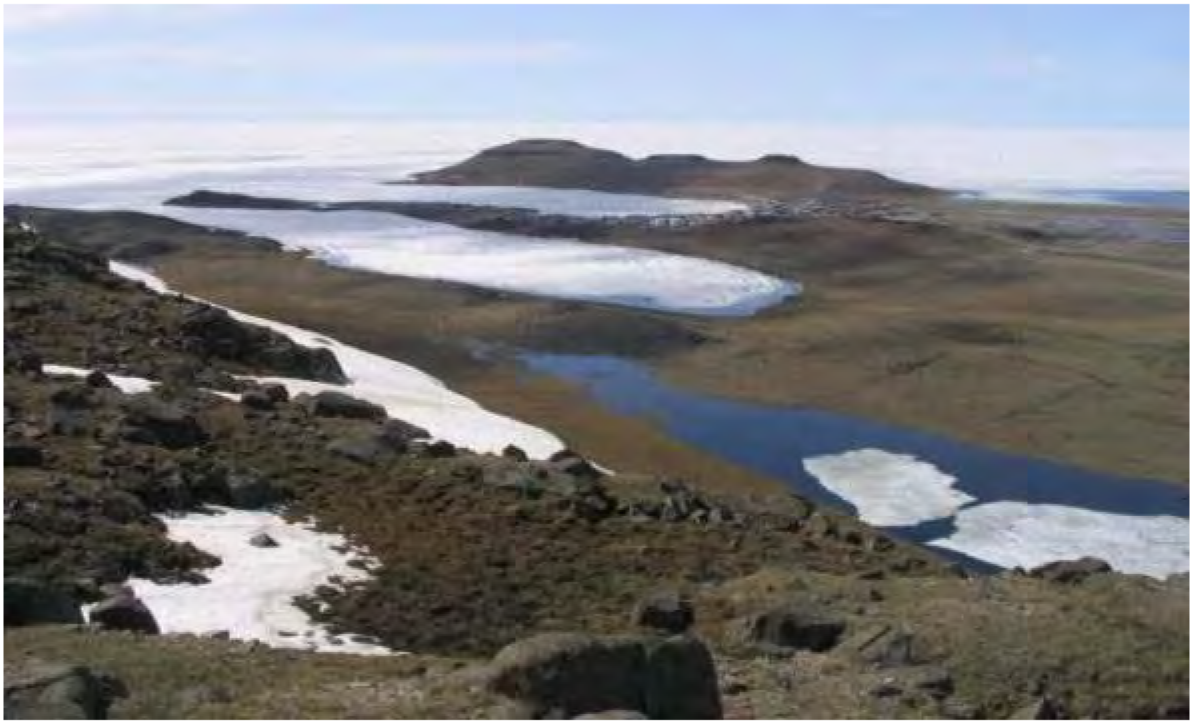
Ulukhaktok Wind Energy Pre-Feasibility Study



Prepared for

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Executive Summary

The Hamlet of Ulukhaktok is an Inuvialuit community on the west coast of Victoria Island and is accessible by air and by summertime barge. The community's electrical load is powered by a diesel-electric generating plant that is owned and operated by the Northwest Territories Power Corporation (NTPC). The plant supplies 2,000 MWh per year of electricity to the hamlet of 400 people. The average load in the community is 227 kW and the minimum and maximum loads are 95 and 470 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 in this community.

In 2006 the Aurora Research Institute established a wind monitoring station on the East Ridge, just east of the hamlet. The wind data analysis shows a long-term annual mean wind speed of 5.8 and 6.6 m/s at 10 and 37 m above ground level. The tallest tower available for a small scale wind development suitable for this community is 37 m tall, such as the EW50 by Entegrity. This turbine was used for the economic analysis in this study.

The wind analysis and modeling is focused towards estimating winds at 37 m above ground level. Four sites were considered for this study: East Ridge, Limestone Hill, the diesel Power Plant Hill, and the Three Hills on the peninsula. Based on the wind analysis and numerical modeling, the long-term annual mean wind speeds for these proposed sites are 6.6, 5.7, 5.6, and 6.2 m/s respectively.

For each of the suggested sites a two-turbine economic analysis was conducted because two turbines reduce the operating cost by roughly 20% compared to one. The table below summarizes the costs for each site (Table 1). The two most favourable sites are the Power Plant Hill and the Three Hills. The estimated capital cost for building on Three Hills is $1,254,000, with a total cost of energy $0.68/kWh. A project at this site will require a $0.26/kWh subsidy to compete with the present avoided cost of diesel at $0.41/kWh. The Power Plant Hill is the cheapest to build at $1,085,000 but is limited by space and has a higher total cost of energy of $0.78/kWh requiring a greater subsidy. There is potential to lower costs with taller towers and large rotor diameter, however subsidies will be required to compete with the costs of diesel-electric generation.

Table 1: Summary of costs to develop a wind project at selected sites in Ulukhaktok.

Ulukhaktok Wind Project Analyses Summary Cost of capital 8% and medium operating cost									
Site	Wind speed at hub m/s	Height ASL m	Capital cost	Capital cost $/kW	Cost $/kWh	Required capital subsidy	Required per kWh subsidy	Diesel kWh displaced	Breakeven fuel $/litre
Three Hills	6.2	53	$ 1,254,000	$ 9,646	$ 0.68	$ 576,000	$ 0.26	228,096	$ 2.45
Power Plant Hill	5.6	32	$ 1,085,000	$ 8,346	$ 0.78	$ 647,000	$ 0.36	176,418	$ 2.81
Limestone Ridge	5.7	42	$ 1,382,000	$ 10,631	$ 0.90	$ 907,000	$ 0.49	185,328	$ 3.24
East Ridge	6.6	182	$ 2,339,000	$ 17,992	$ 1.00	$ 1,534,000	$ 0.58	263,736	$ 3.60

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 wind 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 Ulukhaktok. 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 Ulukhaktok has a population of about 400 people and is located on the west coast of Victoria Island in the Amundsen Gulf. The community is 950 km north-northwest of Yellowknife and is accessible by air and by barge (see Figure 1).

A diesel-electric generating plant that is owned and operated by the Northwest Territories Power Corporation (NTPC) supplies the electrical energy for Ulukhaktok. In May 2006, ARI installed a wind monitoring station east of the community on a bluff at about 182 m above sea level. A progress report was produced to estimate a long-term mean annual wind speed of 6.54 m/s at 30 m AGL for that site (Pinard 2007). Projected to 37 m AGL this is about 6.7 m/s, which makes Ulukhaktok a very suitable candidate for incorporating wind energy into the community's power supply. In this report the height of 37 m will be use for estimating the wind speeds as it corresponds to the height of the tallest tower that is available for a community-scaled wind turbine generator.

The purpose of this report is to examine the potential for wind power generation for the community of Ulukhaktok. This report lists potential sites for a wind development through estimates of wind speeds combined with an economic analysis which estimates the costs of building a wind installation near the hamlet.

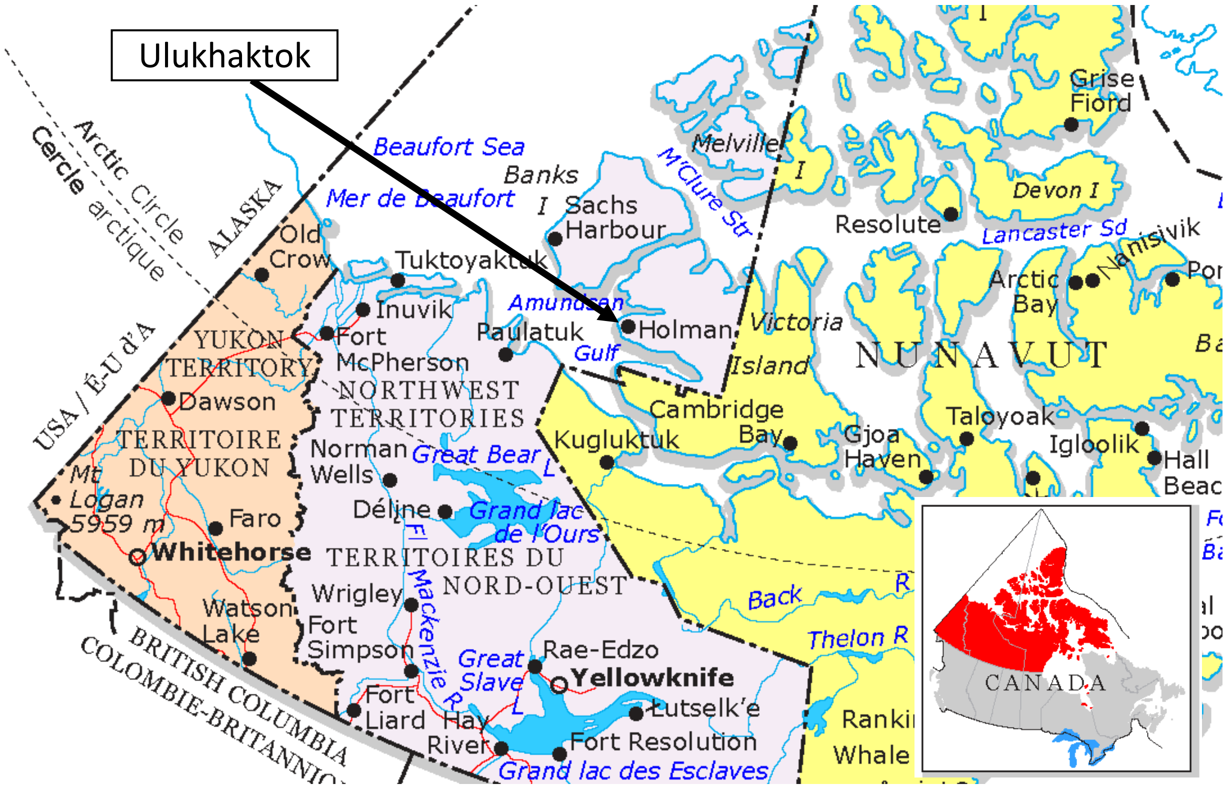

Figure 1: The location of Ulukhaktok (formerly named Holman) in relation to the rest of Canada.

The Wind Data Collecting Stations

The ARI wind monitoring station is a 30 m tower set up with 3 wind speed sensors (anemometers). The sensors are located at 10-, at 20- and 30 m above ground level (AGL) on the tower (See Figure 2). The anemometer booms (1.1 m long) point to the south. One wind vane is installed at the tower top on a boom pointing west and a temperature sensor is at the bottom. The ARI station at the ridge site (See Figure 3) has been up and running since May 22, 2006 and the data used for this study is available to December, 2008.

At the airport there are two stations (Figure 4) that measure the wind speed at 10 m AGL and the weather data for both stations are stored on Environment Canada's website (see http://www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html). The hourly wind data from the two airport stations can also be downloaded in monthly files from the Environment Canada's website.

One of these stations is the airport "auto" station (automatic data collection) located at 30 m above sea level (ASL) and has monitored weather conditions 24 hours a day since 2000. The second is the airport "A" station ("A" meaning that is operated and data collected by the airport staff), which is monitored during office hours (typically 8am to 5pm local time) and its data is recorded at the top of each hour. The airport station has collected data since 1987.

