Paulatuk Wind Energy Pre-Feasibility Study

Prepared for

AURORA RESEARCH INSTITUTE
AURORA COLLEGE

by

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Executive Summary

The Hamlet of Paulatuk is an Inuvialuit community located on the south shore of Darnley Bay in the Amundsen Gulf. The community's electric load is powered by a diesel-electric generating plant owned and operated by the Northwest Territories Power Corporation (NTPC). The plant supplies 1,300 MWh/year of electrical energy to the community of 300 people. The average load in the community is 150 kW and the minimum and maximum loads are 90 and 250 kW. Because of increasing fuel delivery costs and uncertainties over the future price of oil, a wind feasibility study was initiated to examine whether a renewable energy source could provide a more secure energy future for Paulatuk.

In 2005 the Aurora Research Institute established a wind monitoring station (Site #1) east of the community in an open field at about 51 m above sea level. The wind data analysis shows a long-term annual mean wind speed of 5.2 and 5.8 m/s at 10- and 37 m above ground level. In the economic analysis the tallest tower available for a small scale wind project suitable for this community is 37 m tall, such as the EW50 turbine by Entegrity which is used for the economic analysis in this study.

The wind analysis and modeling is focused towards estimating winds at 37 m above ground level. Two proposed sites are considered for wind development in this study (Site #1 was deemed too far from power line for development): Site #2 is at a Quarry close to the ocean coast, and Site #3 is on a ridge by the water reservoir. Based on the wind analysis and numerical modeling, the long-term annual mean wind speeds for these proposed sites are 5.6 and 5.9 m/s, respectively.

The estimated capital cost for building at Site #2 is $534,000 or $8,215/kW, with a total cost of energy of $0.77/kWh. A project at this site will require a $0.34/kWh subsidy to compete with the present avoided cost of diesel at $0.43/kWh. The Site #3 is $617,000 or $9,492/kW and has a total cost of energy of $0.75/kWh, requiring a slightly smaller subsidy of $0.32/kWh. There is potential to lower costs with taller towers and large rotor diameters, however subsidies will still be required to compete with diesel-electric generation.

The next steps recommended are to move the wind monitoring tower to the best location as chosen by the community. Also, the hamlet should explore a consortium to install wind turbines in several communities in a "bulk" purchase to reduce costs, after the initial developments take place in Tuktoyaktuk.

Background

JP Pinard, P.Eng., Ph.D. and John Maissan, P.Eng. of Leading Edge Projects Inc. (the authors) have been retained by the Aurora Research Institute to conduct a pre-feasibility study for wind energy generation in Paulatuk. This study examines wind data from the airport stations, wind monitoring stations, maps, satellite images and makes use of a computer windflow model to identify potential wind monitoring sites around the community. This study provides the information listed below.

1) An analysis of wind data to estimate long-term mean wind speed and direction.
2) Estimates of the wind speeds around the hamlet generated with computer models.
3) A list of potential sites for location of wind equipment.
4) A description of the power system in the hamlet which includes the size, capacity and condition of present system.
5) An analysis of different scenarios of power demands for the hamlet.
6) Preliminary estimates of the cost of wind generation for the hamlet.
7) Estimates of power production and fuel displacement through integration of wind power.
8) An outline of next steps needed to pursue the integration of wind power in the hamlet.

Acronyms

AGL – above ground level

ARI – the Aurora Research Institute

ASL – above sea level

NTPC – Northwest Territories Power Corporation

NTCL – Northern Transportation Company Limited

MCP – Measure-Correlate-Predict, a method for projecting short-term wind measurements to long-term using nearby long-term weather stations such as those at the airport.

WM – wind monitoring site, refers to the site where the wind measurements for wind energy purposes are made.

Introduction

The Hamlet of Paulatuk (Figure 1) has a population of about 300 people and is located on the south shore of Darnley Bay in the Amundsen Gulf. The community is 880 km northwest of Yellowknife and is accessible by air and by barge. A diesel-electric generating plant that is owned and operated by the Northwest Territories Power Corporation (NTPC) supplies the electrical energy for Paulatuk. In June, 2005 ARI installed a wind monitoring station east of the community in an open field at about 51 m above sea level. A report was produced to estimate a long-term mean wind speed of 5.84 m/s at 30 m AGL (Pinard, 2007).

The purpose of this report is to examine the potential for wind power generation by providing a selection of potential sites, estimating the mean annual wind speed and estimating the economics of building a wind installation near the hamlet. The tallest available tower for building a wind energy farm in this community is 37 m. Therefore, the wind speeds in this report are estimated to 37 m above ground level.

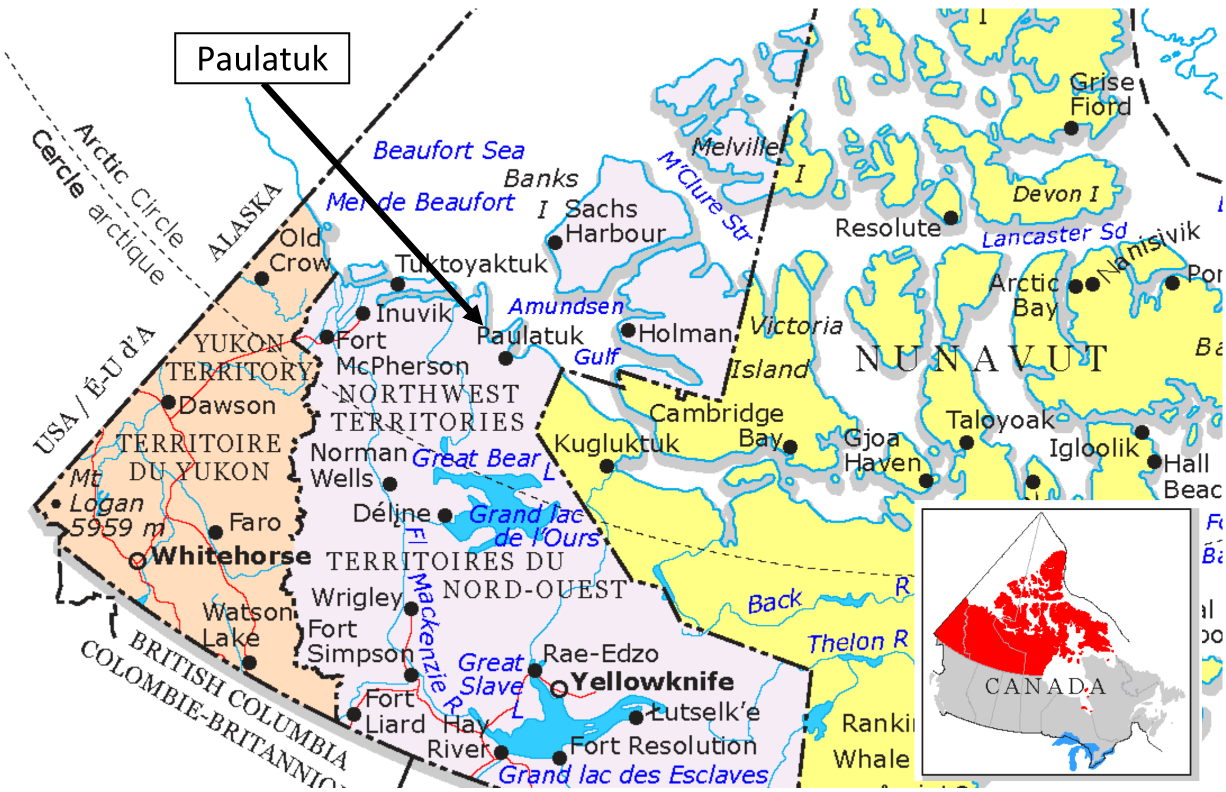

Figure 1: The location of Paulatuk in relation to the rest of Canada.

The Wind Data Collecting Stations

The ARI wind monitoring station at Site #1 is a 30 m tower set up with 3 wind speed sensors (anemometers). The sensors are located at 10-, 20-, and 30 m above ground level (AGL, see Figure 2) on the tower. The anemometer booms (1.1 m long) point to the west-southwest. One wind vane is installed at the tower top on a boom pointing south and a temperature sensor is at the bottom of the tower. The ARI station has been up and running since June 22, 2005 and the data used for this study is available to September, 2008.

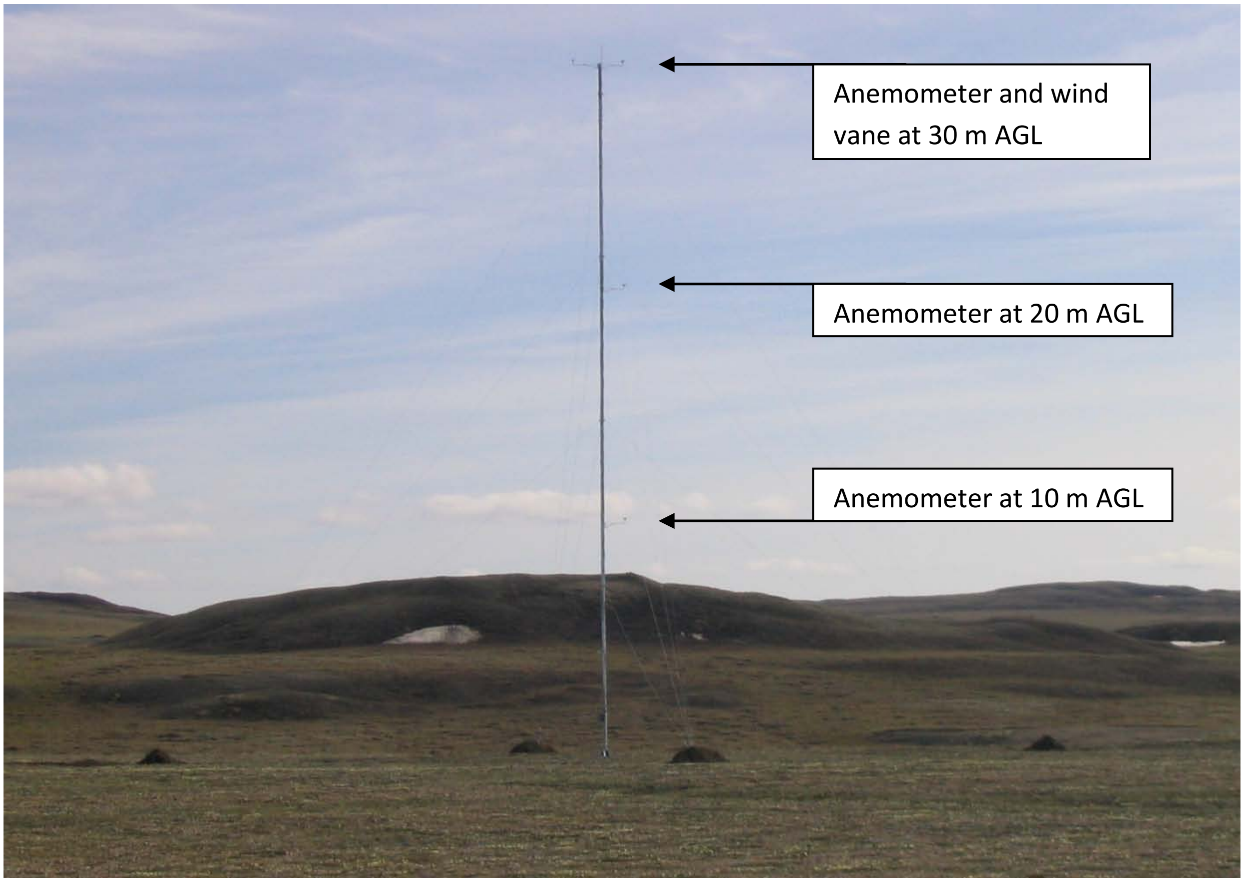

Figure 2: The ARI wind monitoring tower installed east of Paulatuk. It has three anemometers at 10, 20, and 30 m above the ground.

At the airport there are apparently two stations that measure the wind speeds. The weather data for both stations are stored at Environment Canada's website. The hourly data is stored in individual monthly files that can be downloaded from the website (requires several steps, and several minutes, to download each monthly data files). The airport "auto" station (automatic data collection) has recorded weather conditions 24 hours a day since 1994 and the data is stored directly to a data logger. The airport "A" station ("A" meaning that is operated and data collected by the airport staff) is typically monitored during office hours and its data is recorded manually at the top of each hour. The A station has collected data since 1987. Because of its 24-hour availability the auto station data is preferred for comparing to the ARI wind monitoring data set.

The two airport stations are identified in Paulatuk (Figure 3). It has not been clear which station is which. We normally think of an auto station having a more modern sensor as the one identified on a 2 m post in the figure below, however, Environment Canada specifies (through a phone conversation) that the auto is on a 10 m tower. The 10 m tower in Figure 3 is normally associated with the airport operations (i.e. has typically 8 hours of hourly data per day) and is designation with “A”. There are questions remaining whether the auto is on a 10 m tower or the 2 m tower in this case shown in Figure 3.

