Inuvik Wind Energy
Pre-Feasibility Analysis: 2015

Prepared for

AURORA RESEARCH INSTITUTE
AURORA COLLEGE

By

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

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

March 31, 2015

Executive Summary

Wind energy projects of 4.6 MW to 9.2 MW of capacity utilizing Enercon E-70 2.3 MW turbines (the same model used by Diavik) located at either High Point or Storm Hills can produce electricity at costs competitive with diesel power generation and, in some circumstances liquefied natural gas (LNG) power generation, if the wind energy is fully utilized. However, at present Inuvik electricity loads, the utilization would be limited and the costs would slightly exceed the long term cost of diesel generation.

Measurements from a wind monitoring tower installed on a hill 13 km east of Inuvik (referred to as High Point) is showing wind speeds of 5.6 m/s at 29.5 m above ground. Projected to long-term, the average wind speed is estimated to be 6.27 m/s at a height of 57 meters above ground level (AGL), and 6.48 m/s at 74 meters (turbine hub heights). By southern standard this would considered poor, as it represents a class 2 (out of 7) wind resource, however, with high northern fuel costs this wind resource still has the potential to become viable for replacing fossil fuel power generation. The measurements also show that the wind speeds increase during the winter, indicating that the site is above the influence of the inversion layer.

Measurements from ARI sensors at Storm Hills indicate long term wind speeds of 7.77 and 7.92 m/s at 57 and 74 m AGL, respectively. This is a class 5 out of 7, which is considered to be excellent. Storm Hills, like High Point is above the inversion influence and shows higher winter winds. Storm Hills is, however, 60 km north of Inuvik and would require new road and powerline to connect to the town grid.

For this study the project size considered two to four Enercon E-70 2.3 MW wind turbines, thus capacities of 4.6 MW to 9.2 MW. Turbine tower heights of 57 m and 74 m were examined. These are high penetration wind projects which would displace 20% to 40% of the fossil fuel power generation.

A wind project at High Point would have lower capital costs than one at Storm Hills, but because Storm Hills has a substantially higher wind resource, the economics of both sites are very close. A project of three E-70 turbines with a 74 m hub height at High Point would displace fossil fuel generated power at a cost of $0.411 per kWh (levelized over 25 years, with a 4.87% cost of capital). A similar project at Storm Hills would displace fossil fuel generated power at a levelized cost of $0.406 per kWh.

There is also potential for excess wind power sales to improve power project economics. A price on carbon emissions would also improve the relative economics of wind generated power.

Diesel generated power over the same 25 year period would cost $0.390 per kWh and LNG generated power would cost $0.305 per kWh.

With careful planning and perhaps a modest amount capital support, there is potential for a wind energy project for Inuvik to be cost competitive with diesel generation. Further wind monitoring is planned for High Point, after which the wind project will be reassessed.

Introduction

With fossil fuel scarcity becoming more prevalent and climate warming increasing the need to reduce our fossil fuel dependency, the desire for developing renewable energy in the NWT is increasing. The potential for wind energy in Inuvik has been studied several times in the past but the economics have so far been weak.

Over the past several years, the authors (JP Pinard, P.Eng., Ph.D. and John Maissan, P.Eng.) have been retained by the Aurora Research Institute (ARI) to conduct pre-feasibility studies for wind energy generation in various NWT communities, which are typically dependant on diesel for energy production. All of these studies can be found at the ARI website (http://www.nwtresearch.com).

In the Inuvik area, liquefied natural gas (LNG) is now being trucked in to feed the existing gas powered generators which had been using a local gas well to provide electricity and heat for the community. With the local gas source now spent, the community relies on imported diesel and liquefied natural gas (LNG) for electricity, and synthetic natural gas (SNG, a propane/air mixture) and heating oil for heating.

Therefore, there is interest in finding an alternative local energy source that is more cost effective than imported diesel or natural gas, and preferably renewable. The questions that have been posed on the possibility for wind energy development in Inuvik are: how far from Inuvik would a viable wind resource be (within 50 km); how economical would that wind resource be for Inuvik; and, are there any hills adjacent to Inuvik that could provide an economic wind resource for the community?

The community of Inuvik has about 3,600 people and is located on the East Channel of the Mackenzie River Delta. Inuvik is located about 1,086 km northwest of Yellowknife (see Figure 1). The community is accessible by air year round. It is also accessible by road (Dempster Highway) most of the year except during break-up (spring) and freeze-up (fall). Ice roads also link the communities of Aklavik and Tuktoyaktuk to Inuvik in the winter months. A new all-season road to Tuktoyaktuk is presently being constructed.

The average power load in the community is 3.47 megawatts (MW) and the annual energy requirement was estimated at 30,600 megawatt-hours (MWh) in 2013[1]. The community power plant has two gas power generators with a total capacity of 5.6 MW and five diesel generators with a total capacity of 10.265 MW (smallest generator being 2,100 kW), owned and operated by Northwest Territories Power Corporation (NTPC). The present marginal cost of producing electricity from diesel and gas (fuel and variable maintenance only) are estimated at $0.32/kWh and $0.25/kWh, respectively.

In Inuvik the space heating needs are estimated to be in the order 350,000 GJ, or 97,200 MWh annually (GNWT, 2012). This is roughly triple the electricity demand in Inuvik and presents a market opportunity for wintertime excess wind energy use.

[1] Obtained through a request for information to the Northwest Territory Power Corporation (NTPC).

A study (Pinard, 2007) measured wind speeds of 4.3 m/s at a height of 60 m above ground level (AGL) on a communications tower at a site 75 m above sea level (ASL), just east of Inuvik. The report concluded that based on this measurement wind energy development at the site would not be economic for Inuvik. The Arctic Energy Alliance has also produced a summary of the wind potential for the community. In their online report (resource section at www.aea.nt.ca) it is stated that the average wind speed is considered low at 2.68 m/s (height was not noted, likely at 10 m AGL).

In a follow-up study, a new site near Inuvik that was monitored by Environment Canada was discovered to have world class wind speeds (class 5 out of 7; Pinard and Maissan, 2012). This site, called Storm Hills in the study, was showing wind speeds of 6.7 m/s on a 10 m tower located on a hill-top that is 260 m ASL. ARI installed sensors at a communications tower owned by New North Networks and measured wind speeds of 7.3 m/s at 39 m AGL. Long-term mean wind speeds of 7.8 and 8.1 m/s at 60 and 78 m ASL, respectively were estimated from these new measurements (Matangi, 2014). This is still a class 5 out of 7 which is considered excellent. Storm Hills is 60 km north of Inuvik, and the cost of road and power made the site uneconomical for wind power generation unless government subsidies were used and/or the wind project was scaled up. However, with the Inuvik to Tuktoyaktuk road now under construction the road access costs to Storm Hills should be reduced.

In 2014, at the request of NTPC, another hill of comparable height to Storm Hills but much closer to Inuvik was equipped with a 30-m tower and instruments to measure its wind potential. This hill is 240 m ASL and is referred to as High Hill or High Point (this study uses High Point).

The purpose of this study is to re-examine the economics of wind energy development for Inuvik based on the recent measurements at High Point, and to reassess the economic feasibility of a wind energy project at Storm Hills, given the construction of the Inuvik to Tuktoyaktuk highway.

In this study wind climate data is collected, analysed and used to model potential sites for wind energy development and energy output of a selected wind turbine model. For this study the Enercon E-70 2.3 MW, which is used at Diavik, was selected. The economic analysis looks at the costs of building and operating a wind project on High Point and compares it to the cost of a wind project at Storm Hills (for which road access costs have now decreased). This study will also examine the utilization of excess wind energy for space heating in Inuvik. Greenhouse gas emission reductions from these renewable energy forms are estimated. An outline of next steps is given regarding the pursuit of wind energy development and integration in Inuvik.