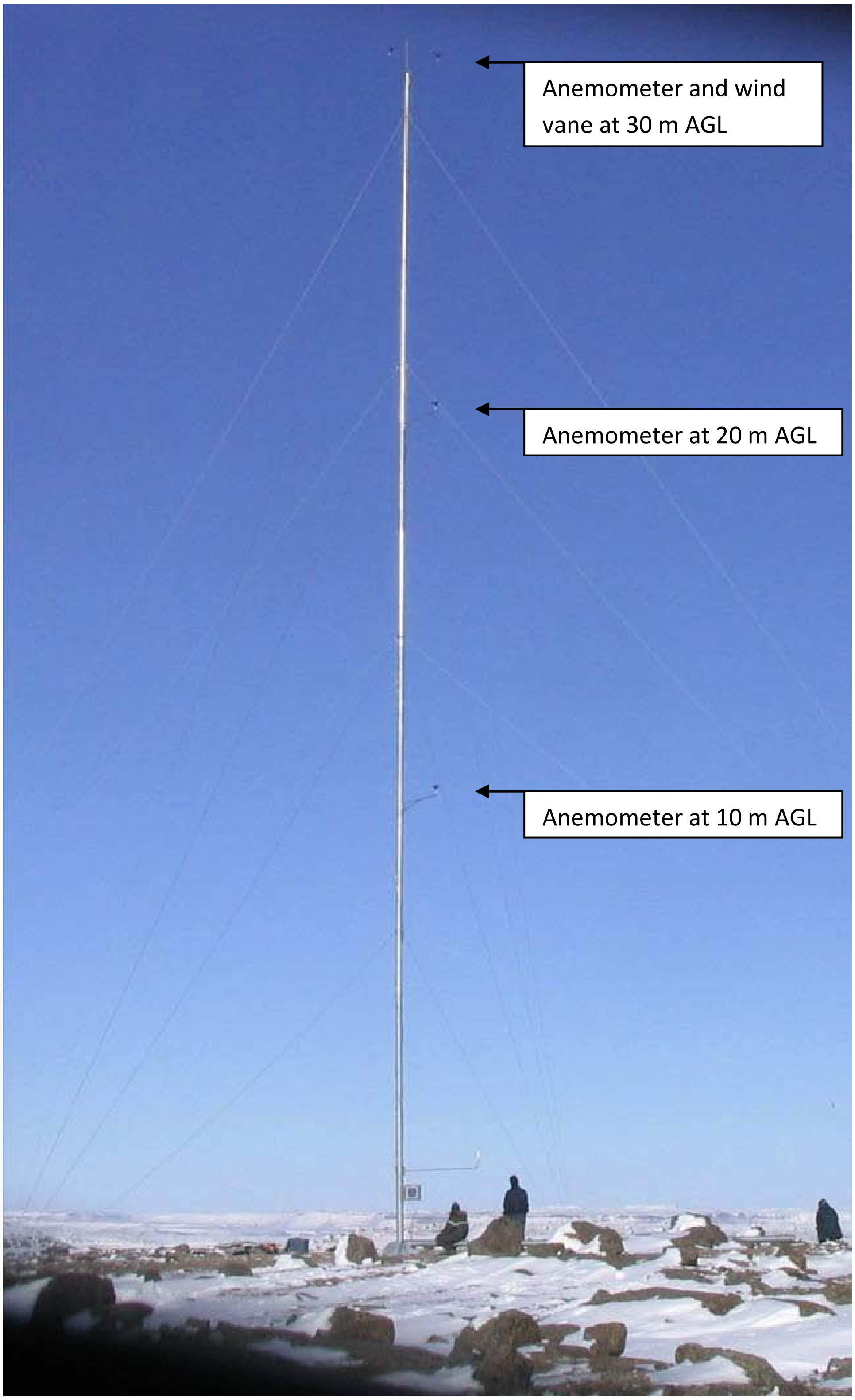

Figure 2: The ARI wind monitoring tower installed at the East Ridge. It has three anemometers at 10, 20, and 30 m above the ground.

Figure 3: View looking east-northeast at the ARI wind monitoring station from the Hamlet Cooperative.

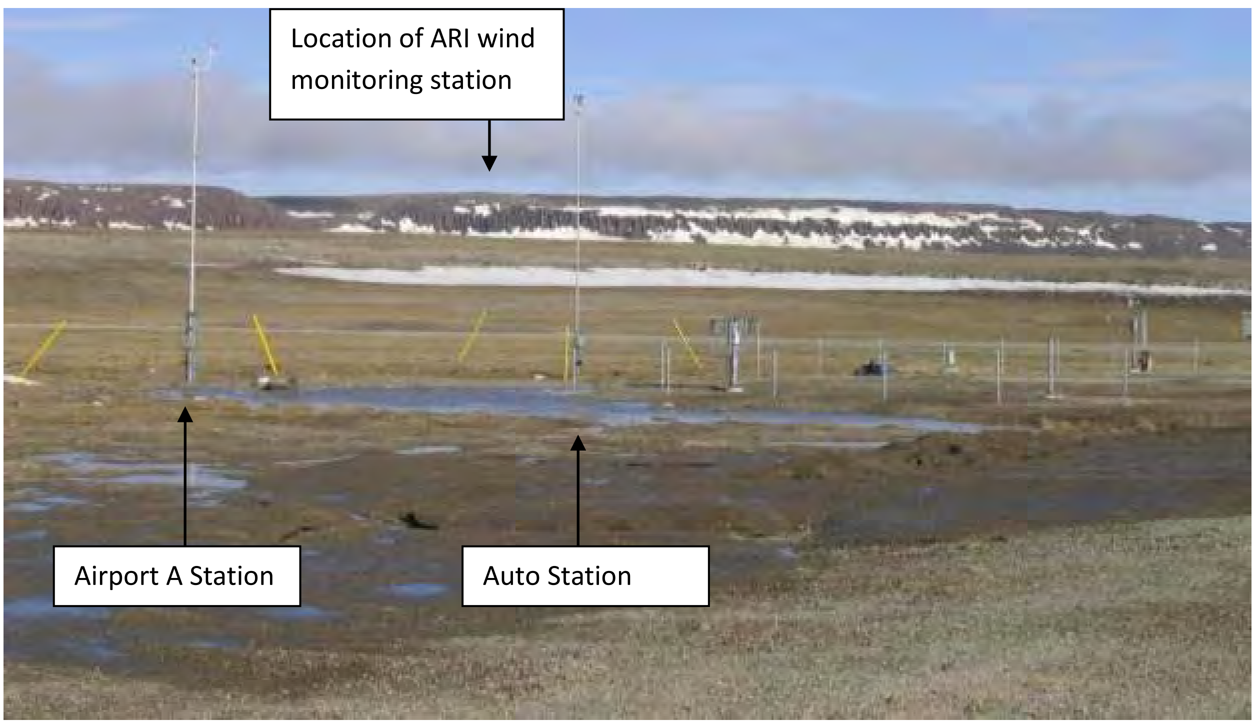

Figure 4: View of what appears to be the Airport A station and the auto stations, next to the airport terminal to the south of this site. The viewer is looking towards the southwest. The East Ridge is in the background and the location of the ARI wind monitoring station is identified.

Wind Direction Analysis

At the Ulukhaktok airport the dominant wind energy comes from the east whereas the ridge measured a very narrow east-southeast wind (Figure 5). The East Ridge site is the most exposed of the two measurement sites since it is located higher than the airport site and there are no land obstructions to the wind here. The stations at the airport are somewhat sheltered by the East Ridge to the southeast and have more exposure to the east beyond the north edge of the hills that make up the East Ridge.

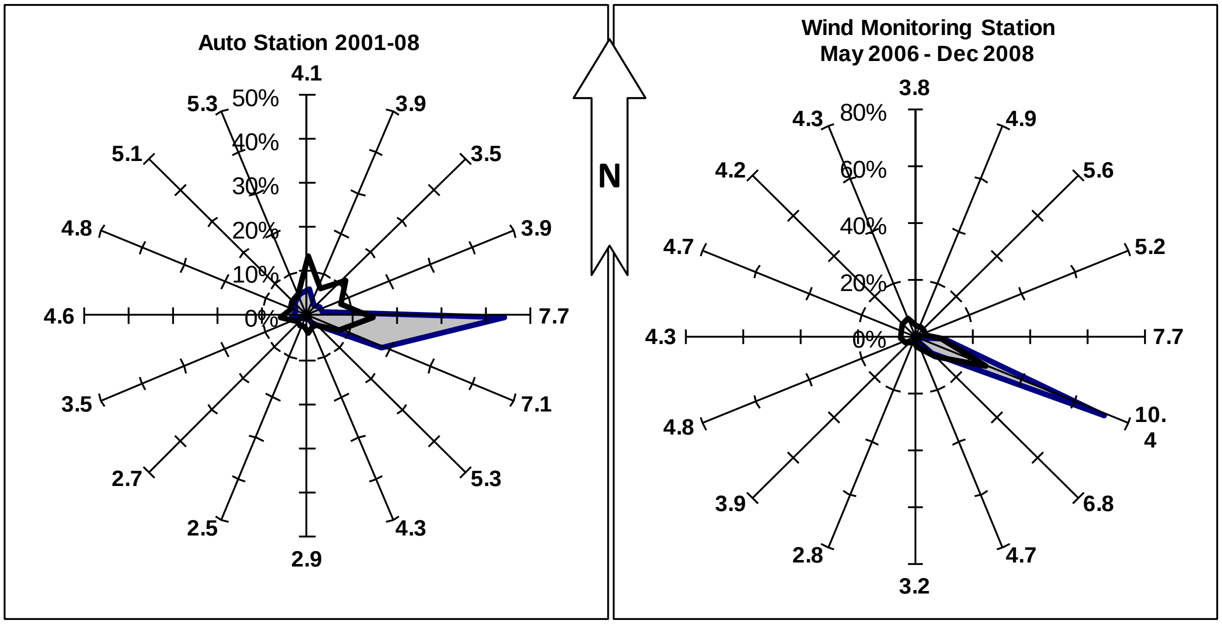

Figure 5: Wind energy roses for the auto station at the airport and the ARI wind monitoring station. The shaded rose is the relative wind energy by direction, and the outlined rose is the wind frequency of occurrence by direction. The mean wind speed by direction sector is indicated at the end of each axis. The outlined area represents the frequency of winds and the shaded area represents the energy in the wind by direction. North is up and west is to the right.

Wind Speed Analysis

Defining the Long-term Mean in Ulukhaktok

At the airport the A station and the auto station are compared to each other for the period 2001-06. During this period the auto station had an annual mean wind speed of 4.79 m/s and the A station was 4.75 m/s; the auto station's mean wind speed was about 1% above the A station during this period.

The auto station recorded a mean wind speed of 4.83 m/s for both the most recent 5-year (2004-08) and eight-year (2001-2008) periods. The standard deviation of the mean annual wind speed about the 8-year mean is 0.20 m/s. A time series of the annual mean wind speed of the auto station at the Ulukhaktok airport is shown (Figure 6). Because of its 24-hour availability the auto station wind data is used for the comparative analysis with the wind 30 m data from the wind energy monitoring station.

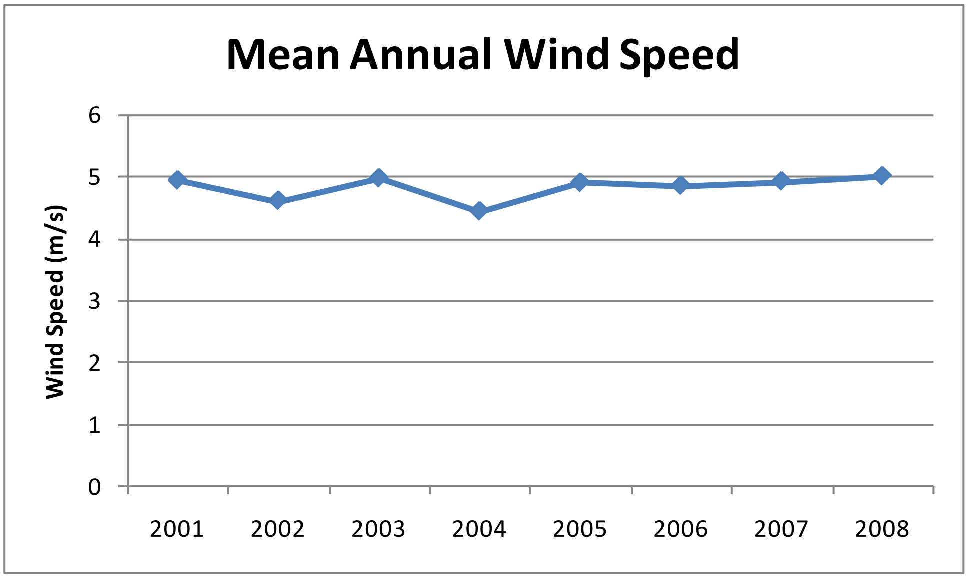

Figure 6: Time series graph of annual means wind speed at the auto station located at the airport.

The long-term monthly wind speed at the airport auto station as shown in Figure 7 reveals the fastest wind during the fall month of October at 6.20 m/s (at 10 m AGL). The winds reach a late winter low of 3.92 m/s (10 m AGL) in March.

The corrected power ratio in Figure 7 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. As the graph shows the corrected power ratio increases to a maximum factor of 1.18 during the winter month of February 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 are shown (Table 2).

