Whati Wind and Solar Energy Pre-Feasibility Analysis

Prepared for

AURORA RESEARCH INSTITUTE
AURORA COLLEGE

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March 28, 2012

Executive Summary

This study provides a preliminary assessment of wind and solar energy potential in the community of Whati.

The Whati community has about 500 inhabitants and is located at the southeast end of Lac La Martre. Whati is located about 164 km northwest of Yellowknife and is accessible by air and by winter road only. The average power use in the community is estimated at about 197 kilowatts (kW) and the 2012 annual energy requirement is estimated to be 1,730 megawatt-hours (MWh).

The ten-year (2001-2010) average wind speed at the airport was measured to be 2.8 m/s at a height of 10 m above ground, which is considered to be moderately low for wind energy potential in the community. The mean solar energy potential according to NASA is 2.78 kWh/m^2/day (daily insolation), which is considered to be good for solar electricity production.

For a potential wind energy project scenario a 100 kW project based on one NorthWind 100 turbine is estimated to cost $15,145 per kW whereas a 110 kW project based on two Endurance E-3120 turbines would cost about $15,968 per kW. The two wind project options would produce power at a levelized cost of about S2.467 and $2.082 per kWh, respectively.

For a potential solar energy project in a net metering home system the installed cost is estimated to be from $10,000 per kW (for a fixed solar array) to $12,500 per kW (dual axis tracking). In a utility scale scenario (50 kW) the installed cost is estimated to be from $8,000 per kW to $10,500 per kW. For an off-grid summer camp a solar system (including battery bank and power equipment) will be expected to cost from $25,000 to $27,500 per kW installed.

The cost of energy from grid connected photovoltaic systems is substantially cheaper at $0.65 to $0.83 per kWh than wind energy but still significantly more expensive than the marginal cost of diesel generation at $0.431 per kWh.

The diesel fuel savings and the greenhouse gas emissions reduction from a fixed array solar energy system in Whati is expected to be 291 litres and 873 kg of CO2 equivalent per kW installed respectively. From a one axis array configuration the fuel savings and greenhouse emissions reduction goes up to 389 litres and 1,167 kg of CO2 equivalent per kW installed respectively.

If Whati is considering alternative energy developments, the use of PV energy generation would be a 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 Whati wish to pursue either a PV or a wind energy project, capital subsidies would be required to make the project cost-effective compared to continued diesel generation.

Introduction

The cost of diesel fuel to serve northern remote communities continues to rise as world supplies become scarce. The need for developing renewable energy is becoming more urgent as communities struggle with rising energy costs. Over the past several years, the authors (JP Pinard, P.Eng., Ph.D. and John Maissan, P.Eng.) have been retained by the Aurora Research Institute (ARI) to conduct pre-feasibility studies for wind energy generation in many diesel-served communities in the NWT. All of these studies are found at the ARI website (http://www.nwtresearch.com, search for “wind energy”). With the decreasing costs of solar technology it has become apparent that solar energy is becoming more attractive for remote communities in the North. In this study, the economic potential for both wind and solar energy is assessed for their viability in Whati.

The community of Whati has about 500 people and is located at the southeast end of Lac La Martre. Whati is located about 164 km northwest of Yellowknife (see Figure 1) and is accessible by air (from Yellowknife) and by winter road only (from Behchoko on the Mackenzie Highway). The average power use in the community was 197 kilowatts (kW) and the 2012 annual energy requirement estimate is 1,730 megawatt-hours (MWh). The community power plant has three diesel generators with a total capacity of 975 kW (one 480 kW, one 320 kW, and one 175 kW), owned and operated by Northwest Territories Power Corporation (NTPC). The marginal cost of producing electricity from diesel (fuel and variable maintenance only) is estimated at $0.431/kWh.

No previous wind or solar resource studies (that the authors are aware of) have been done for Whati. The Arctic Energy Alliance has however 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 is considered low at 2.81 m/s (height was not noted); however the average solar insolation (radiation) is 2.78 kWh/m^2/day which is considered to provide above average solar energy potential for the community.

The purpose of this study is to examine and compare the economics of wind and solar energy development to diesel-generated electricity in Whati. In this study solar and wind climate data is collected, analysed and used to model potential energy output of select wind turbine models and photovoltaic (PV) array configurations. The economic analysis looks at the costs of building and operating a wind or a solar project in the hamlet. Greenhouse gas emission reductions from these renewable energy forms are estimated. An outline of next steps is given regarding the pursuit of wind or solar energy integration in the hamlet.

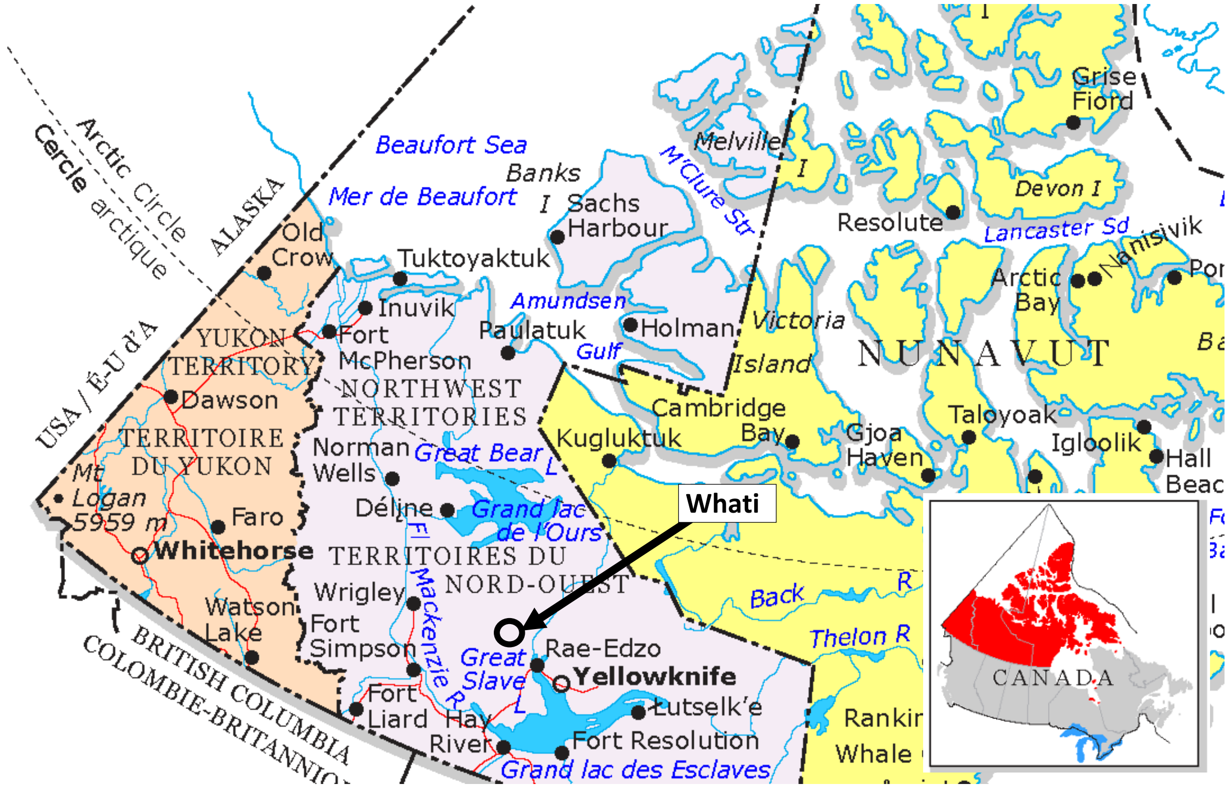

Figure 1: Whati is located in the southwest NWT, about 164 km northwest of Yellowknife.

Wind Climate Assessment

To estimate the wind energy potential in Whati wind speed measurements are required. The wind data used for the wind analysis was extracted from Environment Canada's (EC) climate data, which is available online at their website (www.climate.weatheroffice.ec.gc.ca). According to EC there is a climate (weather) station at the Whati airport (see area map of Figure 5). The data from this station contain hourly measurements of wind speed and direction, temperature, pressure, humidity, and other parameters (solar measurements are not included in these data sets). The wind measurements at this station appear to be made at 10 m above ground level (AGL) which is the standard height for airport weather measurements in Canada.

Wind Speed

Wind data was collected from the website for the 10-year period 2001 to 2010. The 10-year mean wind speed from this set is 2.82 m/s from a height of 10 m AGL at a surface elevation of 271 m above sea level (ASL). Figure 2 shows the monthly average wind speeds (at 10 m AGL) at the airport. On average the monthly wind speed reaches a minimum of about 3.0 m/s in July with two other minimums of 3.1 m/s in February and December and a maximum of 3.7 m/s in March. The minimum monthly wind in July is considered unusual since in most communities winds are usually at a maximum at this time of year.

An analysis of the time series shows no significant trend in the average annual wind speed over the ten-year period.

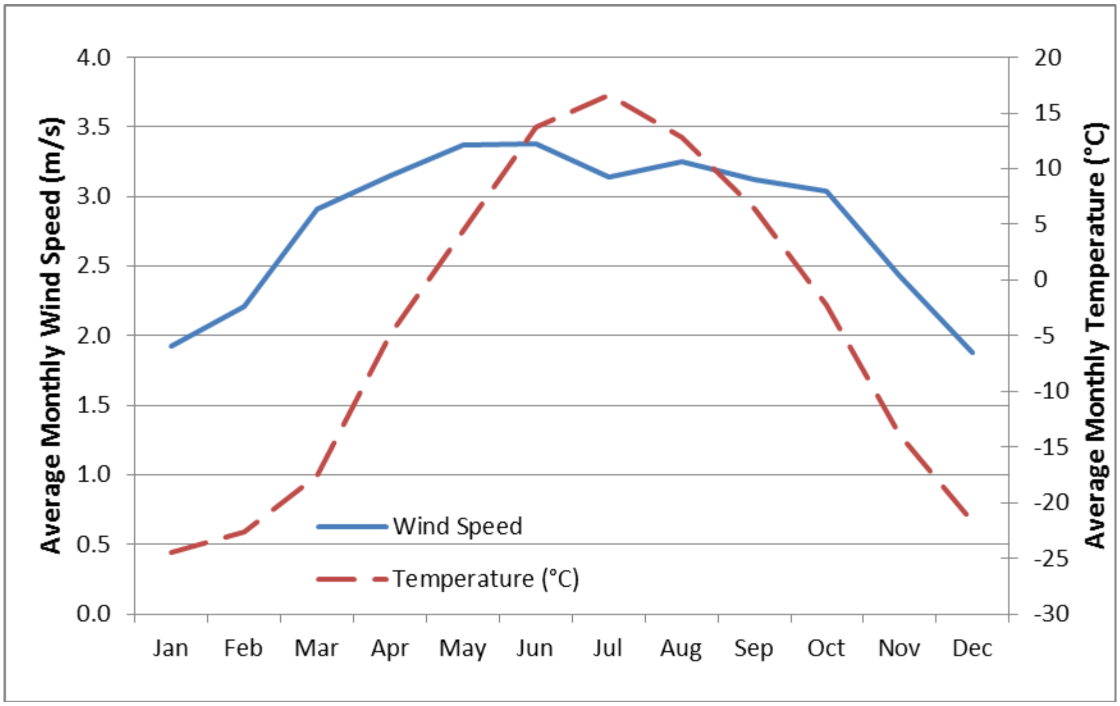

Figure 2: Monthly average wind speed and monthly average temperature at the Whati Airport climate station. The average values are based on ten years (2001-2010) of measurements.

