuses on renewable energy generation and efficiency on the generation side. However, it is important to note that utilities can and do play an important role in improving efficiency on the demand side.

One example is that Golden Valley Electric Association (GVEA), the electricity cooperative that serves Fairbanks, offers inexpensive (or free, to low-income residents) home efficiency audits under a program called "Home$ense". [4] Any residential utility customer may request an energy efficiency specialist to come to their home and perform an energy use assessment. The auditor will also explain ways to reduce electrical usage. Included in the audit are a few small items that promote energy efficiency, such as LED light bulbs, a timer for vehicle plug-ins, and a packet of educational materials on energy efficiency.

Another example is given by Cordova Electric Cooperative (CEC), which serves Cordova, Alaska, an electrically islanded town of approximately 2200 residents. CEC has retrofitted all of the town street lights with LED bulbs, as well as distributed low- or no- cost Compact Fluorescent Bulbs and LEDs to all residents.

3.0 Technology Discussion and Feasibility in the PBCN Communities

The renewable resources and strategies under consideration are discussed here.

3.1 Microgrids

One strategy that SaskPower is considering for PBCN communities is giving them the opportunity to disconnect from the provincial grid and operate as microgrids. Before we enter this discussion, it will be useful to define what a microgrid is in a rural Northern context. In the contiguous United States, and the population centers of developed nations in general, a microrgrid is defined as:

- A small grid (<10s of MW).
- That can be operated in islanded mode.
- That possesses some of its own independent generation capability.
- That possesses its own load demand.
- That can balance its generation with its demand while in islanded mode.

By the above standards, the State grid of Alaska would be considered a microgrid. However, within the Alaskan context, it is not considered as such.

Within Alaska, the microgrids are:

- Even smaller (10s-100s of kW).
- Islanded, all the time, not by choice.
- Must have redundancy; there is no possibility of transmission from elsewhere.
- Must have low risk tolerance; rolling brownouts or blackouts are not permissible in harsh climactic conditions.

The potential for PBCN communities to disconnect from the main Saskatchewan grid and operate as microgrids at times was raised as a solution to the current problem of lightning strikes. During an electrical storm, which is common in the region, lightning can strike 20-30 times per night, causing 5-6 power loss events per summer. [3] The transmission line from the main section of the grid to each PBCN community is some 800 km long and not grounded; therefore, a single lightning strike can take the whole line out of service. During these events, the communities are often out of service for several hours.

If the PBCN communities were given the capability to disconnect from the main grid and temporarily manage their own generation and loads, the regular power outages could be avoided. In order to achieve this, several things would have to be achieved on each microgrid that plans to be islanded. First, they will need some synchronous generation capability, most likely via a diesel generator or set of generators. Secondly, if it is desired to utilize stored energy from the renewable source, they will need some storage capability, most likely via a battery bank. Thirdly, they will need a control system designed by a power control systems expert.

3.2 Solar

Solar power is under consideration despite the high latitude because solar power is proving effective in high latitude regions elsewhere. PBCN communities have also in general quite clear skies, which is a nontrivial factor. For example, Seattle, at latitude 48 degrees has a solar resource is only 11-17% greater than that of Fairbanks, at latitude 65 degrees, due to the former city's famous overcast skies and the latter's famous clear skies. (PVWatts was used for all solar resource calculations. See Table 7 in Appendix for assumptions that were made. [5])

Solar Photovoltaic

Solar photovoltaic (PV) power is the process by which the energy in light is captured and converted directly to electricity using semiconductors that exhibit the photovoltaic effect. In the last decade or so, solar PV has dropped steeply in cost. Solar panels are now a commodity item, and marketed as interchangeable, although in reality they have different useable life spans. It is important to purchase from a reputable manufacturer.

One great advantage that solar PV has demonstrated in Alaska is that it is very robust—it requires no moving parts that would wear out or break. This is an especially advantageous property in rural Northern communities and other austere environments. The risk of downtime is minimized with a solar PV installation because the power generation components are distributed over a larger number of components. Damage to one panel may result in the loss of 300W of production capacity, while the damage to one small wind turbine may result in the loss of 100 kW of production capacity. This effect is magnified in fly-in communities, where repair equipment may not arrive for up to a year (until either summer or winter, depending on the major artery of transport, e.g., ice road, frozen river, or flowing river).

Trackers are not recommended for solar PV in high latitudes because trackers are not cold-tolerant. The moving parts can freeze into place, and any liquids (lubricants, hydraulic fluids) thicken and lose effectiveness. The recommendation instead is to do either a fixed mount, or a mount that is manually adjustable in the vertical direction.

If the number of solar panels is small, adjusting the vertical tilt angle twice a year is optimal. Any more frequently leads to sharply diminishing returns on the time investment. A panel fixed to match its latitude will lose about 30% of the solar irradiation over a tracked panel. Adjusting twice a year reduces the loss to 25%, and adjusting four times per year reduces the loss to 26% [6]. If there are too many panels for manual adjustment, the vertical angle should be set to match the latitude. Alternatively, a vertical mount may be indicated in very high latitudes, where the mismatch between 90 degrees and the actual latitude is smaller; advantages are that a vertical mount encourages shedding of snow and captures reflected light from the snow on the ground, and a sidewall mount saves infrastructure costs.

The azimuthal angle can either be set to 180 degrees, or arranged in a distribution that is optimized for a community's needs. For example, in the Northwest Arctic Borough, fixed arrays have been installed such that the panels cover every azimuthal angle of the sun. The cost of solar panels has dropped so much that they are comparatively inexpensive when compared against the value of the additional power generated by such an arrangement. Figure 2 shows two such arrangements.

Figure 2. Circular Arrays on Deering (L) and Kobuk (R) Water Towers (credit: R. Bensin)

Northern latitudes can be especially good candidates for solar PV generation when the penetration level is small, as in the case of six out of the seven PBCN communities, because the mismatch between peak generation (summer) and peak load (winter) can be absorbed by the Saskatchewan grid. Fairbanks has shown to have a good solar resource due to clear skies, reflected light from the snow (albedo), and the increased PV production ability that occurs in cold temperatures.

PV production increases in cold temperatures, due to increased rates of recombination of charge carriers in the semiconductor materials used. [7][8] Figure 3 shows this relationship qualitatively. The numbers are from a simulation of a double-junction solar cell at a concentration of 1000 suns.

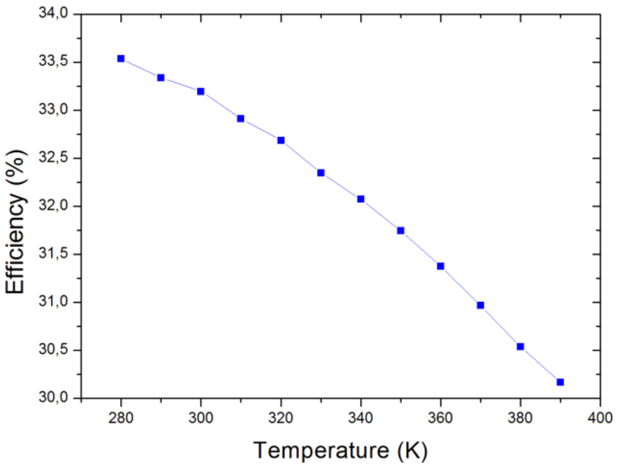


Figure 3. Solar PV Relationship Between Efficiency and Temperature [9]

In Fairbanks, the greatest solar resource availability is in late spring (March to April). This is due to a combination of cold temperatures, the continued presence of snow on the ground (albedo), sunny weather, and unusually clear air (low dust and particulate levels). It should be noted that the albedo effects are best captured when the solar panels are mounted at 90 degrees. This is reasonable in Fairbanks, which is at latitude 65 degrees, so the loss of direct solar irradiation from using vertical panels instead of having the tilt match the latitude is small (about 16% per year), but the gain in reflected light from the snow and in the self-shedding of snow makes it worthwhile. It may be less reasonable for PBCN communities, which are farther south and may gain comparatively more solar resource by matching the tilt angle to the latitude. Any loss in snow albedo effects may be compensated by the better angular match to the sun. For comparison purposes, the loss of direct solar irradiation due to vertical mounting instead of mounting at an angle to match latitude is presented in Table 2.

Table 2. Loss of Solar Irradiation due to Vertical Mounting

Community	Latitude, degrees N	Average Annual production per kW installed, kWhrs/year		Loss in Irradiation from Vertical Mounting, percent
		If panel is tilted to match latitude	If panel is mounted vertically	
Fairbanks, Alaska	65	993	833	16%
Fort McMurray, Alberta	57	1261	1027	19%
The Pas, Manitoba	54	1300	1016	22%

While snow can serve as an advantage due to its albedo, the presence of snow on solar panels themselves can be a problem, because it blocks light, as shown in Figure 4.