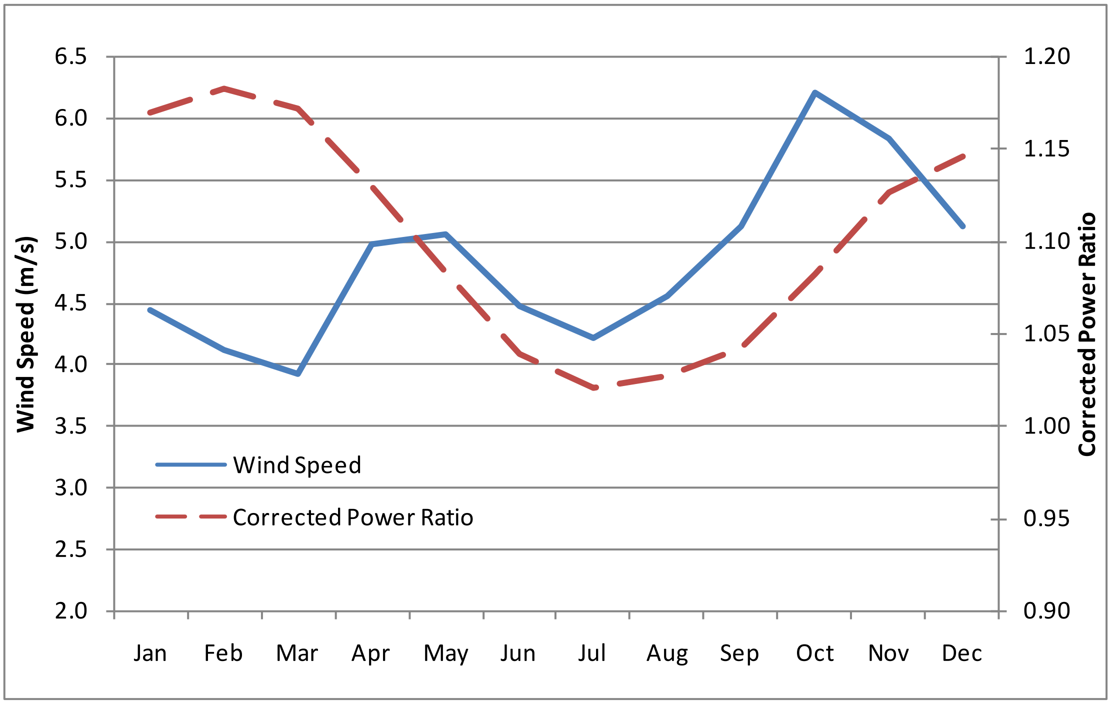

Figure 7: Long-term monthly means of the corrected power ratio and wind speed based on the eight-year (2001-2008) airport auto station data measured at 10 m AGL. The wind speed is referenced to the left side and the air density to the right.

Table 2: Monthly mean values based on airport auto station measurements for the period 2001-2008. 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	4.43	-26.7	101.3	1.43	1.17
February	4.11	-28.8	101.6	1.45	1.18
March	3.92	-26.3	101.7	1.44	1.17
April	4.98	-17.3	101.6	1.38	1.13
May	5.04	-6.7	101.5	1.33	1.08
June	4.47	3.7	101.1	1.27	1.04
July	4.22	7.5	100.7	1.25	1.02
August	4.55	6.1	100.8	1.26	1.03
September	5.12	1.9	100.8	1.28	1.04
October	6.20	-7.8	100.9	1.32	1.08
November	5.82	-18.1	101.1	1.38	1.13
December	5.12	-22.6	100.9	1.40	1.15
Annual	4.83	-11.2	101.2	1.35	1.10

Comparing the Wind Speed from Auto and Wind Monitoring Stations

The period chosen for the comparative study is approximately 2.5 years, from 22 May, 2006 to December 2008 when the ARI WM station was running.

The wind speed correlation between the measurements of the ARI wind monitoring site and the auto station was (Pearson) R= 0.83 when comparing the 30 m wind sensor to the auto 10 m. Between the 10 m sensor at the wind monitoring station and the auto station's 10 m sensor that correlation increased to R=0.84. Whereas R=0 means no correlation and R=1 is perfect correlation, these correlations are considered to be excellent. This correlation coefficient will be used in following sections to estimate the long-term mean for the wind monitoring site.

During this 2.5 year period the auto station recorded a mean wind speed of 5.04 m/s (10 m AGL) whereas the wind monitoring station was 25% faster at 6.25 m/s (10 m AGL). At 20 and 30 m AGL the period mean wind speed at the WM station was 6.46 and 6.67 m/s. The comparisons were similar in the last analysis of wind speeds (Pinard 2007).

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 represented by z_o which as a rule of thumb is 1/10 the height of the grass or brush 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 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.

On the East Ridge area the land surface is a flat polished rock outcrop with a few small boulders ~50 cm diameter and with slightly undulating terrain with depressions that fill with snow during the winter (hence smoothening the surface and reducing z_o). The surface roughness is expected to be between 0.0001 m (0.01 cm), which is the equivalent of snow-covered flat or rolling ground area, and 0.002 m (0.2 cm), which represents natural snow surface (farmland, see Stull 1988). In previous reports (Pinard 2007) the surface roughness z_o was calculated to be 0.0003 m (0.03 cm) which is considered to be the smoothness of snow-covered flat ground. The same roughness value is used here and the vertical profile using the log equation is shown as "U (log)" superimposed on the profile of measured wind speed "U (msd)" (Figure 8).

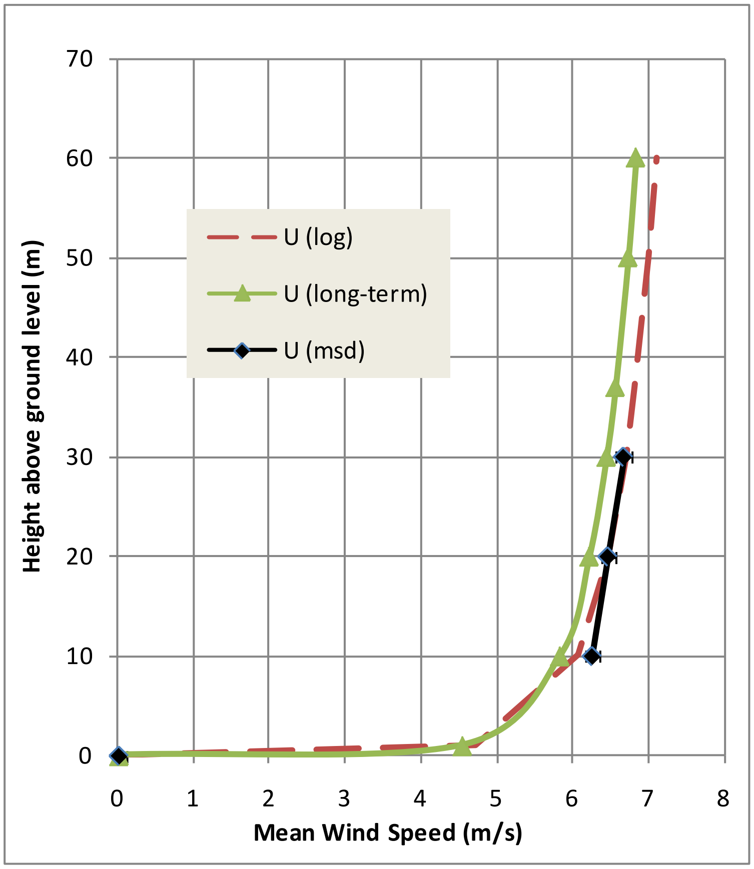

Figure 8: Vertical profiles of the horizontal wind speed at the ARI wind monitoring site on the East Ridge. The vertical profile "U (log)" is fitted to the measurements "U (msd)" and then adjusted to long-term (2001-08) as shown with "U (long-term)". Black whiskers associated with "U (msd)" indicate possible errors of ±0.1 m/s due to sensor inaccuracies.

Projecting to a Longer Term

The annual mean wind speed measured by the auto station has relatively little variability (Figure 6). While the mean wind speed for the 2.5 year period in 2006-08 is 5.04 m/s it drops to 4.83 m/s for both the 5- and 8-year periods. This represents a decrease to 96% of the auto station's short term mean wind speed.

The vertical profile U(log) is adjusted to an eight-year mean U(long-term) using the MCP method of measuring, correlating, and predicting the long-term mean winds (Figure 8). 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 deviations for the reference station, σ_r, and the wind monitoring site, σ_s. These values are listed in Table 2. The estimated long-term (8-year) mean is calculated as 6.21 m/s (at 20 m AGL), this is about 0.96 of the short-term measured value of 6.46 m/s. From the log law formula above the 8-year (2001-08) projected mean of the wind monitoring site at 37 m AGL is 6.56 m/s. The vertical profile of estimated long-term mean for the wind monitoring site is shown (Figure 8 and Table 3).

Table 3: Details of values in the evaluation of the long-term mean wind speed of the wind monitoring station using the MCP method. Bold value indicate the estimated long-term mean wind speed at the site of interest, in this case being the wind monitoring station at the east ridge.

Measure-Correlate-Predict		
Estimated Long-term mean at site (Es) =	**6.21**	m/s at 20m AGL
Estimated Long-term mean at reference (Er) =	4.83	m/s at 10m AGL
Measured site (u_s) =	6.46	m/s at 20m AGL
Measured reference (u_r) =	5.04	m/s at 10m AGL
Measured cross-correlation coefficient (R) =	0.83	
measured standard deviation at site ($?_s$) =	4.81	m/s at 20m AGL
measured standard deviation at reference ($?_r$) =	3.25	m/s at 10m AGL

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 for the 30 m station. In this study the projection error is estimated to be ±0.14 m/s for the 37 m AGL 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 measurement periods of five years or more. Looking at the more conservative estimates of the ten-year mean of 6.56 m/s (at 37 m AGL) the variability may be ±0.39 m/s. In summary we should expect the annual mean wind speed at the East Ridge site to range from 6.17±0.14 to 6.95±0.14 m/s in any given year.

Possible Locations for a Wind Farm in Ulukhaktok

While the East Ridge site is the location with the highest wind speed in the area around Ulukhaktok, it is also the most challenging to develop. There are two possibilities suggested by the authors for road access to the site: one around to the north (ER #1), and the other from the south (ER #2 see Figure 9). The north section would be very difficult to build as there is a lake to traverse at the back end and blasting may be required to cut into steep slopes that lead into the lake. The road to the south may also require blasting and may have a steep grade as well; it was not investigated by the authors by the time of this study.

Table 4: Details of measurements and their projection to longer term and to higher elevations. Bold values indicate the estimated long-term (2001-08) mean wind speed at the wind monitoring station at the East Ridge. These values are also shown in Figure 8 above as "U (long-term)".

Location and measurement period	Height m AGL	Wind speed m/s
Ulukhaktok auto station 2 May 06 to 8 Dec 08:	10	5.04
East Ridge WM 2 May 06 to 8 Dec 08:	10	6.25
	20	6.46
	30	6.67
Ulukhaktok auto station 8-year (2001-08) mean:	10	4.83
Ratio of 8-year mean to 2006-08 for auto:		0.96
East Ridge WM projected to 8-year (2001-08):	10	**5.82**
	20	**6.21**
	30	**6.44**
	37	**6.56**
	50	**6.72**
	60	**6.83**

There are three other areas that were investigated for a wind development and these include 1) Limestone Hill, 2) Three Hills, and 3) the small hill behind the diesel power plant.

Limestone Hill has been suggested locally as a possible location for a small wind farm installation. Limestone Hill is a ridge that runs northeast-to-southwest with an elevation ranging from 42 m ASL (LH #1) at the southwest end and peaking at 71 m ASL at the northeast end (LH#3 in Figure 10). The ridge is nearly perpendicular to the prevailing easterly winds measured is this area. The orientation of this ridge gives it some advantage in that the easterly winds can speed-up over the ridge, and also that the wind turbines can be lined up along the ridge and not interfere with each other with respect to the prevailing winds. This ridge is about 10 to 40 m higher than the airport and so there may be some increases in mean annual winds compared to the airport. Limestone Ridge is, however, shadowed by the upstream East Ridge.

The Three Hills area forms a peninsula that extends out southwest of the hamlet. The Three Hills form a ridge that is about 1 km long in a north-south orientation. As the name implies, the Three Hills site has three knobs of dark gabbro sills that protrude through older limestone. This site is more exposed to prevailing easterly winds than Limestone Hill. There may be four possible wind project locations on the Three Hills (see TH #1 to #4 in Figure 11) but the closest one to the community (TH#4) is the most important one to consider as will be discussed in the economic analysis.

The third other site to consider is the small hill behind (north of) the diesel plant in the community (see Figure 12). This site, although it sheltered by the East Ridge, it is very close to the diesel power plant, which makes it convenient to access and maintain.