Wind Direction

Wind direction must also be taken into account when considering a wind energy project location. A wind rose provides an indication of the dominant wind direction of the area and is very useful for planning the location of a wind project to ensure its maximum capture of wind energy. In Figure 3, the wind rose for Whati has a solid shaded area that represents the relative wind energy by direction. The wind energy by direction is calculated as the frequency of occurrence of the wind in a given direction sector multiplied by the cube of the mean wind speed in the same direction. The given wind energy in each direction is a fraction of the total energy for all directions. According to the wind rose, the wind energy at Whati comes from one dominant east-southeasterly direction, and two other minor directions: west-northwest and north. Therefore, a wind energy project built in the community should have good exposure mainly to those dominant directions if possible.

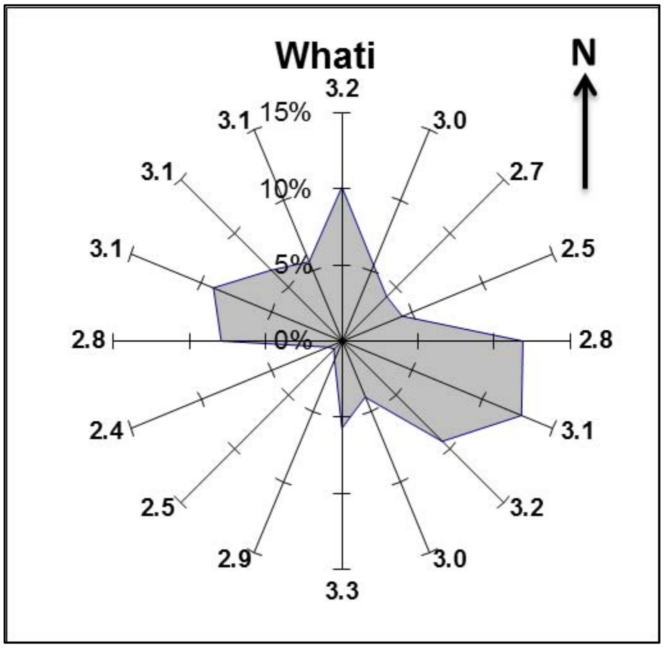

Figure 3: Wind rose showing the wind energy by direction for Whati. The numbers at the end of each axis indicate the average wind speed for that direction. This rose shows that the dominant wind directions are from the east-southeast, then west-northwest and north.

Vertical Projection of Wind Speed

The wind speed measured at 10 m AGL needs to be projected to higher levels to estimate the mean wind speed for wind turbines with taller towers. The wind turbines used for this analysis are at a 37-m height (NorthWind 100) and at a 42.7-m height (Endurance E-3120), and are described later.

Turbulent air flow over rough surfaces tends to generate a vertical profile of horizontal winds that are fairly well predictable. The wind speed profile near the ground is dependent on neutral well mixed air conditions and the roughness of the ground surface. This vertical profile can be defined by the natural log law equation (see Stull, 2000):

$$u_2 = u_1 \frac{\ln(z_2/z_o)}{\ln(z_1/z_o)}$$

Where u_1 is the known wind speed at z_1 (typically at 10 m AGL), and is projected to u_2 at the height z_2. The surface roughness is defined by z_o which as a rule of thumb is 1/10 the height of the grass, brush, or ground undulations surrounding the site where the measurements are made. This equation is considered most accurate up to approximately 100 m above the surface. The surface roughness z_o can be categorised by the type and size of vegetation as well as the hilliness of the ground itself.

In Whati the climate station is near the air field terminal about 250 m northeast of the airstrip centreline in an open area. At the climate station site the surface roughness is estimated to be about z_o = 0.15 m, which is typical of level rough grass fields with few trees (Stull, 2000). Using this surface roughness value and the equation above we calculate the wind speed at 40 m, for example, to be 3.75 m/s (see Figure 4).

In the next stage of analysis, the information from the wind rose and the EC wind speed data are used to run a wind flow model that calculates and visualizes where the best wind sites might be for the Whati area.

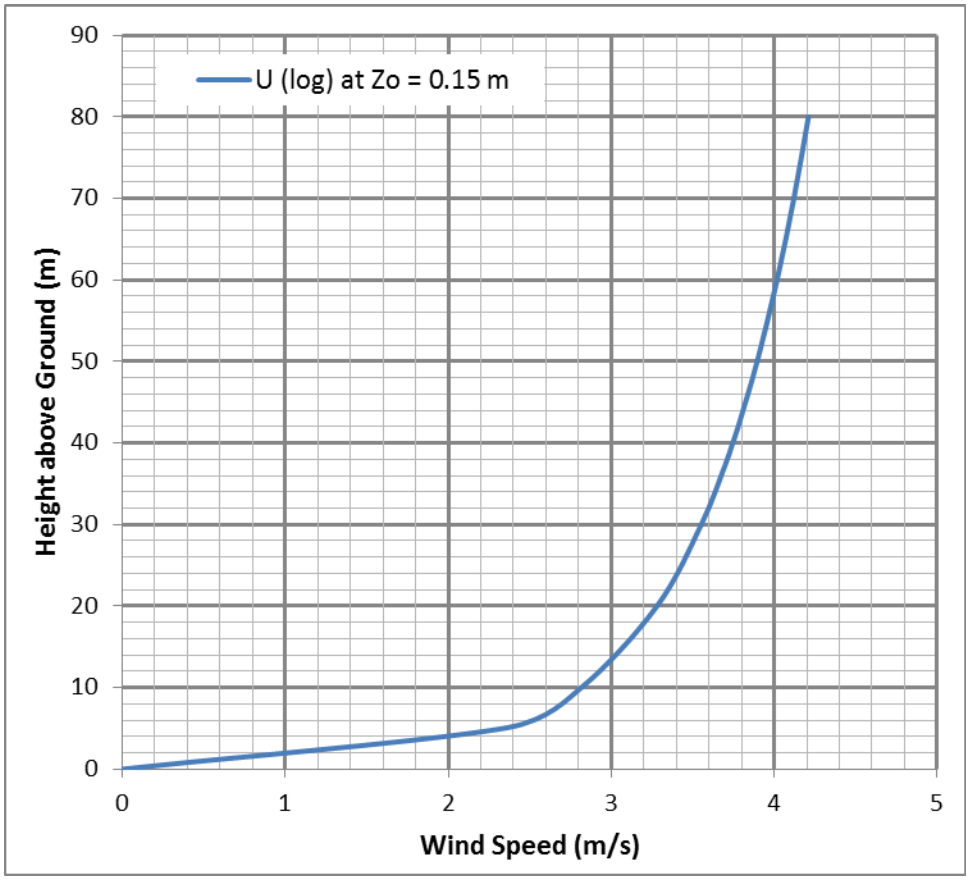

Figure 4: Vertical profile of horizontal wind speed estimated at the Whati climate station.

Site Selection through Wind Flow Modelling

Since we only have one location that has been measured for wind speed we need other tools to help estimate the mean wind speed at other locations. To achieve this we use a numerical wind modelling tool called MS-Micro. Originally based on the boundary-layer wind field theories of Jackson and Hunt (1975), it was modified and made into a useable computer wind modelling tool by Walmsley et al. (1986).

MS-Micro was run for the Whati area using a data elevation model from the Municipal and Community Affairs (MACA) website. The surface roughness values were estimated with lakes being z_o = 0.0001 m (open water and snow-covered ice surface), forested areas being z_o = 0.2 m, and the cleared open ground surfaces z_o = 0.01 m. The model domain has an area that is 8 km square centred at a point shown (as a large grey dot) in Figure 5. The model's surface resolution is approximately 63 m horizontally (128 by 128 grid points), whereas the model grid for wind calculations is approximately 31 m (grid of 256 by 256).

The winds that are applied in the model simulation are normalised, arbitrary wind speeds, and six primary wind directions are applied to the model: those being 0, 90, 113, 135, 270, and 293 degrees for the six main wind directions measured by the wind monitoring station (Figure 3). The model is run four times (for each direction) and the resulting wind speed output are blended into a single output using a scaling based on the wind energy rose of the wind monitoring station. The blended output is a normalised wind output whose contours are scaled up and calibrated to the estimated wind speed at 40 m AGL (above ground level) of 3.75 m/s at the airport climate station. The results of the MS-Micro modelling are shown in Figure 5.

The Whati community sits on a spit on the shore of Lac La Martre which is at about 266 m ASL (above sea level). A ridge rises towards the northeast from Whati to about 286 m ASL at about 800 m from the town centre. The ridge continues to rise to about 300 m ASL at the northeast end, about 3.5 km from town centre. The main road into the community runs along this ridge and so it is very accessible in terms of developing a potential wind project. There is also another ridge about 3 km to the southeast past the airport. This ridge is less accessible and so more difficult to develop.

The wind flow model shows that the highest wind speeds are along main ridge leading to the community. The wind speeds are about 3.9 m/s at the first ridge peak just northeast of town and reach a maximum wind speed of about 4.0 m/s (all at 40 m AGL) at the farthest peak to the northeast along the same ridge. The nearer of the two sites is proposed for considering the economics of a wind installation and they are both shown in Figure 5. Site 1 whose wind speed is predicted to be 3.9 m/s (at 40 m ASL) is just east of a residential part of the community and likely is about 500 m from the nearest 3-phase power line. Site 2 is at the northeast end of the ridge is only marginally better than Site 1 and will need 3 km of 3-phase power line which immediately makes that site uneconomical.

For the purpose of modelling the wind energy production at 37 and 42.7 m AGL (the heights of the two turbines used in this analysis) at the proposed wind turbine sites, we will use similar vertical projections as at the airport site. For simplicity we will assume that both sites have essentially the same wind speed and we take an average of the two sites: 3.9 m/s at 40 m AGL. The new estimated wind speed for the proposed sites is then 3.8 m/s at 37 m AGL and is 3.9 m/s at 42.7 m AGL. These two numbers are used to estimate the energy production through the HOMER Energy model, which is described later in this report.

