Fort Providence
Solar and Wind Monitoring Analysis

Prepared for

AURORA RESEARCH INSTITUTE
AURORA COLLEGE

By

Jean-Paul Pinard, P. Eng., PhD.
703 Wheeler St., Whitehorse, Yukon Y1A 2P6
Tel. (867) 393-2977; Email jpp@northwestel.net,

John F. Maissan, P. Eng., Leading Edge Projects Inc.
219 Falcon Drive, Whitehorse, Yukon Y1A 0A2
Tel. (867) 668-3535; Fax (867) 668-3533; Email john@leprojects.com
And
Annika Trimble (Ed.), Aurora Research Institute
191 Mackenzie Road, Inuvik, NT X0E 0T0
Phone: (867) 777-3298, Fax: (867) 777-4264; Email atrimble@auroracollege.nt.ca

March 31, 2014

Executive Summary

This study provides an update on the solar and wind monitoring activity in the community of Fort Providence. A solar and wind monitoring station was set up on the roof of the office building in the GNWT Transportation yard in the Fort Providence and collected about 31 months of solar and wind data.

Solar radiation sensors established in Fort Providence measured an average daily solar radiation of 2.95 $kWh/m^2/day$ which is same value estimated by NASA. This is considered to be good for solar electricity production.

The wind speeds that were measured from the same station indicated an average of 2.0 m/s for the same 31-month period. This is slightly higher than the two-year (2009-2010) average wind speed of 1.88 m/s measured at a height of 10 m above ground level at the Fort Providence airport. This is considered to be very poor for wind energy potential in the community and the wind energy economics was thus not examined in this study.

A brief analysis of the economics of solar photovoltaic (PV) power generation for Fort Providence is provided in this report. For a residential net metering system of about 5 kW, the installed cost is estimated to be about $5,500 per kW (for a flush roof mounted system). In a larger utility scale project of 50 kW the installed cost is estimated to be about $6,500 per kW.

The 25-year levelized cost of energy (LCOE) from grid connected photovoltaic systems is expected to range from $0.512 per kWh (residential) to $0.582 per kWh (utility), which is more expensive than the 25-year LCOE of diesel generation at $0.356 per kWh. If 2% financing was available for residential PV systems the LCOE would be $0.316 per kWh, below the LCOE of continued diesel generation.

If Fort Providence is considering alternative energy developments, the use of solar energy generation would be a far more attractive option than wind energy. PV systems can be scaled to a community's needs and the equipment is far easier to transport, install, and operate than wind systems. Should Fort Providence wish to pursue a PV project, subsidies would be required to make projects cost-effective (on a commercial basis) compared to continued diesel generation.

Introduction

The community of Fort Providence has about 790 people and is located on the north shore of the Mackenzie River near the mouth of Great Slave Lake. Fort Providence is located about 210 km southwest of Yellowknife (see Figure 1) and is accessible by air, by the all season Yellowknife highway.

On August 31, 2011 a solar and wind monitoring station was installed on the roof of the office building in the GNWT Transportation yard on the east side of the hamlet. The monitoring station consisted of a 2-metre tall tripod attached onto the peak of the roof, which is 5 m above ground level (AGL). Total sensor height was therefore 7 m AGL. The last data set was collected in April, 2014, providing about 31 months of data for analysis.

The average power use in the community is 372 kilowatts (kW) based on the annual generation requirement estimated at 3,261 MWh (Northland Utilities Limited NWT forecast for 2015 in 2014-15 general rate application). The marginal cost of producing electricity from diesel (fuel and variable maintenance only) was estimated to be $0.2929 per kWh. This is based on a forecasted fuel price of $0.965 per litre, a heat rate of 3.67 kWh per litre and a variable O&M cost (by the authors) of $0.03 per kWh.

The Arctic Energy Alliance had produced a summary of the wind and solar potential for the community. In their online report (resource section at www.aea.nt.ca) it is stated that the average wind speed was considered low at 2.76 m/s (height was not noted); however the average solar insolation (radiation) was 2.95 kWh/m^2/day, which is considered to provide high solar energy potential for the community.

The purpose of this study is to provide an analysis on the solar and wind monitoring that was carried out in the community of Fort Providence and also to provide a brief assessment of the economics of solar energy in Fort Providence. Detailed economic analyses were not carried out for wind energy as the wind resource is too low to be practical for power generation.