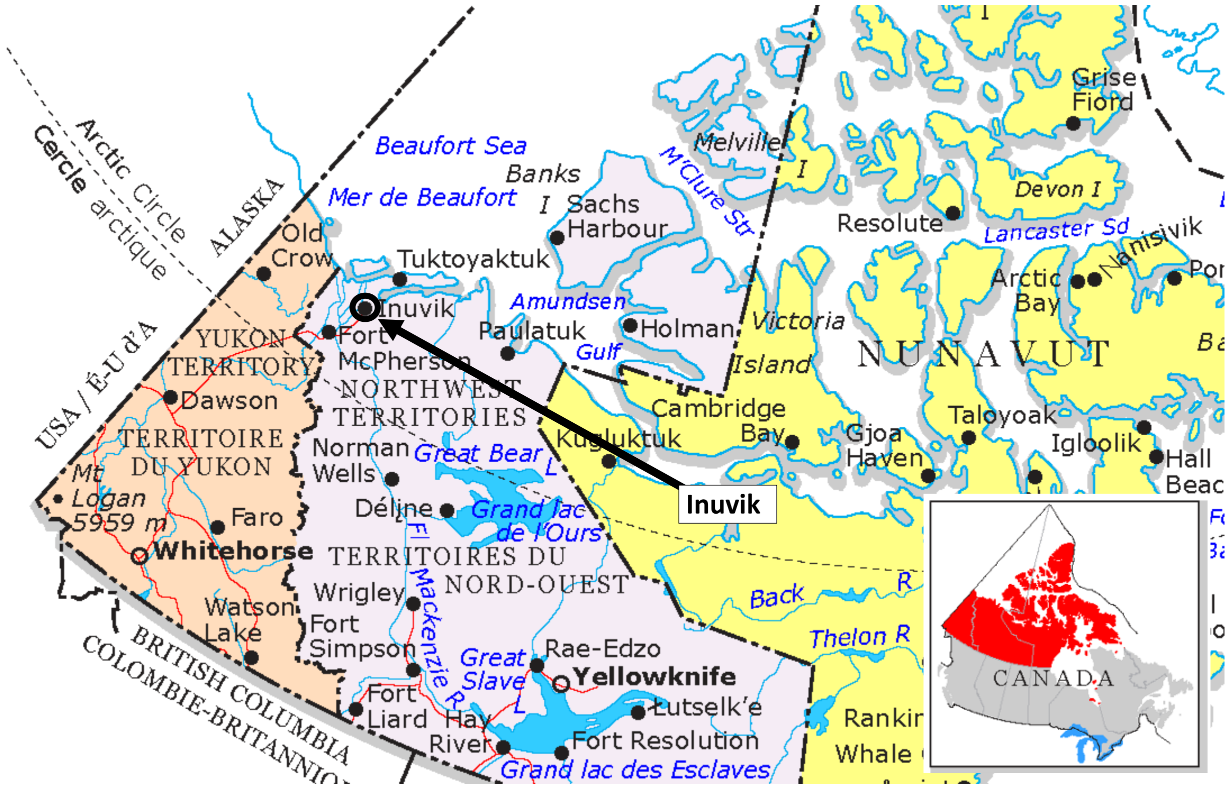

Figure 1: Inuvik is located in the Mackenzie Delta in northwestern NWT, about 1086 km northwest of Yellowknife.

Wind Climate Assessment

The wind data used for this analysis was extracted from the Aurora Research Institute's wind measurements that were made at High Point and at Storm Hills. The monitoring station set up at High Point was located 13 km east of Inuvik and 7 km from the Dempster Highway (see Figure 2). The wind tower was 30 m tall and collected 10-minute wind measurements at 20 and 30 m above ground for a period of about seven months from 20th March to 8th October, 2014. The tower fell due to an anchor failure. Plans are under way to replace the fallen tower with a new robust 60 tower to continue the measurement campaign.

The wind monitoring site at Storm Hills is 60 km north of Inuvik. Wind monitoring equipment was installed on an existing tower owned by New North Networks and measurements were made at 16.5 and 39 m AGL. The 10-minute data was collected from 4th October, 2012 to 7th March, 2014 and has been analysed and reported in Matangi (2014).

Wind data was also collected from the Environment Canada (EC) website (www.climate.weatheroffice.ec.gc.ca) for the Storm Hills EC station and the Inuvik EC climate station near the Inuvik airport for the period 2005 to 2014. The data from these stations contain hourly measurements of wind speed and direction, temperature, pressure, humidity, and other parameters. The wind measurements at these stations are at 10 m AGL.

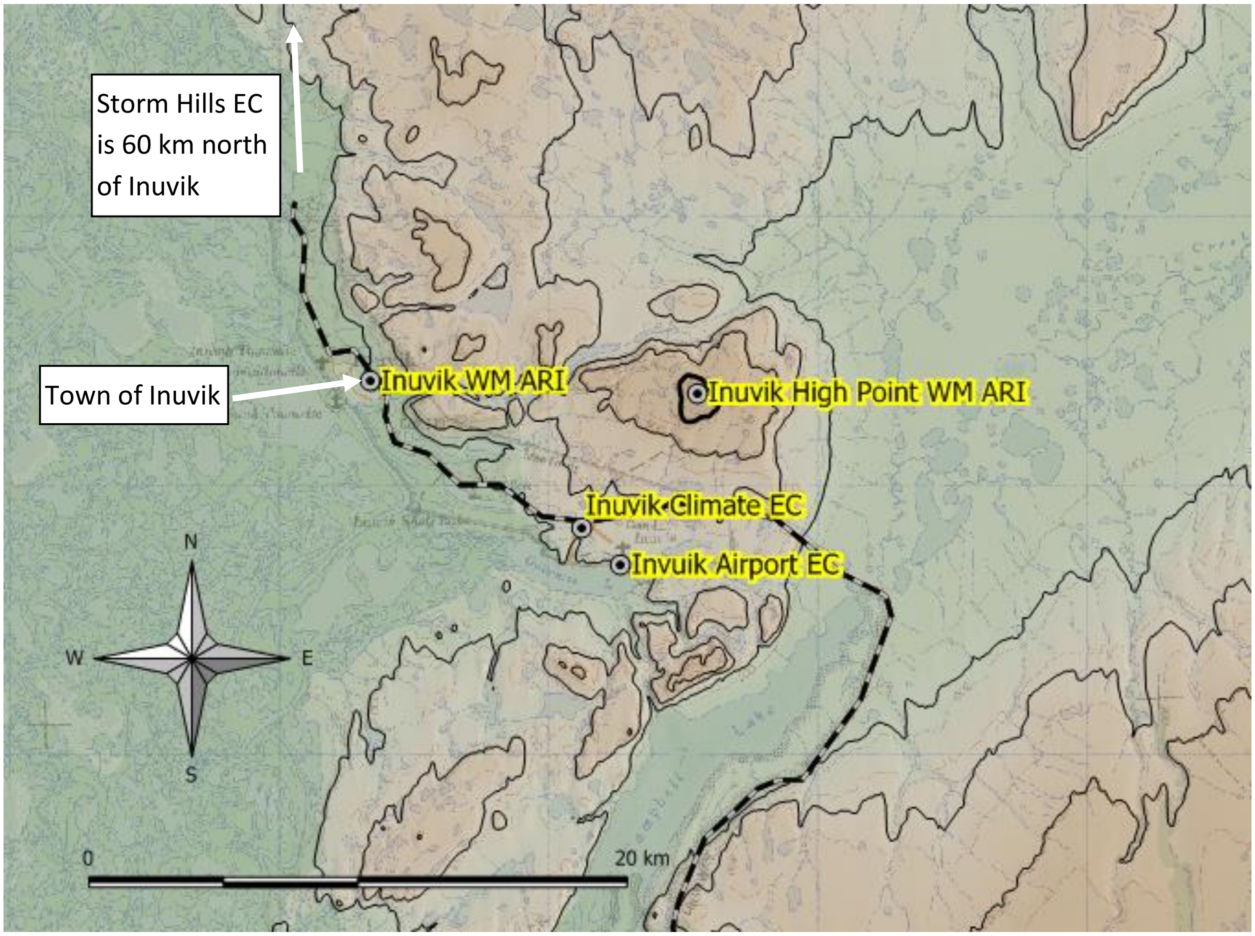

Figure 2: A map of the Inuvik area showing the weather stations (WM: ARI wind monitoring station, EC: Environment Canada weather station) and the topography. The elevation contour lines are at 50 m intervals with the lowest level being at 50 m ASL. The thick line marks 200 m ASL. The dashed line represents the road.

Comparison of Wind Speeds at Different Sites

The High Point measurements were compared to those of both the Inuvik EC climate station and the Storm Hills EC station. As shown in Figure 3, the wind speeds at High Point tend to follow the same wind pattern as Storm Hills 60 km to the north, and correlate less well with the Inuvik EC climate station located only 6.5 km southwest of High Point.