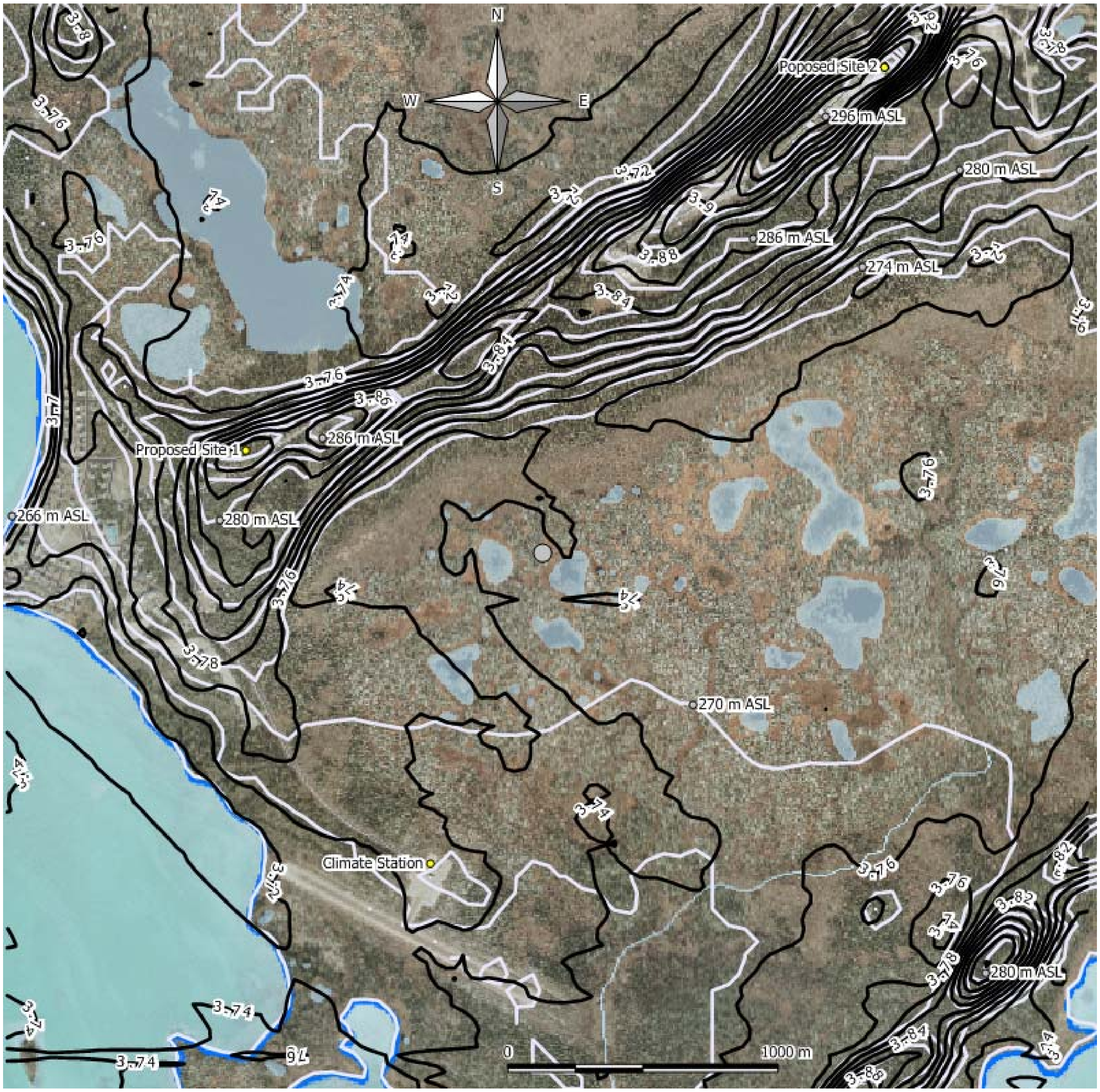

Figure 5: Mean wind speed contours (black lines) based on the numerical model MS-Micro. The wind speeds are modelled at 40 m AGL. The speed contour interval is 0.02 m/s. The model domain covered an area that is 8 km^2 for this analysis, centred at the point indicated by the large grey dot. The elevation contours (light grey) are at 2 m intervals.

Solar Climate Assessment

The information for the solar radiation in this study comes from NASA's Surface Meteorology and Solar Energy (SSE) website (eosweb.larc.nasa.gov/sse/). This site is a renewable energy resource centre that keeps a database of compiled solar, wind and other meteorological data for the purpose of evaluating the renewable energy potential at most locations around the world. This is also the same website from which solar, wind and other meteorological data is officially used for input into the RETScreen and HOMER Energy models (both described later). 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, such as Whati.

Solar Insolation at Whati

From the SSE website solar radiation data was extracted for the Whati area and it is compared with actual measurements that were made in the past at other nearby locations such as Fort Smith, shown in Figure 6 below. These average insolation values represent the monthly average daily solar radiation onto a horizontal plane at the Earth's surface. Typically solar radiation is measured with the sensor pointing straight up on a flat horizontal (leveled) plane. The measurement is given in the form of energy (kWh) per unit area (m^2) per day. Solar photovoltaic panels are typically not set up on a horizontal plane but rather at an angle that is as close to perpendicular to the sun as possible. Different photovoltaic (PV) array configurations exist to address this and will be discussed later in this study.

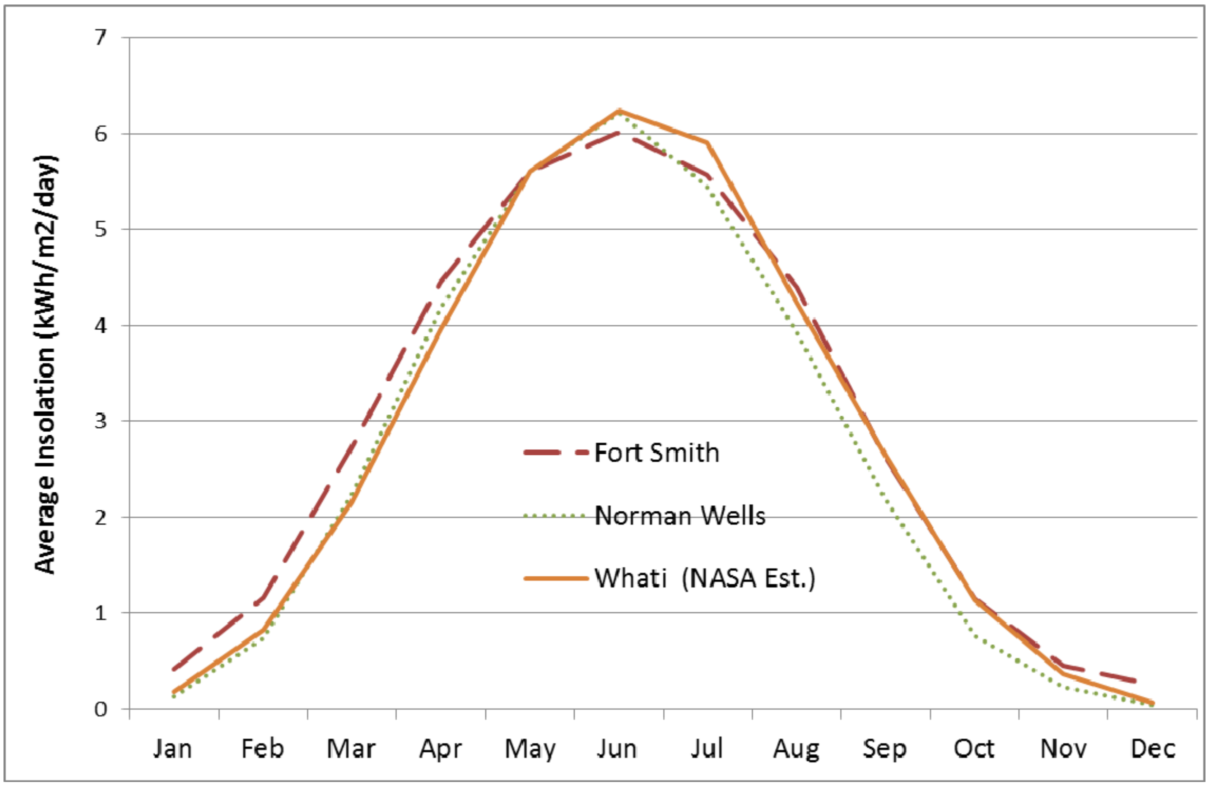

Figure 6: Monthly average insolation, or solar radiation, on a horizontal surface measured at Fort Nelson, Fort Smith, and Norman Wells, and estimated at Whati. All were acquired from the SSE website.

The two nearest locations where there was solar radiation data that was collected in the past are Fort Smith and Norman Wells in the NWT. Fort Smith collected data from 1971 to 1988, and Norman Wells collected data from 1967 to 1987. In Figure 6 we can see that the solar radiation estimated by SSE for Whati is similar to that of Norman Wells in the first half of the year and more closely aligned with the values of Fort Smith in the second half of the year. With respect to latitude, Whati is 250 km south of Norman Wells and 350 km north of Fort Smith. The average annual insolation for Forth Smith and Norman Wells were 3.01 and 2.66 kWh/m^2/day, respectively. The average annual insolation for Whati was estimated to be 2.78 kWh/m^2/day.

Site Selection for Solar Systems

Within the community of Whati, the insolation values are likely similar anywhere that there is an open area 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 being 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 array installation, the best location is close to a powerline in a large field exposed to the south. If a tracking system is selected then the area must be exposed to the east, south, and west.

Community Power Requirements and Costs

The community of Whati has its electricity requirements supplied by an NTPC diesel power plant consisting of three generators: one of 175 kW, one of 320 kW, and one of 480 kW for a total capacity of 975 kW. Residual heat recovered from the plant is used to heat the school. The most recent NTPC General Rate Application (GRA) indicates that the fuel efficiency of the diesel plant is 3.711 kWh per litre.

The 2007-2008 GRA forecast power requirements in the community was 1,730 MWh and since the GRA growth trend was flat, the electrical load for this study was assumed to be 1,730 MWh as well. This represents an average diesel plant load of about 197 kW and a peak load of about 395 kW at a load factor of 49.8% as indicated in the GRA. The authors estimated that the minimum plant load is in the order of 90 kW. Relevant excerpts from NTPC documents are attached as Appendix 1. With the diesel plant fuel efficiency provided above and the expected annual electrical energy produced from diesel this represents about 466,182 litres of diesel fuel consumed for electricity production in the community.

For this prefeasibility study, a wind project size of about 100 kW was selected. This represents a medium penetration level project with a single wind 100 kW turbine or two of 55 kW, and is probably as large as is practical as a first step. A larger project provides economies of scale that a smaller one does not. This study did not examine a higher penetration project as the authors feel that more experience with simpler wind-diesel projects in NWT is required before more technically complicated high penetration systems are taken on.