Figure 4. Solar Panels in Venetie (credit: D. Lockard)

In the 2013-2014 winter, a team in Calumet, Michigan studied snow cover on solar panels mounted at tilt angles of 0, 15, 30, and 45 degrees. They found that snow-related annual energy losses ranged from 5-12% for elevated unobstructed panels where snow could shed clearly, and 29-34% for obstructed modules that could not shed snow freely. [10]

Figure 5. Michigan Snow Accumulation Study [10]

If the total number of solar panels is small, it is not difficult to remove snow from solar panels in dry areas, such as the regions of PBCN and Fairbanks. Indeed, often in Fairbanks, a person will go out with a broom to brush a solar panel clear, but as soon as they even tap the panel with the broom, the snow easily falls off. However, for a larger installation, this may not be feasible.

ACEP has performed a study, the results of which have not yet been published, that involved mounting simulated solar panels (plastic-covered OSB boards) tilted at 65 degrees (matching Fairbanks latitude), and quantifying the amount of time it took to actively clear the panels of snow. It was found that the cost to keep a 1 MW array (4200 130W panels) cleared of snow for one season would have been about 3400 person-hours, at a cost of $50,000 USD ($65,000 CAD) (assuming a rate of $14.60 USD/$18.98 CAD per person-hour), while the additional amount of solar power generated throughout the winter on the cleared panels would be about $19,000 USD ($24,700 CAD). Therefore, if a large amount of labor capital is required to keep a solar installation free of snow, it is not economically advantageous to do so.

A 1 kW PV array would produce about 1000 kWh annually in Fairbanks [5], 1300 kWh annually in The Pas, and 1270 kWh annually in Fort McMurray. All PBCN communities should have a solar resource in between The Pas and Fort McMurray, with the exceptions of Prince Albert, which should closely match The Pas; and Kinoosao and Southend, which should closely match Fort McMurray. The cost of solar PV in Interior Alaska at personal home scale is approximately $8-10 USD ($10.4-13 CAD) per W installed [14], with capacity factors ranging from 6-15%. However, it should be noted that "capacity factor" has less meaning with the semicircular arrays that are designed for constant output, rather than maximizing capacity.

Figure 6 [11] shows installed costs of Alaskan systems for which data was obtained by ACEP. It should be noted that this cost data is very incomplete, and often based on verbal estimates and not public record. The large variation and inconsistency demonstrate the youth of the solar industry in Alaska, as well as the wide range of situations. There is at this point no clear trend between capital cost and installation size in Alaska. Also plotted on Figure 6 are horizontal lines showing two price points throughout the U.S. (which is dominated by the contiguous 48 states), according to Lawrence Berkeley National Laboratory's "Tracking the Sun VII" report, completed in 2013. The median installed price per kW is $4,800 USD/$6240 CAD for systems ≤ 2 kW, and $3,100 USD/$4030 CAD for commercial systems > 1,000 kW. [12]

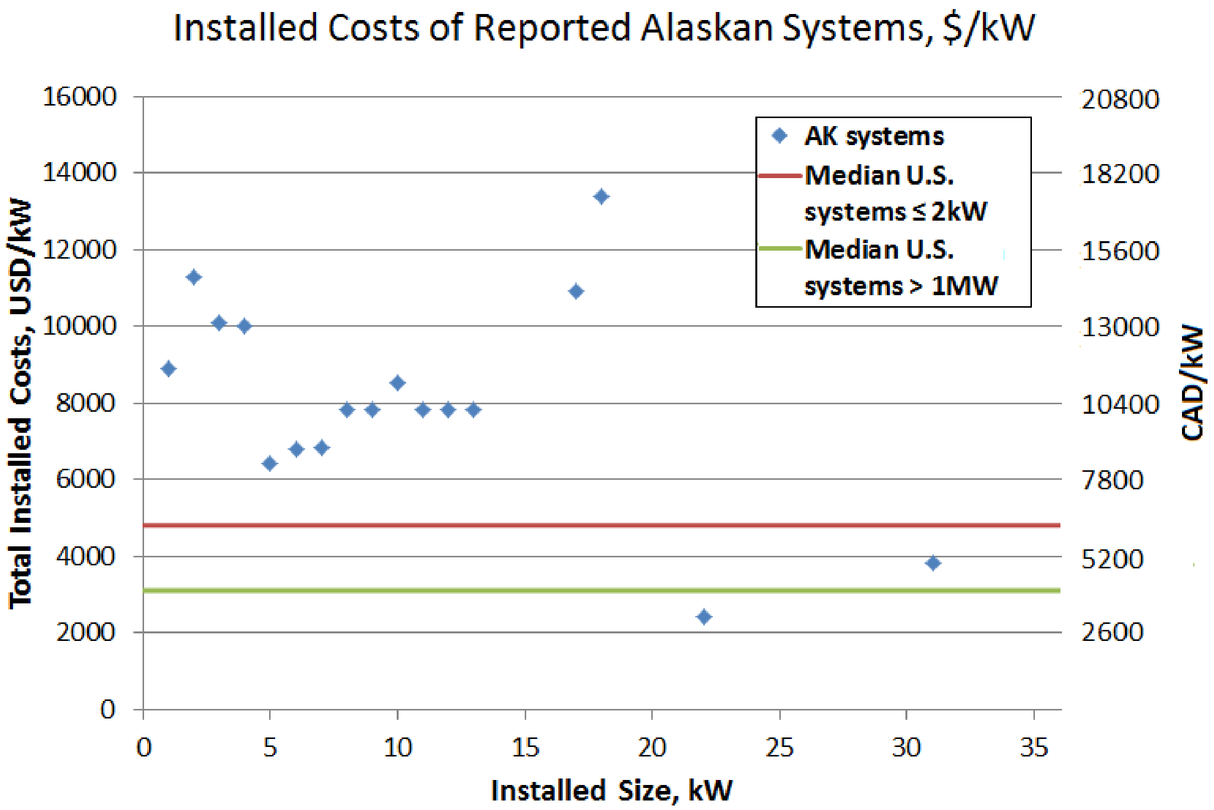


Figure 6. Installed Costs of Alaskan Systems as a Function of Installed Size [11]

According to one Canadian solar PV vendor, they estimate an installed cost at $6000-7000 CAD ($4600-5400 USD) per kW for a ground mount system, and about $5000 CAD ($3800 USD) for a roof mount system. [13] He bases this estimate on 10-20 kW systems in Northern Ontario, and has limited experience in Saskatchewan, but when questioned, he did not anticipate that Saskatchewan prices would be significantly different. It should be noted that roof-mount systems may or may not be ideal, considering the angle and azimuth of the roof in question.

For resource assessment, a pyranometer will measure solar irradiance (solar radiation flux density) in units of W/m^2. One pyranometer ACEP has used successfully is the “CMP11” from Campbell Scientific. For Northern conditions, it should be used with a vented heater, the “CVF4-L”, and it requires a mounting stand, the “CVF3”. It is compatible with their workhorse data logger, the CR800. Together, these three items would cost about $6200 USD/$8060 CAD as of this date and record solar irradiance spanning 0-90 degrees of polar angle and 180 degrees of azimuthal angle at 1-minute intervals. Note that it would not account for snow albedo. However, it should be noted that the already widespread successful deployment of solar PV panels throughout Alaska contraindicates the necessity of detailed resource assessment.

Other notes to consider are:

1) The early PV cell performance degradation can range from 0.2% to 0.7% per year [15].
2) The lifetime of an inverter is 20 years, at which point the inverter will need to be replaced [16].
3) After 30 years, 5% of the solar panels will need to be replaced [16].

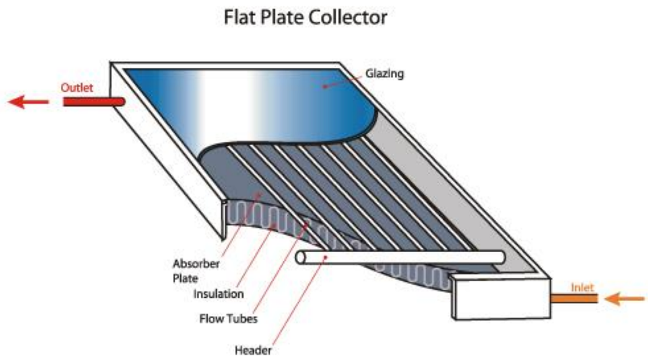
Solar Thermal

Solar thermal energy refers to capture of the sun’s energy in the form of heat, instead of the photovoltaic effect. In cases with high economies of scale and a high solar resource, such as Arizona and Southern California, this heat is used to generate steam, to power a turbine, which then produces electricity. However, in both Alaska and the PBCN regions, the solar resource is insufficient to make this strategy viable. Therefore, this study focuses exclusively on solar thermal for use of the heat itself, for space heating and domestic hot water.