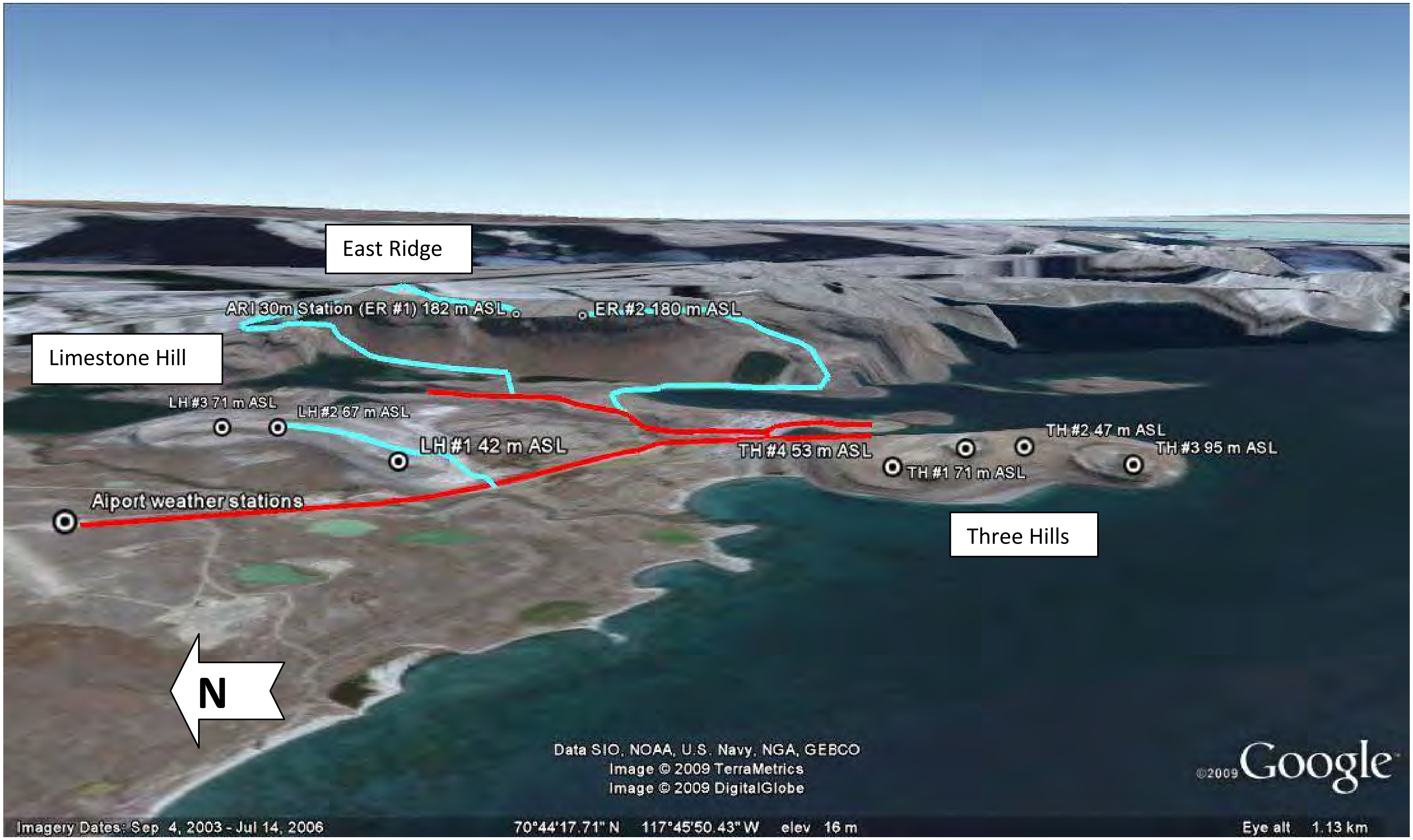

Figure 9: Possible locations for a wind farm. Viewer is looking east-southeast. The red lines are the power line and the blue lines are possible road locations.

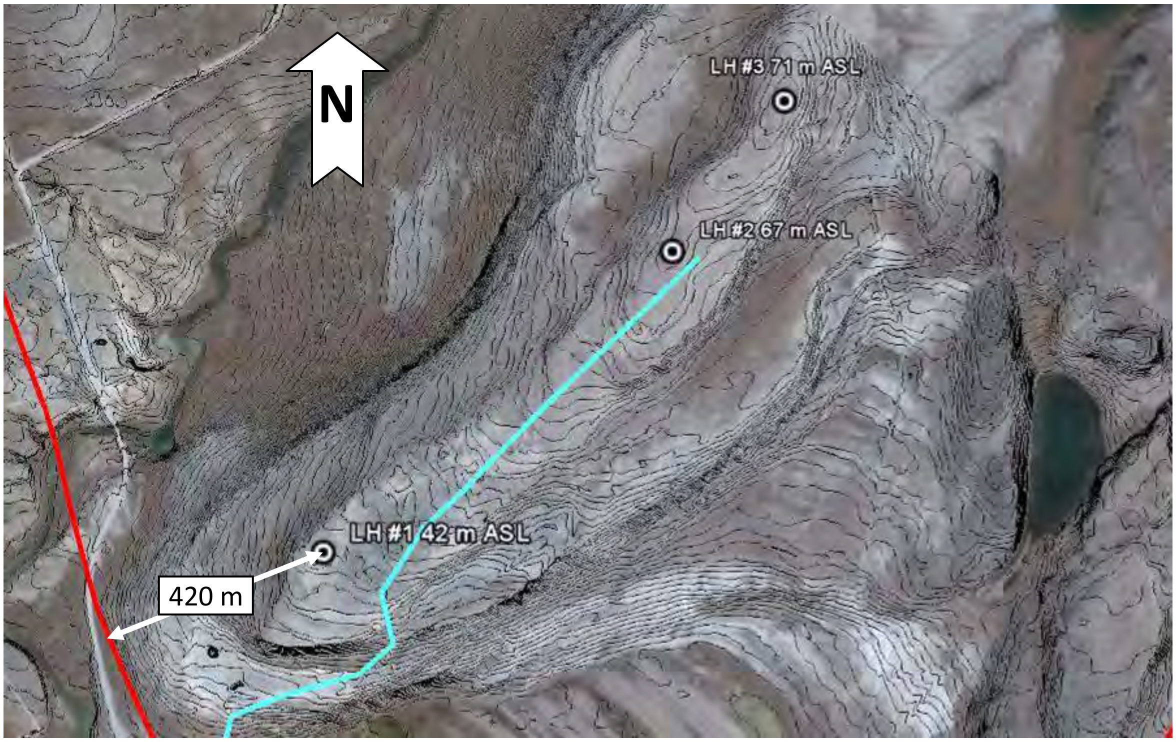

Figure 10: Plan view of Limestone Hill with three possible locations for a wind park. The red line is the power line and the blue line is a possible road. The contours are at 1-metre interval.

Figure 11: Plan view of Three Hills showing four possible locations for a wind park. The red line is the power line.

Figure 12: Plan view of the diesel plant hill the possible location for a wind park. The red line is the power line.

Wind Reduction and Turbulence caused by Obstacles

When investigating potential wind development locations in the Ulukhaktok area it is important to note that the East Ridge acts as a sheltering obstruction to the prevailing east-southeasterly winds that come through the area. Turbines that are sited within 20 H (heights) of a wide obstacle of height H must take into account the possibility of wind speed reduction and turbulence caused by the obstruction (Gipe, 1993).

This obstruction is particularly important in the Arctic where the atmosphere near the surface is typically in the form of an inversion most of the year and more so during the winter. An inversion is a situation where the air at the surface is colder (and denser) than the air immediately above it. Inversions are typically one kilometre thick in the winter and are more intense at the ground surface and in depressions. Because cold air is denser and heavier (than warm air above), it tends to sit in land depressions, preventing warmer air above from mixing downward into this cold surface layer and not be able to push it this cold layer along. Turbines located within the inversion layer especially in a land depression will not be subjected to the same wind speed as those higher up on hills and outside of the more intense part of the inversion.

Figure 13 below is an illustrated profile of the Ulukhaktok area looking north. The wind is from the east-southeast – from the right.

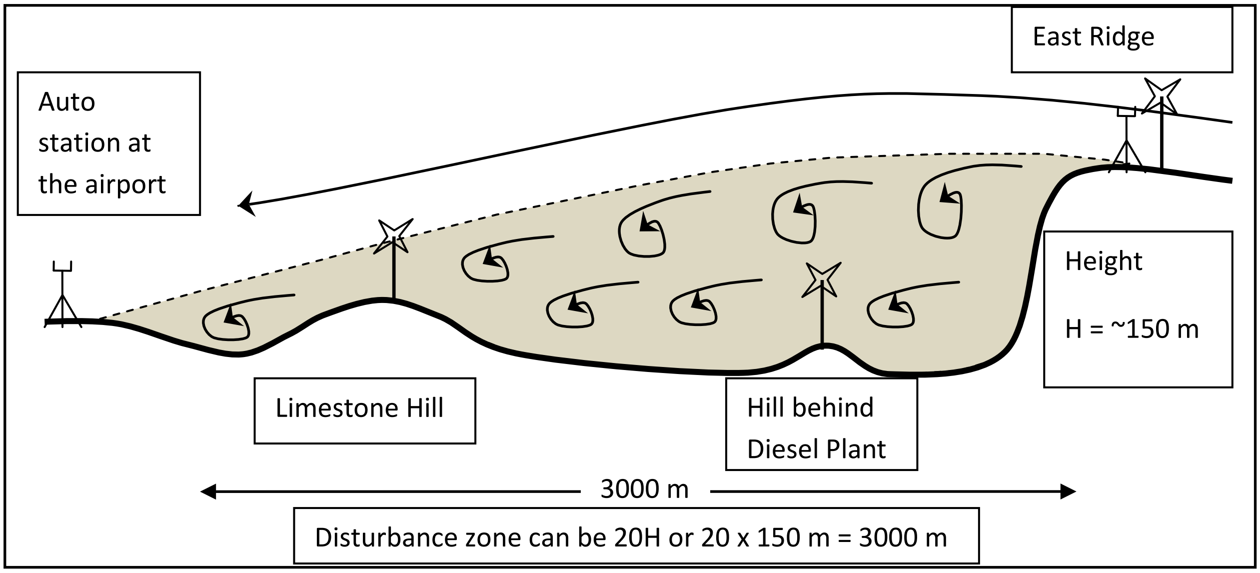

Figure 13: Illustration of effect of wind blocking caused by the East Ridge on areas immediately downstream. The shaded space is an approximation of where the disturbed zone is when the winds come from the east in the winter. The Three Hills (not shown here) is unaffected by this disturbance.

Numerical Modelling with MS-Micro

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

MS-Micro was run for the Ulukhaktok area using data elevation model from the Geobase.ca centre. The surface roughness were estimated with lakes being z_o = 0.00001 m (ice surface) and the ground surface z_o = 0.0003 m. The model domain has an area that is 12 by 12 km with an inner domain that is 6 by 6 km where the wind results are produced. 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).The winds that are applied in the model simulation are normalised, arbitrary winds speed, and one main wind direction is applied to the model that being 110 degrees which is the west-southwest wind direction as measured by the wind monitoring station. The model output is a normalised wind output whose contours are calibrated to the estimated 37 m wind speed of 6.56 m/s at the wind monitoring site. The results of the MS-Micro modeling are shown (Figure 14).

The model results estimate that the winds at the airport to be 5.4 m/s at 37 m AGL. From the auto station data wind speed projected to 37 m is also 5.4 m/s. The MS-Micro results providing a good match like this gives more confidence to the model's predictions in this area. The MS-Micro model tool can be used to estimate wind speed at the other proposed locations. Based on preferred proximity to powerline and other factors, the three most feasible sites identified with this computer model are Three Hill site TH #4, Limestone Hill site LH #1, and the diesel plant Hill site DP (Figure 14). The model estimates that the wind speeds at 37 m AGL are 6.2, 5.7, and 5.6 m/s for the three sites, respectively. These values are used for the economic analysis in the following sections.

Figure 14: Mean wind speed contours based on the numerical model MS-Micro. The wind speeds are modelled at 37 m AGL. The contour interval is 0.2 m/s. The sites are labelled with wind speeds estimated from the model. The four most important sites are indicated by ovals, the site ER #1 is where the wind monitoring took place.

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) filed in late 2006 (see Appendix A) the forecasted energy requirement for 2007/08 was 1,987 MWh and the forecasted peak load was 469kW. The forecasted energy requirement indicates an average load of about 227 kW, and the graphical information provided by NTPC in response to questions on their wind energy request for proposal (RFP) indicates that the recorded minimum is about 140kW but NTPC estimates that the real minimum load would be about 95 kW.

The power plant consists of three diesel-electric generators: one Caterpillar (CAT) of 480 kW capacities, one CAT D379 of 360 kW, and one Detroit Diesel of 320 kW. The CAT D379 is likely the oldest of the units and next up for replacement. According to the GRA the plant fuel efficiency is about 3.616 kWh per litre.

The electrical distribution system is shown as red lines on Figure 14 (and others). It consists of single- and three-phase above ground power lines. The power line to the airport is a single phase line and the line to the pump house (see Figure 14) is a three phase line.

According to the most recent GRA (Appendix A) the forecasted fuel cost was $1.11 per litre or about $0.308 per kWh at the indicated fuel efficiency of 3.6 kWh per litre. However, since the GRA was filed fuel prices went up significantly to about $1.50 per litre (or $0.417 per kWh) in Ulukhaktok (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 forecasted in the 2007/2008 GRA. Appendix B contains a table of electricity costs as a function of fuel price.

Wind Power Project

Wind Turbines

For the purpose 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 on a potential power project in Tuktoyaktuk by the authors and others selected the EW50 as the leading candidate turbine. Although it is larger than NTPC's stated maximum turbine size of 40 kW for this community in their 2008 RFP (see Appendix A) 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 C. 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 gain some economies of scale for a project in Ulukhaktok it was decided to have the project consist of two EW50 wind turbines – a nominal capacity of 100kW or 130kW peak.

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 C). This table was used as a starting point to estimate the annual energy production at each of the four potential wind development sites (East Ridge, Limestone Ridge, three Hills, and Power Plant Hill). 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 Ulukhaktok. 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 (see Figure 15) of the energy actually available to displace diesel generated electricity. Appendix D provides the spreadsheet of these calculations for the wind speeds relevant to Ulukhaktok.