This study also examines solar PV opportunities in one generic seasonal (April to September) off-grid application (e.g. a camp) involving a 1 kW array, and in two grid connected applications. The grid connected options are a 5 kW net metering arrangement by a residential consumer and a 50 kW or larger utility owned project. Unlike wind turbines, PV arrays can be sized in small increments (of about 200 W) and projects can easily be expanded. 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, that is, larger than a 50 kW capacity, with a diesel plant may be as challenging as significant wind capacity due to a requirement for electrical power stabilizing equipment.

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 3.711 kWh displaced. This diesel plant would produce variable (or incremental) electrical energy at a levelized cost of $0.431 per kWh over 20 years with diesel fuel starting at $1.25 per litre and increasing with general inflation (2% in model). These costs include only fuel and $0.03 per kWh variable operation and maintenance (O&M) costs. The economic model assumes that the cost of capital is 7.5%.

Wind Power Project

Developer – Operator

For the purpose of this report it was assumed that a wind project would be a medium penetration project with one or two wind turbines and displace a reasonable amount of diesel consumption without compromising the quality of the electric grid. A larger wind project would require a more complex power and energy control system. A larger project would also create an opportunity to utilise excess wind energy for space heating and eventually other applications (such as local transportation), which would add greater benefits to the community at large. This high level of diesel displacement has however, not been implemented to any great extent in Canada. High penetration systems are being used in Alaska and Australia and could be considered as a future possibility for a project in this community.

For this report it is also assumed that if a wind project were to be developed in Whati it would be done by a developer with wind project experience in the NWT. There is no allowance in the project cost estimates for overcoming a learning curve for inexperienced developers/operators. If a project were to be developed by an inexperienced firm the capital costs would almost certainly be higher. In the opinion of the authors, the project would ideally be developed by or in partnership with the current electrical power supplier (owner of the diesel power plant) in order to make the best use of existing experience, expertise, and infrastructure in the remote communities. As well, the integration of the wind and diesel plants (including power purchase agreement issues) would then be relatively seamless and some overhead costs avoided.

Wind Turbines

Two wind turbine models of appropriate size (capacity) and relatively large rotor diameters were selected for consideration at Whati based on the hamlet's electrical load and relatively low wind speeds. These are the Northern Power Systems NorthWind 100 (100 kW capacity with a 23 m rotor diameter – which is under development but not yet available) and the Endurance E-3120 (55 kW with a 19.2 m rotor). The NorthWind 100 is available with an option that permits operation down to -40°C but the Endurance turbine is not presently available with such an option so a small allowance for low temperature operation (e.g. low temperature lubrication) was included in the pricing.

Energy Production

The annual energy production from each of the selected wind turbines is calculated using the HOMER model. HOMER was developed by the National Renewable Energy Laboratory of the US Government and is now distributed and supported by HOMER Energy (www.homerenergy.com). HOMER is a power system analysis and optimization model. The energy model uses published wind turbine power curves, diesel plant production specifications, and one-year hourly time series measurements of both wind speed and community power load to model the energy output of various power generators. Two project configurations were examined: one NorthWind 100 turbine (100kW), and two E-3120s turbines (total: 110 kW).

The inputs for the HOMER model consist of the three diesel generators described earlier, the wind system and the community load data. The wind resource data used as input for the HOMER is a one-year data set synthesized from the ten-year data set from the climate station measurements at the Whati airport. This wind data was then adjusted for the proposed wind turbine site from the MS-Micro wind flow model resulting in a prediction of an average annual wind speed of 3.8 m/s at the NW100 37m hub height and 3.9 m/s at the E-3120 42.7m hub height.

The energy produced by each of the selected turbines is based on the published power curves, less 5% to adjust for a turbine availability of 95%. An additional 10% of the production is then subtracted to account for losses (turbulence losses, array losses, mechanical losses, cold and icing performance losses, transformer losses, and transmission line losses) to arrive at the net energy production available to displace diesel energy. Net generation is the HOMER calculated ideal generation less availability and other losses (total deduction of 15% from the ideal generation). Appendix 2 presents a table of energy production from the two project configurations with the two wind turbine models described earlier. The net energy produced by each project configuration is also shown in Table 2. Often there is an adjustment for increased production at higher air densities due to cold temperatures which, in this case, would likely be 5% or a bit higher. However, to be conservative no air density adjustments were made in this study.

The calculations indicate that the net energy generation at the annual average wind speed at the turbine hub height represents a capacity factor of about 7.8% for the NorthWind 100 and 10.4% for E-3120. Although both have very low capacity factors due to the low wind speeds, the Endurance E-3120 turbine has a higher capacity factor than the NorthWind 100 because of its relatively larger rotor diameter (designed for low to moderate wind climates).

The energy calculations in Appendix 2 also indicate that one NorthWind 100 (100 kW) and two Endurance E-3210s (110 kW) will produce 683 and 914 kWh per kW installed respectively (divide diesel energy displaced by total power capacity or the wind turbines).

Capital Costs

The estimated capital costs for the two project configurations are presented in Appendix 3 and are summarized below:

1. A 100 kW project based on one NorthWind 100 turbine was estimated to cost about $1,514,500 or $15,1450 per kW;
2. A 110 kW project based on two E-3120 turbines was estimated to cost about $1,756,500 or $15,968 per kW.

The power line required to connect wind project to the community's power system would be modest as the proposed project site (#1) is about 500 m from the nearest power line in the community. An estimate of $100,000 is included for connecting the first turbine. Other major cost items besides the purchase of the turbines and towers are the foundation design and the associated geotechnical work at

$80,000, the foundation costs at $100,000, and the mobilization and demobilization of a crane at about $100,000 also. Crane costs could be higher if the turbine installation does not coincide with the winter road being open.

The capital costs of a wind project are a major energy cost driver, so it is critical for any developer to pay considerable attention to all capital cost components. Larger projects provide economies of scale that reduce costs per unit of installed capacity but for this very small community no real economies of scale exist.

Operating and Maintenance Costs

The annual operating and maintenance cost for a project of one turbine was estimated to be about $20,000 with a second turbine adding $15,000 to this amount. This cost is based on the simple requirements to keep a project running and does not include costs that may be associated with establishing and running a corporation for the wind project only. The effective assumption is that the wind project is owned and operated by an appropriate existing organization involved in other similar activities (e.g. an independent power producer that owns several renewable energy projects and Whati is one of their projects). The operating and maintenance cost is intended to include all overhead, insurance, lease, and tax costs as well as the actual maintenance costs. These O&M costs are equivalent to about $0.29 per kWh for the one turbine NorthWind 100 project and $0.35 per kWh for the two turbine Endurance E-3120 project. These are high because of the relatively low energy production from the wind turbines in the low wind speed regime.

For the economic analysis (presented in the following subsection) the cost of capital was assumed to be 7.5%, which represents a regulated utility. Incorporated in the cost of capital is a return on equity which would be earned by the project owners and is separate and distinct from the annual operating and maintenance costs. The authors believe that funding assistance would likely be necessary to interest a wind project developer and this would increase the effective return on equity or reduce the cost of debt. A project developer would need to calculate the economics of a project based on their own circumstances.

Cost of Wind Energy and Economic Analyses

The levelized cost of wind energy over a 20 year project life was calculated to compare the cost of wind generated electricity to the cost of diesel generation. Appendix 4 presents the economic model outputs of the levelized cost of wind energy for the two project variations and Appendix 5 presents the economic model outputs for continued diesel generation. The variables and assumptions used in the economic model include the project capital cost, its capacity in kW, its annual diesel displacing energy production, the useful life of a wind project (20 years), the cost of capital (7.5%), the general inflation rate (2%), and the annual operating costs. The model calculates the levelized cost of energy over the life of the projects.

For continued diesel generation, the assumptions include a variable operating and maintenance cost of $0.03 per kWh, a plant efficiency of 3.711 kWh per litre, and diesel fuel is assumed to inflate at 2% per year, the same as general inflation. Also the authors did not have access to the present NTPC diesel fuel cost in the community but based on information available have estimated present costs to be about

$1.25 per litre. $1.25 per litre was considered to be reasonable and consistent with fuel costs assumed for other communities for which prefeasibility studies are also being completed at this time (Deline $1.35, Trout Lake $1.00, and Jean Marie River $1.15). Table 1 summarizes the results of the economic modelling.

Table 1: Twenty-year levelized cost of energy for wind projects and continued diesel generation.

Project Configuration	20 year Levelized Cost of Energy ($ per kWh)
One NorthWind 100 turbine	$2.467
Two Endurance E-3120 turbines	$2.082
Diesel generation, $1.25 per litre	$0.431

The economic analyses summarized in the table above indicate that although there is some variation in the levelized cost of energy for different wind project configurations, which is largely a function of the energy capture differences in turbines due to variation in swept area per unit capacity, wind energy is between five to six times as expensive as continued diesel generation. Even with a very modest cost power line, neither wind project configuration was close to diesel generated power in cost. A very large portion of the capital costs of a wind project would need to be subsidized to make a wind project cost competitive with diesel generation.

Of the two turbines considered, the Endurance E-3120 with its large rotor would generate the most cost effective wind energy and thus the lower cost electrical energy. However, the low wind resource in Whati prevents a wind energy development from being economically feasible.

It is possible that with an experienced wind project development industry based on other projects in the Northwest Territories a more cost effective project could be installed in Whati but this would still not produce cost effective energy compared to continued diesel generation. Other renewable energy options for Whati should be considered.

Greenhouse Gas Reductions

Table 2 outlines the diesel fuel and greenhouse gas (GHG) reductions that would be achieved by the two wind projects examined in Whati. The calculations are based on a diesel plant efficiency of 3.29 kWh per litre, and GHG emissions of 3.0 kg carbon dioxide (CO_2) equivalent per litre of diesel fuel consumed.

Table 2: Annual GHG reductions from a wind project of about 100 kW in Whati.

Project Configuration	Diesel Electricity Displaced (kWh)	Diesel Fuel Saved (litres)	GHG Reductions (kg CO_2 equivalent)
One Northwind 100	68,335	19,271	57,813
Two Endurance E-3120s	100,578	28,364	85,091

Wind Power Conclusions

1. Wind power is not a cost effective alternative for diesel power generation in Whati.
2. There are potential wind project sites adjacent to the community of Whati.
3. Based on local airport weather data and computer modelling, the wind speed at 37 and 42.7 m AGL is projected to be 3.8 and 3.9 m/s, respectively.
4. Capital costs for a project of 100 kW (one NorthWind 100) and 110 kW (two Endurance E-3120s) would be $1,514,500 and $1,756,500, respectively.
5. The wind projects considered would produce power at a levelized cost of about S2.467 and $2.082 per kWh respectively.
6. The Endurance E-3120 with its large swept area per kW of capacity would produce lower cost electrical energy than the NorthWind 100 (with a 23 meter rotor).
7. A 100 kW NorthWind 100 project would displace 19,271 litres of diesel fuel and reduce GHG emissions by 57,813 kg of CO_2 equivalent per year and a 110 kW two E-3120 turbine project would displace 28,364 litres of diesel fuel per year and reduce GHG emissions by 85,091 kg of CO_2 equivalent per year.