The solar resource is greatest in the summer, when the heating needs are the least. However, the shoulder seasons (February through April, and August through October), still have a decent solar resource (3-4 kWhr/m^2/day) and a nontrivial heating load. Also, domestic hot water is needed year-round.

The two most common types of solar thermal collectors are flat-plate and evacuated tubes, although some do-it-yourself people in Alaska have used parabolic dishes lined with mirrors, focusing the heat at a coil of tubes filled with glycol mixture. Flat-plate collectors are more common and consist of a protective glass panel enclosing a dark-colored solar collecting medium, through which tubing circulates a heat transfer fluid, as shown in Figure 7.

Figure 7. Flat Plate Solar Collector [17]



A typical residential system used to supplement space heating and domestic hot water uses two 4x8-foot panels.

Evacuated tube collectors have the heat transfer fluid circulating through copper tubing encased in glass tubes connected to a header pipe. The tubes are evacuated of air, eliminating heat loss through convection. As the fluid heats up, it vaporizes and rises into the header pipe, transferring heat via a heat exchanger to another pipe filled with its own fluid to carry the heat to the water tank. From there, the hot water may be used for either space heating or domestic hot water.

A two-panel solar thermal system (each standard-sized panel 4 x 8 feet) could produce approximately 7 million BTUs annually in Fairbanks, offsetting 2050 kWhrs of electricity [14], 9.2 million BTUs (2700 kWhrs) annually in The Pas, and 8.9 million BTUs (2600 kWhrs) annually in Fort McMurray. Table 3 summarizes this and several other scenarios. All PBCN communities should have a solar resource in between The Pas and Fort McMurray, with the exceptions of Prince Albert, which should closely match The Pas; and Kinoosao and Southend, which should closely match Fort McMurray. The cost of solar thermal in Interior Alaska is approximately $4-5 USD ($5.2-6.5 CAD) per W installed. [14]

Table 3. Solar Thermal Cost vs. Benefit Projections Under Several Scenarios

System Description	Estimated Cost, $USD ($CAD)	Cost per Resident	Typical Situation for System	Average Electricity offset, average The Pas and Fort McMurray data	Annual Electricity offset, kWhr, average The Pas and Fort McMurray data
2 panels, 4x8 feet	$5000 ($6500)	$2000 ($2600)	Typical size for individual home in suburban United States or Canada (average size 2-3 people)	300 W	2650
4 panels, 4x8 feet	$7000 ($9100)	$580 ($760)	More appropriate size for home in PBCN community (average size 12 people)	300 W	4100

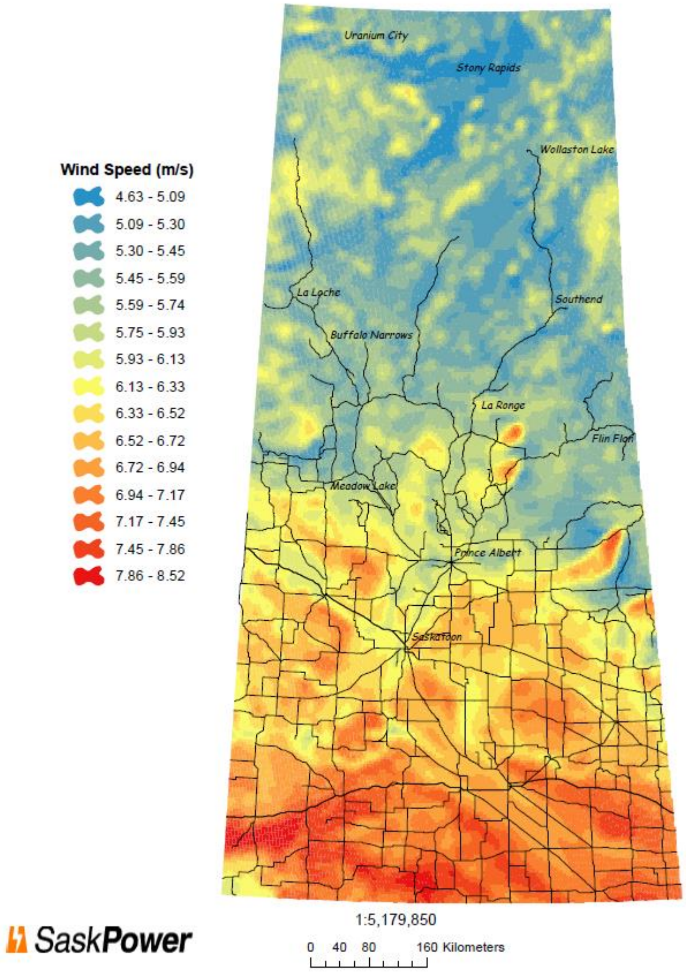
In Fairbanks, solar thermal is not as common as PV despite the lower cost because PV is easier to install and retrofit, while solar thermal requires plumbing and integration into existing mechanical systems. Solar thermal also involves moving parts, which as discussed lend themselves more easily to failure, especially in high latitudes. Nevertheless, solar thermal may be a good option for PBCN communities, particularly if one solar thermal collector array is connected to a heating loop that serves several homes that are located near each other. This is an option since PBCN communities do not appear to have permafrost.

The lifetime of a solar thermal system can range from 10-30 years [18].

3.3 Wind

Saskpower's preliminary studies have indicated Class 3 winds throughout much of the PBCN region. Figure 8 is provided from Saskpower's data:

Figure 8. Wind Resource Map of Saskatchewan [19]



The smallest wind turbines that are economically feasible for utility-scale generation are on the order of 10s to 100s of kW in nameplate capacity, with the higher end of that range being most common in small communities in Alaska. Figure 9 gives the power curve for the Northwind 100, which is a 100 kW wind turbine that is a permanent magnet and direct drive and one of the workhorses in rural Alaska:

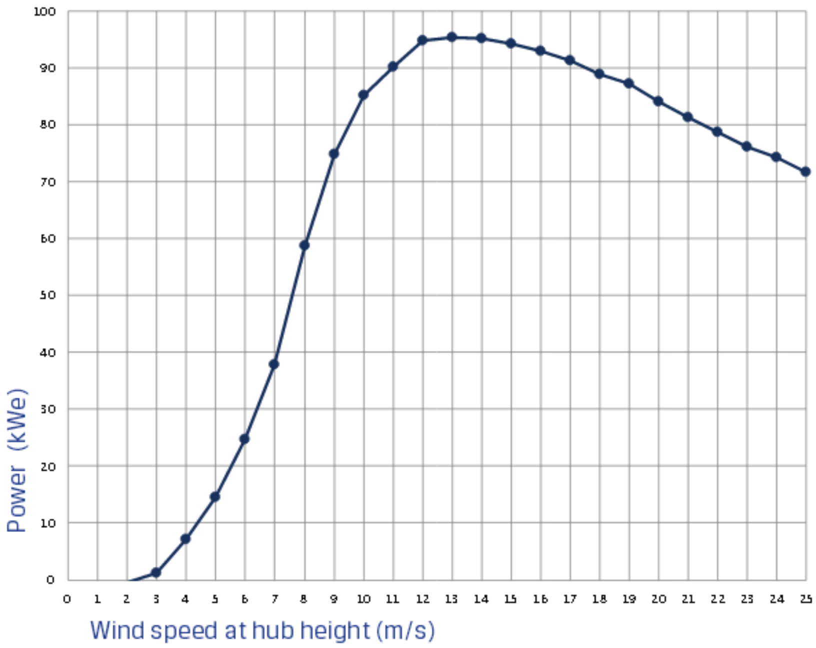


Figure 9. Northwind 100 Power Curve [20]

Wind speeds of 5 m/s, which is typical of Northern Saskatchewan, are not a good fit for a typical power curve for a 100-kW wind turbine. There are many vendors of smaller wind turbines on the market at present, in the 10s of kW range, that would have lower cut-in speeds, but they have a higher cost per kW, and they are untested at the utility scale in Alaska. Therefore, if PBCN communities are interested in harvesting the energy in the wind at lower speeds, they would have to be willing to risk both the higher capital cost per kW and being an early deployer of something not tried and true in another Northern setting.

Wind as an energy resource is notoriously sensitive to local conditions of terrain and thermal gradients. It typically requires location-specific data collection for a minimum of one year (ideally two years) in order to determine whether it will be economical to harvest the power. It is a known and common error that people place too much confidence in anecdotal observational data that tends to be skewed due to the imperfect and subjective observations of humans. One reason for this is that the degree of laminarity of the wind greatly influences its potential for power generation, and humans are poor at judging quantitative amounts of turbulence. A second reason is that often the wind resource varies due to time of year, and humans tend to gather at certain places only at certain times of year, leading to observational bias.