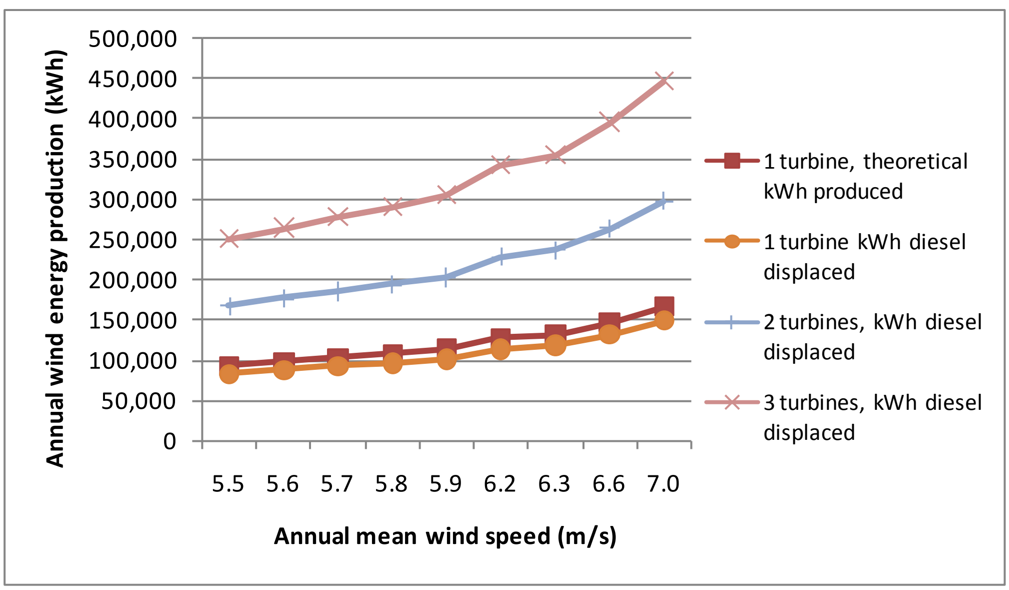

Figure 15: Entegrity EW 50 annual energy production (from Entegrity).

Capital Costs

The capital cost estimates developed for Ulukhaktok 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 Ulukhaktok and the scale of the project as outlined below.

New access road construction was estimated at $100,000 per kilometre for a basic road to meet minimum requirements for project construction and operations. The upgrading of existing lower quality roads was estimated at $40,000 per kilometre. 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, and the upgrading of single phase line to three phases was estimated at $150,000 per kilometre. 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 Ulukhaktok 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 (relative to Tuktoyaktuk estimates) to reflect the remote location and the likely need for more complex negotiations with NTPC as both the turbine and project sizes exceed NTPC's stated limits.

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

1. East Ridge $2,339,000 or $17,992 per kW (calculated using two EW50 wind turbines with a combined peak capacity of 130 kW);
2. Limestone Ridge $1,382,000 or $10,631 per kW;
3. Three Hills (below the peaks) $1,254,000 or $9,646 per kW (a one turbine project here was estimated to cost $814,500 or $12,531 per kW); and
4. Power Plant Hill $1,085,000 or $8,346 per kW.

The East Ridge option is very expensive due to the significant lengths of new road and power lines that would need to be built to access the site; these comprise more than half of the overall capital costs. The power line distance was shortened on the basis that it was thought that it would be possible to build a line down the steep escarpment to shorten the distance. The new power line is to connect to the line that runs to the pump house (Figure 14).

The Limestone Ridge option is assumed to be developed at its south end (LH#1 in Figure 9 and 10) to minimize road and power line distances. The project power line is assumed to connect to the airport power line at the nearest point, but since this is a single phase line upgrading to three phases would be required.

The Three Hills location is assumed to be developed at site TH#4 on the shoulder just northeast of northernmost "knob" (see Figure 11). Choosing this location minimizes the distance of road and power line that would need to be built or upgraded. The nearest power line is single phase however, and probably runs to the community core. If access to the top of the northern two knobs for turbine installation were possible there could be an economic advantage due to the increased altitude and wind speed at hub height. As this site (TH #4) has a higher wind speed regime than all but the East Ridge site, a cost estimate for a single turbine project option was prepared for comparison purposes.

Power Plant Hill (just to the north of the fuel tank storage area, see Figure 12, 13, and 14) was included as it is a site very close to the power plant for which new road and power line lengths would be minimized. The drawback to the site is less exposure to the predominant winds due to its relatively low altitude and location "behind" the East Ridge from the dominant winds.

A capital cost estimate for the increase (or decrease) in project size of one EW50 wind turbine was also prepared. The estimate is $360,500 or $5,546 per kW of capacity (calculated using one EW50 turbine with a peak capacity of 65kW).

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.

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 near a 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 smaller number of turbines proposed 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 (Appendix F).

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.

The measured wind resource at the elevated East Ridge site is 6.6 m/s at turbine hub height, higher than at the other three (lower altitude) sites. Nonetheless, the high capital costs for a road and a power line for this site results in an estimated cost of electricity of about $1.00 per kWh, higher than the other three sites. The lowest capital cost site, the Power Plant Hill, also has the lowest wind resource at 5.6 m/s and the second lowest cost per kWh of electricity at $0.78 per kWh. (A single turbine project here is estimated to produce power at $0.84 per kWh). The Three Hills site has the second lowest capital cost but it has a wind resource of 6.2 m/s and the lowest projected cost of energy at $0.68 per kWh. Limestone Ridge has the second highest capital cost but a modest wind resource of 5.7 m/s results in an electricity cost of $0.90 per kWh (Tables 1 and 4). This illustrates the significant effect the capital costs of projects and the wind resource have on the cost of energy. Each of the four sites is discussed below. For the purposes of calculating the cost per kWh of energy produced it is assumed that all power produced displaced diesel generation.

The East Ridge is the site of a wind monitoring station currently in operation and thus its wind resource is known with a high level of confidence. The wind resource of 6.6 m/s at hub height would yield 263,736 kWh per year from two turbines. Driven by a very high capital cost, the cost of energy from an unsubsidized project (8% cost of capital and $15,000 per year per turbine operating cost) would be $1.00 per kWh. Diesel fuel would need to cost $3.60 per litre for a project to break even under these circumstances. With the present avoided cost of diesel at $0.417 per kWh this site would require capital subsidy of $1,534,260 or a production subsidy of $0.578 per kWh. This site is not a practical site for a project development since it is not only expensive to build the roads and power lines, but access for operations and maintenance would also be challenging – and more costly than the other sites.

The Limestone Ridge site would have the turbine hubs at about 80 meters ASL and would have a wind resource of 5.7 m/s. This would result in 185,328 kWh per year being produced at a cost of $0.90 per kWh, equivalent to $3.24 per litre of diesel fuel. With the present avoided cost of diesel at $0.417 per kWh this site would require capital subsidy of $907,270 or a production subsidy of $0.486 per kWh. This is the second highest cost option after the East Ridge. The road requirement for this site is quite modest but the power line would need to be upgraded all the way back to the community core. However, this is a suitable site for development as it is convenient to get to, it is not likely to be controversial, and there is room to expand a project to the north where the elevation is also higher.

The Three Hills site requires shorter road and power line building or upgrading than the Limestone Ridge site, and is thus less costly to build. The more exposed nature of the site (relative to the higher East Ridge) and slightly higher hub height elevation result in a wind resource of about 6.2 m/s and an annual energy yield of 228,096 kWh per year, substantially better than Limestone Ridge. The projected cost of energy is $0.68 per kWh, equivalent to $2.45 per litre of fuel. With the present avoided cost of diesel at $0.417 per kWh this site would require capital subsidy of $575,900 or a production subsidy of $0.261 per kWh. This is the lowest cost energy of any of the three sites. This site has the potential to be better if access to the top of the hill could be built and turbines installed there. The main concern with this site is that it is reported to be sacred, so development may not be possible.

The Power Plant Hill site was added to the sites being examined as it is very close to the power plant and would thus minimize costly road and power line construction. It would also be very conveniently located for maintenance. The disadvantage is that it is not very high and the wind resource is only 5.6 m/s due to its location in the lee of the East Ridge. The projected energy production for this site is 176,418 kWh per year at a cost of $0.78 per kWh. This is equivalent to $2.81 per litre of diesel fuel, and is the second lowest cost site after the Three Hills site. With the present avoided cost of diesel at $0.417 per kWh this site would require capital subsidy of $647,400 or a production subsidy of $0.364 per kWh.

The projected cost of adding a turbine to any of these four sites was calculated to be about $5,546 per kW, which is still rather costly. Except for the East Ridge where the energy produced would cost about $0.38 per kWh and lower than the present diesel cost estimate of about $0.417 per kWh, the energy produced at the other sites would still be more expensive - ranging from $0.45 to $0.58 per kWh. This underlines the importance of getting practical project experience and the need to use that experience to reduce future project costs.

Two of the project options examined in this study produce power at more than double the present diesel cost of about $0.41 per kWh, and the lowest cost option is still about 66% more expensive than diesel, so if a wind power project is to proceed in Ulukhaktok, subsidies will be required. Detailed spreadsheets that show the cost of power as a function of capital costs, interest costs, operating costs and wind speed are presented in Appendix G, and a summary of the economic analyses is presented in Table 4.

Table 5: Summary of the economic analyses of four possible locations for wind turbines in Ulukhaktok.

Ulukhaktok Wind Project Analyses Summary

Cost of capital 8% and medium operating cost

Site	Capital cost $/kW	Height ASL m	Hub height ASL m	Wind speed at hub m/s	Diesel kWh displaced	Cost $/kWh	Breakeven fuel $/litre
East Ridge two turbines	$ 17,992	182	220	6.6	263,736	$ 1.00	$ 3.60
Incremental turbine	$ 5,546		220	6.6	131,868	$ 0.38	$ 1.37
Limestone Ridge two turbines	$ 10,631	42	80	5.7	185,328	$ 0.90	$ 3.24
Incremental turbine	$ 5,546		80	5.7	92,664	$ 0.55	$ 1.98
Three Hills one turbine	$ 12,531	53	90	6.2	114,048	$ 0.84	$ 3.02
Three Hills two turbines	$ 9,646	53	90	6.2	228,096	$ 0.68	$ 2.45
Incremental turbine	$ 5,546		90	6.2	114,048	$ 0.45	$ 1.62
Power Plant Hill two turbines	$ 8,346	32	70	5.6	176,418	$ 0.78	$ 2.81
Incremental turbine	$ 5,546		70	5.6	88,209	$ 0.58	$ 2.09

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 Ulukhaktok 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 7%. An increase of 7% 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 appear to be within economic reach.

Discussion on Distance to Wind Project Location

Projects such as the one examined in this study, are often 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 about $3,100 per kW for a project composed of two EW50 turbines. To produce wind energy at the same cost as the present project options a site one kilometre further away would need to have a wind resource about 0.6 m/s higher to balance the increased cost. The wind speed would need to be higher than this if the incremental new energy is to be competitive with diesel generation. This calculation shows the challenge of the distance to project sites for 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 130 kW project (that is, two EW50 turbines) at various annual average wind speeds are shown in Table 5 below. The calculations are based on a diesel plant efficiency of 3.6 kWh per litre, and GHG emissions of 3.0 kg CO_2 equivalent per litre of diesel fuel consumed.

Table 6: Annual GHG reductions from a 130 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	176,418	49,005	147,015
5.7	185,328	51,480	154,440
6.2	228,096	63,360	190,080
6.6	263,736	73,260	219,780

Conclusions

1. The analysis of wind measurements in Ulukhaktok 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 Ulukhaktok area.
2. The East Ridge site has the best wind regime at 6.6 m/s annual average, but the distance to the site and challenging access make this site the most expensive to build at $2,339,000, and the least economically attractive at $1.00 per kWh compared to the three other options examined below.
3. The Limestone Ridge site has the second highest capital cost at $1,382,000 but despite being about $1 million lower than East Ridge, a modest wind regime of 5.7 m/s still results in the second highest energy cost of $0.90 per kWh. This site does have easy access and significant room for future expansion.
4. The Three Hills site has an estimated capital cost of $1,254,000 and a robust wind regime of 6.2 m/s to yield the lowest cost energy of the four options at $0.68 per kWh. This is still 66% more expensive than diesel generation. This area is said to have special cultural significance to the community and a wind project development there may not be possible.
5. The Power Plant Hill is the lowest capital cost option at $1,085,000, and despite having the lowest wind resource of all the options of 5.6 m/s annual average, it yields the second lowest cost energy at $0.78 per kWh. This site is very close to the power plant and would be the easiest to develop, but it is somewhat sheltered from the predominant winds and there is only room for two turbines at the site.
6. 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.
7. 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.
8. 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.
9. A wind energy project in Ulukhaktok will require significant financial subsidization.