Solar PV Project

Project Owners

Three different solar PV applications were considered in this study, and in each case the ownership was different. The first application was a small remote camp using a 1 kW PV array. In this case the camp owner was assumed to own the PV project. The second application was a net metering (i.e. grid connected) installation of a 5 kW PV array, assumed to be owned by a private residential power consumer. The residential consumer was assumed to be acting individually as opposed to being part of a larger project involving many homes. The third application was a 50 kW (or larger) grid connected project owned and operated by the utility owning the diesel plant, which in Whati would be NTPC.

PV Equipment

For the 1 kW off-grid and the 5 kW net metering grid connected applications, complete system kits were selected for use in this study. These costs were found to be up to 20% higher than individually sourced components that could be assembled by an owner with appropriate skills and some professional advice. However, the complete kit approach was considered to be a good first approximation on systems and costs. The off-grid kit would include everything – PV modules, fixed array mounting system, charge controller, battery bank, sine wave inverter, power panel/centre, and all required cabling.

The 5 kW net metering kit includes PV modules, micro-inverters, fixed array mounting system, and all cabling (no batteries). Typical PV module sizes are 170 to 230 Watts. For both the off-grid and the net metering applications retail single and dual axis tracking systems were also considered (see Figure 7). The costs of such tracking systems were added to the cost of the kits described.

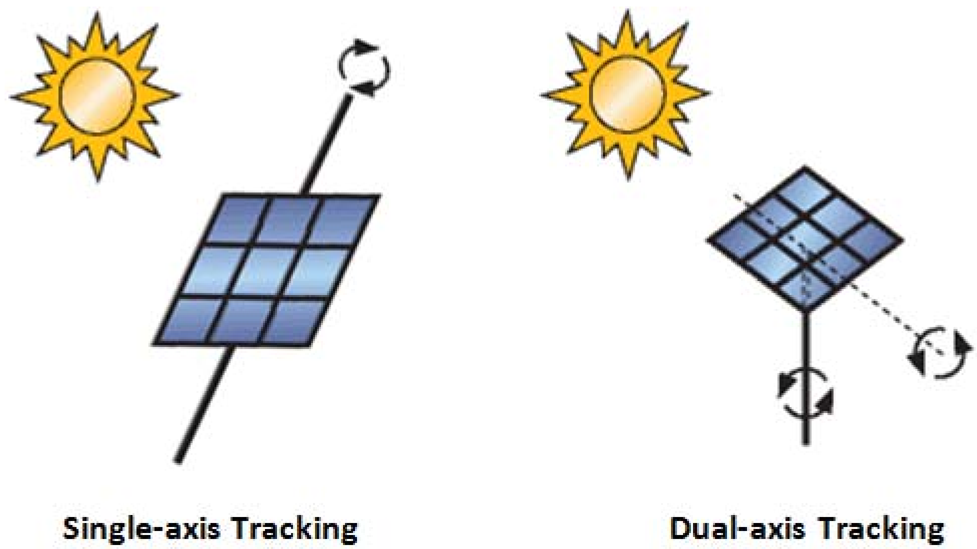

Figure 7: Two most common tracking modes for a solar system with dynamic tracking. A single-axis tracker tracks the sun by rotating around an axis located in the plane of the collector. The axis can have any orientation but in the northern latitudes it is usually pointing south with a tilt that is nearly parallel to the earth's axis. The dual-axis tracker always positions the array surface normal to the beam of the sun by rotating about two axes. Source: www.RETScreen.net.

The 50 kW or larger utility scale project was based on various updated detailed wholesale costing lists and assumed that the utility was experienced in PV projects and closely involved in the subject project. Foundation requirements are uncertain and may contribute to higher costs than projected in this study.

The pricing for PV modules at a wholesale level is very competitive at the moment; some reports indicate that costs have decreased to nearly $1.00 per watt of capacity (compared to a retail cost of about $10/watt in 1990s).

Energy Production

In each of the three PV scale applications energy production from three different PV array configurations are considered: first a fixed array that is tilted at about 45° (from the ground) from April to September and at 90° from October through March; secondly a single axis tracker set at a tilt of 60°; and thirdly a dual axis tracker. The fixed and single axis tracker configurations are assumed to be facing south. The tilt angles that are chosen for each configuration are the most optimum angles that maximize the annual solar energy production in the Whati area. The reason for choosing to tilt the fixed array to 90° in the winter months is to avoid snow build up and subsequent snow clearing requirements. A solar array at any angle less than 90° will often build up with snow and prevent the solar array from producing electricity after a snow fall in the winter. Another advantage to tilting the array to 90° in the winter is the added effect of snow reflectance from the ground to the array, which will improve the performance of the system.

If one chooses to use a fixed array at a permanent angle (the optimum angle would be 55° for Whati's latitude) then the expected annual losses due to snow cover will likely be about 12% (based on work done by Wohlgemuth, 2007) depending on snow fall and weather conditions. It should also be noted that a fixed array configuration set permanently at 55° will produce about 3% less energy than a fixed array adjusted seasonally as indicated above. The total losses will likely amount to 15% if one chooses to use a permanently fixed array system as opposed to one that is adjusted seasonally with the 45° tilt in the summer and 90° tilt in the winter.

The above PV array configurations are 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 CanMET ENERGY 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.

For the utility scale solar system the HOMER Energy model (also used for the wind energy modeling) was used to verify that the 50 kW proposed solar system can be used without producing excess energy and thus requiring grid power stability equipment or storage. This situation will occur during the summer when the community load is smallest and the solar production is greatest.

Using the SSE insolation data (for Whati) and RETScreen's modelling capability, the monthly and annual energy production of each configuration at various tilt angles 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 m2 area), with an efficiency of 14.4%, 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) were assumed in the RETScreen model. The model also included additional losses of 10% for snow shading for the grid connected home and utility systems on trackers; snow shading losses do not apply to the fixed array scenarios, which assume a 90-degree tilt for the winter. Losses are an additional 20% for the off-grid system which uses a charge controller (about 5%) and a battery bank (about 15%).

The result of the RETScreen solar array configuration performance evaluation for Whati are summarised in Figure 8. Projections of the net energy production per kW of array capacity (after losses) at Whati's latitude are outlined in Table 3.

As Table 3 shows, a one kW system on a fixed array will produce about 1079 kWh per year. The total energy production for a 5 kW home based system on a roof using the fixed system will translate into 5,395 kWh per year. A utility scale 50 kW fixed array system in Whati will produce 53,950 kWh per year without producing significant excess electricity.

Figure 8 illustrates how a tracking system will have an advantage over a fixed south-facing configuration. Because the tracker allows the solar array to face the sun from morning through afternoon, it captures about 40% more solar energy, mostly during the summertime. Despite the advantage, the tracking system can be compromised if there is snow build up, shading by buildings, trees, or neighbouring solar tracking arrays. For all configurations the advantage of snow reflectance is seen for the months of March to May.

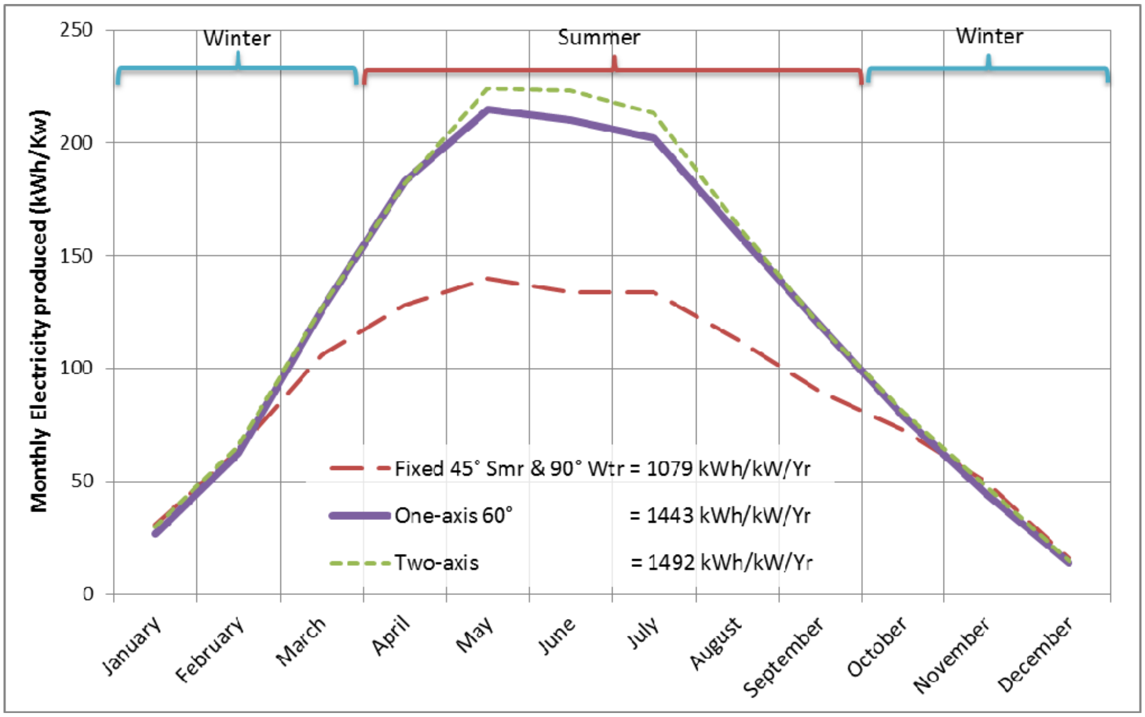

Figure 8: Monthly electricity produced from each type of solar array configuration for Whati, based on RETScreen analysis. Smr = Summer (April to September); Wtr = Winter (October to March).

Table 3: Projected net energy production in Whati. Smr = Summer (April to September); Wtr = Winter (October to March).

System description	Use	Added losses (B = battery, S = snow)	Net annual energy Capacity in kWh / kW	
Off grid summer camp				
Fixed array: 45°	April - September	B: 20%	591	
1 axis tracker: 60°	April - September	B: 20%, S: 10%	871	
2 axis tracker	April - September	B: 20%, S: 10%	900	
Net metering home (on grid)			**1 kW**	**5 kW**
Fixed array: 45° Smr & 90° Wtr	All year		1,079	5,395
1 axis tracker: 60°	All year	S: 10%	1,443	7,215
2 axis track	All year	S: 10%	1,492	7,460
Utility			**1 kW**	**50 kW**
Fixed array: 45° Smr & 90° Wtr	All year		1,079	53,950
1 axis tracker: 60°	All year	S: 10%	1,443	72,150
2 axis track	All year	S: 10%	1,492	74,600

Capital and Operating Costs

Capital costs for the off-grid camp and net metering home applications were based on retail kit costs available on the open market. The authors estimate that knowledgeable owners could buy components and assemble their own systems (with professional advice as required) for about 20% lower capital cost, however, for the purposes of this report the retail kit cost was considered to be a good first approximation.