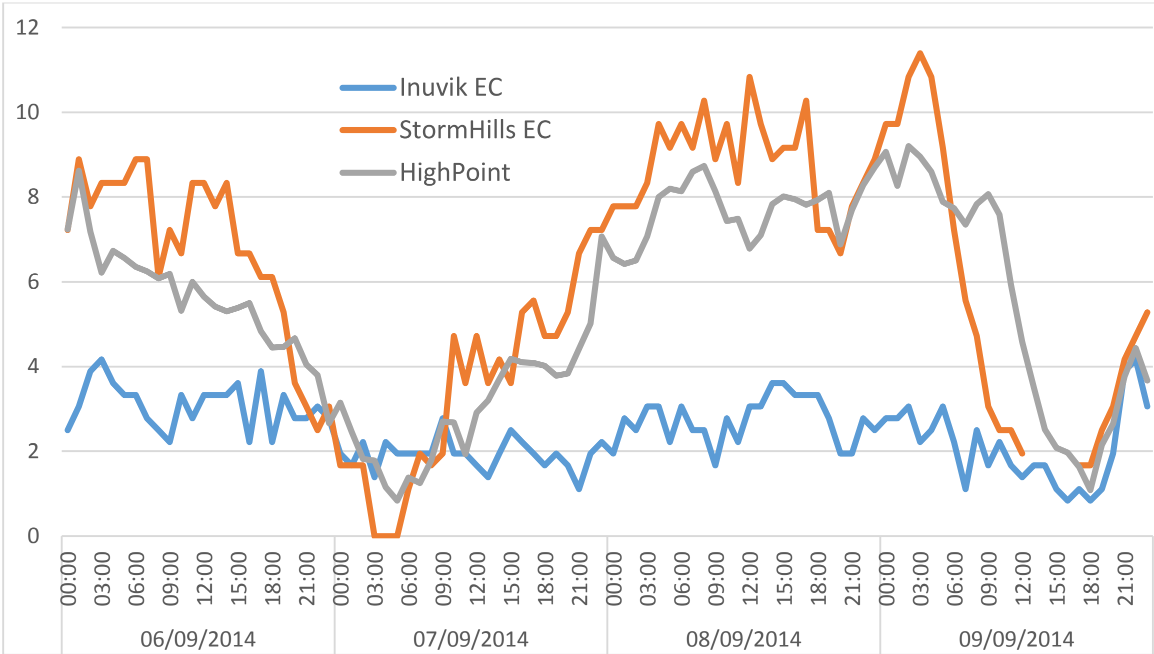

Figure 3: Sample period showing the wind speed behaviour between the ARI wind monitoring station and the EC stations.

The key to the wind speed difference between the Inuvik EC climate station and the other two stations is likely in the difference in elevation between the stations. Storm Hills is at 260 m ASL, nearly the same elevation as High Point (240 m ASL). The Inuvik EC station, on the other hand, is only at 103 m ASL, about 150 m lower than the other two stations. To investigate this further, upper air data collected from weather balloon measurements (gathered every 12 hours) at the Inuvik EC station can be examined. A ten-year (2005 to 2014) sampling of the weather balloon measurements is shown in Figure 4. The monthly profile shows wind speeds at the surface (a 10 m tower at the surface, which is at 103 m ASL), and other heights above sea level.

From this graph (Figure 4) it is evident that lower in the valley the monthly mean wind speeds diminish during the winter months, whereas at about 200 m higher (300 m ASL and above) the winter wind speeds increase. This is also shown in Figure 5, which compares annual mean wind speeds to June and December means for a ten-year (2005-2014) period. This difference in seasonal wind speed patterns between the surface and the upper levels is caused by a winter inversion layer.

Inversions occur during the winter months when normal atmospheric conditions (cool air above, warm air below) become inverted. Inversions trap a dense layer of cold air under a layer of warm air. Even very shallow valleys can act like a bowl, with cold, dense air pooling at the bottom. The snow-covered valley floors reflect rather than absorb the heat from the sun, preventing the normal vertical mixing of warm and cold air. The warm air layer is usually displaced by a strong storm system which restores normal atmospheric conditions and mixing. Both Storm Hills (260 m ASL) and High Point (240 m ASL) are considered high enough to remain above the colder air pools.

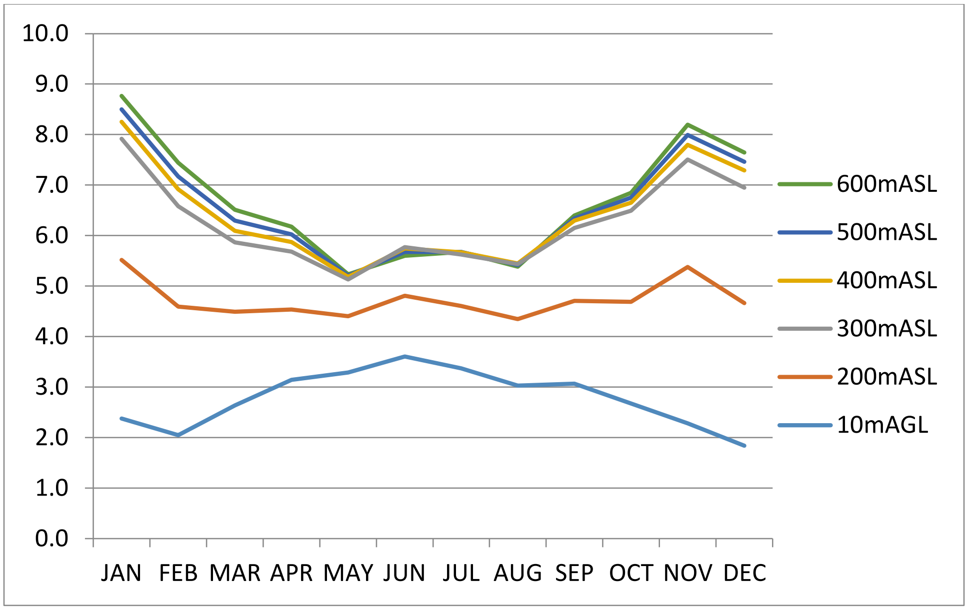

Figure 4: Monthly wind speed pattern collected from weather balloon measurements at different elevations above the Inuvik EC climate station. Note that 10 m AGL is equivalent to 103 m ASL for this site.

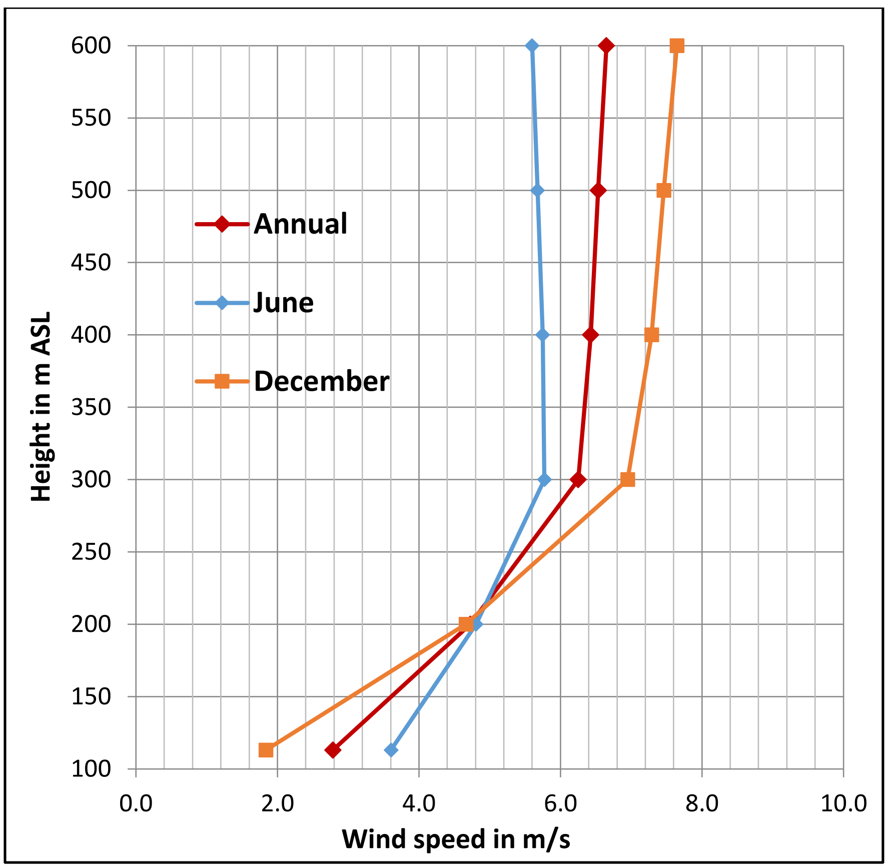

Figure 5: Vertical profile of horizontal wind speed measured by weather balloons released at the Inuvik EC climate station. The average is for the period 2005 to 2014.