The economic analyses look at the costs of building and operating two configurations of solar PV projects in the hamlet, a 5 kW residential net metering installation and a 50 kW utility scale grid connected project. Greenhouse gas emission reductions from these projects are estimated. An outline of next steps is given regarding the pursuit of solar energy integration in the hamlet.

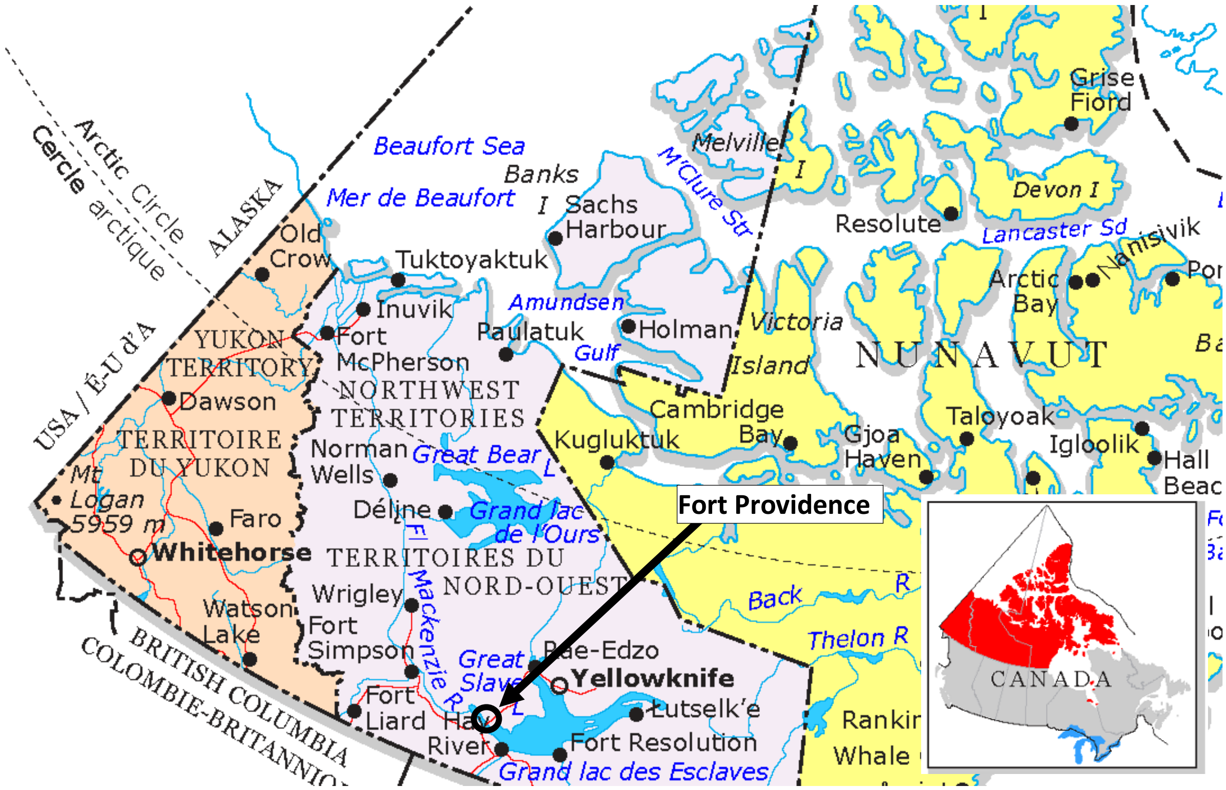

Figure 1: Fort Providence is located in the southwest NWT, about 210 km southwest of Yellowknife.