Costs for solar tracking systems for the off-grid and net metering home application were taken from retail web site price listings and were simply added to the kit cost. For the utility scale configuration, only one supplier was willing and able to supply a price which was indicated to be $US1.00 to $US1.10 per watt of capacity for a single axis system. Consequently, the same retail tracking costs found for larger home systems were also applied to the utility scale project. This may be a bit high for cost but serves as an adequate first approximation.

Capital costs for utility scale PV systems were based on various existing cost breakdowns available and indicated that in southern Canada these projects would probably cost about $6,500 per kW at present. With increased shipping costs and higher installation costs in the north $8,000 per kW was considered to be a reasonable estimate. Tracking costs were added onto these costs.

In all cases operating and maintenance (O&M) costs were estimated at $25 per kW of capacity per year for the PV system and where trackers were used an additional $25 per year per kW of capacity was applied. A summary of the capital and O&M costs appears in Table 4 below. O&M costs are probably low for an off-grid battery based system but the alternative of a gas or diesel generator would also involve significant maintenance so these were considered to be off-setting costs.

Table 4: Capital and operating costs of PV systems

System description	Capital cost $ per kW	O&M cost $ per kW per year
Off grid camp (1 kW battery based)		
Fixed array	$25,000	$25
1 axis tracker	$27,000	$50
2 axis tracker	$27,500	$50
Net metering home (5 kW grid connected)		
Fixed array	$10,000	$25
1 axis tracker	$12,000	$50
2 axis track	$12,500	$50
Utility (50 kW or more)		
Fixed array	$8,000	$25
1 axis tracker	$10,000	$50
2 axis track	$10,500	$50

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 using an economic model that assumed that the cost of capital was 7.5% 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 payback are shown in Table 5.

For the off-grid camp two fuel efficiencies were considered, 2 kWh per litre and 1 kWh per litre, which corresponds roughly to a small diesel generator reasonably well loaded and a Honda 6,500 watt generator with the inverter loaded at about 50%, respectively.

For net metering homes, three PV energy value cases were considered: (1) the subsidized Yellowknife rate of $0.232 per kWh, (2) the unsubsidized community rate of $0.8457 per kWh, and (3) the incremental diesel savings of $0.431 per kWh. Note that the diesel saving of $0.431 per kWh is a 20 year levelized cost also used in wind project analyses. The 25 year levelized cost would be a bit higher but using the same value as in the wind generation option avoids confusion.

For the utility scale project, only the diesel saving of $0.431 per kWh was considered.

For off-grid camps, the 25 year LCOE ranged from $2.73 per kWh with the dual axis tracker to $3.73 per kWh with the fixed array. This compares to $1.22 to $2.43 per kWh from small generators, depending on fuel efficiencies. The simple payback after O&M expenses ranges from about 13 to 36 years, depending on the fuel efficiency of the generator and whether a tracker is used on the PV array. A dual axis tracker and the less fuel efficient generator results in the fastest payback, while the fixed array and more efficient generator results in the longer payback.

Table 5: Summary of PV energy cost and payback ranges

System description	LCOE $/kWh	LCOE* diesel $/kWh	Community rate	Yellowknife rate	Simple payback after maintenance years
Off-grid camp					
Fixed array	$3.73	$1.22 to $2.43			18 to 36
Array on tracker	$2.73 to $2.77	$1.22 to $2.43			13 to 26
Net metering home					
Fixed array	$0.83	$0.431	$0.8457	$0.232	11 to 44
Array on tracker	$0.77	$0.431	$0.8457	$0.232	10 to 42
Utility					
Fixed array	$0.67	$0.431			18
Array on tracker	$0.65	$0.431			18
* the LCOE for camp diesel is over 25 years, for other applications over 20 years					

For PV arrays on grid connected homes, the 25 year LCOE ranges from $0.77 per kWh with a tracker, to $0.83 per kWh with a fixed array (with tilt adjusted twice per year). The modified simple payback at the unsubsidized community rate is 10 to 11 years, at the LCOE diesel cost is 21 to 23 years, and at the subsidized (in Whati) Yellowknife rate is about 42 to 44 years.

For Utility scale projects, the LCOE of PV energy ranges from $0.67 per kWh for fixed and single axis tracked arrays to $0.65 per kWh for a dual axis tracked array. The modified simple paybacks were all about 18 years.

GHG Reductions

GHG reductions are directly proportional to the diesel energy displaced. For this reason off-grid applications (where the alternatives are small diesel or gas generators, which have poor efficiencies compared to utility generators) offer the greatest GHG reductions per unit of capacity. The GHG reductions at seasonal off-grid camps using a single axis tracker would range from 1,307 (436 litres diesel saved) to 2,613 (871 litres of gasoline saved) kg of CO_2 equivalent per year per installed kW of capacity. A dual axis tracker would be marginally better and a fixed array would save 32% less.

The GHG reductions resulting from three scales of solar systems connected to the grid are shown in Table 6. Net metering and utility scale projects all displace fuel at utility power plant fuel efficiencies, which in the case of Whati is 3.711 kWh per litre. These systems would save 872 kg of CO_2 equivalent per kW of installed capacity per year when fixed (with tilt adjusted twice per year), 1,167 kg of CO_2 equivalent per year on a single axis tracker, and 1,206 kg of CO_2 equivalent per year on a dual axis tracker. This assumes all of the installed capacity displaces diesel fuel. Larger projects in which some of the PV energy is surplus to system needs would result in lower GHG reductions.

Table 6: Annual energy productions, fuel savings and GHG reductions from grid-connected solar project scales of 1, 5, or 50 kW in Whati. The two configurations are fixed frame configuration with 45° tilt in summer and 90° in the winter and a single axis tracker.

Project Configuration	Diesel Electricity Displaced (kWh)		Diesel Fuel Saved (litres)		GHG Reductions (kg CO_2 equivalent)	
	fixed	One axis	fixed	One axis	fixed	One axis
Grid-connected – 1 kW	1,079	1,443	291	389	873	1,167
Grid-connected – 5 kW	5,395	7,215	1,454	1,944	4,362	5,832
Grid-connected – 50 kW	53,950	72,150	14,538	19,442	43,614	58,326

PV Project Conclusions

1. PV systems can be utilized in a variety of applications and scaled in size to meet requirements.
2. Complete PV systems of about 1kW of capacity for off-grid applications are likely to cost in the order of $25,000 to $27,500 per kW of installed capacity depending on whether a fixed array or trackers are used.
3. Home size net metering (grid connected) PV systems are likely to cost in the order of $10,000 to $12,500 per kW of installed capacity for fixed and tracker mounted systems, respectively, and

corresponding utility scale projects would likely cost in the order of $8,000 to $10,500 per kW of installed capacity.

4. The cost of energy from grid connected PV systems at $0.65 to $0.83 per kWh is substantially cheaper than energy from wind energy projects in Whati (lowest cost $2.082 per kWh) but still more expensive than the marginal cost of diesel generation at $0.431 per kWh.
5. For both small and utility scale grid connected solar systems there is a small cost advantage to using single axis trackers compared to dual axis or fixed arrays.
6. It is possible that capital costs for grid connected systems could be reduced with larger scale projects or a larger number of projects, but at present it would appear that the resulting energy would still be more costly than diesel generation.

Next Steps

1. If Whati is considering alternative energy developments, the use of PV energy generation would be a 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. If a wind energy development were to be considered seriously for Whati, a wind monitoring mast should be installed at the proposed project site.
3. Following confirmation of the wind resource, a detailed feasibility study could be carried out. Particular attention would be required to minimize capital costs and identify any available support programs.
4. Should Whati wish to pursue either a PV or a wind energy project, subsidies would be required to make the project cost-effective compared to continued diesel generation.
5. If a utility or independent power producer were to pursue a larger scale solar project (larger than 50 kW) then further feasibility work with energy and economic modelling would be recommended to further optimize solar system integration with the diesel plant

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Appendix 1

NORTHWEST TERRITORIES
POWER
CORPORATION

Department of Finance, 4 Capital Drive, Hay River, NT X0E 1G2; *Phone (867) 874-5200 Fax (867) 874-5251*

November 24, 2006

John Hill, Chair
Northwest Territories Public Utilities Board
203-62 Woodland Drive
Box 4211
Hay River, NT

Dear Mr. Hill,

Enclosed are seven copies of Northwest Territories Power Corporation's ("NTPC's") 2006/07 and 2007/08 Phase I General Rate Application and supporting materials ("Phase I Application"). The Phase I Application sets out the forecast costs to supply customers for the two test years, the revenues that are forecast to arise at existing rates, and a consequent shortfall requiring changes to rates.

The Phase I Application addresses company-wide costs, revenues and investments required to determine the NTPC overall revenue requirement. Also included in the Phase I Application is the NTPC's response to various directives of the Northwest Territories Public Utilities Board ("PUB" or "Board") related to revenue requirement matters.

Community-specific revenue requirements and resulting final rate proposals will be addressed as part of NTPC's Phase II Application. In addition, the Phase II Application is expected to address three remaining Board directives from the 2001/03 GRA[1].

[1] Board Directive 10 from Decision 3-2003 regarding time of use rates, Directive 2 from Decision 7-2003 regarding legacy assets in cost-of-service and Directive 3 from Decision 7-2003 regarding cost-of-service for Rae/Edzo (now Behchoko) and Dettah are all properly cost-of-service or rate design topics and are more properly suited to a Phase II filing.