The long term (> six years) monthly average wind speeds from the Inuvik surface stations are shown in Figure 6. The airport (10 m AGL, 68 m ASL) and the Inuvik EC (10 m AGL, 103 m ASL) stations, both reveal winds dropping to about 2 m/s in the winter and increasing to about 3.5 m/s in June.

The Storm Hills (10 m AGL, 261 m ASL), weather balloon (300 m ASL), and High Point (30 m AGL, 240 m ASL) sites all show the reverse pattern: their maximum winds are in the winter instead of the summer. The Storm Hills station measured monthly average winds that reach a minimum of 5.8 m/s in July and August and reach a maximum of 8.4 m/s in January. Similarly, the weather balloon measurements at 300 m ASL show monthly means dropping to 5.1 m/s in May and increasing to 7.9 m/s in January.

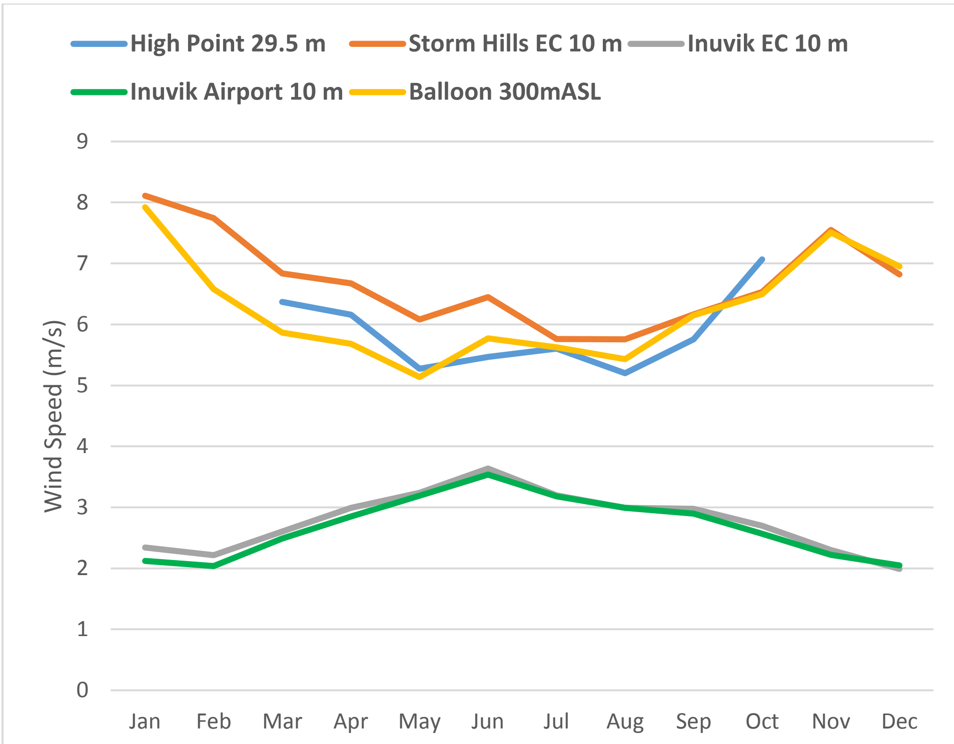

Figure 6: Long term monthly average wind speeds at different stations in the Inuvik area. The balloon measurements are made above the Inuvik EC climate station.

There is evidence of icing on the wind speed sensors at High Point, indicated by the deviation of wind speeds between anemometers installed at different heights. It is known that Storm Hills also has icing issues, as was revealed in a measurement campaign by ARI (Matangi, 2014) and by the fact that the EC Storm Hills station uses heated instruments to keep their wind speed sensors ice-free (Pinard, 2013). It is understood[2] that High Point does not have as severe an icing climate as Storm Hills, but some icing is expected to occur in the winter. The impact of icing on wind speed data has been accounted for in the analysis and is addressed in terms of energy production in later sections of this report.

[2] Personal conversation with local communication businessman Tom Zubko, 2015

Wind Speed Analysis

The wind speeds at the ARI wind monitoring station at High Point are correlated to those of the Storm Hills EC station for the same period in which the two stations ran concurrently. As indicated earlier and as shown in Figure 3, the High Point wind speeds follow Storm Hills EC measurements much more closely than the nearby Inuvik EC station. Also, indications from the nearby weather balloon measurements suggests that the High Point sensors are at an elevation (240 m ASL + 30 m AGL = 270 m ASL) where the wind speeds should increase in the winter.

In comparing High Point with Storm Hills EC there are a couple of issues that arise: the Storm Hills EC station was down for most of 2014 and only became operational on 15th August, 2014; and, the High Point tower went down after 7th October. The period in which both sites are compared is only from 16th August to 7th October, 2014. Another note is that Storm Hills EC has been down for about four years out of the 10-year period selected for this study. The 10-year mean with these gaps is 6.68 m/s whereas picking whole-year periods, which amount to five years, from 2005 to 2007 and mid-2009 to mid-2011, the mean wind speed is 6.69 m/s. For the purpose of this study the five-year mean using whole year periods will be used, as partial years can skew the results (whether favourable or not).

The short-term wind speed measured at the High Point site is adjusted to a five-year mean of the Storm Hills EC station using the MCP method of **M**easuring, **C**orrelating, and **P**redicting the long-term mean winds. The formula is:

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

where E_s is the estimated long term wind speed at the site of the wind monitoring station, μ_s is the measured wind speed at the site, μ_r is the measured reference wind speed (at Storm Hills EC), and E_r is the measured long-term mean wind speed at the reference station (Storm Hills EC). The other variables in the equation are the correlation coefficient R and the standard deviation for the reference station, σ_r, and the wind monitoring site, σ_s. These values are listed in Table 1.

Table 1: Details of values in the evaluation of the long-term mean wind speed of the wind monitoring station at the High Point site using the MCP (measure, correlate, predict) method.

Measure-Correlate-Predict	Values	units	Height AGL
Estimated Long-term mean at site Es =	**5.75**	m/s	29.5 m
Measured Long-term mean at reference Er =	6.69	m/s	10 m
Measured short-term site u_s =	5.62	m/s	29.5 m
Measured short-term reference u_r =	6.46	m/s	10 m
Ratio between long- and short-term =	1.02		
Measured cross-correlation coefficient R =	0.72		
Measured standard deviation at site $theta_s$ =	2.52	m/s	29.5 m
Measured standard deviation at reference $theta_r$ =	3.13	m/s	10 m

The correlation between the High Point met station and the Storm Hills EC station data during that period is R = 0.72, which is considered to be a very good correlation (R = 1.0 is perfect, 0.0 means no correlation). The long-term mean wind speed (5 years from 2005-2007 and mid-2009 to mid-2011), represented by E_r at the Storm Hills EC station is 6.69 m/s at 10 m above ground level. From the above formulae, the five-year projected mean wind speed of the High Point site (E_s) is 5.75 m/s at 29.5 m AGL.

A similar long term projection was made for the measurements made by ARI at the New North Network tower at Storm Hills in Matangi (2014), where the long-term (14 years) mean wind speed was estimated to be 7.83 m/s at 60 m AGL.

Vertical Projection of Wind Speed

The wind speed measured at 29.5 m AGL needs to be projected to higher levels to estimate the mean wind speed for wind turbines with taller towers. The heights for the wind turbines used in this analysis are at 57 m and 74 m (Enercon E-70 2.3 MW) and are described later.

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 (Stull, 2000):

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

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

At the High Point site the ground is relatively flat with small bushes and mainly moss. At the site the surface roughness is estimated to be z_o = 0.02 m using measurements from two heights (20 and 30 m AGL), which is typical of level rough grass fields (Stull, 2000).

The results of the vertical projection model are shown in Table 2 and Figure 7. The annual mean wind speed is expected to be 6.27 and 6.48 m/s at heights of 57 and 74 m, respectively.

Data from ARI's Storm Hills study was also projected to different heights above ground (Matangi, 2014) as shown in Figure 7 along with the High Point measurements. Projected to other heights using the logarithmic law profile, the long-term wind speeds for Storm Hills are 7.77 and 7.92 m/s at 57 and 74 m AGL, respectively.