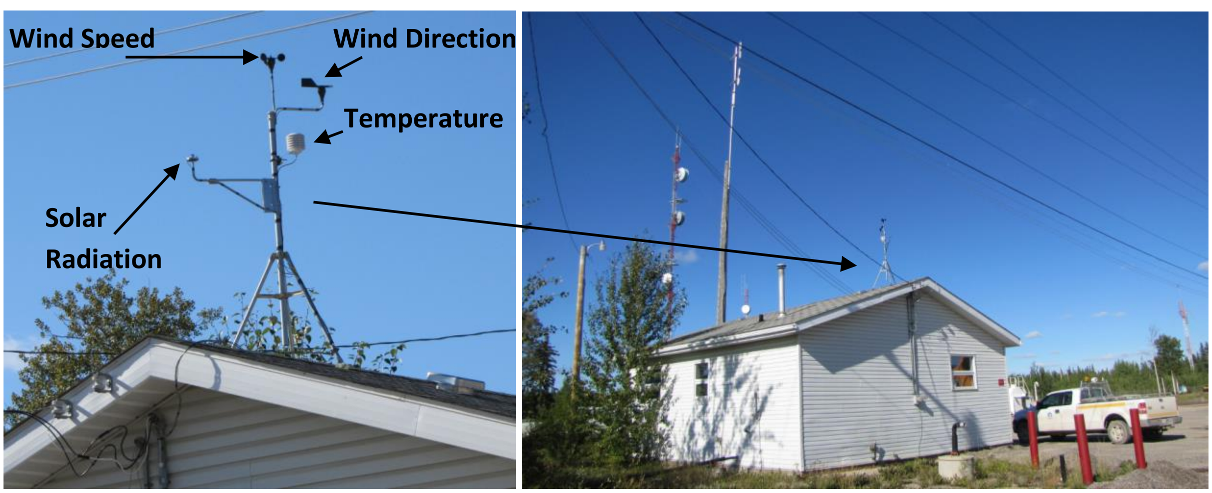

Figure 2: Photos of the monitoring station set on the roof of the office building in the GNWT Transportation yard east of Fort Providence. The boom of the solar radiation sensor is pointing south.

Wind Climate Assessment

The wind data used for the wind analysis was measured at the GNWT transportation yard. The measurement sensors were on a tripod set up on top of the office building at a total height of 7 m AGL. Measurements were averaged to 10-minute intervals and included wind speed, wind direction, temperature and solar insolation.

Wind Speed

The monitoring station on the office building measured a mean wind speed of 2.03 m/s (at 7 m AGL) from September, 2011 to April, 2014. This is slightly higher than the annual average (2009-2010) wind speed of 1.88 m/s at 10 m AGL measured at the Fort Providence airport. Monthly mean wind speeds are shown in Figure 3 below.

Using vertical projection methods as described in other NWT wind energy studies (like the Jean Marie River study by Pinard and Maissan, 2012), a wind speed of 2 m/s at 10 m above ground translates into a mean wind speed of about 3 m/s at 40 m AGL (the height of a typical wind turbine). This is considered inadequate for wind energy production. Therefore, the remainder of this study will focus on options for solar energy.

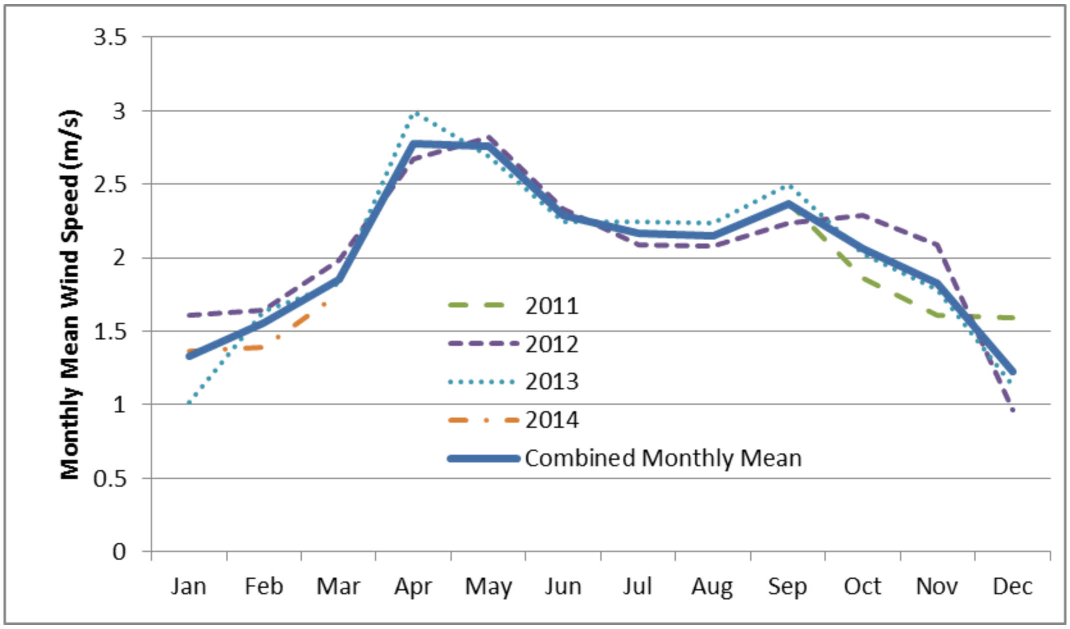

Figure 3 - Monthly mean wind speed in Fort Providence at 7 m above ground on the roof of the GNWT transportation yard office building.