NORTHWEST TERRITORIES POWER CORPORATION

Schedule 3.3.2

2007/08 FORECAST PRODUCTION FUEL COST

Line No.	Plant No.		Generation (kWh)	Plant Efficiency (kWh/L)	Fuel Required (Litres)	Fuel Price ($/L)	Fuel Cost ($000's)
1	101	Yellowknife	1,379,000	3.500	394,000	0.755	297
2	104	Wha Ti	1,730,422	3.711	466,256	0.897	418
3	105	Gameti	975,320	3.398	287,008	0.927	266
4	108	Behchoko	21,125	3.250	6,500	0.778	5
5	110	Lutsel K'e	1,637,723	3.778	433,468	0.896	388
6	201	Fort Smith	465,700	3.277	142,102	0.793	113
7	203	Fort Resolution	60,000	3.459	17,345	0.860	15
8	205	Fort Simpson	8,238,565	3.755	2,193,767	0.862	1,890
9	206	Fort Liard	2,719,334	3.725	730,105	0.877	641
10	207	Wrigley	667,892	3.525	189,491	0.885	168
11	208	Nahanni Butte	372,594	2.511	148,360	0.877	130
12	209	Jean Marie River	339,598	2.749	123,547	0.858	106
13	301	Inuvik Power - D	1,675,500	3.635	460,935	0.797	367
14	304	Norman Wells - D	63,000	3.414	18,451	0.841	16
15	305	Tuktoyaktuk	4,584,515	3.697	1,240,016	1.001	1,241
16	306	Fort McPherson	3,422,267	3.609	948,301	0.926	878
17	307	Aklavik	2,776,285	3.475	798,914	0.914	730
18	308	Deline	2,658,924	3.546	749,826	1.015	761
19	309	Fort Good Hope	2,874,492	3.576	803,823	1.001	804
20	310	Tulita	2,200,488	3.634	605,551	0.905	548
21	311	Paulatuk	1,350,941	3.492	386,914	1.090	422
22	312	Sachs Harbour	907,022	3.189	284,401	1.075	306
23	313	Tsiigehtchic	864,359	3.537	244,353	0.985	241
24	314	Colville Lake	338,554	2.957	114,488	1.133	130
25	315	Ulukhaktok	1,986,962	3.616	549,489	1.111	610
26	**Subtotal - Diesel**		**44,310,582**	**3.603**	**12,337,411**	**0.931**	**11,491**

NATURAL GAS

Line No.	Plant No.		Generation (kWh)	Plant Efficiency (kWh/L)	Fuel Required (m^3)	Fuel Price (m^3)	Fuel Cost ($000's)
27	301	Inuvik	29,773,906	3.399	8,758,336	0.430	3,769
28	**Subtotal - Natural Gas**		**29,773,906**		**8,758,336**		**3,769**

PURCHASED POWER

Line No.	Plant No.		Generation (kWh)	Price ($/kWh)	Cost ($000's)
29	304	Norman Wells	9,305,234	0.279	2,593
30	**Subtotal - Purch. Power**		**9,305,234**	**0.279**	**2,593**

Schedule A.2

Northwest Territories Power Corporation
2006/07 - 2007/08 General Rate Application
Summary of Generation, Sales, and Revenue
104 Wha-ti

Line no.	Description	2002/03 Negotiated Settlement	2004/05 Actual	2005/06 Actual	2006/07 Forecast @ Existing Rates	2007/08 Forecast @ Existing Rates
	SALES AND REVENUE					
	Residential					
1	Sales (MWh)	808	818	812	817	830
2	Customers	102	122	126	125	128
3	Av. MWh Sales/Cust.	7.89	6.71	6.44	6.54	6.46
4	Revenue (000s)	643	655	651	655	665
5	Cents /kWh	79.56	80.02	80.20	80.12	80.16
	General Service					
6	Sales (MWh)	887	738	735	729	722
7	Customers	37	28	31	33	36
8	Av. MWh Sales/Cust.	24.09	26.35	23.72	22.24	20.31
9	Revenue (000s)	656	548	548	546	542
10	Cents /kWh	73.94	74.32	74.48	74.80	75.08
	Wholesale					
11	Sales (MWh)					
12	Customers					
13	Revenue (000s)					
14	Cents /kWh					
	Industrial					
15	Sales (MWh)					
16	Customers					
17	Av. MWh Sales/Cust.					
18	Revenue (000s)					
19	Cents /kWh					
	Streetlights					
20	Sales (MWh)	17	18	21	21	21
21	Revenue (000s)	22	24	27	27	27
22	Cents /kWh	123.70	129.88	129.87	129.89	129.89
	Total Community					
23	**Sales (MWh)**	**1,713**	**1,575**	**1,568**	**1,567**	**1,572**
24	Customers	139	**150**	**157**	**158**	**164**
25	Revenue (000s)	1,320	**1,227**	**1,226**	**1,227**	**1,234**
26	Cents /kWh	77.10	77.93	78.17	78.30	78.49
	GENERATION (MWh)					
27	**Total Station Service**	32.6	23	23	23	23
28	**Total Losses**	116	111	113	135	135
29	***Losses - % of Gen.***	*6.2%*	*6.5%*	*6.6%*	*7.8%*	*7.8%*
30	**Total Generation**	**1,861**	**1,708**	**1,704**	**1,726**	**1,730**
	Source (MWh)					
31	Hydro Generation					
32	Gas Generation					
33	Gas Efficiency					
34	*Cubic Meters (000s)*					
35	Diesel Generation	1,861	1,708	1,704	1,726	1,730
36	Diesel Efficiency	3.147	3.654	3.778	3.711	3.711
37	*Liters (000s)*	*591*	*468*	*451*	*465*	*466*
38	Purchased Power					
39	Total Generation	1,861	1,708	1,704	1,726	1,730
	% of Total Generation					
40	Hydro					
41	Gas					
42	Diesel	*100.0%*	*100.0%*	*100.0%*	*100.0%*	*100.0%*
43	Purchased					
	Peak (kW)					
44	Total Peak	455	370	365	376	378
45	Load Factor	46.7%	52.7%	53.3%	52.3%	52.2%

NORTHWEST TERRITORIES POWER CORPORATION

RATE SCHEDULE

Effective Date: December 1, 2010
Supersedes: November 1, 2008

Zone: Thermal

Residential Government

Monthly Service Charge: $18.00

Energy Charge

Wha Ti	84.57	¢/kWh
Gameti	129.80	¢/kWh
Lutsel K'e	78.53	¢/kWh
Fort Simpson	73.44	¢/kWh
Fort Liard	78.06	¢/kWh
Wrigley	137.92	¢/kWh
Nahanni Butte	166.40	¢/kWh
Jean Marie River	148.70	¢/kWh
Inuvik	60.35	¢/kWh
Tuktoyaktuk	70.80	¢/kWh
Fort McPherson	81.59	¢/kWh
Aklavik	64.84	¢/kWh
Deline	83.20	¢/kWh
Fort Good Hope	72.41	¢/kWh
Tulita	89.51	¢/kWh
Paulatuk	122.92	¢/kWh
Sachs Harbour	152.12	¢/kWh
Tsiigehtchic	112.71	¢/kWh
Colville Lake	230.26	¢/kWh
Ulukhaktok	70.75	¢/kWh

Minimum Monthly Bill: $18.00

Residential Non-Government

Monthly Service Charge: $18.00

Energy Charge: 47.39 ¢/kWh

Minimum Monthly Bill: $18.00

Zone: Thermal

General Service Government

Demand Charge: $8.00/kW

Energy Charge

Wha Ti	78.50 ¢/kWh
Gameti	149.18 ¢/kWh
Lutsel K'e	73.03 ¢/kWh
Fort Simpson	64.34 ¢/kWh
Fort Liard	70.37 ¢/kWh
Wrigley	147.49 ¢/kWh
Nahanni Butte	214.65 ¢/kWh
Jean Marie River	200.65 ¢/kWh
Inuvik	53.68 ¢/kWh
Tuktoyaktuk	62.87 ¢/kWh
Fort McPherson	74.64 ¢/kWh
Aklavik	61.95 ¢/kWh
Deline	78.50 ¢/kWh
Fort Good Hope	63.42 ¢/kWh
Tulita	86.46 ¢/kWh
Paulatuk	116.15 ¢/kWh
Sachs Harbour	142.58 ¢/kWh
Tsiigehtchic	99.84 ¢/kWh
Colville Lake	200.26 ¢/kWh
Ulukhaktok	64.04 ¢/kWh

Minimum Monthly Bill: $40.00

Stand-by Charge: $24.00 /kW

* General Service – Billing Demand shall be the greater of the current month's maximum Demand or the maximum Demand experienced during the 12 month period ending with the current billing month.

* Stand-by eligibility is negotiated with NTPC on a per customer basis and subject to all applicable energy rates and riders.

Zone: Thermal

General Service Non-Government

Demand Charge:	$8.00 /kW
Energy Charge:	40.20 ¢/kWh
Minimum Monthly Bill:	$40.00
Stand-by Charge:	$24.00 /kW

* General Service – Billing Demand shall be the greater of the current month's maximum Demand or the maximum Demand experienced during the 12 month period ending with the current billing month.

* Stand-by eligibility is negotiated with NTPC on a per customer basis and subject to all applicable energy rates and riders.

Appendix 2

Whati wind project calculation of net diesel displaced from HOMER model output									
Minimum diesel plant load 52.5kW (30% of 175kW smallest generator)									
		Losses from generation				Reductions in surplus			
Project configuration	HOMER generation kWh	Availability 95%	Electrical & other 5%	Net generation	HOMER surplus energy kWh	Availability	Electrical & other losses	Net surplus	Diesel displaced kWh
2 Endurance E3120	118,327	5,916	11,833	100,578	604	0	604	0	100,578
1 Northwind 100-23	80,394	4,020	8,039	68,335	62	0	62	0	68,335
Notes:									
Tower Heights		The tallest available tower is used for the selected wind turbines							
Endurance E3120		The Endurance is on a 42.7 m tall tower at which the mean wind speed is estimated to be 3.9 m/s							
Northwind 100		The Northwind 100 in on a 37 m tall tower at which the mean wind speed is estimated to be 3.8 m/s							
Assumptions in reductions of surplus									
For 1 Northwind 100		The very small amount of surplus energy would be consumed by electrical & other losses							
For 2 Endurance E3120s		The very small amount of surplus energy would be consumed by electrical & other losses							

Appendix 3

Whati Wind Project Capital, O&M, and Energy Cost Summary		
Site close to power line		
	medium penetration	medium penetration
Cost category	**1 NPS NW 100kW turbine**	**2 E-3120 50kW turbines**
Project design and Management		
project design	$20,000	$30,000
environmental assessment & permitting	$15,000	$20,000
project management	$30,000	$40,000
Site Preparation		
road construction ($50,000 per km) 600m + 100/turbine	$30,000	$35,000
site & crane pad construction $10,000 per turbine	$10,000	$20,000
powerline construction ($150,000 per km), $100k + 100m/turbine	$100,000	$115,000
Wind Equipment Purchase		
wind turbines including towers & supervisory control system	$425,000	$500,000
transformers	$25,000	$25,000
shipping to Hay River	$50,000	$50,000
shipping Hay River to Whati	$10,000	$10,000
wind dispatch or secondary load controller	$30,000	$30,000
Installation		
geotehnical & foundation design	$80,000	$80,000
foundations	$100,000	$100,000
equipment rental	$30,000	$50,000
crane mob and de-mob	$100,000	$100,000
crane site work	$15,000	$20,000
control buildings	$10,000	$10,000
utility interconnection	$45,000	$45,000
labour - assembly & supervision	$50,000	$70,000
commissioning (simple, dispatch, & sec load)	$20,000	$45,000
travel and accommodation	$30,000	$40,000
Diesel Plant Modifications		
radio / high speed communications	$20,000	$20,000
PLC modifications	$10,000	$10,000
other plant modifications	$20,000	$20,000
Other		
initial spare parts	$5,000	$10,000
Insurance	$15,000	$20,000
other overhead costs (contracts etc.)	$50,000	$50,000
Subtotal construction	**$1,345,000**	**$1,565,000**
Contingency 10%	$134,500	$156,500
TOTAL CONSTRUCTION	**$1,479,500**	**$1,721,500**
Owners Costs		
staff training	$35,000	$35,000
Subtotal owners costs	**$35,000**	**$35,000**
TOTAL PROJECT COST	**$1,514,500**	**$1,756,500**
Installed capacity kW	100	110
Installed cost per kW	**$15,145**	**$15,968**
Annual O&M costs ($20,000 + $15,000/ additional turbine)	$20,000	$35,000
Total annual costs	$20,000	$35,000
Annual net wind energy kWh at hub height	68,335	100,578
Annual diesel energy displaced	68,335	100,578
Levelized cost of energy (LCOE) 20 year life $ per kWh	$2.467	$2.082