Table 2: Details of measurements and their projection to longer term and to higher elevations. Bold values indicate the estimated long-term (5-years, 2005-2007 and mid-2009 to mid-2011) mean wind speed at the High Point wind monitoring site.

Location and measurement period	Height	Wind speed	
Storm Hills EC, 16th Aug, 2014 to 8th Oct, 2014:	10 m AGL	6.46	m/s
High Point, 16th Aug, 2014 to 8th Oct, 2014:	20.5m AGL	5.34	m/s
	29.5m AGL	5.62	m/s
Storm Hills, 5-year 2005-2007 & mid-2009 to mid-2011:	10 m AGL	6.69	m/s
Ratio of 2-month to 5-year mean at Storm Hills:		1.03	
High Point site projected to ten years:	10 m AGL	**4.90**	m/s
	20.5 m AGL	**5.47**	m/s
	29.5 m AGL	**5.75**	m/s
	40 m AGL	**5.99**	m/s
	50 m AGL	**6.17**	m/s
	57 m AGL	**6.27**	m/s
	74 m AGL	**6.48**	m/s
	75 m AGL	**6.49**	m/s
	90 m AGL	**6.63**	m/s
	100 m AGL	**6.72**	m/s

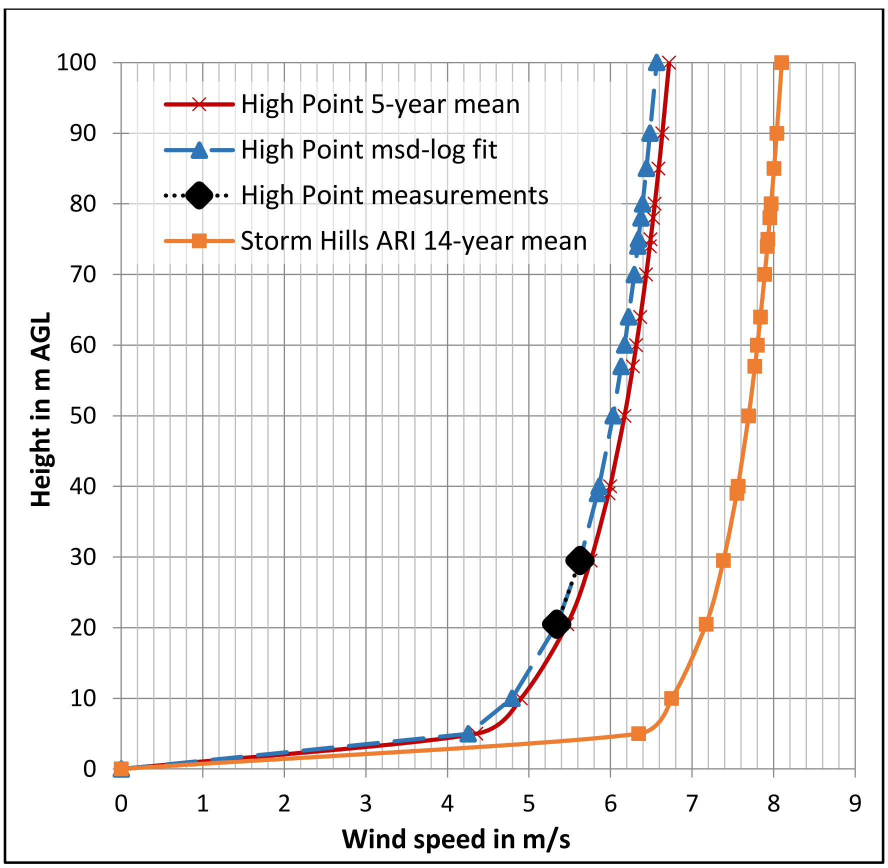

Figure 7: Vertical profile of horizontal wind speed estimated at High Point and at the Storm Hills ARI stations.

Wind Direction

The prevailing wind directions are also considered in planning wind energy project layout to ensure maximum capture of wind energy. A wind rose provides an indication of the dominant wind direction of the area. The wind rose has a solid shaded area that represents the relative wind energy by direction. The wind energy by direction is calculated as the frequency of occurrence of the wind in a given direction sector multiplied by the cube of the mean wind speed in the same direction. The given wind energy in each direction is a fraction of the total energy for all directions. The numbers at the end of each axis indicate the average wind speed for that direction in m/s, and each axis represents its corresponding point on a compass (e.g. north is upwards).

In Figure 8, the wind roses for the weather balloon measurements are compared to those of the High Point station. The wind rose for the weather balloon represent a 10-year (2005-2014) average whereas the High Point station represents seven months. As noted earlier, these two stations are 6.5 km apart and at roughly the same elevation (balloon measurement at 300 m ASL, High Point sensor at 270 m ASL).

According to the longer term wind rose from the balloons released above the Inuvik EC climate station, the wind energy at the High Point site should come mainly from the northwest and the south. At the High Point site, the measurements indicate that dominant winds are from the south and the west. Further measurements at the site should further clarify the differences. It stands therefore that a wind energy project at High Point should have good exposure to the northwest and the south.

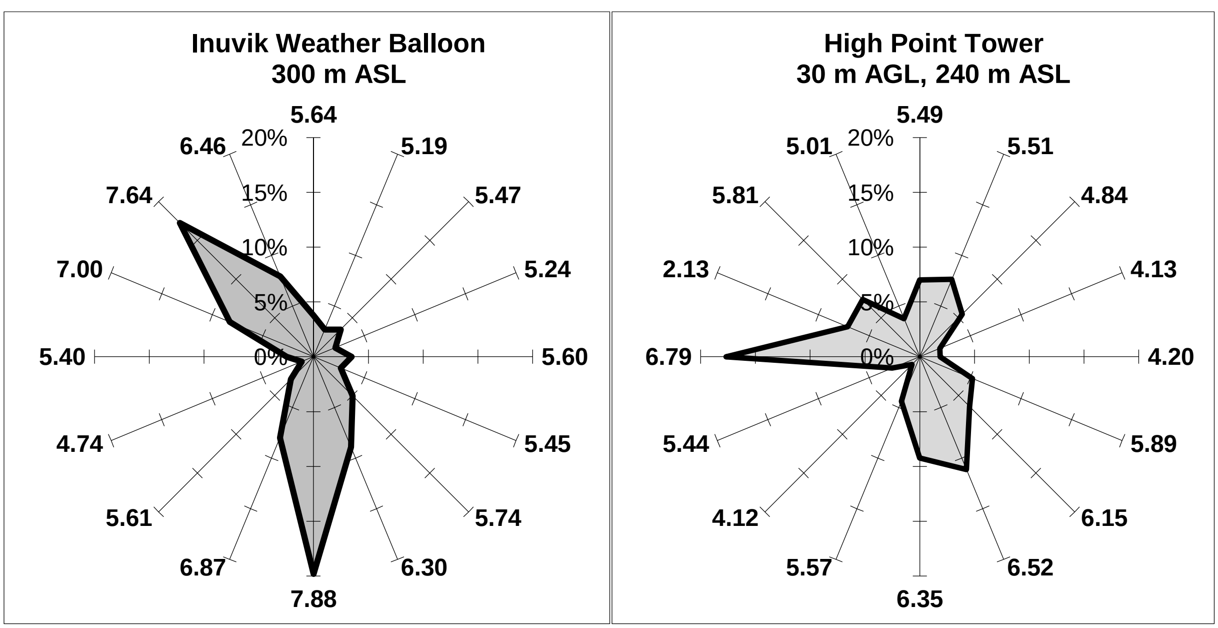

Figure 8: Wind roses showing the wind energy by direction for the Inuvik using data from weather balloons and the High Point wind monitoring station. The areas outlined in grey show the relative wind energy by direction. The mean wind speed by direction is labelled at the end of each axis (m/s). North is towards the top.

Community Power Requirements and Costs

The power in Inuvik is supplied by an NTPC power plant which uses natural gas (gasified LNG) and diesel fuelled generators. Gas is used when available and diesel generation makes up the difference. There are two natural gas reciprocating engine generators of 2.8 MW. There are four diesel generators, one of 2.8 MW, two of 2.5 MW and one of 2.1 MW (converted from gas). Recent information from NTPC indicated that the variable (fuel plus variable operating and maintenance (O&M)) costs are about $0.32 and $0.25 per kWh for diesel and gas fueled generators, respectively.