Solar Climate Assessment

The solar data used here was from the solar radiation sensor on the rooftop of the GNWT Transportation yard's office building as shown in Figure 2. The measurements from the solar sensor are compared to the solar radiation estimates made from NASA's Surface Meteorology and Solar Energy (SSE) website (eosweb.larc.nasa.gov/sse/). The database at SSE is a combination of meteorological observations and numerical modeling that provides an estimate of such things as solar radiation for locations that are lacking in measurements, as is the case at Fort Providence.

Solar Insolation at Fort Providence

Solar radiation data was extracted from the SSE website for the Fort Providence area and compared with actual measurements that were made in the community. Figure 4 shows the monthly average of daily solar radiation measured by the solar sensor. Typically solar radiation is measured with the sensor pointing straight up on a flat horizontal (leveled) plane. The measurement is made in watts per square metres (m^2), but converted to the form of energy (kWh) per unit area (m^2) per day. In contrast, solar photovoltaic panels are typically not set up on a horizontal plane but rather at an angle facing south towards the sun.

In Figure 4 shows that the average solar radiation measured in Fort Providence is similar to the estimates by SSE for the same community. The most visible difference is in the summer months when the measurements show a flatter average monthly solar radiation over the three-month period of May to July. The measured average annual solar radiation was 2.95 compared to the NASA estimates of 2.95 kWh/m2/day. These measurement will be discussed in terms of energy production in a later section.

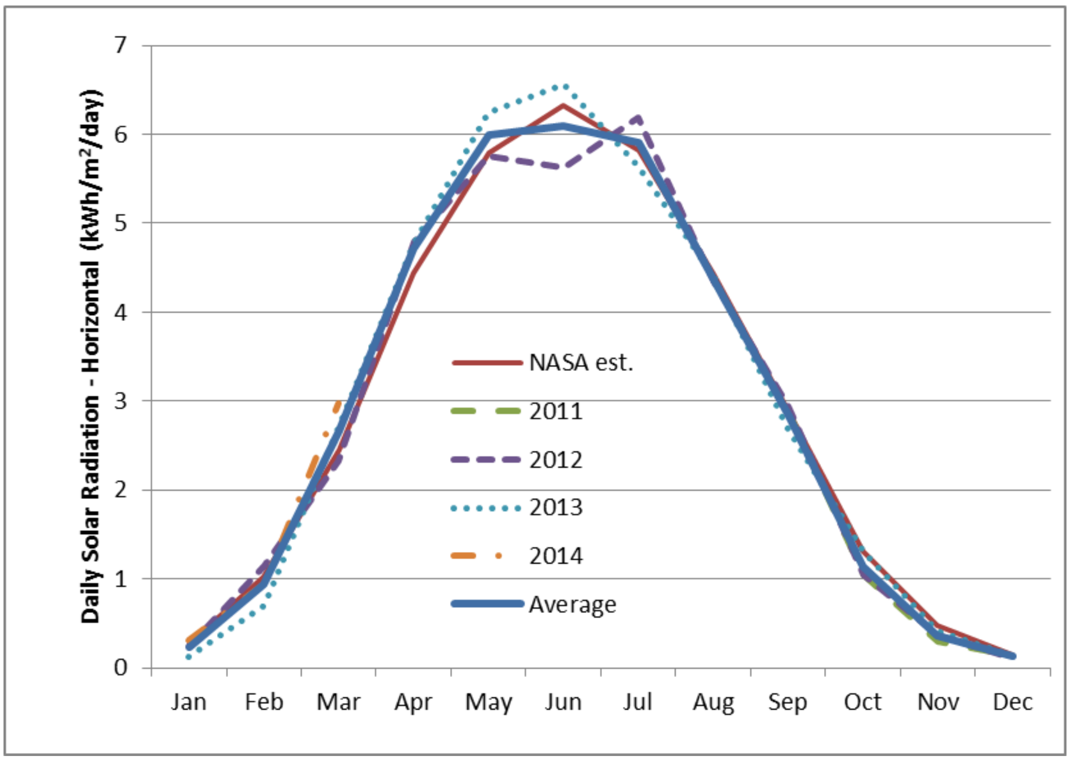

Figure 4: Monthly average insolation, or solar radiation, on a horizontal surface measured at Fort Providence over each of several years, and the "Average" of the four years combined compared to modelled estimates from NASA's SSE website ("NASA est.").