Next Steps

The next steps that would be required to develop a wind project in Ulukhaktok are as follows:

1. Consult with the community of Ulukhaktok to better understand whether a wind project on the Three Hills site is or is not possible.

2. Move the monitoring tower presently on East Ridge to the new site chosen through community consultation.

3. 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.

4. 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) to allow the integration of two or more wind turbines into the power system as proposed in this study.

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

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NORTHWEST TERRITORIES
POWER
CORPORATION

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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.27

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

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)	699	777	806	771	817
2	Customers	174	146	146	149	149
3	Av. MWh Sales/Cust.	4.02	5.32	5.52	5.19	5.47
4	Revenue (000s)	543	598	617	590	624
5	Cents /kWh	*77.77*	*77.01*	*76.52*	*76.56*	*76.34*
	General Service					
6	Sales (MWh)	961	953	1,007	935	974
7	Customers	48	50	52	50	50
8	Av. MWh Sales/Cust.	20.08	19.06	19.36	18.69	19.47
9	Revenue (000s)	674	667	704	656	681
10	Cents /kWh	70.07	69.96	69.94	70.16	69.92
	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)	32	24	25	23	25
21	Revenue (000s)	33	18	23	23	23
22	Cents /kWh	104.08	73.74	94.65	100.72	94.64
	Total Community					
23	**Sales (MWh)**	**1,692**	**1,754**	**1,838**	**1,728**	**1,816**
24	Customers	**222**	**196**	**198**	**199**	**199**
25	Revenue (000s)	**1250**	**1,283**	**1,345**	**1,269**	**1,328**
26	Cents /kWh	73.89	73.14	73.16	73.42	73.15
	GENERATION (MWh)					
27	**Total Station Service**	71	68	62	62	62
28	**Total Losses**	133	119	111	104	110
29	***Losses - % of Gen.***	*7.0%*	*6.1%*	*5.5%*	*5.5%*	*5.5%*
30	**Total Generation**	**1,895**	**1,940**	**2,010**	**1,894**	**1,987**
	Source (MWh)					
31	Hydro Generation					
32	Gas Generation					
33	Gas Efficiency					
34	*Cubic Meters (000s)*					
35	Diesel Generation	1,895	1,940	2,010	1,894	1,987
36	Diesel Efficiency	3.579	3.552	3.675	3.616	3.616
37	*Liters (000s)*	*530*	*546*	*547*	*524*	*549*
38	Purchased Power					
39	Total Generation	1,895	1,940	2,010	1,894	1,987
	% 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	445	430	430	447	469
45	Load Factor	48.6%	51.5%	53.4%	48.3%	48.3%

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.

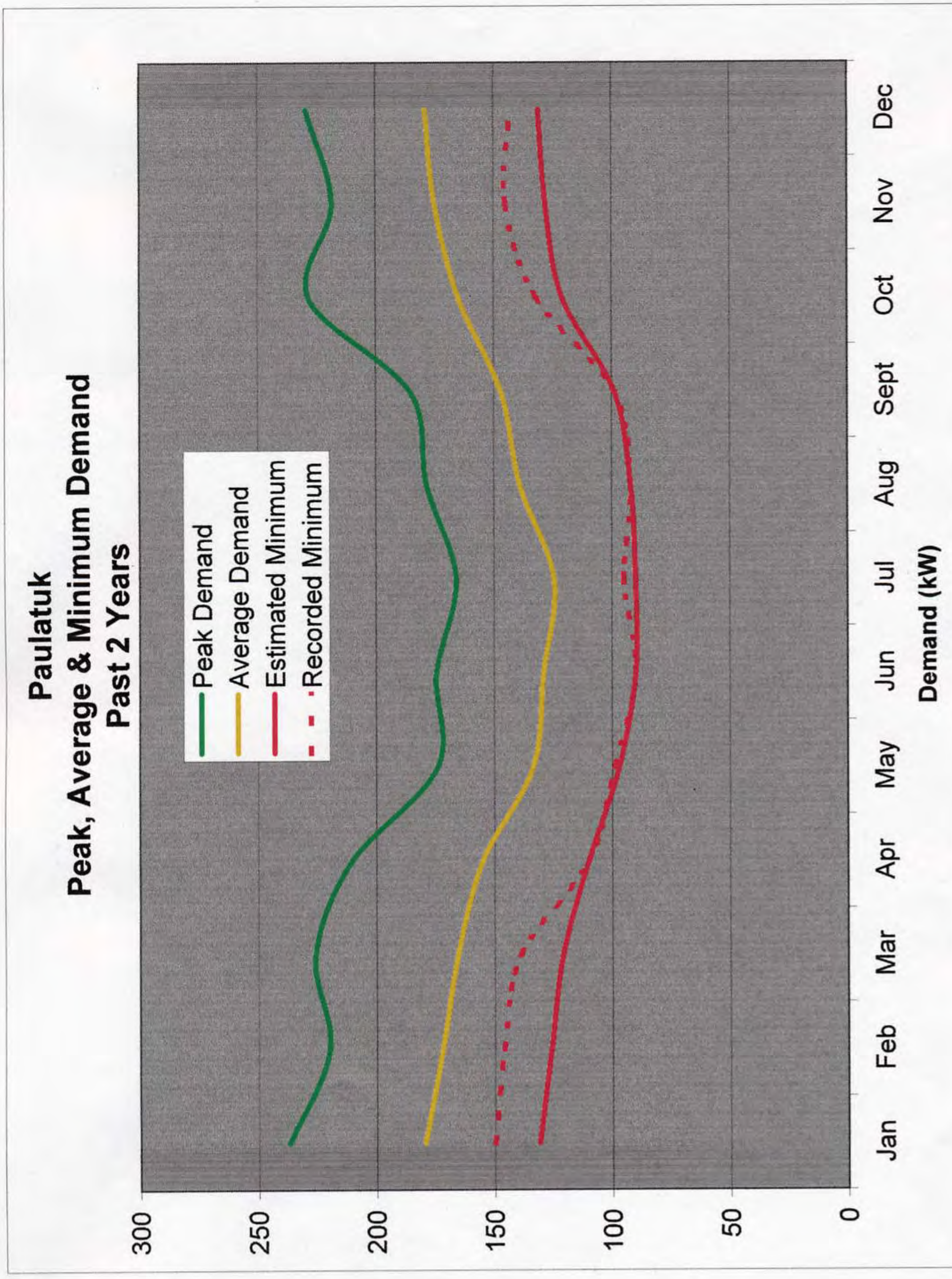
Question 22 Appendix B
Would NTPC allow the installation of a higher capacity wind plant than those stipulated if the maximum wind power to be delivered was limited to the maximum capacity specified?

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".

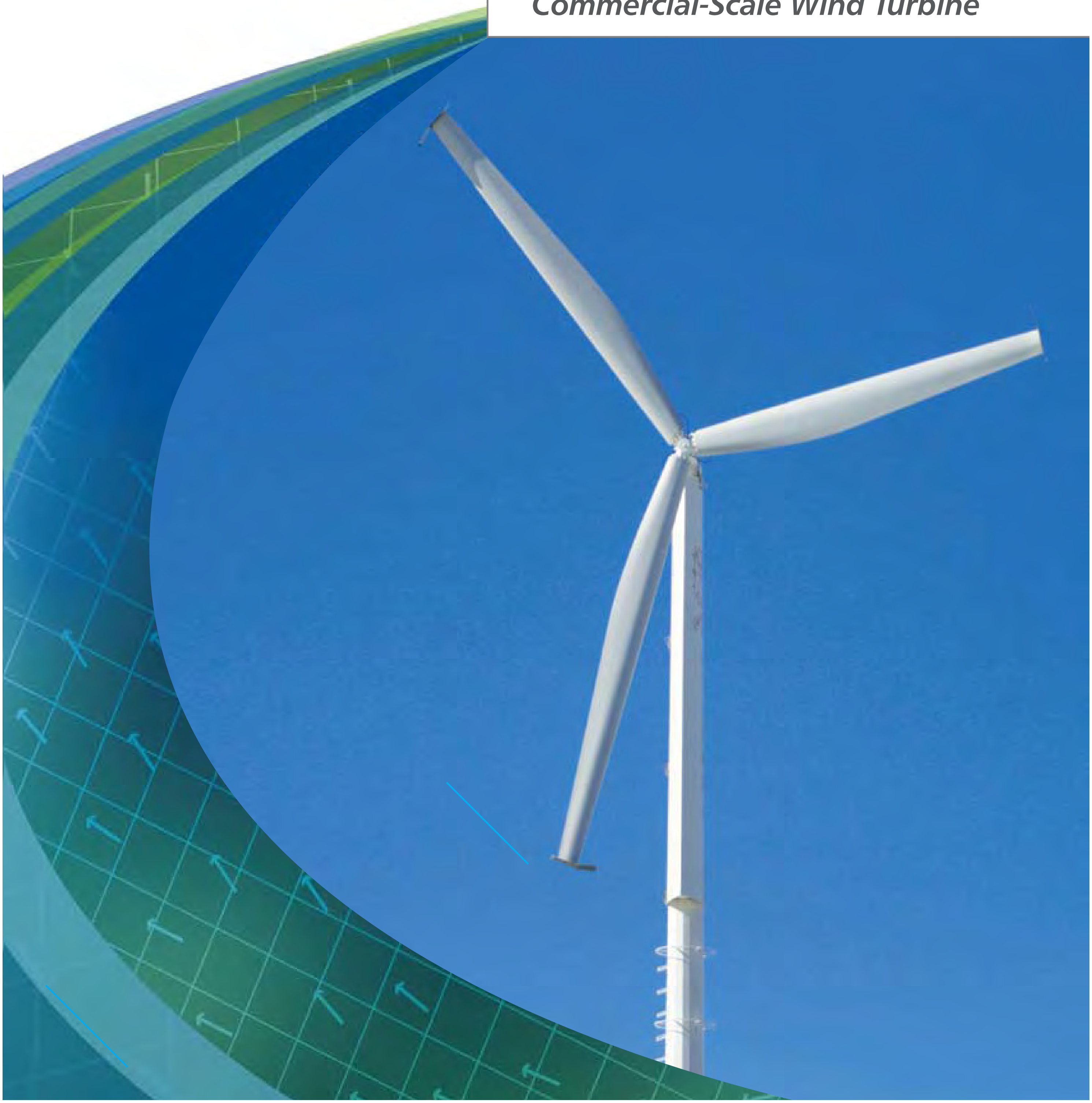
Question 24 Interconnection Guidelines Section 4.1.7, Fault and Line Clearing:
The description in this section appears to assume that the wind plant would not have low voltage ride-through capability. If the wind plant would be able to provide this would this affect NTPC's requirements?


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

Electricity value per kWh as function of diesel fuel cost Ulukhaktok	
Fuel cost per litre	**Diesel fuel cost per kWh, diesel plant efficiency 3.6 kWh per litre**
$0.75	$0.208
$1.00	$0.278
$1.25	$0.347
$1.50	$0.417
$1.75	$0.486
$2.00	$0.556
$2.25	$0.625
$2.50	$0.694
$3.00	$0.833
$3.50	$0.972

Entegrity
WIND SYSTEMS INC.