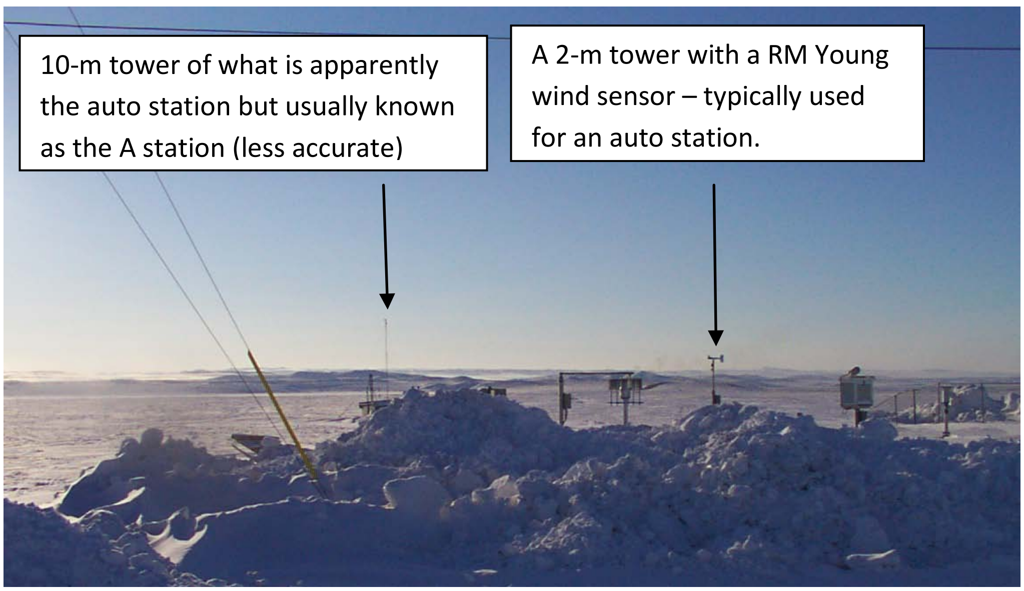

Figure 3: The two weather stations at the Paulatuk airport are the far tower left of centre and the short one to the right with a RM Young wind (speed and direction) sensor.

Wind Direction Analysis

In Paulatuk the dominant wind energy comes from the south to south-southwest as shown (Figure 4). The airport auto station shows more southerly winds in terms of energy than the wind monitoring station. The auto station is less accurate in terms of direction because the wind directions are recorded in 10s of degrees. Based on these wind roses a site that is to be chosen for a wind farm should be situated so as to have the best exposure to the south and south-southwest.

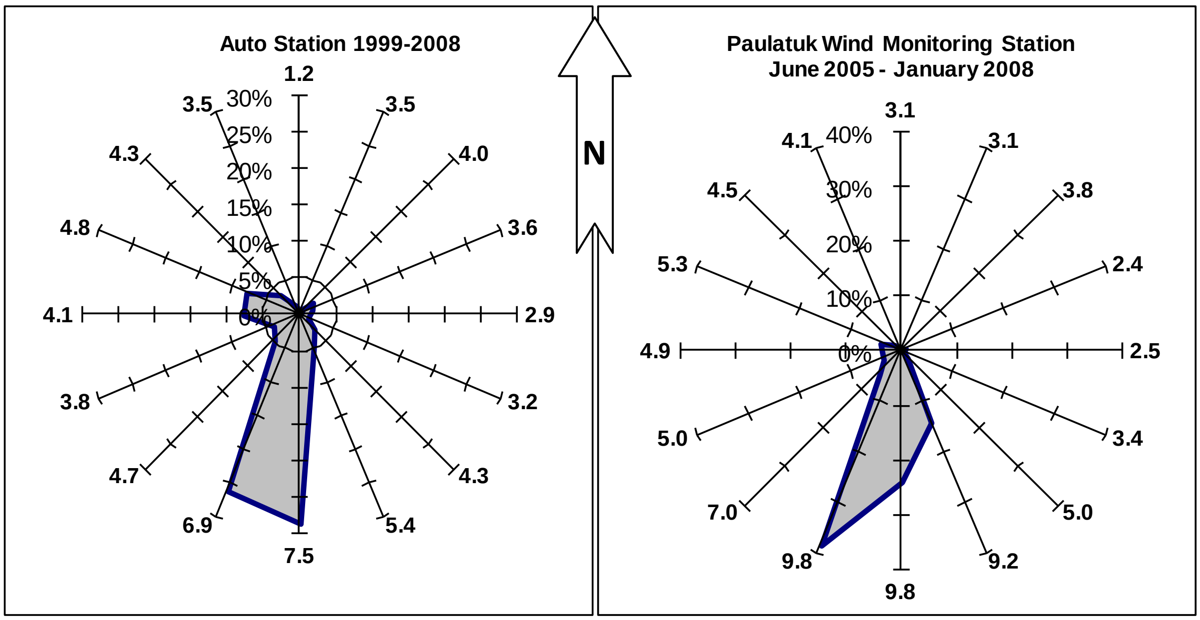

Figure 4: Wind energy roses for both the auto station (at the airport) and the ARI wind monitoring station. The shaded rose is the relative percentage of wind energy by direction. The mean wind speed by direction sector is indicated at the end of each axis. North is up and west is to the right.

Wind Speed Analysis

Defining the Long-term Mean in Paulatuk

At the airport the A station and the auto station are compared to each other for the period 2001-06 (Figure 5). During this period the auto station had an annual mean wind speed of 4.38 m/s and the A station was 4.24 m/s; the auto station's mean wind speed was about 3% above the A station during this period.

The auto station recorded the most recent 5-year (2004-08) mean wind speed of 4.51 m/s whereas the ten-year (1999-2008) mean wind speed was 4.34 m/s. The standard deviation of the mean annual wind speed about the ten -year mean is 0.35 m/s. Although Figure 5 appears to show a trend of increasing wind speed there are other longer term variabilities such as those due to ocean water temperature oscillations like the Arctic Decadal Oscillation (see Bond, 2009) that may be at play. Because of its 24-hour availability the auto station wind data is used for the comparative analysis with the 30 m data from the wind energy monitoring station. The ten-year data set is used as the long-term mean for estimating the wind monitoring station measurements.

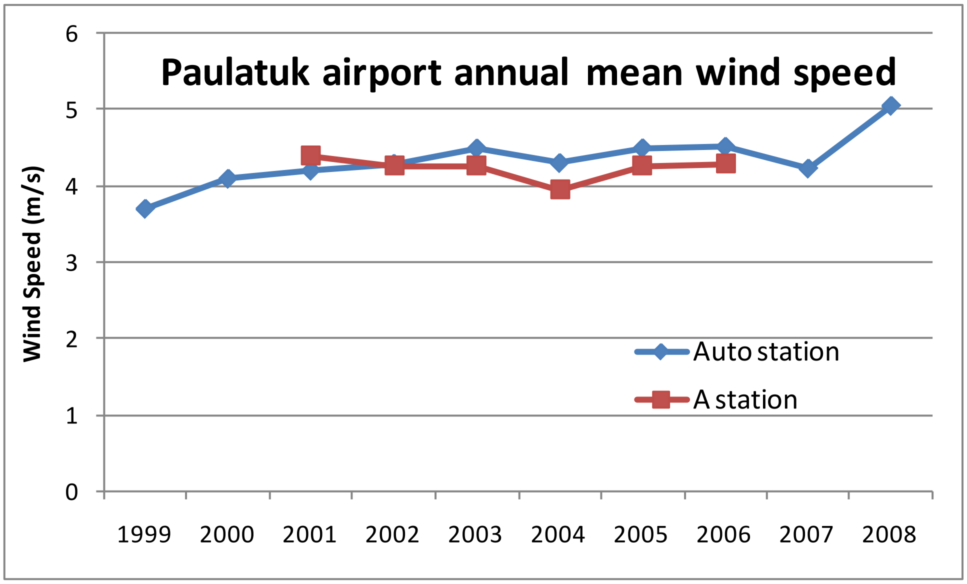

Figure 5: Time series graph comparing the airport's A station to the auto station. The 2001-06 period data for the A station was that extracted for the report Pinard (2007).

The long-term monthly wind speed at the airport auto station reveals faster winds during the winter months and particularly the months of October and January (Figure 6). The highest wind speeds occur in October with an estimate of 5.12 m/s at 10 m AGL. The wind diminishes to the lowest speed during the spring with June having the minimum monthly mean wind speed estimate of 3.64 m/s (10 m AGL).

The corrected power ratio shown in Figure 6 indicates that the effects of lower mean temperatures and the proximity to the ocean causes the air to be denser than the standard assumed air density used for calculating wind turbine power output. The denser air causes the turbines to produce more energy than is calculated at standard air temperature (+15°C) at sea level. The graph (Figure 6) shows that the corrected power ratio increases to a maximum factor of 1.17 during the winter months of February and March but stays above 1 during the entire year. In this report we use 1.10 (10%) as the mean increase in mean power production for our calculations. Additional details of the wind speed and other information monitored at the airport auto station are shown (Table 1).

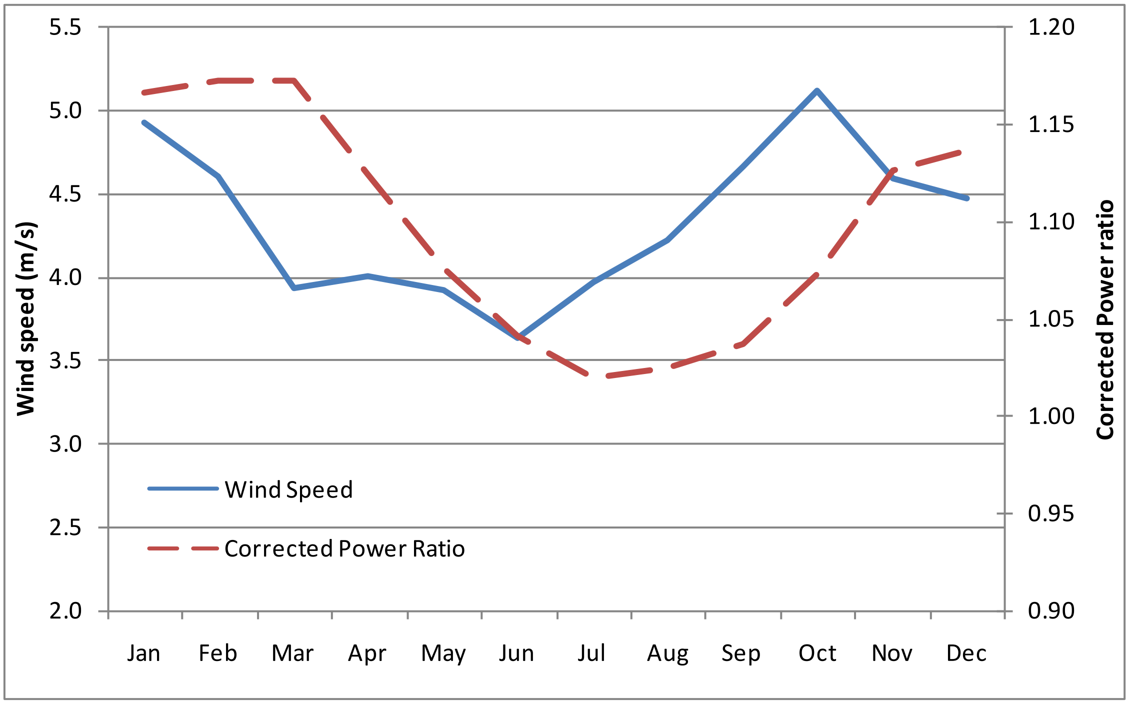

Figure 6: Long-term monthly means of the corrected power ratio and wind speed based on the ten-year (1999-2008) airport data measured at 10-m AGL. The wind speed is referenced to the left side and the air density to the right.

Table 1: Monthly mean values based on airport auto station measurements for the period 1999-2008. The wind speeds are measured at 10 m above ground level (AGL).

	Wind Speed (m/s)	Temperature (°C)	Pressure (kPa)	Density (kg/m^3)	Corrected Power Ratio
January	4.93	-24.9	101.8	1.43	1.17
February	4.61	-25.6	102.0	1.44	1.17
March	3.93	-25.1	102.3	1.44	1.17
April	4.01	-15.3	101.9	1.38	1.12
May	3.92	-4.0	101.9	1.32	1.08
June	3.64	4.3	101.5	1.27	1.04
July	3.97	9.0	101.2	1.25	1.02
August	4.22	7.8	101.2	1.26	1.02
September	4.66	4.1	101.1	1.27	1.04
October	5.12	-4.9	101.2	1.31	1.07
November	4.59	-16.8	101.5	1.38	1.13
December	4.48	-19.8	101.3	1.39	1.14
Annual	4.38	-9.2	101.6	1.34	1.09

Comparing the Wind Speed from the Auto and Wind Monitoring Stations

The period chosen for the comparative study is approximately four years, from 22 June, 2005 to September 2008. The wind speed correlation between the measurements of all three levels at the ARI wind monitoring site and the 10 m auto station was (Pearson) R= 0.86. Whereas R=0 means no correlation and R=1 is perfect correlation, these correlations are considered to be excellent. This correlation coefficient is used in estimating the long-term mean for the wind monitoring site (ARI Site #1).

During the four-year period the auto station recorded a mean wind speed of 4.51 m/s whereas the ARI wind monitoring station at 10 m AGL was 20% faster at 5.38 m/s. The comparisons were similar in the last analysis of wind speeds (Pinard 2007). During the same four-year period the mean wind speed at 20 m AGL was 5.71, but at 30 m they were slower with a mean value of 5.68 m/s. This slower wind at higher level is discussed in following sections.

Projecting to Higher Levels

Turbulent air flow over rough surfaces tends to generate a vertical profile of horizontal winds that are fairly 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. If we know the wind speeds at two heights of say 10 and 30 m then we can also find the value of z_o, look the value up on a roughness chart and compare the land description to the actual ground surrounding the station. With the known z_o we can use the log equation to predict the wind speed at higher elevations.

In the Paulatuk area the land surface is typically tundra with slightly undulating terrain with depressions that fill with snow during the winter (hence smoothening the surface and reducing z_o). The surface roughness based on the measurement is estimated to be 0.0002 m, this is a surface roughness that is somewhere between a flat desert and snow-covered flat or rolling ground. In previous reports the surface roughness z_o was calculated to be 0.0004 m (0.04 cm) which is slightly rougher than the new estimate (Pinard 2007).