Site Selection for Solar Systems

Within the community of Fort Providence, the insolation values are likely similar anywhere that there is an open area toward the south without obstructions such as trees and buildings to shade the solar installation. Ideally the solar PV installation would be next to the power grid. If a home PV installation is considered, it would be best placed on a south-facing roof or on the ground if there is clear exposure to the sun. For a utility scale fixed tilt array installation, the best location is close to a power line in a large field or on a hillside exposed to the south.

Community Power Requirements and Costs

The community of Fort Providence has its electricity requirements supplied by an Northland Utilities Limited (NUL) NWT diesel power plant. The total diesel plant capacity in Fort Providence is 1600 kW, and is comprised of a 600 kW, 500 kW and two 250 kW diesel-electric generators. The most recent NUL NWT GRA (general rate application) indicates that the fuel efficiency of the diesel plant is 3.67 kWh per litre.

Information available from the most recent GRA indicates that power generation requirement in the community is forecast to be about 3,261 MWh for 2015 (there have been declines in recent years). This represents an average diesel plant load of about 372 kW and a peak load of about 620 kW at load factor of 60%. The authors estimated that the minimum plant load would be about 200 kW. With the diesel plant fuel efficiency provided above, and the expected annual electrical energy produced from diesel, this represents about 888,556 litres of diesel fuel consumed for electricity production in the community each year.

In modelling the integration of solar energy with the diesel plant, the authors assumed that the minimum allowable load on the diesel plant is 30% (typical) of the smallest generator that is used to meet the minimum summer load. For a 250 or a 500 kW generator, this is a minimum of 75 or 150 kW. If the minimum load on the grid is 200 kW then it can accommodate a 50 kW capacity solar PV project (minimum load of 200 kW minus the diesel generator's lower efficiency limit of 150 kW) without any special controls.

The authors were concerned that a solar system larger than 50 kW could result in electrical loads on the diesel plant being too low. Larger renewable energy systems could result in some integration challenges. For example, it might become necessary to cut back on the renewable energy supply or to dump the excess electricity from the renewable energy system to outdoor heaters or to store the excess electricity for later use. The storage can take the form of heat, say, in hot water tanks or in batteries which adds another level of complexity to the system. The storage of renewable energy has a future in diesel communities like Fort Providence; however, it is beyond the scope of this study, which is simply to assess the economics of solar energy production. The sizing of the renewable energy systems in this study is such that little storage or power stabilizing technology is anticipated, thus keeping the renewable energy system integration relatively simple.

Considering this, additional advantages of solar energy over wind energy become evident for Fort Providence. PV arrays can be sized in small increments (of about 200 W) and projects can easily be expanded. Unlike wind energy, solar energy is never available at night when electrical loads are at their lowest, but is available only in the daytime when electrical loads are at their highest. As well, the transport and installation of PV equipment is simple compared to wind turbines. The operation of PV systems is also relatively simple, but the integration of significant PV capacity (say over 50 kW in this case) with the diesel plant may be as challenging as integrating significant wind capacity.

For the purposes of this study it has been assumed that the NUL diesel power plant would save diesel fuel at a rate of 1 litre per 3.67 kWh displaced. This diesel plant would produce variable (or incremental) electrical energy in 2014 at $0.2929 ($0.2629 for fuel and $0.03 variable O&M) and at a 25-year levelized cost of $0.356 per kWh with diesel fuel starting at $0.965 per litre and increasing with general inflation (2% in model). These costs include only fuel and $0.03 per kWh for variable operation and maintenance (O&M) costs. The economic model assumes that the cost of capital is 7.34%, NUL NWT's approximate cost of capital in their 2014-2015 GRA.