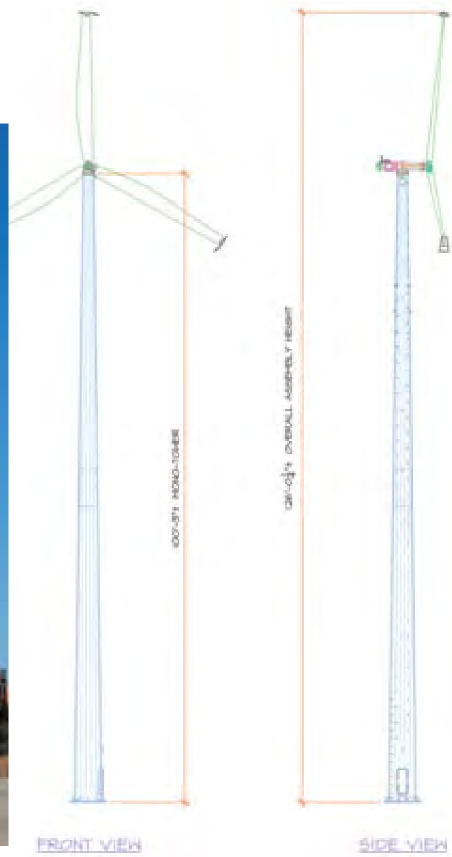
*Manufacturers of the **EW50** Commercial-Scale Wind Turbine*



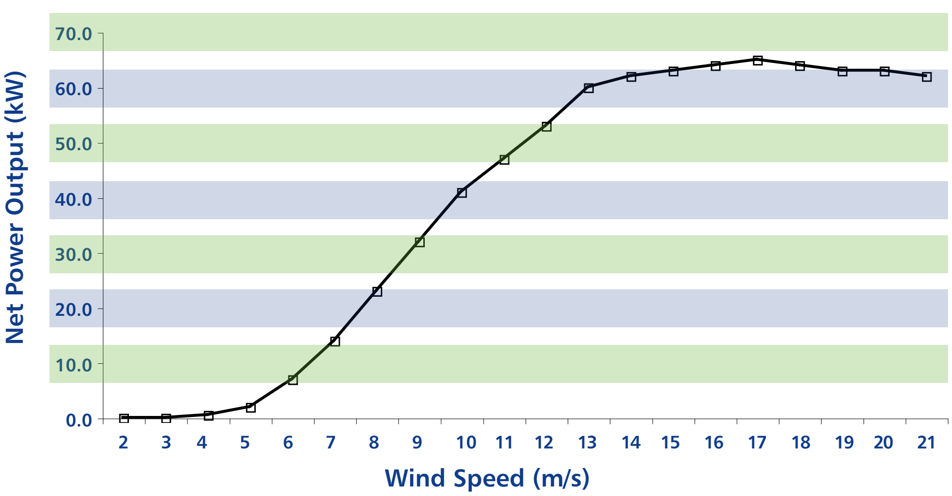
EW50 Power Curve, 60hz

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°
Tilt Angle	0°
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 C

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 C

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 EW 50 annual energy production (from Entegrity)							
Wind Speed m/s	**Theoretical kWh**	**Air density 1.1 adjusted kWh**	**kWh @ 90% availability**	**10% for all losses**	**1 turbine kWh diesel displaced**	**2 turbines, kWh diesel displaced**	**3 turbines, kWh diesel displaced**
5.50	94,000	103,400	93,060	9,306	83,754	167,508	251,262
5.60	99,000	108,900	98,010	9,801	88,209	176,418	264,627
5.70	104,000	114,400	102,960	10,296	92,664	185,328	277,992
5.80	109,000	119,900	107,910	10,791	97,119	194,238	291,357
5.90	114,000	125,400	112,860	11,286	101,574	203,148	304,722
6.20	128,000	140,800	126,720	12,672	114,048	228,096	342,144
6.30	133,000	146,300	131,670	13,167	118,503	237,006	355,509
6.60	148,000	162,800	146,520	14,652	131,868	263,736	395,604
7.00	167,000	183,700	165,330	16,533	148,797	297,594	446,391

Ulukhaktok Project Capital Costs

East Ridge Site

Cost category	Comments	Two EW50 turbines
Project Design & Mgmt		
project design		$20,000
environmental assessment	Might be higher	$12,000
project management		$12,000
Site Preparation		
road construction ($100,000 per km)	5.25 km	$525,000
road upgrading ($40,000 per km)		
powerline construction ($300,000 per km)	2.5 km	$750,000
powerline upgrading 1 to 3 ph ($150,000 per km)		
Wind Equipment Purchase		
wind turbines		$320,000
gin pole		$12,000
shipping		$54,000
transformers		$16,000
wind plant master control		$10,000
Installation		
foundations		$110,000
equipment rental		$15,000
control buildings		$20,000
utility interconnection		$30,000
commissioning		$15,000
labour - assembly & supervision		$25,000
travel and accommodation		$20,000
Diesel Plant Modifications		
high speed comm. & controller		$20,000
SCADA		$30,000
dump load		$20,000
plant modifications		$30,000
Other		
initial spare parts		$10,000
SUBTOTAL CONSTRUCTION		**$2,076,000**
Contingency		$208,000
TOTAL CONSTRUCTION		**$2,284,000**
Owners Costs		
manage project organization		$25,000
negotiate agreements		$30,000
TOTAL OWNERS' COSTS		**$55,000**
TOTAL PROJECT COST		**$2,339,000**
Installed capacity kW		130
Installed cost per kW		**$17,992**

Ulukhaktok Project Capital Costs

Limestone Ridge Site (South end)

Cost category	Comments	Two EW50 turbines
Project Design & Mgmt		
project design		$20,000
environmental assessment		$12,000
project management		$12,000
Site Preparation		
road construction ($100,000 per km)		
road upgrading ($40,000 per km)	0.75 km	$30,000
powerline construction ($300,000 per km)	0.6 km	$180,000
powerline upgrading 1 to 3 ph ($150,000 per km)	1.3 km	$195,000
Wind Equipment Purchase		
wind turbines		$320,000
gin pole		$12,000
shipping		$54,000
transformers		$16,000
wind plant master control		$10,000
Installation		
foundations		$110,000
equipment rental		$15,000
control buildings		$20,000
utility interconnection		$30,000
commissioning		$15,000
labour - assembly & supervision		$25,000
travel and accommodation		$20,000
Diesel Plant Modifications		
high speed comm. & controller		$20,000
SCADA		$30,000
dump load		$20,000
plant modifications		$30,000
Other		
initial spare parts		$10,000
SUBTOTAL CONSTRUCTION		**$1,206,000**
Contingency		$121,000
TOTAL CONSTRUCTION		**$1,327,000**
Owners Costs		
manage project organization		$25,000
negotiate agreements		$30,000
TOTAL OWNERS' COSTS		**$55,000**
TOTAL PROJECT COST		**$1,382,000**
Installed capacity kW		130
Installed cost per kW		**$10,631**

Ulukhaktok Project Capital Costs

Three Hills Site (below peaks)

Cost category	Comments	Two EW50 turbines
Project Design & Mgmt		
project design		$20,000
environmental assessment	Sacred site?	$12,000
project management		$12,000
Site Preparation		
road construction ($100,000 per km)		
road upgrading ($40,000 per km)	0.85 km	$34,000
powerline cnstruction ($300,000 per km)	0.5 km	$150,000
powerline upgrade ($150,000 per km)	0.7 km	$105,000
Wind Equipment Purchase		
wind turbines		$320,000
gin pole		$12,000
shipping		$54,000
transformers		$16,000
wind plant master control		$10,000
Installation		
foundations		$110,000
equipment rental		$15,000
control buildings		$20,000
utility interconnection		$30,000
commissioning		$15,000
labour - assembly & supervision		$25,000
travel and accommodation		$20,000
Diesel Plant Modifications		
high speed comm. & controller		$20,000
SCADA		$30,000
dump load		$20,000
plant modifications		$30,000
Other		
initial spare parts		$10,000
SUBTOTAL CONSTRUCTION		**$1,090,000**
Contingency		$109,000
TOTAL CONSTRUCTION		**$1,199,000**
Owners Costs		
manage project organization		$25,000
negotiate agreements		$30,000
TOTAL OWNERS' COSTS		**$55,000**
TOTAL PROJECT COST		**$1,254,000**
Installed capacity kW		130
Installed cost per kW		**$9,646**

Ulukhaktok Project Capital Costs		
Three Hills Site (below peaks)		
Cost category	**Comments**	**One EW50 turbine**
Project Design & Mgmt		
project design		$10,000
environmental assessment	Sacred site?	$10,000
project management		$10,000
Site Preparation		
road construction ($100,000 per km)		
road upgrading ($40,000 per km)	0.85 km	$34,000
powerline construction ($300,000 per km)	0.5 km	$150,000
powerline upgrade ($150,000 per km)	0.7 km	$105,000
Wind Equipment Purchase		
wind turbines		$160,000
gin pole		$12,000
shipping		$29,500
transformers		$8,000
wind plant master control		$10,000
Installation		
foundations		$60,000
equipment rental		$10,000
control buildings		$10,000
utility interconnection		$20,000
commissioning		$10,000
labour - assembly & supervision		$15,000
travel and accommodation		$10,000
Diesel Plant Modifications		
high speed comm. & controller		$10,000
SCADA		
dump load		$5,000
plant modifications		$15,000
Other		
initial spare parts		$5,000
SUBTOTAL CONSTRUCTION		**$708,500**
Contingency		$71,000
TOTAL CONSTRUCTION		**$779,500**
Owners Costs		
manage project organization		$15,000
negotiate agreements		$20,000
TOTAL OWNERS' COSTS		**$35,000**
TOTAL PROJECT COST		**$814,500**
Installed capacity kW		65
Installed cost per kW		**$12,531**

Ulukhaktok Project Capital Costs

Power Plant Hill Site

Cost category	Comments	Two EW50 turbines
Project Design & Mgmt		
project design		$20,000
environmental assessment		$12,000
project management		$12,000
Site Preparation		
road construction ($100,000 per km)	0.30 km	$30,000
road upgrading ($40,000 per km)		
powerline construction ($300,000 per km)	0.35 km	$105,000
powerline upgrading 1 to 3 ph ($150,000 per km)		
Wind Equipment Purchase		
wind turbines		$320,000
gin pole		$12,000
shipping		$54,000
transformers		$16,000
wind plant master control		$10,000
Installation		
foundations		$110,000
equipment rental		$15,000
control buildings		$20,000
utility interconnection		$30,000
commissioning		$15,000
labour - assembly & supervision		$25,000
travel and accommodation		$20,000
Diesel Plant Modifications		
high speed comm. & controller		$20,000
SCADA		$30,000
dump load		$20,000
plant modifications		$30,000
Other		
initial spare parts		$10,000
SUBTOTAL CONSTRUCTION		**$936,000**
Contingency		$94,000
TOTAL CONSTRUCTION		**$1,030,000**
Owners Costs		
manage project organization		$25,000
negotiate agreements		$30,000
TOTAL OWNERS' COSTS		**$55,000**
TOTAL PROJECT COST		**$1,085,000**
Installed capacity kW		130
Installed cost per kW		**$8,346**

Ulukhaktok Project Capital Costs

Incremental additional turbine

Cost category	Comments	One EW50 turbine
Project Design & Mgmt		
project design		$2,000
environmental assessment		$2,000
project management		$2,000
Site Preparation		
road upgrading / construction ($100,000 per km)	0.1 km	$10,000
new powerline ($300,000 per km)	0.1 km	$30,000
powerline upgrade ($150,000 per km)		
Wind Equipment Purchase		
wind turbines		$160,000
gin pole		$0
shipping		$29,500
transformers		$8,000
wind plant master control		$0
Installation		
foundations		$50,000
equipment rental		$5,000
control buildings		$0
utility interconnection		$0
commissioning		$5,000
labour - assembly & supervision		$10,000
travel and accommodation		$5,000
Diesel Plant Modifications		
high speed comm. & controller		$0
SCADA		$0
dump load		$0
plant modifications		$0
Other		
initial spare parts		$5,000
SUBTOTAL CONSTRUCTION		**$323,500**
Contingency		$32,000
TOTAL CONSTRUCTION		**$355,500**
Owners Costs		
manage project organization		$5,000
negotiate agreements		$0
TOTAL OWNERS' COSTS		**$5,000**
TOTAL PROJECT COST		**$360,500**
Installed capacity kW		65
Installed cost per kW		**$5,546**

Ulukhaktok two 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

Two turbine 130 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
$5,546	130	$720,980	$71,665	$20,000	$30,000	$40,000	$91,665	$101,665	$111,665
$7,500	130	$975,000	$96,915	$20,000	$30,000	$40,000	$116,915	$126,915	$136,915
$8,346	130	$1,084,980	$107,847	$20,000	$30,000	$40,000	$127,847	$137,847	$147,847
$9,646	130	$1,253,980	$124,646	$20,000	$30,000	$40,000	$144,646	$154,646	$164,646
$10,631	130	$1,382,030	$137,374	$20,000	$30,000	$40,000	$157,374	$167,374	$177,374
$12,531	130	$1,629,030	$161,926	$20,000	$30,000	$40,000	$181,926	$191,926	$201,926
$18,000	130	$2,340,000	$232,596	$20,000	$30,000	$40,000	$252,596	$262,596	$272,596

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
$5,546	130	$720,980	$61,644	$20,000	$30,000	$40,000	$81,644	$91,644	$101,644
$7,500	130	$975,000	$83,363	$20,000	$30,000	$40,000	$103,363	$113,363	$123,363
$8,346	130	$1,084,980	$92,766	$20,000	$30,000	$40,000	$112,766	$122,766	$132,766
$9,646	130	$1,253,980	$107,215	$20,000	$30,000	$40,000	$127,215	$137,215	$147,215
$10,631	130	$1,382,030	$118,164	$20,000	$30,000	$40,000	$138,164	$148,164	$158,164
$12,531	130	$1,629,030	$139,282	$20,000	$30,000	$40,000	$159,282	$169,282	$179,282
$18,000	130	$2,340,000	$200,070	$20,000	$30,000	$40,000	$220,070	$230,070	$240,070

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
$5,546	130	$720,980	$52,271	$20,000	$30,000	$40,000	$72,271	$82,271	$92,271
$7,500	130	$975,000	$70,688	$20,000	$30,000	$40,000	$90,688	$100,688	$110,688
$8,346	130	$1,084,980	$78,661	$20,000	$30,000	$40,000	$98,661	$108,661	$118,661
$9,646	130	$1,253,980	$90,914	$20,000	$30,000	$40,000	$110,914	$120,914	$130,914
$10,631	130	$1,382,030	$100,197	$20,000	$30,000	$40,000	$120,197	$130,197	$140,197
$12,531	130	$1,629,030	$118,105	$20,000	$30,000	$40,000	$138,105	$148,105	$158,105
$18,000	130	$2,340,000	$169,650	$20,000	$30,000	$40,000	$189,650	$199,650	$209,650