The four profiles of wind speeds are shown (Figure 7). The measured wind (shown as “U (msd)”) shows that the top anemometer (30 m AGL) is measuring slower winds than the 20 m anemometer. The three anemometers are compared to each other in the time series graph (Figure 8). During events of low wind speeds (below 4 m/s, see oval in Figure 8) the 30 m anemometer reports slower winds than the other two anemometers at 10- and 20 m. By filtering out the lower wind speeds and re-fitting the rest of the measurements to the average wind speeds of the lower sensors we found that the wind speed profile improved and made a better match with a natural log profile with a surface roughness of z_o = 0.0002 m (see “U(msd-filtered)” in Figure 7). So using the above formula and the z_o we project the measurements to higher elevations as shown with “U(log)” in Figure 7.

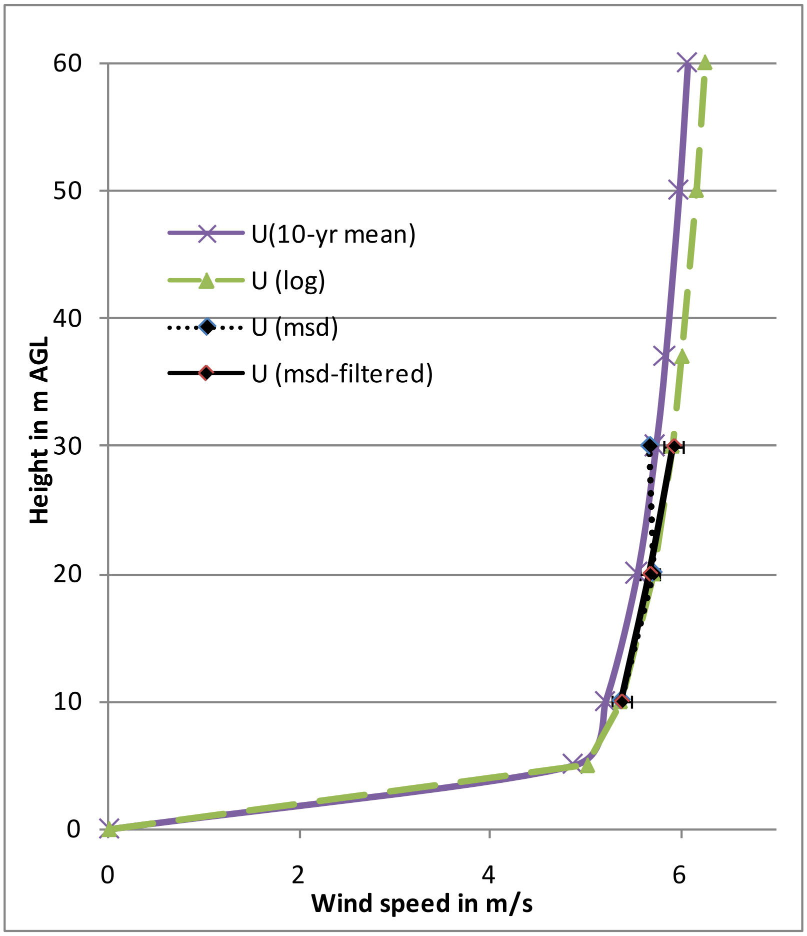

Figure 7: Vertical profiles of horizontal wind speeds at the ARI wind monitoring station. See above for discussion of U(msd) and U(msd-filtered). The vertical profile “U(log)” is fitted to the filtered measurements “U(msd-filtered)” and then adjusted to the long-term profile U(10-yr mean). Black whiskers associated with “U (msd-filtered)” indicate possible errors of ±0.1 m/s due to sensor inaccuracies.

New calibrated anemometers have been added to the Paulatuk wind monitoring station (site #1) at 20 and 30 m AGL. The new data suggest that the instruments at 30 m AGL are measuring similar wind speeds to each other at that level. They both however exhibit the same occasional behaviour discussed above at the lower wind speeds. This may then be due to a natural phenomenon known as a low-level jet, a downslope, or a drainage wind. A downslope wind is caused by gravity pulling down a slope the near-surface, heavier air that has been cooled by the cold snow surface. This downslope wind on its own typically has wind speeds ranging from 2 to 4 m/s and whose location of maximum wind speed range from a few metres to a few tens of metres above ground. In this case it seems that the maximum wind speed occurs around 20 m AGL. In Paulatuk the land rises towards the south and it is very conceivable that, on calmer days a sheet of near-surface air drains down the slope north towards Paulatuk. These types of winds are usually not significant for wind energy production, and they must be filtered out as done so above to avoid skewing the wind profile estimates.

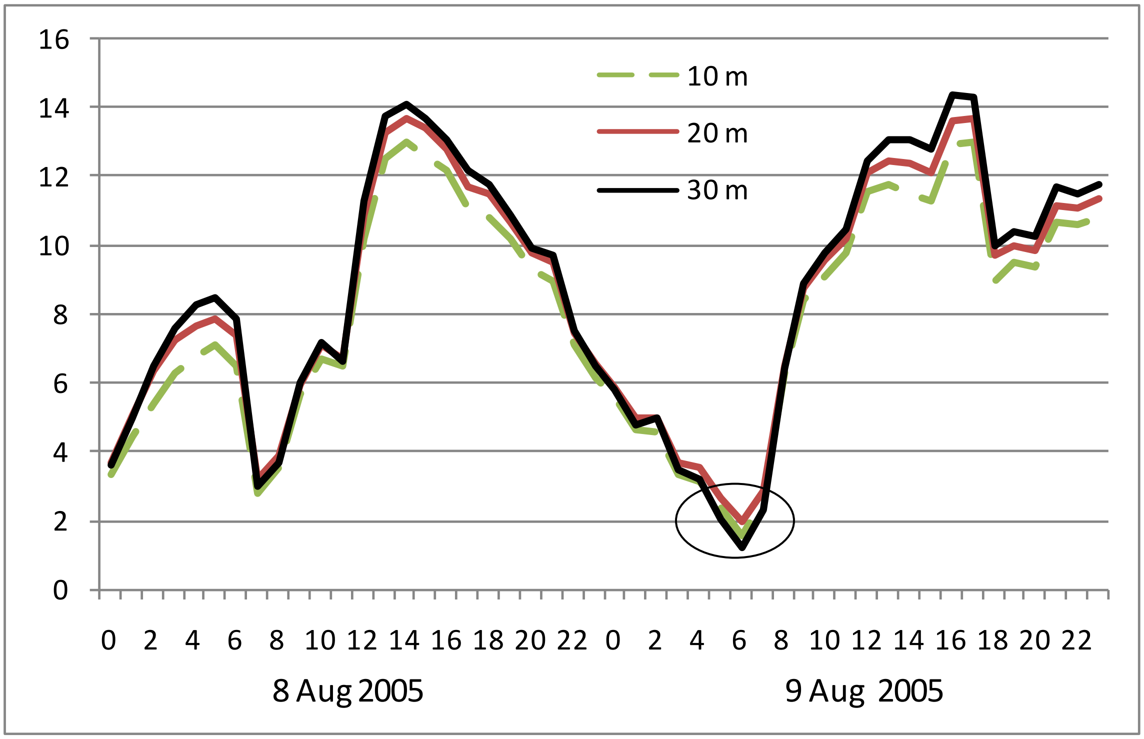

Figure 8: A time series graph comparing the anemometers at 10 m, 20 m, and 30 m at Site #1. Note (oval) that at low wind speeds the 30 m anemometer registers a lower speed than the 10, and 20 m anemometers.

Projecting to a Longer Term

The short-term wind speed profile discussed above is adjusted to a ten-year mean [U(10-yr mean) in Figure 7] using the MCP method of measuring, correlating, and predicting the long-term mean winds. The formula is:

$$E_s = \mu_s + \frac{R \cdot \sigma_s}{\sigma_r}(E_r - \mu_r),$$

where E_s is the estimated long term wind speed at the site of the wind monitoring station, μ_s is the measured wind speed at the site, μ_r is the measure reference wind speed, and E_r is the measured long-term mean wind speed at the reference station. The other variables in the equation are the correlation coefficient R and the standard deviation for the reference station, σ_r, and the wind monitoring site, σ_s. These values are listed (Table 2). From the above formulae the ten-year (1999-08) projected mean of the new site is 5.2 m/s and 5.83 m/s at 10 and 37 m AGL, respectively. The vertical profile of estimated long-term mean for the wind monitoring site (ARI Site #1) is shown (Figure 7 and Table 3).

Table 2: Details of values in the evaluation of the long-term mean wind speed of the wind monitoring station (Site #1) using the MCP method.

Measure-Correlate-Predict	10 m AGL	
Estimated Long-term mean at site Es =	**5.20**	m/s
Estimated Long-term mean at reference Er =	4.34	m/s
Measured site u_s =	5.38	m/s
Measured reference u_r =	4.51	m/s
Measured cross-correlation coefficient R =	0.86	
measured standard deviation at site $theta_s$ =	4.03	m/s
measured standard deviation at reference $theta_r$ =	3.22	m/s

Errors and Uncertainties in Measurement, Correlation, and Prediction

In making measurements, long-term predictions, and projections, errors are likely to occur. The typical error in the anemometer measurements from the wind (30 m towers) monitoring station is less than 0.1 m/s for wind speed ranging 5 to 25 m/s, which is less than a 2% error. The airport measurements are also considered better than 2% and thus within 0.1 m/s. The error from wind speeds projected to a higher level above ground was calculated by matching logarithmic profiles to the ±0.1 m/s extremes of the mean wind speeds at 10 and 30 m. In this study the projection error is estimated to be ±0.14 m/s for the 37 m estimate.

To reduce further errors due to shadow effect (slowing down anemometers) by towers the anemometers have been placed on 1.1 m booms away from the direction where the lowest frequency of wind occurs.

The reason for projecting wind speeds to long-term is to reduce errors in the long-term variability over the shorter term measurements. Thus the MCP method described above is meant to reduce such error. There is still however some variability in the long-term measurements, Pinard (2007) describes that the variability in the annual mean wind speed is less than 6% for measurements periods of five years or more. Looking at the more conservative estimates of the ten-year mean of 5.83 m/s (at 37 m AGL) the variability may be ±0.35 m/s. In summary we should expect the annual mean wind speed at the wind monitoring site to range from 5.48±0.14 to 6.18±0.14 m/s in any given year.

Numerical Modelling with MS-Micro

Since we only have two locations that are measured 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 Paulatuk area using a data elevation model from the Geobase.ca centre. The surface roughness values were estimated with lakes being z_o = 0.00001 m (ice surface) and the ground surface z_o = 0.0002 m. The model domain has an area that is 6 km square centred at a point shown in Figure 9 below. The model's surface (elevation) resolution is about 75 m horizontally (128 by 128 grid points), whereas the model grid for wind calculations is about 45 m (grid of 256 by 256).

Table 3: Details of measurements and their projection to longer term and to higher elevations. Bold values indicate the estimated long-term (10-years, 1999-2008) mean wind speed at the wind monitoring station (Site #1). These values are also shown in Figure 7 above as "U (10-yr mean)".

Location and measurement period	Height	Wind speed	
Paulatuk auto station, 22 June 05 to 2008	10 m AGL	4.51	m/s
Paulatuk WM Site #1, 22 June 05 to 2008	10 m AGL	5.38	m/s
	20 m AGL	5.71	m/s
	30 m AGL	5.68	m/s
Paulatuk auto station ten-year (1999-2008) mean:	10 m AGL	4.34	m/s
Ratio of 2005-08 to ten-year mean at auto station:		0.96	
Paulatuk WM Site #1 projected to ten years:	10 m AGL	**5.20**	m/s
	20 m AGL	**5.54**	m/s
	30 m AGL	**5.73**	m/s
	37 m AGL	**5.83**	m/s
	50 m AGL	**5.98**	m/s
	60 m AGL	**6.07**	m/s

The winds that are applied in the model simulation are normalised, arbitrary wind speeds, and three main wind directions are applied to the model: those being 160, 180, and 200 degrees for the three main wind directions measured by the wind monitoring station. The model is run three times 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 37 m AGL of 5.8 m/s at the ARI wind monitoring site (WM or Site #1). The results of the MS-Micro modelling are shown (Figure 9).

The model results suggest that the winds at the airport should be about 5.7 m/s (at 37 m AGL), from the auto station measurements of 4.34 m/s with the assumption that these were made at 10 m AGL, the wind speed projected to 37 m is 4.6 m/s. However, it has not been clear from information given by Environment Canada that the auto is at 10 m AGL: from Figure 3 it is possible that the auto station is at ~2 m AGL. If this is the case, then a measured wind speed of 4.34 m/s at, say 2 m AGL, will result in a projected wind speed of 5.71 m/s at 37 m AGL. This new estimate is identical to the MS-Micro results.

The MS-Micro tool can now be used to estimate the wind speed at two proposed locations. Site #2 (5 m ASL) which is near the quarry is estimated to have a long-term (10-year) mean wind speed of 5.6 m/s. Site #3 (30 m ASL) which is on a small hill by the water reservoir is estimated to have a long-term mean wind speed of 5.9 m/s. The two sites are shown (Figure 10 and Figure 11).

Figure 9: Mean wind speed contours based on the numerical model MS-Micro. The wind speeds are modelled at 37 m AGL. The contour interval is 0.1 m/s. The sites are labelled with wind speeds estimated from the model.

Figure 10: Panoramic shot of the area of interest from the water pumping station. Photographer is facing northeast.