Therefore, it is possible that some localized regions on PBCN lands may have a good wind resource, but it is unknown. Anecdotal evidence suggests such, especially on the shores of the large lakes. Wind cannot be recommended for any extremely local setting (such as the mouth of a valley, or the edge of a large lake) without recommending first a resource assessment, which involves erection of an anemometer collecting wind data at intervals on the order of minutes, for at least one year that is “typical” in weather for the location. Two years is often suggested in academic literature. The meteorological tower should reach as close as possible to the height of the projected wind turbine. Published relationships do exist between wind speed and height, but as they are empirically derived, they are not as trustworthy as actual data collected at the true location.

One anemometer ACEP has used successfully that is suitable for Northern conditions, inexpensive, and from a reputable company is the “RM Young Wind Monitor, Alpine Version”, which can record wind speed and direction at 1-minute intervals. Campbell Scientific sells this is a stock item, and it is compatible with their workhorse data logger, the CR800. Together, these two items would cost under $3000 USD ($3900 CAD) as of this date. A meteorological tower of height 40 meters would cost about $50,000 USD ($65,000 CAD) over a two-year life cycle, including about $15,000 USD ($19,500 CAD) to remove it at the end. A typical tower height for a 100-kW turbine would be 20-40 meters. [21][22]

3.4 Heat Pumps

Heat pumps can use the ground, a body of water, or air as a heat source. They use electricity; however, the main “fuel” is the heat contained in the source. The heat pump takes the heat from the source and uses electricity to collect it and pump it into the space to be heated.

A heat pump moves heat via the phase change of a refrigerant in a refrigeration cycle. The refrigerant absorbs heat as it evaporates in the evaporator, which is a set of heat exchanger coils imbedded in the source (outside air, ground, or water). This gas then enters a compressor, which uses electricity to raise the pressure and thus temperature of the refrigerant gas until it is suitable for space heating. The gas then enters the space to be heated, where it passes through a set of indoor heat exchanger coils and condenses, releasing its latent heat. Finally, the now-liquid refrigerant moves into a throttling valve, where it expands and drops in pressure, and begins the cycle again.

The heat can be distributed throughout the space using either a fan and forced air ducting, or a water loop to heat hydronically.

Heat pumps use electricity to power the pumps, fan, compressor, and any other auxiliary components, all of which drive the compression cycle to move the heat from the source to the space to be heated. However, the actual heat comes not from the electricity, but rather from the source. Therefore, heat pumps have theoretical “efficiencies” that can be greater than 100%. In fact, they should be over 100%; otherwise the electricity alone should have just been used for resistance heat. Rather than “efficiency”, the term “coefficient of performance” is used. The coefficient of performance (COP) is defined as (the amount of space heating provided)/(the electricity used). It should be in units of energy over energy, so unitless.

A heat pump typically uses about the same amount of current as a refrigerator: smaller systems draw about 10 amps of current, while larger systems may draw up to 20 amps [23]. Because heat pumps still utilize electricity, however small the amount, they are not recommended where the cost of electrical power is high, and a lower cost heat source is available. For example, cordwood at $300 USD ($390 CAD) per cord equates to $0.051 USD ($0.066 CAD) per kWhr in heat. A heat pump with a modest COP of 3 would cost $0.032 USD ($0.042 CAD) per kWhr in heat in PBCN, but $0.069 USD ($0.090 CAD) per kWhr in heat in Fairbanks. Therefore, the cost per unit of heat for the heat pump would be more economical than cordwood in PBCN, but not in Fairbanks.

In the United States, heat pumps are referred to in units of “tons of cooling” since they are analogous to refrigeration pumps. A ton of cooling is the heat of fusion required to melt 1 ton (2000 lbs) of ice at 0°C in 24 hours, and is equivalent to 12,000 BTUs per hour or the heat equivalent of 3.5 kW.

It should be noted that in 2012, there was an increase in efficiency of heat pumps in the United States. In that year, R22 was banned as a refrigerant due to its being an ozone depleter. It was replaced with R410a, which is less efficient at thermal transfer. In response, larger heat exchangers were designed, which led to a net increase in heat pump efficiency.

Heat pumps and their associated components require some skill to install, which may either serve as a barrier to implementation, or an economic and training opportunity. Heat pump organizations such as the International Ground Source Heat Pump Association (IGSHPA) offer training to installers and designers, and some heat pump manufacturers themselves offer formal training. They usually also offer support from their engineers and designers when their systems are being installed. Having IGSHPA training is becoming an industry standard [24]. The IGSHPA provides a three-day training workshop, but it is offered in limited locations.

Air-Source Heat Pumps

Air-source heat pumps (ASHP) use the outside air as a heat source. Because of this, they are typically used only in climates that have less severe winters, where the air temperature does not typically remain below 0°C for extended periods of time. In Alaska, ASHPs are only indicated in the Southeast region, where the winters are milder and the cost of electricity is very low, due to the high usage of hydroelectricity. Although the PBCN communities do satisfy the criteria of having access to relatively inexpensive electricity, they have a similar heating load to the Interior of Alaska, so ASHPs are not recommended.

Ground-Source Heat Pumps

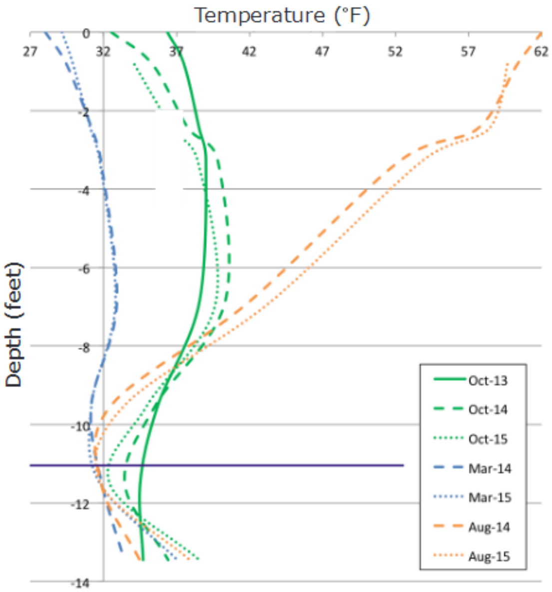
Ground-Source Heat Pumps (GSHP) use the ground as a heat source. During the summer, the heat is recharged by the sun. GSHPs take advantage of the time lag between the seasonal shift in outside air temperature, and the temperature of the ground. In Fairbanks, air temperatures can drop below freezing in October, but the active layer of the ground does not freeze until November or December. Some 40-50 GSHPs are installed in the Fairbanks area [24], and they have proven to be effective thus far.

The pipes in the ground can have several configurations. In Interior Alaska, both horizontal and vertical heat exchangers are options. Horizontal heat exchangers are laid at a specific depth, and can be either a series of coiled loops of piping, or long, straight pipes horizontally drilled into the ground, requiring less excavation. Vertical heat exchangers are a series of deep wells that extract energy from a borehole of depth ranging from 100-250 feet.

However, there is some concern in this high latitude over whether the solar heat in the summer is sufficient to recharge the temperature of the ground.

In November 2013, the Cold Climate Housing Research Center (CCHRC) in Fairbanks installed a GSHP on its grounds, with a plan to monitor the COP for ten years. If the ground does not sufficiently recharge each year, the COP should drop correspondingly. The COP of the heat pump dropped from 3.6 the first winter to 3.3 the second, and the temperature of the ground dropped from 1.4°C in October 2013 to 0.22°C in October 2015 at the level of the heat extraction coil (based on monthly average measurements). The ground was also observably colder near the coil, as show in Figure 10.

Figure 10. Ground Temperatures Under the Ground Loop of CCHRC's heat pump [25]



Every year, the temperature near the coil dropped. In October of 2015, it barely came above freezing. The owner of the company that installed the heat pump, Alaska Geothermal LLC, is confident that within another several years, it will reach a steady state, at which the solar recharge of the ground in the summer will equal the heat removed in winter, but this has not been observed yet. CCHRC has made no statement either in support of or against this assertion.

One option for recharging the heat to the ground is hybrid GSHPs, which use solar thermal panels to recharge the ground in the summer. A study on a school heat pump Tianjin, China showed that the COP can be improved by up to 0.25 with solar assistance to a single-source heat pump [26]. It is not clear, however, whether the added capital cost justifies the boost in COP.

Some lessons learned from existing GSHP installations in Fairbanks follow.

Selection of the ground loop location is important. It should be well exposed to solar radiation, and not on a North-facing slope. The ground should remain as close to constant temperature as possible. In the Fairbanks area, the most successful systems are situated in alluvial valleys with shallow water tables. This gives both alluvial soils with high thermal conductivity, and high water content with good consistency of temperature.