Appendix 4

Leading Edge Projects Generation LCOE Economic Model											
Project: Wha Ti 1 NorthWind 100 wind turbine - low penetration $20k O&M											
Capital cost	$1,514,500	$15,145/kW	Capacity	100	kW	Fixed O&M	$20,000	per year	Discount rate	5.39%	
Cost of capital	7.50%	Debt & equity	Annual Energy	68,335	kWh	Variable O&M	$0.00	per kWh			
Inflation	2.00%	per year	Project life	20	Years	Capacity factor					
Year	**Capital**	**Cost of Cap**	**Depreciation**	**Fixed O&M**	**Variable O&M**	**Total Ann cost**	**Ann energy**	**Cost per kWh**	**Discounted cost**	**Discounted energy**	**Discounted cost per kWh**
1	$1,514,500	$113,588	$75,725	$20,000	$0	$209,313	68,335	$3.063	$209,313	68,335	$3.063
2	$1,438,775	$107,908	$75,725	$20,400	$0	$204,033	68,335	$2.986	$193,594	64,839	$2.986
3	$1,363,050	$102,229	$75,725	$20,808	$0	$198,762	68,335	$2.909	$178,944	61,521	$2.909
4	$1,287,325	$96,549	$75,725	$21,224	$0	$193,499	68,335	$2.832	$165,292	58,374	$2.832
5	$1,211,600	$90,870	$75,725	$21,649	$0	$188,244	68,335	$2.755	$152,576	55,387	$2.755
6	$1,135,875	$85,191	$75,725	$22,082	$0	$182,997	68,335	$2.678	$140,735	52,554	$2.678
7	$1,060,150	$79,511	$75,725	$22,523	$0	$177,759	68,335	$2.601	$129,713	49,865	$2.601
8	$984,425	$73,832	$75,725	$22,974	$0	$172,531	68,335	$2.525	$119,456	47,314	$2.525
9	$908,700	$68,153	$75,725	$23,433	$0	$167,311	68,335	$2.448	$109,915	44,893	$2.448
10	$832,975	$62,473	$75,725	$23,902	$0	$162,100	68,335	$2.372	$101,043	42,596	$2.372
11	$757,250	$56,794	$75,725	$24,380	$0	$156,899	68,335	$2.296	$92,797	40,417	$2.296
12	$681,525	$51,114	$75,725	$24,867	$0	$151,707	68,335	$2.220	$85,136	38,349	$2.220
13	$605,800	$45,435	$75,725	$25,365	$0	$146,525	68,335	$2.144	$78,021	36,387	$2.144
14	$530,075	$39,756	$75,725	$25,872	$0	$141,353	68,335	$2.069	$71,416	34,525	$2.069
15	$454,350	$34,076	$75,725	$26,390	$0	$136,191	68,335	$1.993	$65,288	32,759	$1.993
16	$378,625	$28,397	$75,725	$26,917	$0	$131,039	68,335	$1.918	$59,604	31,083	$1.918
17	$302,900	$22,718	$75,725	$27,456	$0	$125,898	68,335	$1.842	$54,336	29,492	$1.842
18	$227,175	$17,038	$75,725	$28,005	$0	$120,768	68,335	$1.767	$49,455	27,984	$1.767
19	$151,450	$11,359	$75,725	$28,565	$0	$115,649	68,335	$1.692	$44,936	26,552	$1.692
20	$75,725	$5,679	$75,725	$29,136	$0	$110,541	68,335	$1.618	$40,753	25,193	$1.618
									$2,142,325	868,417	$2.467
Real levelized cost of energy					**$2.467**						

Appendix 4

Leading Edge Projects Generation LCOE Economic Model

Project: Wha Ti 2 Endurance E3120 wind turbines - medium+ penetration $35k O&M

Capital cost	$1,756,500	$15,968/kW	Capacity	110	kW	Fixed O&M	$35,000	per year	Discount rate	5.39%	
Cost of capital	7.50%	Debt & equity	Annual Energy	100,578	kWh	Variable O&M	$0.00	per kWh			
Inflation	2.00%	per year	Project life	20	Years	Capacity factor					
Year	**Capital**	**Cost of Cap**	**Depreciation**	**Fixed O&M**	**Variable O&M**	**Total Ann cost**	**Ann energy**	**Cost per kWh**	**Discounted cost**	**Discounted energy**	**Discounted cost per kWh**
1	$1,756,500	$131,738	$87,825	$35,000	$0	$254,563	100,578	$2.531	$254,563	100,578	$2.531
2	$1,668,675	$125,151	$87,825	$35,700	$0	$248,676	100,578	$2.472	$235,953	95,432	$2.472
3	$1,580,850	$118,564	$87,825	$36,414	$0	$242,803	100,578	$2.414	$218,593	90,550	$2.414
4	$1,493,025	$111,977	$87,825	$37,142	$0	$236,944	100,578	$2.356	$202,405	85,917	$2.356
5	$1,405,200	$105,390	$87,825	$37,885	$0	$231,100	100,578	$2.298	$187,313	81,521	$2.298
6	$1,317,375	$98,803	$87,825	$38,643	$0	$225,271	100,578	$2.240	$173,246	77,350	$2.240
7	$1,229,550	$92,216	$87,825	$39,416	$0	$219,457	100,578	$2.182	$160,140	73,393	$2.182
8	$1,141,725	$85,629	$87,825	$40,204	$0	$213,658	100,578	$2.124	$147,932	69,638	$2.124
9	$1,053,900	$79,043	$87,825	$41,008	$0	$207,876	100,578	$2.067	$136,564	66,075	$2.067
10	$966,075	$72,456	$87,825	$41,828	$0	$202,109	100,578	$2.009	$125,983	62,694	$2.009
11	$878,250	$65,869	$87,825	$42,665	$0	$196,359	100,578	$1.952	$116,136	59,487	$1.952
12	$790,425	$59,282	$87,825	$43,518	$0	$190,625	100,578	$1.895	$106,977	56,443	$1.895
13	$702,600	$52,695	$87,825	$44,388	$0	$184,908	100,578	$1.838	$98,459	53,555	$1.838
14	$614,775	$46,108	$87,825	$45,276	$0	$179,209	100,578	$1.782	$90,543	50,815	$1.782
15	$526,950	$39,521	$87,825	$46,182	$0	$173,528	100,578	$1.725	$83,187	48,216	$1.725
16	$439,125	$32,934	$87,825	$47,105	$0	$167,865	100,578	$1.669	$76,355	45,749	$1.669
17	$351,300	$26,348	$87,825	$48,047	$0	$162,220	100,578	$1.613	$70,012	43,408	$1.613
18	$263,475	$19,761	$87,825	$49,008	$0	$156,594	100,578	$1.557	$64,126	41,187	$1.557
19	$175,650	$13,174	$87,825	$49,989	$0	$150,987	100,578	$1.501	$58,667	39,080	$1.501
20	$87,825	$6,587	$87,825	$50,988	$0	$145,400	100,578	$1.446	$53,605	37,080	$1.446
									$2,660,757	1,278,168	$2.082
Real levelized cost of energy					**$2.082**						

Appendix 5

Leading Edge Projects Generation LCOE Economic Model

Project: Wha Ti incremental diesel generation, 3.711 kWh per litre, fuel at $1.25 per litre, fuel inflation at 2% per year, variable O&M $0.03 per kWh

Capital cost	$0		Capacity		kW	Fixed O&M	$3,000	per year	Discount rate	5.39%	
Cost of capital	7.50%	Debt & equity	Annual Energy	100,000	kWh	Fuel	$0.337	per kWh			
Inflation	2.00%	per year	Project life	20	Years	Capacity factor			Fuel inflation	2.00%	

Year	Capital	Cost of Cap	Depreciation	Fixed O&M	Variable O&M	Total Ann cost	Ann energy	Cost per kWh	Discounted cost	Discounted energy	Discounted cost per kWh
1	$0	$0	$0	$3,000	$33,700	$36,700	100,000	$0.367	$36,700	100,000	$0.367
2	$0	$0	$0	$3,060	$34,374	$37,434	100,000	$0.374	$35,519	94,884	$0.374
3	$0	$0	$0	$3,121	$35,061	$38,183	100,000	$0.382	$34,376	90,029	$0.382
4	$0	$0	$0	$3,184	$35,763	$38,946	100,000	$0.389	$33,269	85,423	$0.389
5	$0	$0	$0	$3,247	$36,478	$39,725	100,000	$0.397	$32,198	81,053	$0.397
6	$0	$0	$0	$3,312	$37,208	$40,520	100,000	$0.405	$31,162	76,906	$0.405
7	$0	$0	$0	$3,378	$37,952	$41,330	100,000	$0.413	$30,159	72,971	$0.413
8	$0	$0	$0	$3,446	$38,711	$42,157	100,000	$0.422	$29,188	69,238	$0.422
9	$0	$0	$0	$3,515	$39,485	$43,000	100,000	$0.430	$28,249	65,695	$0.430
10	$0	$0	$0	$3,585	$40,275	$43,860	100,000	$0.439	$27,340	62,334	$0.439
11	$0	$0	$0	$3,657	$41,080	$44,737	100,000	$0.447	$26,460	59,145	$0.447
12	$0	$0	$0	$3,730	$41,902	$45,632	100,000	$0.456	$25,608	56,119	$0.456
13	$0	$0	$0	$3,805	$42,740	$46,544	100,000	$0.465	$24,784	53,248	$0.465
14	$0	$0	$0	$3,881	$43,595	$47,475	100,000	$0.475	$23,986	50,523	$0.475
15	$0	$0	$0	$3,958	$44,466	$48,425	100,000	$0.484	$23,214	47,938	$0.484
16	$0	$0	$0	$4,038	$45,356	$49,393	100,000	$0.494	$22,467	45,486	$0.494
17	$0	$0	$0	$4,118	$46,263	$50,381	100,000	$0.504	$21,744	43,159	$0.504
18	$0	$0	$0	$4,201	$47,188	$51,389	100,000	$0.514	$21,044	40,950	$0.514
19	$0	$0	$0	$4,285	$48,132	$52,417	100,000	$0.524	$20,367	38,855	$0.524
20	$0	$0	$0	$4,370	$49,095	$53,465	100,000	$0.535	$19,711	36,867	$0.535
									$547,544	1,270,823	$0.431
Real levelized cost of energy					**$0.431**						