The 2013 (gross) energy generated by the power plant was about 30,600 MWh indicating an average electrical load of 3.47 MW. The peak demand was 5.6 MW and the authors estimate that the minimum demand would be about 1.5 MW. This study compares the levelized cost of energy (LCOE) from the potential wind projects with a 25 year life to the LCOE of continued gas and diesel generation over the same length of time.

The levelized variable (fuel plus O&M) LCOE of electrical energy for diesel generation over 25 years was calculated to be $0.390 per kWh based on a present day cost of about $0.32 per kWh and increasing with general inflation at 2% per year. The LCOE of energy for gas generation (from LNG) over 25 years was calculated to be $0.305 per kWh based on a present day variable cost of $0.25 per kWh.

Space heating with synthetic natural gas (SNG) in Inuvik costs about $0.145 per kWh based on $35.44 per GJ of delivered heat and a seasonal efficiency of 85% to 90%. With heating oil it is about $0.10 to $0.12 per kWh of delivered heat, based on oil prices of $1.20 to $1.30 per litre and a seasonal efficiency of 75% to 80%. These costs are mentioned since displacing SNG or oil heat is a potential market for excess wind energy.

Wind Power Project

Overview

Wind project options of 4.6 MW (two E-70 2.3 MW turbines), 6.9 MW (three turbines) and 9.2 MW (4 turbines were selected for this study. This represents what would normally be considered high penetration systems as there would, at times, be more wind energy available than required for electricity in the community. A larger wind project benefits from economies of scale in the purchase and installation of equipment.

A larger project also reduces fixed costs per kW of installed capacity, driving energy costs per kWh down, and creates an opportunity to utilize excess wind energy for space heating, electrical heat storage, load shifting, and eventually other applications (such as local transportation using electric vehicles). These opportunities would provide additional benefits from the wind project to the community. This high level of diesel displacement has, however, not yet been implemented to any great extent in Canada, but high penetration systems are being used in Alaska and Australia. In order to facilitate the displacement of fossil fuel power generation, the project cost includes $2 million for the installation of a 500 kW diesel generator that can keep the electrical grid stable at 40% loading in order to allow as much displacement of diesel and LNG power generation as possible. It is possible that other technologies not provided for or examined in this report could result in a greater displacement of fossil fuel generated power.

Developer – Operator

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

Wind Turbines

The wind turbine selected for this study is the Enercon E-70 2.3 MW turbine. The E-70 is the wind turbine used in the successful Diavik Diamond Mine wind project. This model has a blade heating system to overcome icing effects, and is made with steel designed for sustained performance in the north, allowing the turbine to produce power in temperatures down to -40°C. The E-70 has a 71 meter diameter rotor and has several options for turbine height including 57 m (used at Diavik) and 74 m (among others). Both the 57 m and the 74 m towers were considered in this study.

While Enercon has a reputation for having high quality and high cost products, they also have a reputation as producing the most reliable wind turbines on the market. Enercon's stated interest in supplying wind turbines to the north and their experience at Diavik (and at the Raglan mine in Nunavik, in the far north of Quebec) makes them a logical choice for this prefeasibility study. A full feasibility study should also consider other suppliers.

Energy Production

The annual energy production from the selected wind turbine is calculated using a combination of HOMER model and Excel spreadsheet calculations. HOMER is a power system analysis and optimization model that was developed by the National Renewable Energy Laboratory of the US Government and is distributed and supported by HOMER Energy (http://www.homerenergy.com). Applicable to this study, the energy model uses published wind turbine power curves, diesel plant production specifications, and one-year hourly time series measurements of both wind speed and community power load to model the energy output of various power generators.

The inputs for the HOMER model consist of the five generators described earlier (NTPC's 300 kW black-start generator is not included in the model), the turbine options, and the community load data. The wind resource data used as input for HOMER is a one-year data set synthesized for High Point from the from the High Point measurements and the longer term Storm Hills data with which High Point is correlated.

The energy produced by the selected turbine is based on the published power curves less 20% to adjust for turbine availability and various losses (turbulence losses, array losses, mechanical losses, cold and icing performance losses, transformer losses, and transmission line losses) to arrive at the net energy production available to displace diesel energy. The annual net energy production by each of the project configurations at each of the two sites (High Point and Storm Hills) is presented in Table 3 below. Often there is an adjustment for increased production at higher air densities due to cold temperatures which, in this case, would likely be 5% or a bit higher. However, to be conservative no air density adjustments were made in this study. The net capacity factor (NCF) is also provided in the table, which is the ratio of a turbine's actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time.

Table 3: Annual gross and net energy generation, diesel displaced, and excess wind by each configuration at High Point and Storm Hills for a wind turbine with a 57 m hub height.

Turbine Configuration	High Point Site, 6.3 m/s at 57 m AGL					
	Gross Wind Generated (kWh)	Net Wind Generated (kWh)	Diesel/LNG Displaced (kWh)	% of load Displaced	Excess Wind (kWh)	% Excess of Net Wind
Two 2.3 MW E70s	8,743,076	6,995,480	5,908,137	19.2%	1,087,343	16%
Three 2.3 MW E70s	13,114,614	10,492,793	7,791,703	25.3%	2,701,090	26%
Four 2.3 MW E70s	17,486,152	13,990,960	9,329,380	30.3%	4,661,580	33%
	NCF:	17.36%				
Turbine Configuration	**Storm Hills Site, 7.8 m/s at 57 m AGL**					
	Gross Wind Generated (kWh)	**Net Wind Generated (kWh)**	**Diesel/LNG Displaced (kWh)**	**% of load Displaced**	**Excess Wind (kWh)**	**% Excess of Net Wind**
Two 2.3 MW E70s	13,339,474	10,670,710	8,422,992	27.4%	2,247,718	21%
Three 2.3 MW E70s	20,009,211	16,006,198	10,748,956	34.9%	5,257,242	33%
Four 2.3 MW E70s	26,678,948	21,341,420	12,671,695	41.2%	8,669,725	41%
	NCF:	26.50%				

Table 4 is similar to Table 3 except that it provides data on the 74 meter tower option at the two sites. The taller tower was considered because the wind speed at a 57 m hub height at High Point is quite modest, and a taller tower will result in higher power generation due to exposure to higher wind speeds.

Table 4: Annual gross and net energy generation, diesel displaced, and excess wind by each configuration at High Point and Storm Hills for a wind turbine with a 74 m hub height.

Turbine Configuration	High Point Site, 6.5 m/s at 74 m AGL					
	Gross Wind Generated (kWh)	Net Wind Generated (kWh)	Diesel/LNG Displaced (kWh)	% of load Displaced	Excess Wind (kWh)	% Excess of Net Wind
Two 2.3 MW E70s	9,394,458	7,515,889	6,283,330	20.4%	1,232,559	16%
Three 2.3 MW E70s	14,091,687	11,274,305	8,233,100	26.8%	3,041,205	27%
Four 2.3 MW E70s	18,788,916	15,031,777	9,838,859	32.0%	5,192,918	35%
	NCF:	18.70%				
Turbine Configuration	**Storm Hills Site, 7.9 m/s at 74 m AGL**					
	Gross Wind Generated (kWh)	**Net Wind Generated (kWh)**	**Diesel/LNG Displaced (kWh)**	**% of load Displaced**	**Excess Wind (kWh)**	**% Excess of Net Wind**
Two 2.3 MW E70s	13,775,144	11,020,874	8,649,158	28.1%	2,371,716	22%
Three 2.3 MW E70s	20,662,716	16,531,765	11,003,676	35.8%	5,528,089	33%
Four 2.3 MW E70s	27,550,288	22,041,748	12,967,296	42.1%	9,074,452	41%
	NCF:	27.30%				

Space Heating Opportunity

There may be an opportunity to utilize the excess wind energy available from the above configurations for space heating purposes. Though a detailed cost-benefit analysis of this matter is beyond the scope of this study, it can still be explored in general terms. Storing excess wind energy in batteries (for a few hours or a few days) for subsequent use when wind energy generation is lower is an expensive proposition. However, using the electricity directly as heat for space heating, or storing it as heat for that purpose, has been shown to be a cost effective way to achieve two main purposes that are relevant to Inuvik: it can increase grid stability, and displace gas or heating oil. Storing electricity as heat is referred to as electric thermal storage, or ETS. More information on this technology can be found in a study completed for the Energy Solutions Centre (Yukon Government) by Zanasi et al. (2014).

Recent work with wind-diesel systems in Alaska has shown that using wind in combination with a smart grid and ETS technology can displace not just diesel electricity but also space heating oil (see http://www.iesconnect.net/projects/chaninik-wind-group-smart-metering/).