Although existing heating systems have been successfully retrofitted with GSHPs, it requires careful planning to integrate with a home's existing heat distribution system. Designing the GSHP from the start will enable optimization of sizing and design [24].

When sizing the GSHP, one consideration is whether it will be used for domestic hot water. Most homeowners in Fairbanks use a separate system for domestic hot water.[27]

Usage of GSHPs in both Alaska and Canada have been limited by factors such as high capital costs, site-specific engineering required for each system, and COPs that are less than manufacturers indicate [28].

Typical COPs achieved by GSHPs in Alaska range from 2.0–3.5 [27]. Due to the highly site-specific nature of installation, costs vary widely, with 13 systems ranging from $17,000 – 45,000 USD ($22,100–58,500 CAD) and averaging $32,000 USD ($41,600 CAD). The energy savings also vary widely, but *every system examined saves energy*.

The life expectancy is over 20 years.

Water-Source Heat Pumps

Water-Source Heat Pumps (WSHP) use a body of water as a heat source. Similar to the solid ground, a large body of water will lag the outside air temperature each season. Water has an additional advantage in that it requires no drilling to imbed a heat exchanger of complicated geometry, which could maximize surface area. However, water also has a very large heat capacity, which is an advantage when drawing heat from it, but a disadvantage when the sun is recharging it in summer. Lake temperatures in Fairbanks peak perfectly out of phase with peak heating season.

One lake source heat pump is already installed and operational in Deschambault Lake, at the high school. It was installed in 2005. Local operators report that the first year, there were a few problems, but after a learning curve, the heat pump has worked reasonably well; and they have witnessed no drop in COP over the years. It has two heat loops installed into the lake: one that is far and deep, and the other that is close and shallow. This covers the range of temperatures that occurs due to thermal stratification of the lake. Both domestic hot water and space heating are on the loop from the heat pump. The heating supplied by the heat pump is sufficient to be the sole source of heat during the milder shoulder seasons, but they supplement heat with a boiler during the deep winter (December through March). Every three months, a trained person from Johnson Controls, who designed the control system, comes to do maintenance on the heat pump.

In Fairbanks, there are some 12 WSHPs, to good effect, achieving COPs of 3.1-3.5 as measured, 3.5-3.8 as reported by installer [29]. In Seward, Alaska, which is situated on a bay, a seawater heat pump is achieving COPs ranging from 2.5-3.5 [30].

A typical cost for a new installation of a 10-ton lake loop would be about $36,000 USD ($46,800 CAD), while a 10-ton ground loop would be about $50,000 USD ($65,000 CAD) [29]. This is enough heating power for a 6000 square-foot space. In theory, costs could be reduced by heating more than one home on a single loop, but it is unclear whether the local water temperature would sufficiently recharge under such a scenario.

The life expectancy is over 20 years.

3.5 Biomass

Biomass is one of the oldest energy sources in the world. In lower latitudes with higher population densities and stronger infrastructural and human capital, biomass energy today tends to mean refined biofuels such as ethanol. However, in Northern climates, the value of heat alone is so high that the value of merely burning biomass, without investing energy in any conversion processes, is maximized. In Alaska, space heating is 80% of the stationary power generation. [31] The PBCN communities are very similar to rural Alaskan communities in this way—high heat loads and low labor availability. Therefore, the highest value of biomass is in burning it and using the heat directly. Therefore, this section discusses only the usage of woody biomass for heat and power.

It should be noted that the energy density of woody biomass is much lower than that of conventional fuels, and this is especially true of Northern trees, which are much less dense than trees at lower latitudes. For example, anthracite coal, for which Pennsylvania is famous, contains 22-28 million BTUs per ton, while Alaskan wood chips contain about 9 million BTUs per ton. Furthermore, the more the wood is processed, refined, dried, and made fungible and transportable, the more energy is input. In other words, it takes energy to make the fuel into a finer energy product. Table 4 outlines the options, in order from least processing and least convenience, to most processing and most convenience. Also provided are data for coal and heating oil, for comparison purposes.

Table 4. Types of Biomass Fuels in Northern Climates

Type of Fuel	Typical Unit	Typical Price per Unit USD (CAD)	Typical Energy Content per Unit	Resulting Price per kWhr USD (CAD)
cordwood, spruce, 20% moisture	cord	$300 (390)	16 million BTUs per cord	$0.051 (0.066)
cordwood, birch, 20% moisture	cord	$350 (455)	20 million BTUs per cord	$0.048 (0.062)
mixed species chips, 45% moisture	ton	$40 (52)	8.8 million BTUs per ton	$0.012 (0.016)
mixed species pellets, 20% moisture	ton	$350 (455)	14 million BTUs per ton	$0.085 (0.111)
Alaskan coal (sub-bituminus)	ton	$70 (91)	15.2 million BTUs per ton	$0.016 (0.021)
heating oil #2, 2009	US gallon	$4.5 (5.85)	138,700 BTUs per gallon	$0.102 (0.133)
heating oil #2, 2016	US gallon	$2.8 (3.64)	138,700 BTUs per gallon	$0.063 (0.082)

Some lines in Table 4 require explanation.

Cordwood: Ideally, all fuel should be burned at around 20% moisture content to maximize efficiency, minimize air pollution, and save costs (obtaining more heat per cord). In Alaska, it is typical to purchase or harvest firewood “green”, which wood sellers will sell for a lower cost (about $50 USD/$65 CAD) less per cord), then split it and allow it to “season” (dry) on one’s own property before burning. The typical recommendation in lower latitudes where wood stoves are in common use, such as New England, is to allow cordwood to dry for two years before burning. However, in Interior Alaska, the air is so arid that cordwood only needs to be exposed to one summer before reaching 20% moisture content [32]. In the PBCN regions, this will need to be tested. Prices given for cordwood in Table 4 are prices for seasoned wood.

Mixed species chips: Although, as mentioned, fuel should be burned at around 20% moisture content, this is not easy to obtain with chips. A bin or pile of chips does not breathe, since air does not penetrate beyond the first few inches of surface. In theory, the wood should be allowed to dry before it is chipped. In practice, this rarely happens. The highest quality chips come from lumber mills. They grind the slabwood edges into chips, which are usually clean and low in undesirable components such as roots, spruce needles, and dirt, which cause slag in combustion chambers. The most economical chips come from wood that is cleared for fire remediation. These trees are often fed through a chipper with all needles and root balls attached, which leads to a low quality of chip. On the other hand, this is essentially a "free" fuel source, since the wood was going to be cut anyway. The 45% moisture content reported in Table 4 reflects more typical actual usage, although it's not ideal. If chips get wet (rained-on), they can recover (dry out) with time.

Pellets: As a processed, value-added product, pellets are expected to arrive from the manufacturer at a guaranteed moisture content. They should also be guaranteed with regard to other factors, such as percentage contaminants. One disadvantage of pellets is that, if they do become wet, they will disintegrate and become unusable. Pellets also require a lot of energy to manufacture, because they use high temperatures and pressures. In areas where energy is expensive, which tend to be areas where alternative energy is in demand, they can be uneconomical. In Table 4, two lines for two different costs of heating oil are present. When heating oil is about $3.75 USD ($4.88 CAD) per gallon, the cost per kWhr is even with the cost of chips. During the past several years in Alaska, that threshold was crossed. The cost of heating oil dropped from a high of over $4.50 USD ($5.85 CAD) per gallon to about $2.80 USD ($3.64 CAD) per gallon. During that time, the only pellet mill in Interior Alaska, Superior Pellet, dropped to under half its prior production rate, and had to lay off employees.

Both chips and pellets when stored indoors carry the risk of outgassing carbon monoxide. It is recommended that both chips and pellets are stored in well-ventilated enclosures [33][34].

Biomass Resource Management

Unlike other renewable energy sources such as solar and wind, biomass does not renew itself indefinitely. It either takes active management, or long time period to regenerate itself. It also may not necessarily regenerate at the same density, or at all. Healthy forests are also necessary for overall ecosystem health, preventing erosion, maintaining healthy habitat for wildlife, absorbing pollutants, and moderating climate. For these reasons, it requires careful examination to ensure that the resource is not unrecoverably depleted.

Forest harvesting in Saskatchewan requires a license. Reserve lands are under the jurisdiction of the federal government, and provincial legislation regarding forestry is not applicable.

A map of license areas is available from the Saskatchewan Government [35]. The license holder must submit an annual operating plan in order to harvest forest products, and license holders are required to reforest land that they have harvested. License holders who have harvested forest products must pay dues (stumpage) to the government and forest management fees to a Trust Fund (for payment of renewal and other related costs). [36]

Mee-Toos Forest Products Ltd is the PBCN-owned company that manages its forest products on some 15,000 square kilometers of its traditional lands. It holds a long-term license (Forest Management License Agreement). Mee-Toos' renewal costs are managed under the Mee-Toos Management Trust Fund Agreement, and their forestry rights are maintained under a Term Supply License [37].