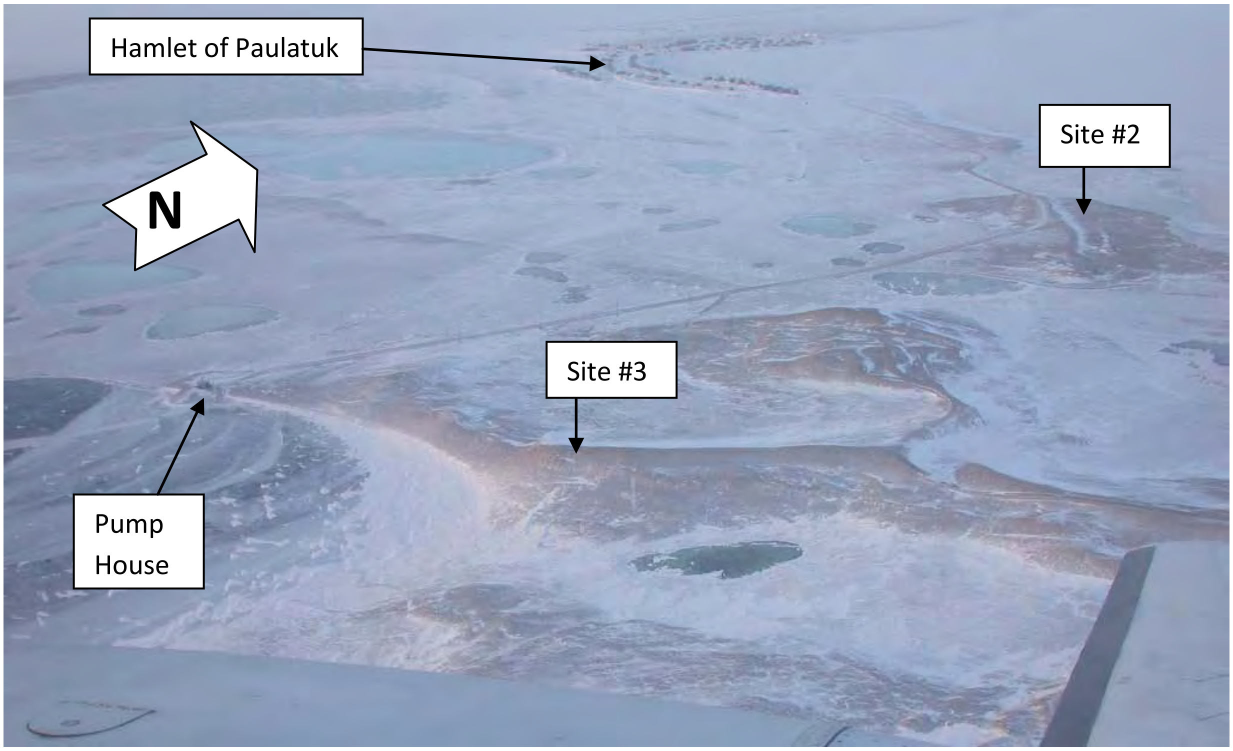

Figure 11: Aerial view of Paulatuk and the areas where a wind park could be established.
The Hamlet is in the distance at the top of the photo.

Power Requirements and Costs

The diesel-electric power plant in the community, as well as the distribution system, is owned and operated by NTPC. According to NTPC's 2006/07 and 2007/08 General Rate Application (GRA; see Appendix A) the forecasted energy requirement for 2007/08 was 1,351 MWh and the forecasted peak load was 254 kW. The forecasted energy requirement indicates an average load of about 154 kW, and the graphical information provided by NTPC in response to questions on their wind energy Request for Proposals (RFP) indicates that the recorded minimum and the real minimum load would be about 90 kW (see Appendix B).

The power plant consists of three Detroit Diesel diesel-electric generators: one of 200 kW capacity and two of 320 kW. The electrical distribution system consists of single- and three-phase above ground power lines. The power line to the pump house (see Figure 11) is a three phase line (see Figure 10).

According to the most recent GRA (Appendix A) the forecasted fuel cost was $1.09 per litre or about $0.311 per kWh at the indicated fuel efficiency of 3.5 kWh per litre. However, since the GRA was filed fuel prices went up significantly in the summer of 2008 to about $1.50 per litre (about $0.429 per kWh) in Paulatuk (author's estimates), and have come down again since the summer of 2008 refuelling. There is considerable uncertainty about future oil prices, except that they are likely to be higher than forecast in the GRA. Appendix C contains a table of electricity costs as a function of fuel price.

Wind Power Project

Wind Turbines

For the purposes of this study only one model of wind turbine was considered, the Entegrity EW50 (formerly called the EW15). This is a nominal 50kW capacity wind turbine with a peak output of about 65 kW, and has a rotor diameter of 15 meters. It is available with a tilt up tower 37 meters high, which is the tower proposed in this report. This turbine was chosen for this study because recent work (Maissan, 2008) on a potential power project in Tuktoyaktuk by the authors, and others, selected the EW50 as the leading candidate turbine. Although slightly larger than NTPC's stated maximum turbine size of 50 kW for this community in their 2008 RFP for wind power, this turbine more closely meets the requirements than the other turbine most seriously considered for Tuktoyaktuk (the Northern Power Systems' NorthWind 100 which has a capacity of 100 kW). Information on the EW50 is provided in Appendix D. There are few wind turbines in the 25 kW to 50 kW size range and none with any track record in the northern climates.

Entegrity has indicated recently that they are developing a larger diameter rotor for this turbine to make it more suitable for lower wind speed regimes (e.g. 5-6 m/s annual mean). In these regimes the higher energy production from a larger rotor is expected to reduce the average cost of electricity produced. Entegrity expects the new rotor will be available in 2011.

In order to examine the economies of scale for a project in Paulatuk it was decided to estimate the incremental increase in cost of a project consisting of two EW50 wind turbines – a nominal capacity of

100kW, or 130kW peak. This is significantly greater than NTPC's stated maximum total allowable wind capacity of 80 kW.

Energy Production

The expected annual energy produced by the Entegrity wind turbine as a function of annual average wind speeds and height above sea level is detailed in a table provided by Entegrity (see Appendix D). This table was used as a starting point to estimate the annual energy production at each of the two potential wind development sites. The authors call the expected annual energy from this table the "theoretical energy" produced as various adjustments need to be made to these numbers to arrive at a realistic expectation of annual energy produced. This process is described in the following paragraph.

The theoretical energy is first increased by 10% for the higher air density of the cold climate of Paulatuk. Then the energy produced is then reduced by 10% for turbine downtime allowance. This is a higher downtime allowance than would be used in more accessible areas of Canada as the authors believe that this remote cold climate location will result in a higher percentage of down time. Then a further reduction of 10% is applied to account for losses for various reasons including icing losses, low temperature start-up losses, and electrical losses (power lines and transformers). The result is an estimate of the energy actually available to displace diesel generated electricity. Appendix E provides the spreadsheet of these calculations for the wind speeds relevant to Paulatuk.

Capital Costs

The capital cost estimates developed for Paulatuk were based on the detailed capital cost estimates prepared for the Tuktoyaktuk wind energy project in the report *Technical Aspects of a Wind Project for Tuktoyaktuk, NWT* (Maissan, 2008). Adjustments were made in some components to reflect the increased remoteness of Paulatuk and the scale of the project as outlined below.

Upgrading of existing lower quality roads was estimated at $40,000 per kilometre, however since both of the sites examined were very near an existing road only a nominal amount was allocated for this requirement. New overhead power lines were estimated to cost $300,000 per km based on an NTPC estimate of $250,000 per km for Gameti two years ago. The estimated distance to the existing three phase pump house (see Figure 11) power line was used. Turbine shipping costs were based on a trucking cost estimate of $20,000 per turbine to Hay River (a cost estimate of $19,000 was provided in 2008), plus the NTCL published cost (for 2008 but rounded up a bit) for two containers from Hay River to Paulatuk for each turbine. A reduction of $5,000 was applied to the second turbine on the basis of the volume being shipped. Foundations were estimated to be about $60,000 each for one with a reduction of $10,000 for doing two at the same time. Finally, owner's costs were adjusted slightly (relative to Tuktoyaktuk estimates) to reflect the likely need for more complex negotiations with NTPC as the turbine size exceed NTPC's stated limits.

The capital cost estimates for a one turbine project at each of the two identified sites are as follows (details are presented in Appendix F):

1. Site #2 $534,000 or $8,215 per kW (calculated using one EW50 turbine operating at a peak capacity of 65 kW); and
2. Site #3 $617,000 or $9,492 per kW.

Site #1 is the location of the present monitoring tower and the distance to power lines would make this site very expensive compared to Sites #2 and #3. It was thus not considered in this study.

Site #2 is located at the last significant bend in the road before the pump house. It seems to be a former gravel quarry. It appears that a wind turbine could be located on either side of the road. Road access costs and power line connection costs are very low as they both traverse the site. The power line is a three phase line. There is room at this site for a second wind turbine if desired.

Site #3 is at the top of a relatively small ridge just to the east of the pump house. An access road runs through the site and the distance to the three phase pump house is about 0.35 km. There also appears to be room for a second wind turbine at this site.

The capital cost estimate for an increase in project size from one to two EW50 wind turbine at either site was prepared and is $478,000 or $7,354 per kW.

The authors have put their best efforts into preparing realistic capital cost estimates but are still concerned about their ability to be accurate on a number of line items. In particular, costs for roads, power lines, foundations, and owner's costs are significant contributors to the overall project costs yet these are not based on practical experience. Without the benefit of one or more project installations and a significant effort on minimizing costs, it is hard to have a high level of confidence in these particular cost numbers. In this study it was assumed that the turbine could be connected to the pump house power line.

The authors also believe that it would make economic sense to design, plan, and install a number of community projects in a coordinated fashion (although not necessarily all in one year). This would allow a number of cost components to be shared among projects rather than be replicated in each one. Costs components such as project design, project management, negotiation of agreements, and environmental assessments could be decreased for all projects involved. Such an approach would also allow some economies of scale in the purchasing of equipment, the shipping of equipment, the installation of projects, and the commissioning and testing.

Annual Costs

Annual costs, as estimated in this report, have two main components. The largest by far is the repayment of the capital costs of the projects. Three different interest rates (costs of capital) were examined; 8% (which is approximately the commercial cost of capital), 6%, and 4%. The latter two numbers effectively indicate project subsidies. Repayment was assumed to take place over 20 years in a mortgage type of approach (equal payments in each of the 20 years).

Three different levels of operating and maintenance costs (not including the repayment of capital) were considered: $10,000, $15,000, and $20,000 per year per turbine. The $15,000 per year per turbine figure is the expected annual cost with $10,000 and $20,000 per year being low and high operating cost variations. These figures are $5,000 per year higher than estimated for Tuktoyaktuk due to the fact that there is only a single turbine, or two at most, involved and the more remote nature of the community. A detailed table of annual costs as a function of capital costs, interest costs, and operating costs is presented in Appendix G.

Cost of Wind Energy and Economic Analyses

For the following discussion an interest rate of 8% and an operating cost of $15,000 per turbine are assumed. For the purposes of calculating the cost per kWh of energy produced it is also assumed that all power produced displaced diesel generation.

The calculated wind resource at Site #2 is 5.6 m/s to 5.7 m/s at the turbine hub height of 37 meters. This is a bit lower than at Site #3 which has a wind speed of 5.9 m/s. The costs for road access and a power line for Site #2 are very low as they both run through the site. The estimated cost of electricity is $0.73 to $0.77 per kWh, equivalent to diesel fuel costing $2.60 to $2.70 per litre. With the present avoided cost of diesel at $0.429 per kWh this site would require capital subsidy of $304,525 or a production subsidy of $0.343 per kWh.

Site #3 also has road access, but about 0.35 km of new power line would be required to reach the pump house power line. Although this site has a higher wind resource of 5.9 m/s, the cost of electricity is projected to be $0.75 per kWh, essentially identical to Site #2. With the present avoided cost of diesel at $0.429 per kWh this site would require capital subsidy of $330,005 or a production subsidy of $0.322 per kWh. This illustrates the significant effect the capital costs of projects have on the cost of energy.

The project cost of the incremental electricity from a second wind turbine at site 2 was estimated to be about $0.69 per kWh, and about $0.62 per kWh at Site #3. This is equivalent to diesel fuel costing about $2.40 and $2.20 per litre, respectively. The difference of $0.07 per kWh is entirely due to the difference in wind resource at hub height. This illustrates the desirability of selecting sites (and taller wind turbine towers) that maximize the wind resource available to the turbine.

All of these costs are substantially above the present estimated diesel cost of about $0.43 per kWh, even the incremental cost of an additional turbine at Site #3 is almost 1.5 times as high. Without subsidies wind energy projects of the size and cost projected in this study as thus not viable.

Reducing the interest cost (cost of capital) to 4 % from 8% reduces the cost of wind generated electricity by $0.16 per kWh. Reducing the operating cost by $5,000 per year per turbine reduces the cost of electricity by about $0.05 per kWh. The importance of constructing projects at minimum cost and operating them at minimum possible cost becomes readily apparent from an examination of these numbers. Appendix H presents detailed spreadsheets that show the cost of power as a function of capital costs, interest costs, operating costs, and wind speeds.

Discussion on Turbine Tower and Rotor

The authors have been interested in taller towers and increased rotor diameters for wind generators to increase energy production in small remote communities. The wind profile information in Paulatuk indicates that at 50 meters AGL the wind speed would be about 0.15 m/s higher than at 37 meters AGL, the specified EW50 tower height. This higher wind speed would be expected to increase energy production by about 6%. An increase of 6% in energy production could cover an increase in capital costs of close to $50,000 per turbine without increasing the per kWh costs. To put it another way: to decrease the cost of energy produced, the installed cost of the 50 meter tower would need to be less than $50,000 per turbine. To produce energy on the margin at costs competitive with present diesel costs, the installed cost would need to be about $25,000 per turbine or less.