According to the report *Concept Study of Inuvik Energy Supply* Options (GNWT, 2012), 90% of the space heating needs in Inuvik are met by synthetic natural gas (SNG, a propane/air mixture) and the rest is met by heating oil (diesel) and wood. Natural gas use for space heating was estimated to be in the order 350,000 GJ, or 97,200 MWh annually (GNWT, 2012). A portion of this space heating market could be met with the excess wind energy available from a wind project developed in Inuvik.

Based on space heating with fuel oil costing $1.20 to $1.30 per litre and a seasonal furnace efficiency of 75% to 80%, the heat has a value of about $0.10 to $0.12 per kWh. With SNG the present residential rate is $35.44 per GJ, converting to heating at a seasonal furnace efficiency of 85 to 90%, the SNG heat has a value of about $0.145 per kWh. Realistically the value of wind energy used for space heating is no more than $0.10 per kWh – perhaps less if capital investments are required to take advantage of this heat source. These calculations do not include a cost for carbon emissions[3], which would add to wind energy's cost effectiveness.

A modelling exercise using the methods reported in Zanasi et al. (2014) was used to estimate the amount of the excess wind that could be captured by ETS or electric base heating alone. The model uses a one year sampling of local airport temperature and converts it to space heating load using a linear relation that depends on typical room temperature and design heat load[4] of a building. Using a typical ETS[5] power and energy storage specifications the model can calculate how much of the excess wind energy can be captured and stored for space heating. Referring to Table 3, a wind project at High Point consisting of two E-70 wind turbines (57 m hub height) would result in 1,087,343 kWh of excess wind energy. For this two-turbine case the model estimates that about 36% of the excess wind energy could be captured by space heating through ETS and 16% with electric baseboard only. This portion increases to 45% captured by ETS with four turbines at High Point producing an excess of 4.66 million kWh per year. The rest of the excess wind energy could be captured by domestic hot water tanks, electric vehicles or electric vehicle hybrids.

Capital Costs

The estimated capital costs for the three project configurations at each of the two sites (High Point and Storm Hills) and at each of the two turbine hub heights (57 m and 74 m) are presented in Appendix 1. Table 5 summarizes the capital costs and unit capital costs for each of the 12 cases.

The capital costs outlined in Appendix 1 are based on the authors' experience in estimating costs within the last five years. Many of the cost components are based on quotes or budget estimates provided for those components in other projects. Increases representing inflation and the project locations were added. Specific cost quotes for the E-70 wind turbines for this project could not be obtained without signing non-disclosure agreements with the manufacturer. This means cost and other information could not be provided in a report which is to be made public unless included within summarized information in a manner which would prevent back calculation of this proprietary material. The authors felt that reasonable approximations of these costs could be made without the proprietary information. If a

[3] Carbon pricing was adopted by BC as a carbon tax and there is a movement to adopt a form of carbon pricing in other provinces and territories in Canada.

[4] Design heat load is how much heating power a building needs to keep a room temperature of 18°C at an outdoor design temperature of, say. -43°C.

[5] Technical data for ETS can be found, for example, at: http://www.steffes.com/About-Us/product-downloads.html.

potential wind project proceeds to more detailed study, this proprietary information would need to be obtained but kept confidential.

Table 5: Summary of wind project estimated capital costs.

Wind Project Configuration and Capacity	Location	Hub Height, m	Capital Cost	Unit Cost, $/kW
Two E-70s, 4.6 MW	High Point	57	$26,617,500	$5,786
Three E-70s, 6.9 MW	High Point	57	$32,706,000	$4,740
Four E-70s, 9.2 MW	High Point	57	$38,794,500	$4,217
Two E-70s, 4.6 MW	Storm Hills	57	$42,237,500	$9,182
Three E-70s, 6.9 MW	Storm Hills	57	$48,326,000	$7,004
Four E-70s, 9.2 MW	Storm Hills	57	$53,414,500	$5,915
Two E-70s, 4.6 MW	High Point	74	$27,101,500	$5,892
Three E-70s, 6.9 MW	High Point	74	$33,377,000	$4,837
Four E-70s, 9.2 MW	High Point	74	$39,652,500	$4,310
Two E-70s, 4.6 MW	Storm Hills	74	$42,721,500	$9,287
Three E-70s, 6.9 MW	Storm Hills	74	$48,997,000	$7,101
Four E-70s, 9.2 MW	Storm Hills	74	$55,272,500	$6,008

The costs for a road and power line to connect a wind project at High Point to Inuvik's power system are moderate at $1.75 million and $3.8 million, respectively, not including on-site road and collector system requirements. However, High Point has a lower wind resource of 6.27 m/s at 57 m AGL and 6.48 m/s at 74 m AGL. By comparison, Storm Hills as a very good wind resource of 7.77 m/s at 57 m AGL and 7.92 m/s at 74 m AGL. The road and power line costs for Storm Hills are estimated to be $4.75 million and $15.0 million, respectively.

For the High Point site, an access road would be 7 km from the highway but a power line from the site to the NTPC power plant will be about 19 km. For Storm Hills the access road from the new Tuktoyaktuk Road is estimated to be 19 km and the power line from Storm Hills to the NTPC power plant would be about 75 km (following the road). The increased road and power line lengths for the Storm Hills site makes the capital cost overrun risk higher than for the High Point site.

The authors wish to emphasize that the estimated costs of $200,000 per kilometer for power line (25kV assumed) following a road and $250,000 per kilometer for a road (basic resource access road only – not a government standard all-weather road) are based on personal judgment for basic requirements completed as frugally as possible. A study by Kerr Wood Leidal for NTPC (Joyce, 2012) provided significantly higher unit cost estimates. These costs would need to be examined critically in a full feasibility study.

The annual operating and maintenance (O&M) cost for a project of two to four E-70 turbines was estimated to be about $125 per kW of capacity per year based on a detailed study carried out in New Brunswick a few years ago, and new inputs from various sources (though the New Brunswick study on a 15 MW project concluded that the O&M costs would be about $78.50 per kW per year, in the authors' judgment, the comparable O&M cost in Inuvik for a somewhat smaller project was likely to be higher). These costs are based on the simple requirements to keep a project running and the assumption that the wind project would be owned and operated by an appropriate existing organization involved in other similar activities (e.g. NTPC or an independent power producer that owns several renewable energy projects). The operating and maintenance cost is intended to include all overhead, insurance, lease, and tax costs as well as the actual maintenance costs. This annual cost is equivalent to about 3% of the installed capital costs of wind projects (without roads and power lines). The annual costs converts to about $0.05 to $0.08 per kWh because of the variation in energy production from the wind projects depending on the site and hub height. Moderating the fairly high cost is the use of a turbine with proven performance in the north and from a manufacturer that reputedly has the most reliable wind turbines in the industry.

For the economic analysis (presented in the following subsection), the cost of capital was assumed to be 6.58%, which represents a regulated utility (NTPC's 2012 GRA request). Incorporated in the cost of capital is a return on equity which would be earned by the project owners, and is separate and distinct from the annual operating and maintenance costs. The authors believe that a private wind project developer may consider a project in this area to represent a high risk and may require a higher return on equity than a regulated utility would. A project developer would need to calculate the economics of a project based on their own circumstances.

Cost of Wind Energy and Economic Analysis

The levelized cost of energy (LCOE) for wind over a 25 year project life was calculated to compare the cost of wind generated electricity to the cost of diesel generated power. Appendix 1 presents the results of the economic model outputs of the levelized cost of wind energy for the three project configurations at each of the two sites with both the 57 m and 74 m turbines. Simplified economic model runs were also conducted for the variable diesel and LNG power generation costs assuming fuel costs increase with the cost of inflation (2%) only.

The variables and assumptions used in the economic model include the project capital cost, project capacity in kW, its annual energy production (net production and fossil fuel displacing), the useful life of a wind project (25 years), the cost of capital (a blend of debt and equity costs) (6.58%), the general inflation rate (2%), the discount rate applied to future costs and future benefits (4.49%) in order to levelize them over 25 years, and the annual operating costs. The model calculates the levelized cost of energy (LCOE) over the life of the projects. In the economic modelling all cases assume that the electrical load will remain constant, that there is no carbon cost.

For continued diesel power generation, the assumption is that the variable cost (fuel and variable O&M) is $0.32 per kWh. For continued LNG power generation, the assumption is that the variable cost (fuel and variable O&M) is $0.25 per kWh. In both cases, the inflation rate is assumed to be 2% and the discount rate is 4.49%.