Forest in the Mee-Toos license area is dominated by black spruce, jack pine, and trembling aspen, along with some white birch and white spruce. For heating purposes, white birch is best at 21.7 million BTUs per cord [38], but jack pine (17.1 million BTUs per cord [38]) is most plentiful. Regeneration of trees is similar to that of Alaska: white and black spruce take about 90 years to mature, while pine, birch and aspen take about 75 years. [36]

From a provincial perspective, Saskatchewan currently has 34 million hectares of publicly owned forests [39]. Also, it has centralized and public guidelines for active management, such as replanting after harvest, and cutting trees for fire remediation [40]. This requires more person-power than is available in Alaska.

Figure 11 shows the Saskatchewan forest zones.

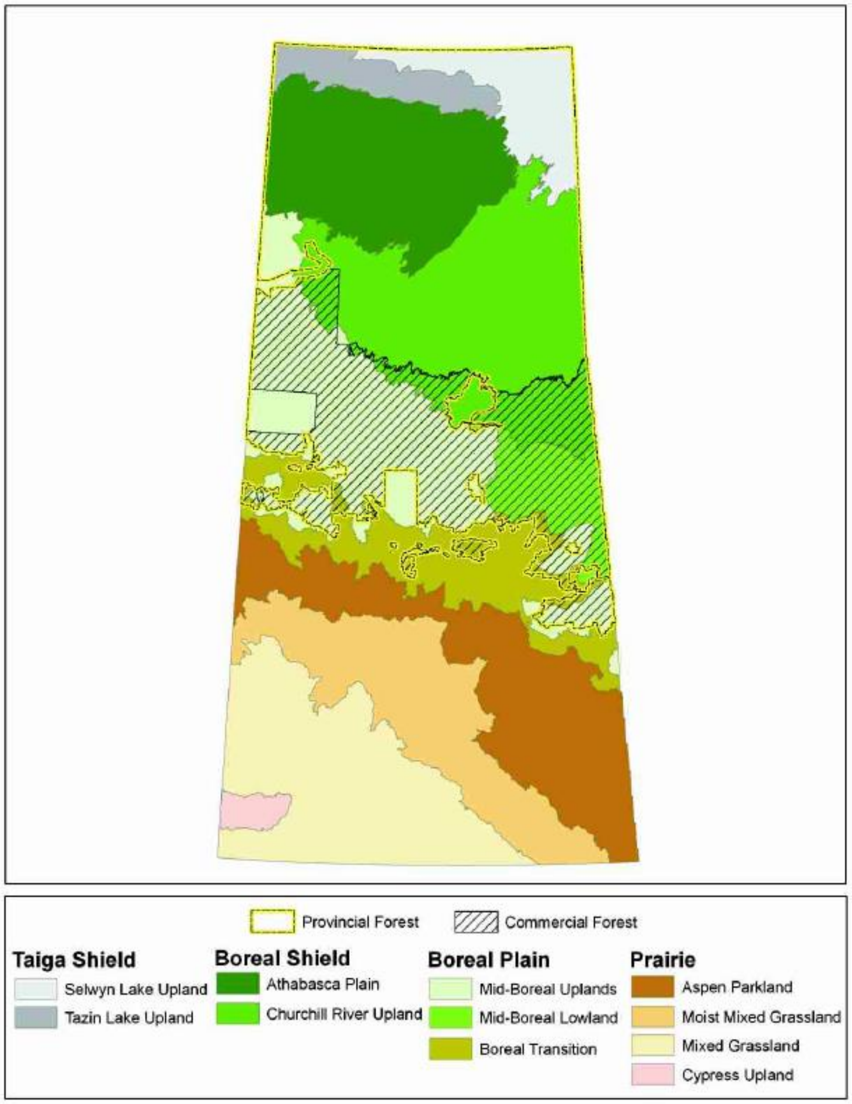


Figure 11. Saskatchewan Forests and the Commercial Forest Zone, and the Ecoregions [40]

The availability is also much higher. From the “2012 Report of Saskatchewan Forests”:

> *… the area of forest harvested each year is much less than that disturbed by wildfires and forest insects. Forest managers are working to make human disturbances associated with logging more closely resemble natural disturbances and at harvest levels that would ensure sustainable forest management is achieved. The third indicator, the proportion of sustainable harvest level utilized, tracks this important measure of sustainability over time. The fourth indicator, forest regeneration, relates to long-term forest productivity as the proportion of timber harvested area successfully regenerated, or in other words, the trees are restored in harvested areas to an accepted and measurable standard. Forests that are regenerated successfully are essential to a long-term sustainable flow of wood products and the maintenance of ecosystem diversity and productivity. [39]*

Additionally,

> *The HVS [Harvest Volume Schedule] for Saskatchewan’s forests has been relatively constant between seven and eight million cubic meters of timber per year. Each licensed forest area (forest management agreement areas and area-based term supply licence areas) have an HVS calculated for them. While the forest could sustain this harvest level, in the northern portion of the commercial forest zone the lower quality of wood, higher harvest and transportation costs, and limited infrastructure will affect how much of the available volume is realized. [39]*

At this scale of observation, it appears that there is sufficient biomass resource to make it a viable energy product in the PBCN communities. It is recommended that the PBCN communities consult with a local forester regarding a renewable harvest rate, and suggested replanting rate, if any, of their forests. Alberta’s Reforestation Standard was most recently revised in 2010, and provides metrics for renewal success [41].

Societal Benefits of Biomass

In Alaska, biomass harvesting, processing, and using has led to other societal benefits. Three case studies are presented here.

1) On Prince of Wales Island (total dispersed population 5600), biomass energy was kicked off in 2012 in the communities of Thorne Bay and Coffman Cove. Excess heat from biomass boilers heating schools and community buildings is now being sent to greenhouses, which both extend the growing season and protect vegetables from the widespread deer population. In 2013, the first greenhouse was built in Thorne Bay (population 500); during its first growing season, it was only half utilized, and produced over 1,200 heads of lettuce. In Coffman Cove (population 200), an experimental greenhouse orchard was planted in 2014, testing apples, cherries, plums, and domesticated blueberries. The school is also raising chickens, utilizing the droppings for fertilizer and education the children in the full-circle farm ethos.

No schools in the Southeast Island School District (SISD) of Prince of Wales have a kitchen. Historically, school lunches consisted entirely of heated frozen meals that had very low nutritional value. The addition of fresh salads to the students’ daily fare is building lifetime habits of healthy eating. An educational curriculum, which the students have named "The Seed of Knowledge," has also been developed around horticulture, incorporating biology, math, and business. Help was sought for the horticultural component from the University of Alaska Fairbanks.

In addition, SISD has purchased a vacant restaurant (the only one in Thorne Bay), and is having the students manage and staff it, earning money and learning business management skills. The menu is based around student-grown produce from the greenhouses, student-produced eggs from four schools, and a student-run bakery. Excess vegetables are sold to a local organic produce market, whose owner reports that most of the bags of spring mix brought from the school sells out within a single day.

2) In the village of Tanana (population 250), starting in 2007, the City converted several community buildings (including the washeteria, the school, and the fire station) from heating oil to biomass cordwood heat, and extended an open call to local residents that the City would purchase firewood at a fixed price per cord. In response, a micro-economy developed around harvesting and selling firewood to the City. Money spent by the City of Tanana was retained in the community rather than being sent to heating fuel companies. Local youths interviewed mentioned saving money for college. Each wood-fired boiler displaces annually about 5000-6000 gallons of diesel. The money saved by the City has enabled building a new children’s playground, and improvement and weatherization of the school and teacher housing. Lining the school's walls with foam board resulted in saving 7000 gallons of oil in the first year.

3) In Tok (population 1300), a biomass boiler was installed in the school in 2010. It now saves $350,000 USD ($455,000 CAD) annually in avoided fuel oil costs, and has enabled recovery of the school music program and installation of a greenhouse, which has provided fresh vegetables for the school, and has become incorporated into the educational curriculum with biology and agricultural components.

Biomass for Heat Alone

Use of biomass for heat alone is compelling in Northern latitudes because the heat loads are tremendous. In Alaska, space heating is 80% of the stationary power generation. [31]

In private homes, woody biomass usage tends to fuel direct radiant heat, burning wood in the space to be heated. Cordwood wood stoves are common not just because of the fuel cost savings, but also because of the pleasantness of the “feel” of radiant heat in private homes. Pellets are easier to handle, and pellet stoves can be set to a thermostat setting, with pellets being automatically fed into the stove when the temperature drops. This adds a convenience that makes it a direct substitute for more conventional heating methods. Cordwood stoves, have, however, the advantage of requiring no power, which provides the security in the event of power outage, which is a nontrivial matter in regions where loss of heat can be lethal. A typical usage of a private home would be 4-10 cords of wood per year.