The energy output of a turbine is proportional to its rotor diameter, so if the EW50 rotor diameter were increased by 1 meter from 15 meters to 16 meters the rotor area and energy production would increase by about 13.7%. Such an increase in energy production would result in lower energy costs than the present options identified in this study if the installed cost of the larger rotor EW50 were about $90,000 per turbine or less. To produce energy on the margin at costs equal to or less than the present diesel generation cost, the cost per turbine would need to be about $45,000 or less.

Given that the cost of the EW50 is about $160,000 at present, both the taller tower and the larger diameter rotor options would appear to be within economic reach.

Discussion on Distance to Wind Project Location

Projects such as the one examined in this study, often are presented with options on location, and so the question is, how far can one go to justify access to a higher wind resource? If the authors' assumptions on power line and road costs are accurate, the increased cost for one kilometre of distance in new road and power line is about $400,000 or over $6,150 per kW for a project composed of one EW50 turbine. This compares to $7,677 per kW for a project without road or power line costs. To produce wind energy at the same cost as a project without road or power line cost, a site one kilometre further away would need to produce about 80% more energy to be cost equal. For the EW50 this would require an increase in wind speed from 5.7 m/s to about 7.5 m/s. This calculation shows the challenge of the distance to project sites for very small community projects.

Greenhouse Gas Reductions

For the purposes of this report it has been assumed that all of the electrical energy available to reduce diesel generation does in fact reduce diesel generation. While it may be a bit optimistic it is a reasonable first approximation.

The diesel fuel and Greenhouse Gas (GHG) reductions that would be achieved by a 65 kW project (that is, one EW50 turbine with peak operating capacity of 65 kW) at various annual average wind speeds are shown in Table 4 below. The calculations are based on a diesel plant efficiency of 3.5 kWh per litre, and GHG emissions of 3.0 kg CO_2 equivalent per litre of diesel fuel consumed.

Table 4: Annual GHG reductions from a 65 kW wind project by wind speed

Wind speed, m/s	Diesel electricity displaced, kWh	Diesel fuel saved, litres	GHG reductions, kg CO_2 equivalent
5.6	88,209	25,200	75,600
5.7	92,664	26,475	79,425
5.8	97,119	27,750	83,250
5.9	101,574	29,020	87,060

Conclusions

1. The analysis of wind measurements in Paulatuk combined with a computer windflow model gives a reasonable estimate of long-term wind speed for several key locations for wind turbine development in the Paulatuk area.

2. Site #3 has the slightly better wind regime at 5.9 m/s annual average, but the 0.35 km new power line distance to the site makes the energy produced at this site about the same cost as from site #2 where the wind speed regime is 5.6 to 5.7 m/s. Site #3 is more desirable because of its slightly higher wind speed, particularly if a project expansion two turbines is a possibility.

3. The capital cost for a project (of one EW50 turbine) at Site #3 was estimated to be $617,000 or $9,492 per kW. This would make the cost of energy about $0.75 per kWh without any subsidies (8% cost of capital and an operating cost of $15,000 per year).

4. The capital cost of a project at Site #2 was estimated to be $534,000 or $8,215 per kW. This would make the cost of energy about $0.73 to $0.77 per kWh without any subsidies.

5. There is potential to lower the cost of wind energy somewhat if taller towers and/or larger diameter rotors become available for the EW50 wind turbine.

6. Without the experience of installing and operating wind-diesel projects in remote communities it will be difficult to develop more accurate capital and operating cost estimates.

7. The capital costs of power lines and roads make it uneconomical to install projects outside the immediate vicinity of the existing power lines and roads.

8. A wind energy project in Paulatuk will require significant financial subsidization in order to succeed.

Next Steps

The next steps that would be required to develop a wind project in Paulatuk are listed below:

1. Explore the possibility of coordinating several wind projects in the various Beaufort communities at the same time. This will reduce the capital costs by taking advantage of economies of scale in the design of projects, the bulk purchasing of equipment, the installation of wind projects, in the management of projects, and in negotiating agreements with parties such as NTPC.

2. Engage into a discussion with the NTPC technical staff on the following issues:

    a. The costs of constructing or upgrading power lines in remote communities
    b. Connecting wind turbines to existing power lines
    c. Changing their wind turbine power limitation (stated in the NTPC RFP, Appendix A) to allow the integration of a 65 kW wind turbine into the power system as proposed in this study.

3. Identify sources of funding assistance that could reduce wind energy costs to those of diesel generation.

4. If and when a project is likely to proceed, both site 2 and site 3 should be examined to determine which site is most desirable.

5. The wind monitoring station should be moved to the selected site for continued monitoring of the wind climate and the eventual performance monitoring of the wind turbines.

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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.23

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

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)	389	554	523	491	500
2	Customers	85	88	87	88	91
3	Av. MWh Sales/Cust.	4.57	6.29	6.01	5.59	5.51
4	Revenue (000s)	385	541	512	482	491
5	Cents /kWh	99.05	97.72	97.90	98.19	98.24
	General Service					
6	Sales (MWh)	416	680	674	649	662
7	Customers	32	36	36	37	36
8	Av. MWh Sales/Cust.	12.84	18.88	18.73	17.55	18.17
9	Revenue (000s)	381	621	622	600	611
10	Cents /kWh	91.53	91.34	92.21	92.47	92.35
	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)	35	25	25	23	25
21	Revenue (000s)	38	27	27	26	26
22	Cents /kWh	107.69	107.29	107.29	113.08	107.29
	Total Community					
23	**Sales (MWh)**	**839**	**1,258**	**1,222**	**1,163**	**1,187**
24	Customers	**117**	**124**	**123**	**125**	**127**
25	Revenue (000s)	**803**	**1,189**	**1,161**	**1,109**	**1,129**
26	Cents /kWh	95.68	94.47	94.95	95.29	95.14
	GENERATION (MWh)					
27	**Total Station Service**	86	50	53	53	53
28	**Total Losses**	69	107	69	109	112
29	***Losses - % of Gen.***	*7.0%*	*7.5%*	*5.1%*	*8.2%*	*8.3%*
30	**Total Generation**	**994**	**1,415**	**1,344**	**1,325**	**1,351**
	Source (MWh)					
31	Hydro Generation					
32	Gas Generation					
33	Gas Efficiency					
34	*Cubic Meters (000s)*					
35	Diesel Generation	994	1,415	1,344	1,325	1,351
36	Diesel Efficiency	3.397	3.508	3.481	3.492	3.492
37	*Liters (000s)*	*293*	*403*	*386*	*380*	*387*
38	Purchased Power					
39	Total Generation	994	1,415	1,344	1,325	1,351
	% 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	214	258	258	249	254
45	Load Factor	53.0%	62.6%	59.5%	60.8%	60.8%

NORTHWEST TERRITORIES POWER CORPORATION

Request For Proposals

WIND GENERATION IN THE NORTHWEST TERRITORIES

RFP No. 20804

APPENDIX A – EXAMPLE OF PURCHASE PRICE BASED ON NOVEMBER 1 2007 FUEL PRICES (SEE SECTION 3.3 FOR A PRICING DISCUSSION)

DIESEL	Fuel Price ($/L)	$/KWh
Wha Ti	0.979	$ 0.26
Gameti	1.059	$ 0.31
Behchoko	0.778	$ 0.24
Lutsel K'e	1.016	$ 0.27
Fort Simpson	0.931	$ 0.25
Fort Liard	1.066	$ 0.29
Wrigley	0.956	$ 0.27
Nahanni Butte	0.958	$ 0.38
Jean Marie River	0.956	$ 0.35
Tuktoyaktuk	1.055	$ 0.29
Fort McPherson	1.137	$ 0.32
Aklavik	1.030	$ 0.30
Deline	1.125	$ 0.32
Fort Good Hope	1.096	$ 0.31
Tulita	0.998	$ 0.27
Paulatuk	1.226	$ 0.35
Sachs Harbour	1.167	$ 0.37
Tsiigehtchic	1.137	$ 0.32
Colville Lake	1.265	$ 0.43
Ulukhaktok	1.191	$ 0.33
NATURAL GAS	**Fuel Price ($/m^3)**	**$/kWh**
Inuvik	0.438	$ 0.13

Fuel Price is effective November 1 2007.

APPENDIX B – LOAD FORECASTS INCLUDING PEAK LOAD

Communities listed in the Aurora Wind study.

Community	Forecast Peak (kW) 2007/2008	Maximum Wind Generation (kW)	
		Single Unit	Multiple Units
Inuvik	5,691	1,000	1,500
Tuktoyaktuk	851	100	250
Paulatuk	254	50	80
Sachs Harbour	209	40	60
Ulukhaktok	469	40	100

Other Communities Available for Wind Generation

Wha Ti	378	TBD	TBD
Gameti	214	TBD	TBD
Behchoko	1,422	TBD	TBD
Lutsel K'e	361	TBD	TBD
Fort Simpson	1,537	TBD	TBD
Fort Liard	527	TBD	TBD
Wrigley	173	TBD	TBD
Nahanni Butte	128	TBD	TBD
Jean Marie River	78	TBD	TBD
Fort McPherson	757	TBD	TBD
Aklavik	636	TBD	TBD
Deline	541	TBD	TBD
Fort Good Hope	634	TBD	TBD
Tulita	537	TBD	TBD
Tsiigehtchic	236	TBD	TBD
Colville Lake	103	TBD	TBD

TBD – for those communities listed as "to be determined", bidders are requested to contact NTPC to provide the maximum wind penetration that will be allowed.

Northwest Territories Power Corporation
WIND RFP NO. 20804
ADDENDUM #1

The responses to the Wind RFP questions forming this Addendum are for this RFP only and should not be viewed as corporate policy.

The Aurora Research Institute has conducted several wind studies which can be found on their website http://www.nwtresearch.com/resources/publications.aspx

Question 1 Appendix B
Is penetration level negotiable if there has been demonstrated experience with higher penetration levels in other areas and if higher penetration levels improves the economics of the project?

Response
This RFP is currently allowing a relatively high penetration for a system of this size. Higher penetration levels may be allowed on a community specific basis only after a period of time operating at or below the penetration levels given.

Question 2 Appendix B
If a medium penetration project is economic will it be possible for the wind plant owner to transport thermal energy to clients on NTPCs wires at no cost?

Response
This would be a matter for future consideration should a project proceed from low penetration to medium penetration. NTPC anticipates that in such a circumstance, NTPC would collaborate in setting up some capacity for interruptible power.

Question 3 Section 3.2 Available Locations
Can you please provide further details on the load profile, as well as a map outlining the location of generating plants and substations for the following communities?
o Tuktoyaktut,
o Paulatuk,
o Sachs Harbour and
o Ulukhaktok

Response
Please refer to the attached for distribution drawings and attached load graphs.

For topographical views, Google Earth can be used with the following coordinates:
Tuktoyaktuk - 69 25' 12.06"N ; 133 00' 01.64"W
Sachs Harbour - 71 59' 10.91"N ; 125 15'12.19"W
Holman - 70 44' 13.07"N ; 117 45' 48.88"W
Substations for the communities are located at the power plants.

Response

The wind system should be run on NTPC station service, so that power consumption during periods of non-generation (heaters, control systems, etc.) could be supplied as if this were part of the plant. This arrangement also supports NTPC's preference for the system to be connected at the existing power station rather than somewhere out on the grid. The wind installation would be charged for energy consumed at the avoided cost of diesel subject to the PUB approved prices and efficiencies.

Question 17 Appendix B

Please explain in detail the methodology used to arrive at the maximum size single wind turbines for each of the five communities listed.

Response

The single unit size is dictated by the minimum loads for the community. It reflects what NTPC considers the maximum penetration NTPC would be comfortable accepting from a system with no load controls. In most cases it is 50 to 65% of the minimum load, rounded up to the nearest 10 kW.

Question 18 Appendix B

Is NTPC aware that its stipulations for maximum single turbine size for Paulatuk, Sachs Harbour and Ulukhaktok effectively eliminates every available community size wind turbine on the market? If not is NTPC prepared to be flexible on this point?

Response

In order to protect the reliability of power to the customers it is essential the wind generators not be oversized for the system. The RFP was written to accommodate simply connected wind conversion systems however it does not preclude a more complex control system. The limitations on these communities will ensure the stability of a simply connected wind conversion system during periods of low demand and high wind.

NTPC did not do an exhaustive search for what was commercially available in terms of rated output. If the proponent is suggesting that there is nothing available under 100 kW, then in those communities where the demand often dips well below 100 kW a simple system may not be feasible, and some type of advanced wind-diesel interface would be required. This would require that the proponent be prepared to demonstrate satisfactory operation of the system proposed, in a real life setting.

Question 19 Appendix B

If the installed wind plant capacity is such that the stipulated maximum is exceeded, is NTPC prepared to allow excess amounts to be delivered to end point users of this excess for uses such as space and water heating if metered separately from "normal" consumption? If so what conditions would apply?

Response
Please refer to question 2.

Question 20 Appendix B
Please explain in detail the methodology used to arrive at the maximum wind generation using multiple wind turbines.

Response
The multiple unit size was included to allow greater penetrations if some of the capacity could be positively removed from the grid. This would allow simple installations to have a capacity greater than the minimum loads, because some of the capacity could be easily isolated as the demand or system stability decreased. This capacity is generally 50 to 65% of the low monthly average demand, and about 50% of the overall annual average demand.

Question 21 Appendix B
Would NTPC consider alteration of its diesel plant to allow for higher wind capacity penetration levels, for example by adding a smaller or low load diesel generator?