Solar PV Project

Project Owners and PV Equipment

Two different solar PV applications were considered in this study, and in each case the ownership was different. The first application is a residential net metering installation of a 5 kW PV array (i.e. grid connected), assumed to be owned by the residential customer. The residential consumer was assumed to be acting individually as opposed to being part of a larger project involving many homes. The second application is a larger grid connected project of 50 kW owned and operated by the utility owning the diesel plant.

Energy Production

The above PV array configurations were analysed for their theoretical performances through the use of the RETScreen Clean Energy Project Analysis Software. RETScreen (Microsoft Excel - based) is a decision support tool developed and supported by the CanmetENERGY research centre of Natural Resources Canada (NRCan). The software is free-of-charge and is used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs). More information on the software can be found at www.retscreen.net.

Using the solar radiation measurements for Fort Providence and RETScreen's modelling capability, the monthly and annual energy production of each configuration were evaluated. RETScreen's solar modelling tool takes into account such factors as ground (snow) reflectance, inverter efficiency, solar cell types and sizes to calculate monthly energy production from these difference array configurations.

The RETScreen energy production calculations are based on an array of generic PV modules with total power capacity of 1 kW (7 m^2 area), with an efficiency of 14.0%, a temperature coefficient of 0.40%, and a nominal operating cell temperature of 45°C. Losses of 10% from inverter inefficiency (90% efficiency assumed) and 15% from miscellaneous sources (including module ageing and snow shading in the winter) were assumed in the model.

The tilt angle chosen for modelling the utility ground mounted fixed array is 50°. This tilt angle was chosen as it maximizes annual solar energy production in the Fort Providence area. For the net metering project modeling the authors chose a flush roof mounted array with a 20° tilt (representing a roof pitch between 4:12 and 5:12) and assumed it to be south facing. Flush mounting on roof surfaces is a common and inexpensive way of installing PV arrays on homes as it minimizes engineering design and permitting conditions.

The results of the RETScreen evaluations for Fort Providence are summarised in Figure 5 as monthly mean solar energy production. Here the NASA estimated and the measured solar radiation are modelled using a PV array at a 50° tilt angle facing south and are then compared to each other. The energy modelling using the measured solar radiation is also applied to the 20° tilt angle (also facing south) for the case of the flush mounted residential roof top installation. The RETScreen results are also compared to the actual production of the 104 kW PV project in Fort Simpson. The PV system in Fort Simpson consists of two arrays that are connected to the town's local diesel grid; it is shown in Figure 6. The larger 60.6 kW array was installed in January 2012 and the second 43.4 kW array in February 2013.

The comparison of monthly solar energy production between the modelled and the actual production at Fort Simpson suggests that losses during the summer are overestimated (i.e. inverter and line losses are not so great) while during the winter they are underestimated (snow cover, shadowing such as one array shadowing the other, lower solar incident angle on panels, and lower electrical efficiency of the inverter at lower power flows). Losses due to snow cover have been estimate at about 12% based on work done by Wohlgemuth (2007).

Modelling of the net annual energy production per kW of array capacity (after losses) at Fort Providence is outlined in Table 1. As Table 1 shows, a 1 kW system on a fixed array facing south and tilted to 50 degrees from horizontal may produce about 1063 kWh per installed kW per year based on the solar resource measurements made at Fort Providence. For a flush mounted rooftop PV array, the annual energy production may be reduced by about 8% to 980 kWh per kW. The total energy production for a 5 kW home based system flat on a roof will translate into 4,900 kWh per year. A utility scale 50 kW fixed array system in Fort Providence will produce 53,150 kWh per year without producing significant excess electricity.