Biomass is rapidly coming into wider use in larger community buildings, such as schools, tribal halls, and community centers, throughout rural Alaska. For larger buildings such as those, a simple radiant heat system is insufficient. For these, the most common types of wood-fired heaters are hydronic boilers. It is more efficient (both in terms of energy and manpower) to use the biomass to heat a fluid, and then circulate the fluid throughout the space to be heated. Instead of controlling the heat output by controlling the air intake and/or venting, as one does with a home-scale wood stove, the heat output is modulated by controlling the fluid circulation rate. By decoupling the combustion process from the heat output, the burn rate and oxygen intake may be optimized for clean, efficient burning. Typically, the boiler heats water directly, and the heat is then transferred to a water/glycol mix, for circulation throughout the building. The water and glycol loops also serve as thermal storage.

In Alaska, hydronic heating systems in community buildings burn cordwood, chips, and pellets. They range from a 100,000s of BTU/hr to 5.5 million BTU/hr. Cordwood lends itself to smaller systems; it involves more labor, and smaller communities not on the road system don’t have access to chippers or chips. In these small communities, managing of cordwood leads to job creation. In the coldest part of the year, the cordwood-fired boiler that heats the Village Council building in Gulkana (population 120) needs to be stoked and reloaded with wood four times per day. In Tanana (population 300), most of the city buildings (washeteria, school, fire station, etc.) are heated with cordwood-fired boilers, and the City will purchase firewood at a set rate ($250 USD/$325 CAD per cord when the program started in 2007, $300 USD/$390 CAD per cord today). The City also offers chainsaws on a loan-to-purchase program, which encourages young locals to earn money. Casual conversation with village youths makes the program sound very inspirational and productive: many of them spoke of saving money for education.

In most of the cases of Alaskan village community buildings, the oil-fired heater was left in place and plumbed into the same hydronic loop as a backup heating source.

The price range on biomass boilers is wide. A 5.5-million-BTU chip-fired system on the road system, which heats a 77,000 square-foot school, cost $2.8 million USD ($3.64 M CAD) to purchase and install. It consumes about 500 tons of chips per year at $60 USD ($78 CAD) per ton. In Tanana, which is off the road system (air or river access only), the washeteria heating system utilized two 425,000 BTU/hr cordwood-fired systems. The cost, which included a new boiler building, was under $100,000 USD ($130,000 CAD). It burns through 50 cords of wood annually, at $300 USD ($390 CAD)per cord.

The life expectancy of a biomass-fired hydronic boiler is about 20 years with proper maintenance. In rural areas, proper maintenance is often overlooked.

Biomass Combined Heat and Power (CHP)

In Alaska, CHP using biomass is only in use in one location—at the Tok High School. It is a system that was custom-built from salvaged parts, and as such it is not suitable for cost or efficiency comparison. Nevertheless, it does serve as proof of concept. It uses a 5.5-million BTU chip-fired boiler, which was originally purchased to heat the 88,000 square foot school. Tok clears local land for fire remediation, and has access to its own chipper, so to them, fuel costs are negligible. Therefore, they added a steam turbine that currently produces 60 kW, matching the average load of the school and covering 75% of electricity needs. It's an "after-market" alteration of a boiler that was not intended to produce steam, and as such it requires a full-time maintenance person who is fully dedicated to his job. In addition, when it is creating electricity, it provides far more heat than the school needs—they often open windows and doors, even in deep wintertime. Uses are being sought for the heat. A greenhouse was built to provide vegetables to school lunches. A district heating system to neighboring city buildings is under assessment.

Biomass- fired combined heat and power is in common use on larger scales, especially in Northern Europe, where heat is an important resource. A list of biomass-fired power plants in the United States is available from *Biomass Magazine* [42]. However, it's on a larger scale than rural Alaska or the size of SaskPower communities. Biomass-fired CHP on scales on the order of 100s of kWs is a rapidly developing area of active research, which vendors are promoting for use in individual communities or businesses, such as farms. Several options that are market-ready, but have NOT been tested in Alaska, are outlined in Table 5.

Table 5. Several Small-Scale CHP Biomass Options

Technology	Market Ready?	Some Vendors	Typical Size	Typical Price Per Unit, USD (CAD)	Relevant Manufacturer-Suggested Fuels
Gasification	Yes	GEK, Volter, Spanner, Ökofen	40-100 kW electrical, with ~100 kW heat (Ökofen claims they can go down to 1 kW)	$200,000 USD ($260,000 CAD) for 40 kW electrical	Clean chips, pellets
MicroTurbine	Yes	Practical Steam	50 kW	$300,000 - $400,000 USD ($390,000 - $520,000 CAD)	Clean chips, pellets
Stirling Engine	So they claim	Pelletmatic e-max	50 kW	$30,000 USD ($39,000 CAD)	Pellets
Reciprocating Engine	No	n/a	n/a	n/a	n/a
Organic Rankine Cycle	In theory	Electratherm, Pratt and Whitney	10s-100s of kW	$1 M USD ($1.3 M CAD) for a 280 kW, $200,000 USD ($260,000 CAD) for a 50 kW	Flexible

Organic Rankine Cycles have been tested in Alaska, but only for excess heat. The economics do not look promising for burning fuel solely for the ORC.

Several signs look very promising for small-scale CHP as an option for PBCN:

First, there is an adequate biomass resource.

Second, heat is in demand. The economics do not look promising for small-scale CHP if only the electricity, but not the heat, is used.

Third, job creation is a priority, and harvesting and processing of biomass, and running the CHP plant, will create jobs.

Fourth, biomass can create a steady, predictable power supply, unlike wind and solar, which are intermittent and unpredictable. This makes biomass CHP a good candidate for Kinoosao. Biomass can be depended upon, and the fuel supply can be predicted.

4.0 Summary of Technical Findings and Recommendations

Findings and recommendations are summarized in Table 6.

Table 6. Summary of Findings and Recommendations for PBCN Communities

Technology	Approximate Cost per kW installed, USD	Approximate Cost per kW installed, Canadian dollars at 1USD=1.3CAD	Pros	Cons	Recommendation
Solar PV	$3800-10,000	$5000-13,000	Robust, no moving parts, mature technology	Intermittent Supply	Yes
Solar Thermal	$4000-5000	$5200-6500	Heat is high value in Northern Climates	Fragile, require infrastructure and planning	Yes, for people who are willing to have the infrastructure put in
Wind	unknown	unknown	Diversification of energy portfolio	Expensive, intermittent	Not at present, but resource assessment could be interesting/ useful.
Air Source Heat Pumps	n/a	n/a	Robust, low maintenance	Not economical in deep cold	No
Ground Source Heat Pumps	$2000-12,000	$2600-15,600	Robust, low maintenance	COP lower in cold regions; ground may not sufficiently recharge each summer	Yes, with reservations; remain in contact with Cold Climate Housing Research Center as their data accumulates
Water Source Heat Pumps	$2000-12,000	$2600-15,600	Robust, low maintenance	COP lower in cold regions	Yes
Biomass heat	$1000-3000	$1300-3900	High availability, can base load	Must manage harvest and regrowth rate	Yes
Biomass combined heat and power (CHP)	unknown	unknown	High availability, can base load	Must manage harvest and regrowth rate	Yes, with caution; PBCN would be the “first deployer” of a new technology

Solar PV is recommended for any PBCN community that wants it. The suggestion is raised panels (so snow has room to shed) at a fixed tilt, or with manual tilt adjustment twice per year. Brushing snow off the panels should be done if it can be done so with minimal time and cost.

Solar thermal is recommended for any PBCN community that is willing to do the legwork on designing the plumbing and piping and integration that is required.

Wind is not recommended without further resource assessment.

Air-source heat pumps are not recommended.

Ground-source and lake-source heat pumps are recommended, but they require some skill to install. Heat pump organizations such as the International Ground Source Heat Pump Association (IGSHPA) offer training to installers and designers, and some heat pump manufacturers themselves offer formal training. They usually also offer support from their engineers and designers when their systems are being installed. Having IGSHPA training is becoming an industry standard [24]. The IGSHPA provides a three-day training workshop, but it is offered in limited locations.

Biomass is recommended without reservation for heat alone, with some reservation for combined heat and power due to its lack of testing history on small scales in North America. The Alaska Center for Energy and Power would like to test one small-scale CHP system in its Laboratory. If we do, we will share results. Daisy Huang of ACEP also has a grant proposal out to probe further feasibility of small-scale CHP in Alaska. If she is funded, she will share results. If biomass CHP looks to be viable, it’s an excellent candidate for Kinoosao, since it can support base load reliably.