Response
Not for this RFP, however in future if a project was expanding to medium penetration, this might be considered, especially where plant capacity upgrade is being planned. Other than planned capacity upgrade, such a modification would have to be revenue neutral from our customer point of view.

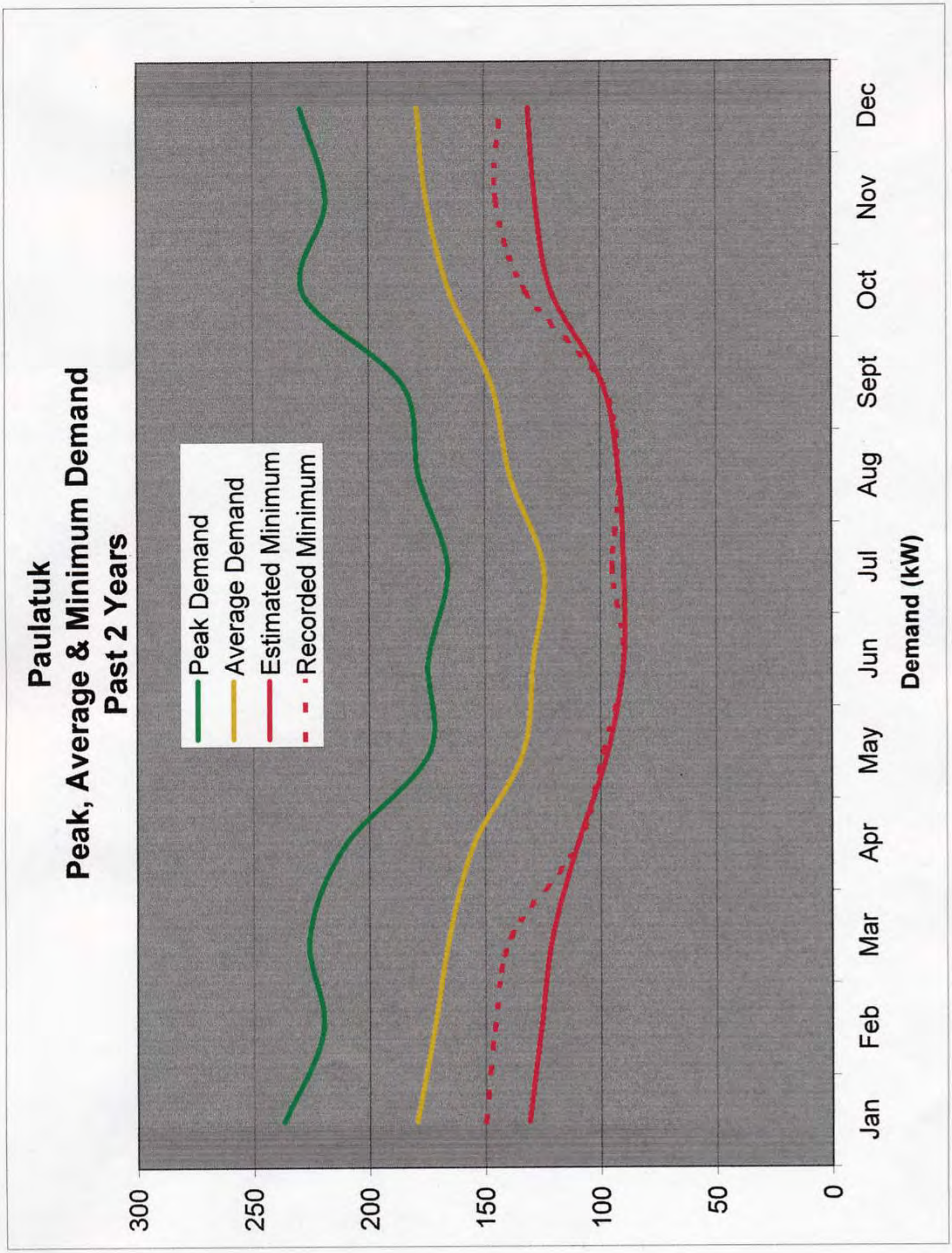
Question 22 Appendix B
Would NTPC allow the installation of a higher capacity wind plant than those stipulated if the maximum wind power to be delivered was limited to the maximum capacity specified?

Response
Please refer to question 2.

Question 23 Interconnection Guidelines Section 4.1.3
Does NTPC guarantee these standards to its customers?

Response
NTPC does not guarantee these standards to its customers. The industry standards provided in Section 4.1.3 are provided as "guidance to appropriate performance".

Question 24 Interconnection Guidelines Section 4.1.7, Fault and Line Clearing:
The description in this section appears to assume that the wind plant would not have low voltage ride-through capability. If the wind plant would be able to provide this would this affect NTPC's requirements?


Paulatuk
Peak, Average & Minimum Demand
Past 2 Years
Peak Demand
Average Demand
Estimated Minimum
Recorded Minimum
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
Demand (kW)

Electricity value per kWh as function of diesel fuel cost Paulatuk	
Fuel cost per litre	Diesel fuel cost per kWh, diesel plant efficiency 3.5 kWh per litre
$1.00	$0.286
$1.25	$0.357
$1.50	$0.429
$1.75	$0.500
$2.00	$0.571
$2.25	$0.643
$2.50	$0.714
$3.00	$0.857
$3.50	$1.000

Appendix D

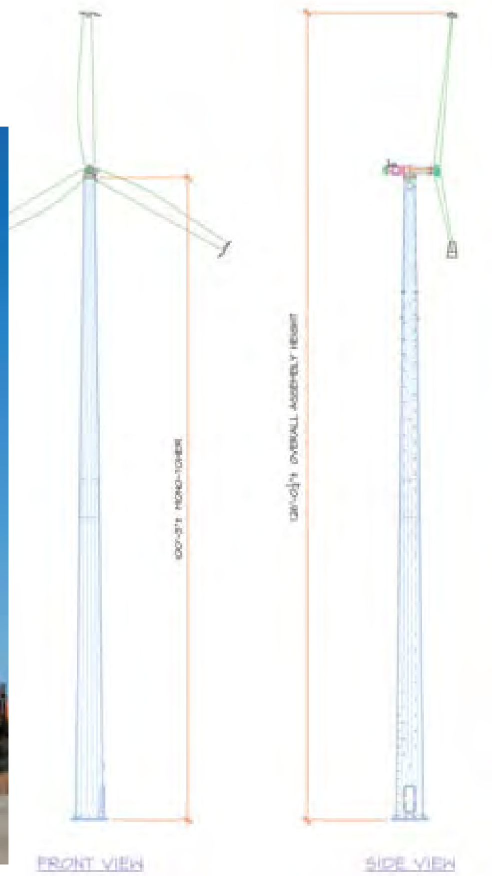
Entegrity
WIND SYSTEMS INC.

Manufacturers of the EW50 Commercial-Scale Wind Turbine

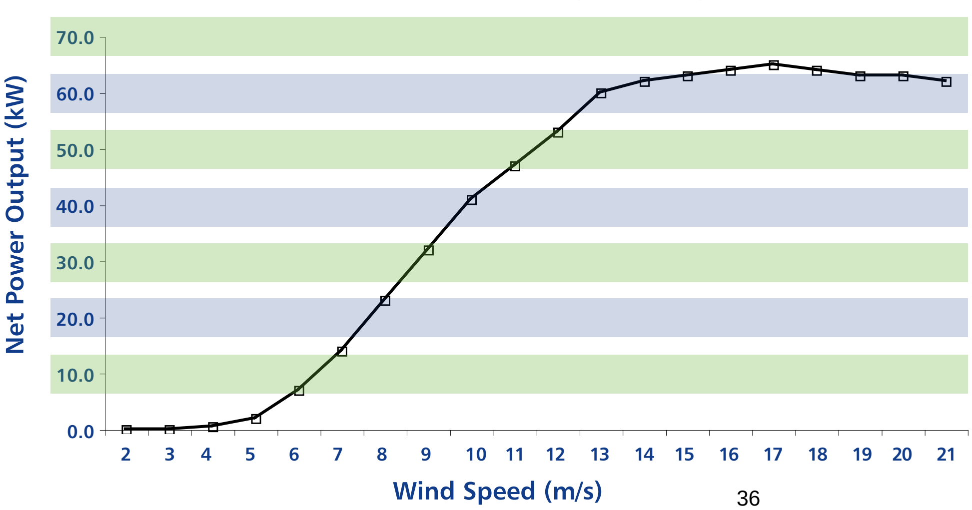
EW50 Power Curve, 60hz

Entegrity Wind Systems is a leading manufacturer of commercial-scale wind turbines with installations worldwide. The EW50 is a 50-kilowatt wind turbine generator designed to supplement electric power generation for large buildings, industry, commercial operations, large farms, communities, schools, and remote locations.

The EW50 is an ideal investment to combat rising utility rates by enabling owners to secure their costs for electrical energy against higher future costs. The EW50 has a 30-year design life and comes with a 5-year warranty and 5-year O&M agreement.



EW 50 Power Curve (Sea Level)



Expected Annual Net Energy Production

Wind Speed (m/s)	Wind Speed (mph)	AEP Sea Level (kWh)
4	8.9	33000
4.5	10.1	51000
5	11.2	71000
5.5	12.3	94000
6	13.4	119000
6.5	14.5	143000
7	15.6	167000
7.5	16.8	190000
8	17.9	212000
8.5	19	232000
9	20.1	250000
9.5	21.2	265000
10	22.4	278000
10.5	23.5	289000
11	24.6	297000

EW50 Specifications

1. SYSTEM

Type	3 ϕ Grid Connected
Configuration	Horizontal Axis
Rotor Diameter	15 m (49.2 ft)
Centerline Hub Ht.	31.1 m (102 ft)

2. PERFORMANCE PARAMETERS

Rated Electrical Power	50 kW @11.3 m/s (25.3 mph)
Wind Speed Ratings	
Cut-in	4.0 m/s (8.9 mph)
Shut-down (high wind)	25 m/s (56 mph)
Design Speed	59.5 m/s (133 mph)
Average Annual Output	Class 2 115,000kWh
at Sea Level	Class 3 149,000kWh
	Class 4 177,000kWh

3. ROTOR

Type of Hub	Fixed Pitch
Rotor Diameter	15 m (49.2 ft)
Swept Area	177 m2 (1902 ft2)
Number of Blades	3
Rotor Solidity	0.077
Rotor Speed @ 50kW Nameplate Capacity	65 rpm
Location Relative to Tower	Downwind
Cone Angle	6^o
Tilt Angle	0^o
Rotor Tip Speed	51 m/s (114 mph) @ 60 Hz
Design Tip Speed Ratio	6.1

4. BLADE

Length	7.2 m (23.7 ft)
Material	Epoxy /glass fiber
Blade Weight	150 kg (330 lbs) approximate

5. GENERATOR

Type3 phase/4 pole asynchronous	
Frequency	60 Hz
Voltage	3 phase @ 50/60 Hz, 415-600
kW @ Rated Wind Speed	50 kW
kW @ Peak Continuous	66 kW
Insulation	Class F
Enclosure	Totally Enclosed Air Over

6. TRANSMISSION

Type	Planetary
Housing	Ductile Iron
Ratio (rotor to generator sp)	1 to 28.25 (60 Hz)
Rating, output horse power	88
Lubrication	Synthetic gear oil/non-toxic
Heater (option)	Arctic version, electric

7. YAW SYSTEM

Normal	Free, Passive
Electrical	Twist Cable

8. TOWER

Type	Free standing monopole or galvanized lattice
Lattice Tower Heights	80’, 100’, 120’
Monopole Tower Heights	80’, 100’, 120’
Monopole Options	Ladder, Finish

9. FOUNDATION

Type	Monolithic Slab or Custom

10. CONTROL SYSTEM

Type	Microprocessor based
Communications	Cellular or Internet/Ethernet connection to central computer for energy monitor and maintenance dispatch
Enclosures	NEMA 1, NEMA 4 (optional)
Soft Start	Optional

11. ROTOR SPEED CONTROL

Running	Passive stall regulation
Start-up	Aerodynamic
Shut-down	Aerodynamic tip brake
	Parking brake for servicing

12. BRAKE SYSTEM CONTROL

Fail-safe aerodynamic and parking brakes

13. APPROXIMATE SYSTEM DESIGN WEIGHTS

100’ Lattice Tower	3,210 kg (7,080 lb)
100’ Monopole Tower	7,281 kg (16,051 lb)
Rotor & Drive Train	2,420 kg (5,340 lb)

14. DESIGN LIFE

30 Years

15. DESIGN STANDARDS

IEEE 1547 compliant, CE certified, UL listed

16. DOCUMENTATION

Installation Guide and Operation and Maintenance Manual

17. SCHEDULED MAINTENANCE

Semi-annual

EW50 SPECIFICATIONS

Entegrity WIND SYSTEMS INC.

Entegrity Wind Systems

Entegrity Wind Systems Inc. is a privately held corporation with offices in Boulder, Colorado and manufacturing in Charlottetown, Prince Edward Island, Canada and Montreal, Quebec. The company has over 30 employees with years of experience in wind and distributed energy.

The EW50 is based on the Atlantic Orient Corporation 15/50 design and includes a NREL-patented blade design, robust drive train and a sophisticated monitoring and control system. Entegrity engineers and technicians are committed to continuous improvement. The EW50 outperforms its predecessors, while maintaining the same simple, durable configuration.

Entegrity's staff of technicians and comprehensive network of partners ensure that the EW50 fleet exceeds performance expectations. Our project development engineers and technical staff are available to assist in the planning of your wind energy project.