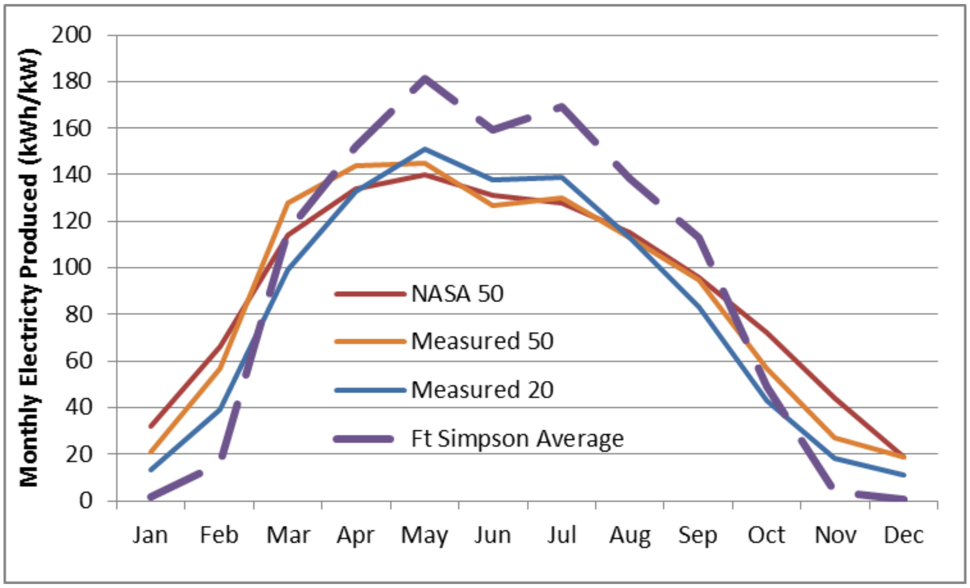

Figure 5: Monthly electricity production modelled using RETScreen, using the NASA estimates and the measurements made in Fort Providence. The optimum angles used for the comparison are a 50° tilt from horizontal ("NASA 50" and "Measured 50"), facing due south. The measured data applied to the 20° tilt angle ("Measured 20") is for the case where a solar system would be flush mounted on the roof of a house that would have a roof pitch of between 4:12 and 5:12. These are compared to actual solar production in nearby Fort Simpson.

Table 1: Modelled net energy production using RETScreen for Fort Providence based on solar radiation estimated by NASA and on locally measured solar radiation. All are compared to actual production in nearby Fort Simpson.

	Tilt Angle (° from horizontal)	Annual production (kWh per kW installed)
NASA estimates	50	1091
Measurements	50	1063
Measurements	20	980
Ft Simpson PV	~40	1099

Figure 6: Solar PV array installed in Fort Simpson which is 130 km northwest of Fort Providence. Photo from the SkyFireEnergy website.

Capital and Operating Costs

Capital costs for the net metering residential applications were based on recent experience for professionally installed systems by supplier-installers in the north. Expected installed costs are about $27,500 or $5,500 per kW of capacity.

Capital costs for a utility scale PV system of 50 kW was based on recent experience in the north for roof or simple ground mounted systems. These are higher than typical costs for larger utility scale installations in the south, which can be derived from various existing cost breakdowns available. These indicated that in southern Canada commercial size projects would probably cost as little as $3,000 per kW at the present time. With increased shipping costs and higher installation costs in the north, $325,000 for a 50 kW system or $6,500 per kW would be considered to be a reasonable estimate for these smaller simple utility scale projects (no tracking systems – where solar panels follow the path of the sun throughout the day). With tracking systems the costs might be $2,000 to $3,000 per kW higher.

Table 2: Capital and operating costs of PV systems

System description	Capital cost ($ per kW)	O&M cost ($ per kW per year)
Net metering home (5 kW grid connected)		
Flush mounted fixed array (20°)	$5,500	$25
Utility (approximately 50 kW)		
Ground mounted fixed array (50°)	$6,500	$25

In all cases operating and maintenance costs were estimated at $25 per kW of capacity per year. A summary of the operating and capital costs appears in Table 2 above.

Cost of PV Energy and Economic Analysis

The levelized cost of energy (LCOE) for PV was examined on the basis of a 25 year project life (some solar products now carry a 25-year warranty) using an economic model that assumed that the cost of capital was 7.34% and that the inflation rate was 2% per year. As well, a modified simple payback was calculated. This consisted of offsetting the O&M cost on the basis of kWh at the applicable marginal rate and then using the savings on the remainder to pay off the capital. The resulting costs and paybacks are shown in Table 3.

For the residential net metering case, four PV energy value cases were considered: (1) the subsidized Yellowknife rate of $0.2996 per kWh (including GST), (2) the thermal zone run-out rate of $0.6137 per kWh (including GST), (3) the former community based rate of $0.48 per kWh (including GST), and (4) the 25-year LCOE of diesel which is $0.356 per kWh. Note that the LCOE of diesel generation is based on fuel starting at $0.965 per litre and increasing at 2% per year with the rate of inflation.