5.0 Case Studies of Two Alaskan Utility Companies

This section outlines the history, formation, and current business model of two different Alaskan utilities. They are presented as case studies for rural local distribution utilities.

5.1 Alaska Village Electric Cooperative (AVEC)

AVEC is a member-owned non-profit electric cooperative that serves 22,000 Alaskans in 53 villages [43], spanning the largest geographic region of any retail electric cooperative in the world [44]. The AVEC communities are predominantly inhabited by Alaska Natives, and they are very diverse both geographically and culturally, covering both Interior and Coastal regions. Athabascan, Yup'ik, and Iñupiaq people are among the cultures encompassed. Each community is electrically islanded and predominantly powered by diesel. The AVEC service area is geographically the largest of any retail electric cooperative in the world.

Figure 12. Map of AVEC Communities

In AVEC communities, the local governments are responsible for hiring plant operators and are in charge of the day-to-day operation of the community power plant and distribution system. However, AVEC employs traveling linemen and technicians to service its member communities because there is not enough work in any single community to keep trained technicians employed full time. AVEC uses remote meters in its communities. This allows the cooperative to remotely read meters and to remotely connect and disconnect power.

Each member is required to pay a monthly $5 customer charge [45]. The rates charged to customers are made up of non-fuel costs such as plant operations and administrative cost and fuel costs which represent each community's actual fuel cost per kWh. AVEC currently charges a flat postage stamp rate of $0.30/kWh for non-fuel costs across all member communities. However the fuel cost charge does vary by community since it represents the actual cost of the fuel which varies by delivery method. For example, a coastal community that receives its fuel shipments by ocean-going barge will have lower delivery costs than a community that receives its fuel shipments by air because it is cheaper to deliver fuel by barge than by airplane. AVEC communities qualify for the Power Cost Equalization (PCE) program which, based on a formula, gives each residential accountholder a per kWh subsidy for the first 500 kWh consumed per month. This helps reduce the cost of electricity in rural communities, many of which have per kWh rates three to five times higher than rates in urban areas of the state.

AVEC purchases fuel, nearly 6 million gallons annually, for all member communities in bulk resulting in cost savings. The majority of AVEC communities receive their fuel shipments by barge. To reduce costs associated with fuel transportation, a subsidiary of AVEC built two shallow draft tugs and barges to deliver both fuel and freight to member villages. The vessels are chartered and operated under contract by Vitus Marine [43]. Most communities receive only several fuel shipments per year because they are not accessible by roads. Delivered fuel is stored in bulk fuel tanks at tank farms and is accessed as needed. AVEC covers more physical distance than any other retail electric cooperative in the world. The cooperative is unusual in that most of its member communities have islanded micro-grids. The communities are not physically connected to one another by an intertie and cannot purchase electricity from each other. This increases the need for back-up generation in each community. [46]

AVEC is a non-profit cooperative. Profits the cooperative earns, referred to as margins, are distributed to its member-owners in the form of capital credit refunds[47]. Capital credits are margins the cooperative earns in years when revenue exceeds costs. These margins are allocated to members in proportion to the amount of electricity purchased in the year the margin was earned. Capital credits are used as equity to reduce the cooperative's need to borrow in order to fund new projects or maintenance. After a period of 25 years, if approved by the Board of Directors after reviewing the financial health of the cooperative, capital credits are retired and refunded to members. Most recently, AVEC's board refunded one-fifteenth of their total accumulated margins, $1.65 million, to people who were AVEC members in 1991 [47]. In addition to capital credits, AVEC periodically receives funding in the form a grants from the Denali Commission, the United States Department of Agriculture, Alaska Energy Authority, and the Renewable Energy Grant Fund.

AVEC continues to grow and periodically acquires existing utilities. Most recently, AVEC purchased the Bethel Utilities Corporation (BUC) for $5 million. In October of 2013, the Regulatory Commission of Alaska approved the transfer of BUC's operating certificate to AVEC. AVEC took over operations in May of 2014 after BUC's assets were transferred. The acquisition of BUC by AVEC was mutually beneficial. Bethel residents benefited from lower electric rates resulting from AVEC's tax-free status. Existing AVEC customers also benefited because the acquisition added a town with a population of 6,200 residents and many new accounts over which to spread AVEC's fixed costs [48].

AVEC began nearly 50 years ago with just three communities. The cooperative has grown considerably, now operating more than 170 diesel generators in 49 powerhouses across 56 communities. The cooperative also has a fleet of 34 wind turbines across 15 member communities [49]. Through AVEC, access to reliable electricity has improved the quality of life throughout rural communities in Alaska.

5.2 TDX Power

TDX Power, Inc., established in 1998, is a subsidiary of Tanadgusix Corporation, the Alaska Native village corporation for St. Paul Island created under the Alaska Native Claims Settlement Act of 1971 [50]. TDX Power is an investor-owned, for-profit business headquartered in Anchorage, Alaska. One third of TDX Power's profits get passed up to Tanadgusix Corporation, which then divides the profits among operations, reinvestment, and dividends paid to shareholders. The Tanadgusix Corporation has a multilayered ownership and organization structure. TDX Power is set up under Tanadgusix Corporation's holding company, TDX Holding LLC.

The company's first project was a hybrid wind-diesel power plant installed on St. Paul Island. Initially a single 225-kW Vestas V27 wind turbine was integrated with the diesel generator. The hybrid plant provided electricity and heat for an industrial facility, reducing the facility's fuel consumption by 45%. Two additional Vestas V27 wind turbines were later installed, and the project was connected to the St. Paul municipal utility grid to provide electricity to the community [51].

In addition to TDX Wind Power in St. Paul, TDX Power owns, operates, and maintains four electric utilities which are regulated by the Regulatory Commission of Alaska. Each of these utilities is a subsidiary of TDX Power. TDX Power has expanded its operations by purchasing existing utilities throughout Alaska, including TDX Adak Generating in Adak (purchased from the City of Adak), TDX Manley Generating in Manley (purchased from United Utilities), TDX North Slope Generating in Deadhorse (purchased from Arctic Utilities Inc.), and Aleutian Wind Energy in Sand Point. The subsidiary utilities are managed by TDX Power [51].

Sand Point Generating, a utility operator and energy services contractor, and TDX Power Services, an electrical contracting company, are subsidiaries of TDX Holdings, set up separately from TDX Power but managed by TDX Power operations staff. Sand Point Generating is an Alaska Native Corporation certified Small Business, under 8(a) status, which makes it eligible for federal contracting opportunities. The United States Small Business Administration (SBA) specifically established the 8(a) certification program to help small, disadvantaged businesses compete in the federal marketplace [52]. TDX Power Service's 8(a) application is pending SBA approval.

TDX Power's is governed by a five-member board of directors, which meets four times per year. Board members are elected following the TDX Corporate annual meeting and serve for a term of one year. Three of the five serving board members must be shareholders in the Tanadgusix Corporation. The TDX Power board of directors controls the subsidiary utilities. Each subsidiary utility plant has a site manager to operate the plant. However, TDX Power dispatches traveling power linemen, mechanics, and technicians to plants for repairs and bills the subsidiary utilities for the services. Each utility has its own tariff and rate structure. TDX Power helps the individual utilities determine their rates and the company represents the subsidiary utilities before the Regulatory Commission of Alaska, which regulates public utilities in the state [51].

In addition to managing its subsidiary utilities, TDX Power provides renewable energy support including reconnaissance, feasibility studies, conceptual design, installation, and system integration. The company has provided renewable energy support for projects in Sandpoint, Nikolski, Tatitlek, Adak, and St. Paul Island. TDX Power also holds government contracts covering tasks such as design, construction, and operation. Customers include Raytheon Technical Service Company, U.S. Army Corps of Engineers, U.S. Air Force, CH2M Hill, Department of Homeland Security, U.S. Coast Guard, and the Boeing Company. TDX Power has expressed interest in expanding its federal contracting endeavors [51].

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Appendix A

Assumptions Made for Solar Resource Assessments

Table 7. Assumptions Made for Solar Resource Assessments Using PVWatts

Item	Assumption Made
Azimuthal Angle	180 degrees (due South)
Soiling Losses	2%
Shading Losses	3%
Snow Losses	0%
Mismatch (electrical losses due to manufacturing inconsistencies) Losses	2%
Wiring Resistive Losses	2%
Losses in Electrical Connections	0.5%
Losses due to Light-Induced Degradation of PV cells	1.5%
Nameplate Rating Mismatch Losses	1%
Age Losses	0%
Downtime Losses (scheduled and unscheduled maintenance, grid outages, etc.)	3%