EW50 Timeline

1980's
Over 700 Enertech 44/40 machines installed in California

1991
Atlantic Orient Corporation founded in Vermont, USA – AOC 15/50 prototype based on Enertech 44/40

1993
AOC 15/50 installed at:
- North Cape, PE, Canada (AWTS)
- Rocky Flats, CO (NREL)
- Bushland, Texas (USDA)

1993-2002
48 AOC 15/50 installations worldwide

1996
The AOC 15/50 design was selected for round robin testing by four national government laboratories to validate testing procedures:
- US National Renewable Energy Laboratory (NREL) in Colorado
- Atlantic Wind Test Site (WEICan) in PE, Canada
- Risø National Laboratory in Denmark
- The Center for Renewable Energy Sources (CRES) in Greece

1998
Entegrity Partners, L.P. invests in AOC

1999
8 installations completed for Kotzebue, AK

2002
Entegrity Wind Systems Inc. is formed
Manufacturing is located in Canada

2004
AOC 15/50 Turbine name changed to EW15, owned by Entegrity Wind Systems Inc.

2005
U.S. Sales Office formed

2006
Shallowater, Texas – 5 turbines installed at the school district

3 more installations to Kotzebue, totaling 14 turbines

2007
Installations increased by 236%

Quinter, Kansas – 1st Monopole installation at a school in Kansas

2008
Turbine name change to EW50
- Denotes rated capacity

Entegrity WIND SYSTEMS INC.

4855 Riverbend Road #100 Boulder, CO 80301
303.440.8799 | www.entegritywind.com

Appendix D
EW50 Wind Turbine
Expected Annual Net Energy Production

Average Wind Speed		Annual Energy Output (kWh), Weibull distribution k=2.0, Select Elevations						
m/s	mph	Sea Level	1000'	2000'	3000'	4000'	5000'	6000'
4	8.9	33000	32000	31000	30000	29000	28000	27000
4.1	9.2	36000	34000	33000	32000	31000	30000	29000
4.2	9.4	39000	37000	36000	35000	34000	33000	32000
4.3	9.6	43000	41000	40000	39000	37000	36000	35000
4.4	9.8	47000	45000	44000	42000	41000	40000	38000
4.5	10.1	51000	49000	47000	46000	44000	43000	41000
4.6	10.3	55000	53000	51000	50000	48000	46000	45000
4.7	10.5	59000	57000	55000	53000	51000	50000	48000
4.8	10.7	63000	61000	59000	57000	55000	53000	51000
4.9	11	67000	65000	63000	61000	59000	57000	55000
5	11.2	71000	68000	66000	64000	62000	60000	58000
5.1	11.4	76000	73000	71000	69000	66000	64000	62000
5.2	11.6	80000	77000	75000	72000	70000	68000	65000
5.3	11.8	85000	82000	79000	77000	74000	72000	69000
5.4	12.1	90000	87000	84000	81000	79000	76000	73000
5.5	12.3	94000	91000	88000	85000	82000	80000	77000
5.6	12.5	99000	96000	93000	90000	87000	84000	81000
5.7	12.7	104000	100000	97000	94000	91000	88000	85000
5.8	13	109000	105000	102000	99000	96000	92000	89000
5.9	13.2	114000	110000	107000	103000	100000	97000	93000
6	13.4	119000	115000	111000	108000	104000	101000	97000
6.1	13.6	123000	119000	115000	112000	108000	104000	101000
6.2	13.9	128000	124000	120000	116000	112000	108000	105000
6.3	14.1	133000	129000	125000	121000	117000	113000	109000
6.4	14.3	138000	133000	129000	125000	121000	117000	113000
6.5	14.5	143000	138000	134000	130000	126000	121000	117000
6.6	14.8	148000	143000	139000	134000	130000	126000	121000
6.7	15	153000	148000	143000	139000	134000	130000	125000
6.8	15.2	158000	153000	148000	143000	139000	134000	129000
6.9	15.4	162000	157000	152000	147000	142000	137000	133000
7	15.6	167000	162000	157000	152000	147000	142000	137000
7.1	15.9	172000	166000	161000	156000	151000	146000	141000
7.2	16.1	177000	171000	166000	161000	155000	150000	145000
7.3	16.3	181000	175000	170000	164000	159000	154000	148000
7.4	16.5	186000	180000	174000	169000	163000	158000	152000

Appendix D

Average Wind Speed		Annual Energy Output (kWh), Weibull distribution k=2.0, Select Elevations						
m/s	mph	Sea Level	1000'	2000'	3000'	4000'	5000'	6000'
7.5	16.8	190000	184000	178000	173000	167000	161000	156000
7.6	17	195000	189000	183000	177000	171000	166000	160000
7.7	17.2	199000	193000	187000	181000	175000	169000	163000
7.8	17.4	204000	197000	191000	185000	179000	173000	167000
7.9	17.7	208000	201000	195000	189000	183000	177000	170000
8	17.9	212000	205000	199000	193000	186000	180000	174000
8.1	18.1	216000	209000	203000	196000	190000	183000	177000
8.2	18.3	220000	213000	206000	200000	193000	187000	180000
8.3	18.6	224000	217000	210000	204000	197000	190000	184000
8.4	18.8	228000	221000	214000	207000	200000	194000	187000
8.5	19	232000	225000	218000	211000	204000	197000	190000
8.6	19.2	236000	228000	221000	214000	207000	200000	193000
8.7	19.4	239000	231000	224000	217000	210000	203000	196000
8.8	19.7	243000	235000	228000	221000	214000	206000	199000
8.9	19.9	246000	238000	231000	224000	216000	209000	202000
9	20.1	250000	242000	235000	227000	220000	212000	205000
9.1	20.3	253000	245000	237000	230000	222000	215000	207000
9.2	20.6	256000	248000	240000	233000	225000	217000	210000
9.3	20.8	259000	251000	243000	235000	228000	220000	212000
9.4	21	262000	254000	246000	238000	230000	223000	215000
9.5	21.2	265000	257000	249000	241000	233000	225000	217000
9.6	21.5	268000	260000	252000	244000	236000	228000	220000
9.7	21.7	271000	262000	254000	246000	238000	230000	222000
9.8	21.9	273000	264000	256000	248000	240000	232000	224000
9.9	22.1	276000	267000	259000	251000	243000	234000	226000
10	22.4	278000	269000	261000	253000	244000	236000	228000
10.1	22.6	281000	272000	264000	255000	247000	239000	230000
10.2	22.8	283000	274000	266000	257000	249000	240000	232000
10.3	23	285000	276000	268000	259000	251000	242000	234000
10.4	23.2	287000	278000	269000	261000	252000	244000	235000
10.5	23.5	289000	280000	271000	263000	254000	246000	237000
10.6	23.7	291000	282000	273000	265000	256000	247000	239000
10.7	23.9	292000	283000	274000	265000	257000	248000	239000
10.8	24.1	294000	285000	276000	267000	259000	250000	241000
10.9	24.4	296000	287000	278000	269000	260000	252000	243000
11	24.6	297000	288000	279000	270000	261000	252000	244000

Entegrity EW50 annual energy production (from Entegrity)						
Wind Speed m/s	**Theoretical kWh**	**Air density 1.1 adjusted kWh**	**kWh @ 90% availability**	**10% for all losses**	**kWh diesel displaced**	**2 turbines, kWh diesel displaced**
5.50	94,000	103,400	93,060	9,306	83,754	167,508
5.60	99,000	108,900	98,010	9,801	88,209	176,418
5.70	104,000	114,400	102,960	10,296	92,664	185,328
5.80	109,000	119,900	107,910	10,791	97,119	194,238
5.90	114,000	125,400	112,860	11,286	101,574	203,148
6.00	119,000	130,900	117,810	11,781	106,029	212,058
6.10	123,000	135,300	121,770	12,177	109,593	219,186
6.20	128,000	140,800	126,720	12,672	114,048	228,096
6.40	138,000	151,800	136,620	13,662	122,958	245,916

Paulatuk Project Capital Costs Site 2		
Possible site closest to power line and road		
	low penetration	medium penetration
Cost category	**One EW50 turbines**	**Two EW50 turbines**
Project Design & Mgmt		
project design	$10,000	$20,000
environmental assessment	$10,000	$12,000
project management	$10,000	$12,000
Site Preparation		
road construction ($100,000 per km)		
road upgrading ($40,000 per km), nominal only	$5,000	$10,000
powerline construction ($300,000 per km), 0.1 km	$30,000	$60,000
powerline upgrading 1 to 3 ph ($150,000 per km)		
Wind Equipment Purchase		
wind turbines	$160,000	$320,000
Gin pole	$12,000	$12,000
shipping	$29,000	$53,000
transformers	$8,000	$16,000
wind plant master control	$10,000	$10,000
Installation		
foundations	$60,000	$110,000
equipment rental	$10,000	$15,000
control buildings	$10,000	$20,000
utility interconnection	$20,000	$30,000
commissioning	$10,000	$15,000
labour - assembly & supervision	$15,000	$25,000
travel and accommodation	$10,000	$20,000
Diesel Plant Modifications		
high speed comm. & controller	$10,000	$20,000
SCADA		$30,000
dump load	$5,000	$20,000
plant modifications	$15,000	$30,000
Other		
initial spare parts	$5,000	$10,000
SUBTOTAL CONSTRUCTION	**$454,000**	**$870,000**
Contingency	$45,000	$87,000
TOTAL CONSTRUCTION	**$499,000**	**$957,000**
Owners Costs		
manage project organization	$15,000	$25,000
negotiate agreements	$20,000	$30,000
TOTAL OWNERS' COSTS	**$35,000**	**$55,000**
TOTAL PROJECT COST	**$534,000**	**$1,012,000**
Installed capacity kW	65	130
Installed cost per kW	**$8,215**	**$7,785**
Incremental larger plant cost per kW		**$7,354**

Paulatuk Project Capital Costs Site 3

Possible best wind site as close as possible to power line and road

	low penetration	medium penetration
Cost category	**One EW50 turbines**	**Two EW50 turbines**
Project Design & Mgmt		
project design	$10,000	$20,000
environmental assessment	$10,000	$12,000
project management	$10,000	$12,000
Site Preparation		
road construction ($100,000 per km)		
road upgrading ($40,000 per km), nominal only	$5,000	$10,000
powerline construction ($300,000 per km), 0.35 km	$105,000	$135,000
powerline upgrading 1 to 3 ph ($150,000 per km)		
Wind Equipment Purchase		
wind turbines	$160,000	$320,000
Gin pole	$12,000	$12,000
shipping	$29,000	$53,000
transformers	$8,000	$16,000
wind plant master control	$10,000	$10,000
Installation		
foundations	$60,000	$110,000
equipment rental	$10,000	$15,000
control buildings	$10,000	$20,000
utility interconnection	$20,000	$30,000
commissioning	$10,000	$15,000
labour - assembly & supervision	$15,000	$25,000
travel and accommodation	$10,000	$20,000
Diesel Plant Modifications		
high speed comm. & controller	$10,000	$20,000
SCADA		$30,000
dump load	$5,000	$20,000
plant modifications	$15,000	$30,000
Other		
initial spare parts	$5,000	$10,000
SUBTOTAL CONSTRUCTION	**$529,000**	**$945,000**
Contingency	$53,000	$95,000
TOTAL CONSTRUCTION	**$582,000**	**$1,040,000**
Owners Costs		
manage project organization	$15,000	$25,000
negotiate agreements	$20,000	$30,000
TOTAL OWNERS' COSTS	**$35,000**	**$55,000**
TOTAL PROJECT COST	**$617,000**	**$1,095,000**
Installed capacity kW	65	130
Installed cost per kW	**$9,492**	**$8,423**
Incremental larger plant cost per kW		**$7,354**

Paulatuk one EW50 turbine project annual costs as a function of capital and operating costs

Mortgage style repayments over 20 years at 8%, 6% and 4% interest

One turbine 65 kW project

Capital cost per kW	kW capacity	Total capital	Annual mortgage cost @ 8%, 20 yrs	Low ann operating cost	Med ann operating cost	High ann operating cost	Total Ann cost low	Total Ann cost med	Total Ann cost high
$7,000	65	$455,000	$45,227	$10,000	$15,000	$20,000	$55,227	$60,227	$65,227
$7,354	65	$478,010	$47,514	$10,000	$15,000	$20,000	$57,514	$62,514	$67,514
$7,785	65	$506,025	$50,299	$10,000	$15,000	$20,000	$60,299	$65,299	$70,299
$8,215	65	$533,975	$53,077	$10,000	$15,000	$20,000	$63,077	$68,077	$73,077
$8,423	65	$547,495	$54,421	$10,000	$15,000	$20,000	$64,421	$69,421	$74,421
$9,492	65	$616,980	$61,328	$10,000	$15,000	$20,000	$71,328	$76,328	$81,328
$10,000	65	$650,000	$64,610	$10,000	$15,000	$20,000	$74,610	$79,610	$84,610

Capital cost per kW	kW capacity	Total capital	Annual mortgage cost @ 6%, 20 yrs	Low ann operating cost	Med ann operating cost	High ann operating cost	Total Ann cost low	Total Ann cost med	Total Ann cost high
$7,000	65	$455,000	$38,903	$10,000	$15,000	$20,000	$48,903	$53,903	$58,903
$7,354	65	$478,010	$40,870	$10,000	$15,000	$20,000	$50,870	$55,870	$60,870
$7,785	65	$506,025	$43,265	$10,000	$15,000	$20,000	$53,265	$58,265	$63,265
$8,215	65	$533,975	$45,655	$10,000	$15,000	$20,000	$55,655	$60,655	$65,655
$8,423	65	$547,495	$46,811	$10,000	$15,000	$20,000	$56,811	$61,811	$66,811
$9,492	65	$616,980	$52,752	$10,000	$15,000	$20,000	$62,752	$67,752	$72,752
$10,000	65	$650,000	$55,575	$10,000	$15,000	$20,000	$65,575	$70,575	$75,575