Ulukhaktok 2 turbine project electricity cost as a function of wind speed and capital cost (low operating cost)

	=	Viable at fuel cost of $1.00 per liter, diesel fuel cost $0.278 per kWh
	=	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 $1.75 per liter, diesel fuel cost $0.486 per kWh plus subsidy of $0.15 for total of $0.636 per kWh

		m/s >	5.50	5.60	5.70	5.80	5.90	6.20	6.30	6.60	7.00
	8% Interest	kWh >	167,508	176,418	185,328	194,238	203,148	228,096	237,006	263,736	297,594
Capital cost per kW	Total Ann cost low op cost		Cost per kWh below								
$5,546	$91,665		$0.547	$0.520	$0.495	$0.472	$0.451	$0.402	$0.387	$0.348	$0.308
$7,500	$116,915		$0.698	$0.663	$0.631	$0.602	$0.576	$0.513	$0.493	$0.443	$0.393
$8,346	$127,847		$0.763	$0.725	$0.690	$0.658	$0.629	$0.560	$0.539	$0.485	$0.430
$9,646	$144,646		$0.864	$0.820	$0.780	$0.745	$0.712	$0.634	$0.610	$0.548	$0.486
$10,631	$157,374		$0.940	$0.892	$0.849	$0.810	$0.775	$0.690	$0.664	$0.597	$0.529
$12,531	$181,926		$1.086	$1.031	$0.982	$0.937	$0.896	$0.798	$0.768	$0.690	$0.611
$18,000	$252,596		$1.508	$1.432	$1.363	$1.300	$1.243	$1.107	$1.066	$0.958	$0.849

		m/s >	5.50	5.60	5.70	5.80	5.90	6.20	6.30	6.60	7.00
	6% Interest	kWh >	167,508	176,418	185,328	194,238	203,148	228,096	237,006	263,736	297,594
Capital cost per kW	Total Ann cost low op cost		Cost per kWh below								
$5,546	$81,644		$0.487	$0.463	$0.441	$0.420	$0.402	$0.358	$0.344	$0.310	$0.274
$7,500	$103,363		$0.617	$0.586	$0.558	$0.532	$0.509	$0.453	$0.436	$0.392	$0.347
$8,346	$112,766		$0.673	$0.639	$0.608	$0.581	$0.555	$0.494	$0.476	$0.428	$0.379
$9,646	$127,215		$0.759	$0.721	$0.686	$0.655	$0.626	$0.558	$0.537	$0.482	$0.427
$10,631	$138,164		$0.825	$0.783	$0.746	$0.711	$0.680	$0.606	$0.583	$0.524	$0.464
$12,531	$159,282		$0.951	$0.903	$0.859	$0.820	$0.784	$0.698	$0.672	$0.604	$0.535
$18,000	$220,070		$1.314	$1.247	$1.187	$1.133	$1.083	$0.965	$0.929	$0.834	$0.739

		m/s >	5.50	5.60	5.70	5.80	5.90	6.20	6.30	6.60	7.00
	4% Interest	kWh >	167,508	176,418	185,328	194,238	203,148	228,096	237,006	263,736	297,594
Capital cost per kW	Total Ann cost low op cost		Cost per kWh below								
$5,546	$72,271		$0.431	$0.410	$0.390	$0.372	$0.356	$0.317	$0.305	$0.274	$0.243
$7,500	$90,688		$0.541	$0.514	$0.489	$0.467	$0.446	$0.398	$0.383	$0.344	$0.305
$8,346	$98,661		$0.589	$0.559	$0.532	$0.508	$0.486	$0.433	$0.416	$0.374	$0.332
$9,646	$110,914		$0.662	$0.629	$0.598	$0.571	$0.546	$0.486	$0.468	$0.421	$0.373
$10,631	$120,197		$0.718	$0.681	$0.649	$0.619	$0.592	$0.527	$0.507	$0.456	$0.404
$12,531	$138,105		$0.824	$0.783	$0.745	$0.711	$0.680	$0.605	$0.583	$0.524	$0.464
$18,000	$189,650		$1.132	$1.075	$1.023	$0.976	$0.934	$0.831	$0.800	$0.719	$0.637

Ulukhaktok 2 turbine project electricity cost as a function of wind speed and capital cost (medium operating cost)

(yellow)	=	Viable at fuel cost of $1.00 per liter, diesel fuel cost $0.278 per kWh
(light green)	=	Viable at fuel cost of $1.25 per liter, diesel fuel cost $0.347 per kWh
(blue)	=	Viable at fuel cost of $1.50 per liter, diesel fuel cost $0.417 per kWh
(purple)	=	Viable at fuel cost of $1.75 per liter, diesel fuel cost $0.486 per kWh
(pink)	=	Viable at fuel cost of $2.00 per liter, diesel fuel cost $0.556 per kWh
(grey)	=	Viable at fuel cost of $1.75 per liter, diesel fuel cost $0.486 per kWh plus subsidy of $0.15 for total of $0.636 per kWh

		m/s >	5.50	5.60	5.70	5.80	5.90	6.20	6.30	6.60	7.00
	8% Interest	**kWh >**	167,508	176,418	185,328	194,238	203,148	228,096	237,006	263,736	297,594
Capital cost per kW	**Total Ann cost med op cost**		**Cost per kWh below**								
$5,546	$101,665		$0.607	$0.576	$0.549	$0.523	$0.500	$0.446	$0.429	$0.385	$0.342
$7,500	$126,915		$0.758	$0.719	$0.685	$0.653	$0.625	$0.556	$0.535	$0.481	$0.426
$8,346	$137,847		$0.823	$0.781	$0.744	$0.710	$0.679	$0.604	$0.582	$0.523	$0.463
$9,646	$154,646		$0.923	$0.877	$0.834	$0.796	$0.761	$0.678	$0.652	$0.586	$0.520
$10,631	$167,374		$0.999	$0.949	$0.903	$0.862	$0.824	$0.734	$0.706	$0.635	$0.562
$12,531	$191,926		$1.146	$1.088	$1.036	$0.988	$0.945	$0.841	$0.810	$0.728	$0.645
$18,000	$262,596		$1.568	$1.488	$1.417	$1.352	$1.293	$1.151	$1.108	$0.996	$0.882

		m/s >	5.50	5.60	5.70	5.80	5.90	6.20	6.30	6.60	7.00
	6% Interest	**kWh >**	167,508	176,418	185,328	194,238	203,148	228,096	237,006	263,736	297,594
Capital cost per kW	**Total Ann cost med op cost**		**Cost per kWh below**								
$5,546	$91,644		$0.547	$0.519	$0.494	$0.472	$0.451	$0.402	$0.387	$0.347	$0.308
$7,500	$113,363		$0.677	$0.643	$0.612	$0.584	$0.558	$0.497	$0.478	$0.430	$0.381
$8,346	$122,766		$0.733	$0.696	$0.662	$0.632	$0.604	$0.538	$0.518	$0.465	$0.413
$9,646	$137,215		$0.819	$0.778	$0.740	$0.706	$0.675	$0.602	$0.579	$0.520	$0.461
$10,631	$148,164		$0.885	$0.840	$0.799	$0.763	$0.729	$0.650	$0.625	$0.562	$0.498
$12,531	$169,282		$1.011	$0.960	$0.913	$0.872	$0.833	$0.742	$0.714	$0.642	$0.569
$18,000	$230,070		$1.373	$1.304	$1.241	$1.184	$1.133	$1.009	$0.971	$0.872	$0.773

		m/s >	5.50	5.60	5.70	5.80	5.90	6.20	6.30	6.60	7.00
	4% Interest	**kWh >**	167,508	176,418	185,328	194,238	203,148	228,096	237,006	263,736	297,594
Capital cost per kW	**Total Ann cost med op cost**		**Cost per kWh below**								
$5,546	$82,271		$0.491	$0.466	$0.444	$0.424	$0.405	$0.361	$0.347	$0.312	$0.276
$7,500	$100,688		$0.601	$0.571	$0.543	$0.518	$0.496	$0.441	$0.425	$0.382	$0.338
$8,346	$108,661		$0.649	$0.616	$0.586	$0.559	$0.535	$0.476	$0.458	$0.412	$0.365
$9,646	$120,914		$0.722	$0.685	$0.652	$0.623	$0.595	$0.530	$0.510	$0.458	$0.406
$10,631	$130,197		$0.777	$0.738	$0.703	$0.670	$0.641	$0.571	$0.549	$0.494	$0.437
$12,531	$148,105		$0.884	$0.840	$0.799	$0.762	$0.729	$0.649	$0.625	$0.562	$0.498
$18,000	$199,650		$1.192	$1.132	$1.077	$1.028	$0.983	$0.875	$0.842	$0.757	$0.671

Ulukhaktok 2 turbine project electricity cost as a function of wind speed and capital cost (high operating cost)

	=	Viable at fuel cost of $1.00 per liter, diesel fuel cost $0.278 per kWh
	=	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 $1.75 per liter, diesel fuel cost $0.486 per kWh plus subsidy of $0.15 for total of $0.636 per kWh

		m/s >	5.50	5.60	5.70	5.80	5.90	6.20	6.30	6.60	7.00
	8% Interest	**kWh >**	167,508	176,418	185,328	194,238	203,148	228,096	237,006	263,736	297,594
Capital cost per kW	**Total Ann cost high op cost**		**Cost per kWh below**								
$5,546	$111,665		$0.667	$0.633	$0.603	$0.575	$0.550	$0.490	$0.471	$0.423	$0.375
$7,500	$136,915		$0.817	$0.776	$0.739	$0.705	$0.674	$0.600	$0.578	$0.519	$0.460
$8,346	$147,847		$0.883	$0.838	$0.798	$0.761	$0.728	$0.648	$0.624	$0.561	$0.497
$9,646	$164,646		$0.983	$0.933	$0.888	$0.848	$0.810	$0.722	$0.695	$0.624	$0.553
$10,631	$177,374		$1.059	$1.005	$0.957	$0.913	$0.873	$0.778	$0.748	$0.673	$0.596
$12,531	$201,926		$1.205	$1.145	$1.090	$1.040	$0.994	$0.885	$0.852	$0.766	$0.679
$18,000	$272,596		$1.627	$1.545	$1.471	$1.403	$1.342	$1.195	$1.150	$1.034	$0.916

		m/s >	5.50	5.60	5.70	5.80	5.90	6.20	6.30	6.60	7.00
	6% Interest	**kWh >**	167,508	176,418	185,328	194,238	203,148	228,096	237,006	263,736	297,594
Capital cost per kW	**Total Ann cost high op cost**		**Cost per kWh below**								
$5,546	$101,644		$0.607	$0.576	$0.548	$0.523	$0.500	$0.446	$0.429	$0.385	$0.342
$7,500	$123,363		$0.736	$0.699	$0.666	$0.635	$0.607	$0.541	$0.521	$0.468	$0.415
$8,346	$132,766		$0.793	$0.753	$0.716	$0.684	$0.654	$0.582	$0.560	$0.503	$0.446
$9,646	$147,215		$0.879	$0.834	$0.794	$0.758	$0.725	$0.645	$0.621	$0.558	$0.495
$10,631	$158,164		$0.944	$0.897	$0.853	$0.814	$0.779	$0.693	$0.667	$0.600	$0.531
$12,531	$179,282		$1.070	$1.016	$0.967	$0.923	$0.883	$0.786	$0.756	$0.680	$0.602
$18,000	$240,070		$1.433	$1.361	$1.295	$1.236	$1.182	$1.052	$1.013	$0.910	$0.807

		m/s >	5.50	5.60	5.70	5.80	5.90	6.20	6.30	6.60	7.00
	4% Interest	**kWh >**	167,508	176,418	185,328	194,238	203,148	228,096	237,006	263,736	297,594
Capital cost per kW	**Total Ann cost high op cost**		**Cost per kWh below**								
$5,546	$92,271		$0.551	$0.523	$0.498	$0.475	$0.454	$0.405	$0.389	$0.350	$0.310
$7,500	$110,688		$0.661	$0.627	$0.597	$0.570	$0.545	$0.485	$0.467	$0.420	$0.372
$8,346	$118,661		$0.708	$0.673	$0.640	$0.611	$0.584	$0.520	$0.501	$0.450	$0.399
$9,646	$130,914		$0.782	$0.742	$0.706	$0.674	$0.644	$0.574	$0.552	$0.496	$0.440
$10,631	$140,197		$0.837	$0.795	$0.756	$0.722	$0.690	$0.615	$0.592	$0.532	$0.471
$12,531	$158,105		$0.944	$0.896	$0.853	$0.814	$0.778	$0.693	$0.667	$0.599	$0.531
$18,000	$209,650		$1.252	$1.188	$1.131	$1.079	$1.032	$0.919	$0.885	$0.795	$0.704