For residential net metering PV systems, the 25 year LCOE was estimated to be $0.512 per kWh. The modified simple payback at the subsidized Yellowknife rate is 20.5 years, at the thermal zone run-out rate is 9.5 years and at the community rate is 12.3 years. At the 25-year LCOE of diesel at $0.356 per kWh the modified simple payback is 17 years. If a residential consumer had access to financing at 2%, the LCOE of PV energy would drop to $0.316, lower than the LCOE of diesel energy.

For a utility scale project, the LCOE of PV energy was calculated to be $0.582 per kWh. The modified simple payback was estimated to be about 27.1 years. NUL could consider the installation of a smaller diesel generator in Fort Providence to allow a higher penetration level of solar PV. A reduction in the cost of capital would reduce the LCOE of solar PV to $0.368 per kWh, approaching the LCOE of diesel.

Table 3: Summary of PV energy cost and payback ranges.

System description	LCOE $/kWh	LCOE diesel $/kWh	Yellowknife rate	Thermal zone run-out rate	Former community rate	Simple payback after maintenance years
Residential net metering						
Fixed array	$0.512	$0.356	$0.2996	$0.6137	$0.48	9.5 to 20.5
Utility						
Fixed array	$0.582	$0.356				27.1

Greenhouse Gas Reductions

Greenhouse gas (GHG) reductions are directly proportional to the diesel energy displaced, about 3 kg of CO_2 equivalent per litre of diesel. The GHG reductions resulting from solar systems connected to the grid are shown in Table 4. Net metering and utility scale projects both displace fuel at utility power plant fuel efficiencies, which in the case of Fort Providence is 3.67 kWh per litre. The residential roof mounted PV system examined would save 801 kg of CO_2 equivalent per kW of installed capacity per year and the utility ground mounted system would save 869 kg of CO_2 equivalent per kW of installed capacity per year. Larger projects in which some of the PV energy is surplus to system needs would result in lower GHG reductions.

Table 4: Annual energy productions, fuel savings and GHG reductions from roof mounted residential and utility ground mounted grid-connected solar projects of 5 and 50 kW respectively in Fort Providence. The roof mounted configurations are flush mounted at 20° tilt (between 4:12 and 5:12 pitch roof) and the utility project is ground mounted with a fixed tilt of 50°.

Project Configuration	Diesel Electricity Displaced (kWh)	Diesel Fuel Saved (litres)	GHG Reductions (kg CO_2 equivalent)
Roof mounted 5 kW	4,900	1,335	4,005
Utility ground mounted 50 kW	53,150	14,482	43,447

PV Project Conclusions

1. PV systems can be utilized in a variety of applications and scaled in size to meet requirements.
2. Residential net metering flush mounted PV systems of about 5kW are likely to cost in the order of $27,000 or $5,500 per kW of installed capacity.
3. Utility scale ground mounted fixed tilt PV projects of about 50 kW would likely cost in the order of $325,000 or $6,500 per kW of installed capacity
4. The 25-year LCOE cost of energy from grid connected PV systems at $0.512 to $0.582 per kWh is more expensive than the LCOE of diesel generation at $0.356 per kWh. The calculations assume a cost of capital of 7.34%, and an inflation rate of 2%.
5. If 2% financing were available to residential consumers, the LCOE of solar PV would drop to $0.316 per kWh, lower than the LCOE of continued diesel generation. For a utility scale system 2% cost of capital would reduce the LCOE to $0.368 per kWh, close to continued diesel generation.
6. On a commercial basis PV generation appears uneconomical but the simple payback, after maintenance costs, for residential consumers is within the lifespan of the project.

Next Steps

1. If Fort Providence is considering alternative energy developments, the use of PV energy generation would be a far more attractive option than wind energy. PV systems can be scaled to a community's needs and the equipment is far easier to transport, install, and operate than wind systems.
2. Should Fort Providence wish to pursue a utility scale PV project, a subsidy would be required to make the project cost-effective compared to continued diesel generation, or the utility would need to partner with community organizations or the local First Nation if they have access to grants to lower the net capital cost of a project.
3. Given the small size of the Fort Providence electrical load, installing residential scale net metering projects may be more practical than having the utility undertake a 50 kW project.

References

Pinard, JP, and John F. Maissan, 2012. **Jean Marie River Wind and Solar Energy Pre-Feasibility Analysis**. For the Aurora Research Institute.

Wohlgemuth, D., 2007. **Solar Photovoltaics in the NWT, Jean Marie River Band Office, System Overview**. Summary paper for the Arctic Energy Alliance.