Capital cost per kW	kW capacity	Total capital	Annual mortgage cost @ 4%, 20 yrs	Low ann operating cost	Med ann operating cost	High ann operating cost	Total Ann cost low	Total Ann cost med	Total Ann cost high
$7,000	65	$455,000	$32,988	$10,000	$15,000	$20,000	$42,988	$47,988	$52,988
$7,354	65	$478,010	$34,656	$10,000	$15,000	$20,000	$44,656	$49,656	$54,656
$7,785	65	$506,025	$36,687	$10,000	$15,000	$20,000	$46,687	$51,687	$56,687
$8,215	65	$533,975	$38,713	$10,000	$15,000	$20,000	$48,713	$53,713	$58,713
$8,423	65	$547,495	$39,693	$10,000	$15,000	$20,000	$49,693	$54,693	$59,693
$9,492	65	$616,980	$44,731	$10,000	$15,000	$20,000	$54,731	$59,731	$64,731
$10,000	65	$650,000	$47,125	$10,000	$15,000	$20,000	$57,125	$62,125	$67,125

Appendix H

One EW50 Turbine Project Electricity Cost with Low Operating Costs

Paulatuk 1 turbine project electricity cost as a function of wind speed and capital cost (low operating cost)

	=	Viable at fuel cost of $1.25 per liter, diesel fuel cost $0.347 per kWh
	=	Viable at fuel cost of $1.50 per liter, diesel fuel cost $0.417 per kWh
	=	Viable at fuel cost of $1.75 per liter, diesel fuel cost $0.486 per kWh
	=	Viable at fuel cost of $2.00 per liter, diesel fuel cost $0.556 per kWh
	=	Viable at fuel cost of $2.50 per liter, diesel fuel cost $0.714 per kWh

		m/s >	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.40
	8% Interest	**kWh >**	83,754	88,209	92,664	97,119	101,574	106,029	109,593	114,048	122,958
Capital cost per kW	**Total Ann cost low op cost**		**Cost per kWh below**								
$7,000	$55,227		$0.659	$0.626	$0.596	$0.569	$0.544	$0.521	$0.504	$0.484	$0.449
$7,354	$57,514		$0.687	$0.652	$0.621	$0.592	$0.566	$0.542	$0.525	$0.504	$0.468
$7,785	$60,299		$0.720	$0.684	$0.651	$0.621	$0.594	$0.569	$0.550	$0.529	$0.490
$8,215	$63,077		$0.753	$0.715	$0.681	$0.649	$0.621	$0.595	$0.576	$0.553	$0.513
$8,423	$64,421		$0.769	$0.730	$0.695	$0.663	$0.634	$0.608	$0.588	$0.565	$0.524
$9,492	$71,328		$0.852	$0.809	$0.770	$0.734	$0.702	$0.673	$0.651	$0.625	$0.580
$10,000	$74,610		$0.891	$0.846	$0.805	$0.768	$0.735	$0.704	$0.681	$0.654	$0.607

		m/s >	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.40
	6% Interest	**kWh >**	83,754	88,209	92,664	97,119	101,574	106,029	109,593	114,048	122,958
Capital cost per kW	**Total Ann cost low op cost**		**Cost per kWh below**								
$7,000	$48,903		$0.584	$0.554	$0.528	$0.504	$0.481	$0.461	$0.446	$0.429	$0.398
$7,354	$50,870		$0.607	$0.577	$0.549	$0.524	$0.501	$0.480	$0.464	$0.446	$0.414
$7,785	$53,265		$0.636	$0.604	$0.575	$0.548	$0.524	$0.502	$0.486	$0.467	$0.433
$8,215	$55,655		$0.665	$0.631	$0.601	$0.573	$0.548	$0.525	$0.508	$0.488	$0.453
$8,423	$56,811		$0.678	$0.644	$0.613	$0.585	$0.559	$0.536	$0.518	$0.498	$0.462
$9,492	$62,752		$0.749	$0.711	$0.677	$0.646	$0.618	$0.592	$0.573	$0.550	$0.510
$10,000	$65,575		$0.783	$0.743	$0.708	$0.675	$0.646	$0.618	$0.598	$0.575	$0.533

		m/s >	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.40
	4% Interest	**kWh >**	83,754	88,209	92,664	97,119	101,574	106,029	109,593	114,048	122,958
Capital cost per kW	**Total Ann cost low op cost**		**Cost per kWh below**								
$7,000	$42,988		$0.513	$0.487	$0.464	$0.443	$0.423	$0.405	$0.392	$0.377	$0.350
$7,354	$44,656		$0.533	$0.506	$0.482	$0.460	$0.440	$0.421	$0.407	$0.392	$0.363
$7,785	$46,687		$0.557	$0.529	$0.504	$0.481	$0.460	$0.440	$0.426	$0.409	$0.380
$8,215	$48,713		$0.582	$0.552	$0.526	$0.502	$0.480	$0.459	$0.444	$0.427	$0.396
$8,423	$49,693		$0.593	$0.563	$0.536	$0.512	$0.489	$0.469	$0.453	$0.436	$0.404
$9,492	$54,731		$0.653	$0.620	$0.591	$0.564	$0.539	$0.516	$0.499	$0.480	$0.445
$10,000	$57,125		$0.682	$0.648	$0.616	$0.588	$0.562	$0.539	$0.521	$0.501	$0.465

Appendix H

One EW50 Turbine Project Electricity Cost with Medium Operating Costs

Paulatuk 1 turbine project electricity cost as a function of wind speed and capital cost (medium operating cost)

Yellow	=	Viable at fuel cost of $1.25 per liter, diesel fuel cost $0.347 per kWh
Light green	=	Viable at fuel cost of $1.50 per liter, diesel fuel cost $0.417 per kWh
Blue	=	Viable at fuel cost of $1.75 per liter, diesel fuel cost $0.486 per kWh
Purple	=	Viable at fuel cost of $2.00 per liter, diesel fuel cost $0.556 per kWh
Pink	=	Viable at fuel cost of $2.50 per liter, diesel fuel cost $0.714 per kWh

		m/s >	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.40
	8% Interest	**kWh >**	83,754	88,209	92,664	97,119	101,574	106,029	109,593	114,048	122,958
Capital cost per kW	**Total Ann cost med op cost**	**Cost per kWh below**									
$7,000	$60,227		$0.719	$0.683	$0.650	$0.620	$0.593	$0.568	$0.550	$0.528	$0.490
$7,354	$62,514		$0.746	$0.709	$0.675	$0.644	$0.615	$0.590	$0.570	$0.548	$0.508
$7,785	$65,299		$0.780	$0.740	$0.705	$0.672	$0.643	$0.616	$0.596	$0.573	$0.531
$8,215	$68,077		$0.813	$0.772	$0.735	$0.701	$0.670	$0.642	$0.621	$0.597	$0.554
$8,423	$69,421		$0.829	$0.787	$0.749	$0.715	$0.683	$0.655	$0.633	$0.609	$0.565
$9,492	$76,328		$0.911	$0.865	$0.824	$0.786	$0.751	$0.720	$0.696	$0.669	$0.621
$10,000	$79,610		$0.951	$0.903	$0.859	$0.820	$0.784	$0.751	$0.726	$0.698	$0.647

		m/s >	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.40
	6% Interest	**kWh >**	83,754	88,209	92,664	97,119	101,574	106,029	109,593	114,048	122,958
Capital cost per kW	**Total Ann cost med op cost**		**Cost per kWh below**								
$7,000	$53,903		$0.644	$0.611	$0.582	$0.555	$0.531	$0.508	$0.492	$0.473	$0.438
$7,354	$55,870		$0.667	$0.633	$0.603	$0.575	$0.550	$0.527	$0.510	$0.490	$0.454
$7,785	$58,265		$0.696	$0.661	$0.629	$0.600	$0.574	$0.550	$0.532	$0.511	$0.474
$8,215	$60,655		$0.724	$0.688	$0.655	$0.625	$0.597	$0.572	$0.553	$0.532	$0.493
$8,423	$61,811		$0.738	$0.701	$0.667	$0.636	$0.609	$0.583	$0.564	$0.542	$0.503
$9,492	$67,752		$0.809	$0.768	$0.731	$0.698	$0.667	$0.639	$0.618	$0.594	$0.551
$10,000	$70,575		$0.843	$0.800	$0.762	$0.727	$0.695	$0.666	$0.644	$0.619	$0.574

		m/s >	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.40
	4% Interest	**kWh >**	83,754	88,209	92,664	97,119	101,574	106,029	109,593	114,048	122,958
Capital cost per kW	**Total Ann cost med op cost**		**Cost per kWh below**								
$7,000	$47,988		$0.573	$0.544	$0.518	$0.494	$0.472	$0.453	$0.438	$0.421	$0.390
$7,354	$49,656		$0.593	$0.563	$0.536	$0.511	$0.489	$0.468	$0.453	$0.435	$0.404
$7,785	$51,687		$0.617	$0.586	$0.558	$0.532	$0.509	$0.487	$0.472	$0.453	$0.420
$8,215	$53,713		$0.641	$0.609	$0.580	$0.553	$0.529	$0.507	$0.490	$0.471	$0.437
$8,423	$54,693		$0.653	$0.620	$0.590	$0.563	$0.538	$0.516	$0.499	$0.480	$0.445
$9,492	$59,731		$0.713	$0.677	$0.645	$0.615	$0.588	$0.563	$0.545	$0.524	$0.486
$10,000	$62,125		$0.742	$0.704	$0.670	$0.640	$0.612	$0.586	$0.567	$0.545	$0.505

Appendix H

One EW50 Trubine Project Electricity Cost with High Operating Costs

Paulatuk 1 turbine project electricity cost as a function of wind speed and capital cost (high operating cost)

	=	Viable at fuel cost of $1.25 per liter, diesel fuel cost $0.347 per kWh
	=	Viable at fuel cost of $1.50 per liter, diesel fuel cost $0.417 per kWh
	=	Viable at fuel cost of $1.75 per liter, diesel fuel cost $0.486 per kWh
	=	Viable at fuel cost of $2.00 per liter, diesel fuel cost $0.556 per kWh
	=	Viable at fuel cost of $2.50 per liter, diesel fuel cost $0.714 per kWh

		m/s >	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.40
	8% Interest	**kWh >**	83,754	88,209	92,664	97,119	101,574	106,029	109,593	114,048	122,958
Capital cost per kW	**Total Ann cost high op cost**		**Cost per kWh below**								
$7,000	$65,227		$0.779	$0.739	$0.704	$0.672	$0.642	$0.615	$0.595	$0.572	$0.530
$7,354	$67,514		$0.806	$0.765	$0.729	$0.695	$0.665	$0.637	$0.616	$0.592	$0.549
$7,785	$70,299		$0.839	$0.797	$0.759	$0.724	$0.692	$0.663	$0.641	$0.616	$0.572
$8,215	$73,077		$0.873	$0.828	$0.789	$0.752	$0.719	$0.689	$0.667	$0.641	$0.594
$8,423	$74,421		$0.889	$0.844	$0.803	$0.766	$0.733	$0.702	$0.679	$0.653	$0.605
$9,492	$81,328		$0.971	$0.922	$0.878	$0.837	$0.801	$0.767	$0.742	$0.713	$0.661
$10,000	$84,610		$1.010	$0.959	$0.913	$0.871	$0.833	$0.798	$0.772	$0.742	$0.688

		m/s >	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.40
	6% Interest	**kWh >**	83,754	88,209	92,664	97,119	101,574	106,029	109,593	114,048	122,958
Capital cost per kW	**Total Ann cost high op cost**		**Cost per kWh below**								
$7,000	$58,903		$0.703	$0.668	$0.636	$0.606	$0.580	$0.556	$0.537	$0.516	$0.479
$7,354	$60,870		$0.727	$0.690	$0.657	$0.627	$0.599	$0.574	$0.555	$0.534	$0.495
$7,785	$63,265		$0.755	$0.717	$0.683	$0.651	$0.623	$0.597	$0.577	$0.555	$0.515
$8,215	$65,655		$0.784	$0.744	$0.709	$0.676	$0.646	$0.619	$0.599	$0.576	$0.534
$8,423	$66,811		$0.798	$0.757	$0.721	$0.688	$0.658	$0.630	$0.610	$0.586	$0.543
$9,492	$72,752		$0.869	$0.825	$0.785	$0.749	$0.716	$0.686	$0.664	$0.638	$0.592
$10,000	$75,575		$0.902	$0.857	$0.816	$0.778	$0.744	$0.713	$0.690	$0.663	$0.615

		m/s >	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.40
	4% Interest	**kWh >**	83,754	88,209	92,664	97,119	101,574	106,029	109,593	114,048	122,958
Capital cost per kW	**Total Ann cost high op cost**		**Cost per kWh below**								
$7,000	$52,988		$0.633	$0.601	$0.572	$0.546	$0.522	$0.500	$0.483	$0.465	$0.431
$7,354	$54,656		$0.653	$0.620	$0.590	$0.563	$0.538	$0.515	$0.499	$0.479	$0.445
$7,785	$56,687		$0.677	$0.643	$0.612	$0.584	$0.558	$0.535	$0.517	$0.497	$0.461
$8,215	$58,713		$0.701	$0.666	$0.634	$0.605	$0.578	$0.554	$0.536	$0.515	$0.478
$8,423	$59,693		$0.713	$0.677	$0.644	$0.615	$0.588	$0.563	$0.545	$0.523	$0.485
$9,492	$64,731		$0.773	$0.734	$0.699	$0.667	$0.637	$0.611	$0.591	$0.568	$0.526
$10,000	$67,125		$0.801	$0.761	$0.724	$0.691	$0.661	$0.633	$0.612	$0.589	$0.546