Table 6 summarizes the results of the economic modeling for the wind projects and indicates that power can be generated cost effectively when some economies of scale in project size are achieved and when the wind generated power is fully utilized. Projects of four turbines at High Point and projects of three or four turbines at Storm Hills (which has a much higher wind regime) are competitive with diesel and LNG power generation over the long term.

However, if only the electricity that displaces fossil fuels is considered (rather than all net wind energy being used), all wind project options are $0.06 to $0.08 per kWh more expensive than diesel, and $0.15 to $0.17 per kWh more expensive than the use of LNG. Note though, that these calculations include no allowance for a carbon cost, no allowance for electrical load growth, and no fossil fuel cost increase beyond inflation.

Table 6: Summary of economic modeling at each of the two study sites.

Project Site	**25-year Levelized Cost of Energy, $ per kWh**		
	Two E-70s	**Three E-70s**	**Four E-70s**
High Point: net energy			
Turbine hubs at 57 m	$0.406	$0.350	$0.323
Turbine hubs at 74 m	$0.383	$0.331	$0.305
High Point: fossil fuel displacing energy			
Turbine hubs at 57 m	$0.480	$0.472	$0.484
Turbine hubs at 74 m	$0.458	$0.453	$0.466
Storm Hills: net energy			
Turbine hubs at 57 m	$0.383	$0.308	$0.270
Turbine hubs at 74 m	$0.374	$0.301	$0.265
Storm Hills: fossil fuel displacing energy			
Turbine hubs at 57 m	$0.485	$0.458	$0.455
Turbine hubs at 74 m	$0.477	$0.453	$0.450
Fossil Fuels			
Diesel power generation	$0.390		
LNG power generation	$0.305		

The High Point and Storm Hills sites display relatively similar costs, despite Storm Hills being so much farther from Inuvik. The significantly higher costs for road and power lines for this site are offset by much higher wind speeds. However, the longer access road and power line lengths for Storm Hills carries higher risk of capital and O&M cost overruns.

The authors examined two tower heights for the express purpose of capturing higher wind speeds at High Point. Although the 57 meter tower is used at Diavik, the 74 meter tower is an option too, as are taller towers (85 m, 98 m, and 113 m); however, the towers taller than 74 m require much bigger and more expensive cranes. It would also need to be verified which of the taller turbines or cranes are available for cold climate applications.

The energy cost sensitivity to capital cost variations was examined for the cases where only wind energy displacing only fossil fuel generated electricity was valued. In these cases, it was found that a 10% change in capital cost alters the LCOE of power by about 3.5 cents per kWh (the range was from 3.2 to 3.6 cents per kWh). This suggests that capital costs would need to be reduced by 20% or more for wind energy to be competitive (at both sites) with long term diesel costs.

The energy cost sensitivity to O&M cost variations was examined in a similar fashion. Changes in O&M costs of 10% were found to change the LCOE of energy from 1 to 1.3 cents per kWh. The cost of energy from projects are thus less sensitive to O&M cost variations than to capital cost variations.

The authors understand that the NTPC cost of capital applicable to thermal communities (such as Inuvik) is 4.87% rather than 6.58% (because equity cost is not included). Table 7 below examines the effect of the lower cost of capital (without changing the discount rate of 4.49% applicable to a 6.58% cost of capital). The lower cost of capital brings the LCOE of energy displacing fossil fuels to within 1 to 2 cents per kWh of the LCOE of diesel generation.

Table 7: Effect of reduced cost of capital on the LCOE.

Project Site	**25-year levelized cost of energy, $ per kWh**		
	Two E-70s	**Three E-70s**	**Four E-70s**
High Point: fossil fuel displacing energy			
Turbine hubs at 74 m, cost of capital 6.58%	$0.458	$0.453	$0.466
Turbine hubs at 74 m, cost of capital 4.87%	$0.413	$0.411	$0.424
Storm Hills: fossil fuel displacing energy			
Turbine hubs at 74 m, cost of capital 6.58%	$0.477	$0.453	$0.450
Turbine hubs at 74 m, cost of capital 4.87%	$0.426	$0.406	$0.406
Fossil fuels			
Diesel power generation	$0.390		
LNG power generation	$0.305		

Greenhouse Gas Reductions

Table 8 outlines the diesel fuel and greenhouse gas (GHG) reductions (end point combustion only) that would be achieved by the wind projects examined for Inuvik. Life cycle emissions reductions would be larger. The calculations are based on a diesel plant efficiency of 3.635 kWh per litre, and GHG emissions of 3.0 kg carbon dioxide (CO_2) equivalent per litre of diesel fuel consumed.

Power generation in reciprocating engines fueled with gas (including from LNG) is typically about the same fuel efficiency as diesel generation. However, the end point combustion of gas produces about 25% less than diesel generation, but again life cycle emissions would be larger.

The calculation of life cycle emissions of diesel and natural gas generated power are beyond the scope of this report.

Table 8: Annual greenhouse gas (GHG) reductions from Inuvik area wind projects.

Project Configuration and Site	**Annual Diesel Electricity Displaced, kWh**	**Annual Diesel Fuel Saved, litres**	**Annual GHG Reductions, kg CO_2 equivalent**
High Point, 57 m			
Two E-70s	5,908,137	1,625,347	4,876,042
Three E-70s	7,791,703	2,143,522	6,430,566
Four E-70s	9,329,380	2,566,542	7,699,626
High Point, 74 m			
Two E-70s	6,283,330	1,728,564	5,185,692
Three E-70s	8,233,100	2,264,952	6,794,856
Four E-70s	9,838,859	2,706,701	8,120,104
Storm Hills, 57 m			
Two E-70s	8,422,992	2,317,192	6,951,575
Three E-70s	10,748,956	2,957,072	8,871,215
Four E-70s	12,671,695	3,486,023	10,458,070
Storm Hills, 74 m			
Two E-70s	8,649,158	2,379,411	7,138,232
Three E-70s	11,003,676	3,027,146	9,081,438
Four E-70s	12,967,296	3,567344	10,702,032

Conclusions

1. The projected annual average wind speed at High Point is 6.27 m/s at 57 m AGL and 6.48 m/s at 74 m AGL, and at Storm Hills the projected wind speeds are 7.77 m/s at 57 m AGL and 7.92 m/s at 74 m AGL.
2. The 25 year variable LCOE of diesel power generation was calculated to be $0.390 per kWh and of LNG power generation $0.305 per kWh.
3. The High Point site near Inuvik appears to have about the same potential for wind power generation as the Storm Hills site.
4. High Point has a lower wind resource than Storm Hills but road and power line costs for this site would be substantially less than for Storm Hills. This also reduces capital and O&M cost overrun risks for High Point.
5. Both potential project sites can produce wind energy at costs competitive with the long term costs of diesel and LNG power generation if three or four turbines are deployed with full utilization of the energy produced. However, considering only the energy that can displace fossil fuel power generation at present Inuvik electrical loads, the costs will, at best (with a 4.87% cost of capital), still be slightly higher than diesel generation.
6. Factors that reduce the cost of wind energy include taller wind turbine towers, lower cost of capital, and increased wind energy utilization.
7. If opportunities are found for the sale of excess wind energy, the economics of the potential wind projects will improve.

Next Steps

1. If a wind project at High Point is to be considered further, the next step would be to install a meteorological mast of at least 60 meters to more accurately evaluate the wind resource at the site.
2. Consideration should be given to the possibility of increasing the market for renewable-sourced electricity in Inuvik so as to improve the economics of a wind project through increased size and utilization.
3. Once accurate wind speed data is in hand for High Point, the two potential wind project sites could be re-evaluated. At that time a thorough feasibility study that more accurately identifies costs and examines alternative project configurations (including turbine supplier options, tower heights, and technologies to increase displacement of fossil fuel generated power) is probably warranted.

References

GNWT, 2012. **Concept Study of Inuvik Energy Supply Options**. Published by the Interdepartmental Energy Coordinating Committee of the GNWT.

Joyce, Stefan, 2012. **Road and Power Line Cost Estimate for Wind Power Development in the Inuvialuit Settlement Region**. Technical Memorandum by Kerr Wood Leidal. Submitted to NTPC.

Matangi, Adrian, 2014. **Wind Resource Assessment: Storm Hills, NWT**. Report prepared by Sea Breeze for Aurora Research Institute.

Pinard, JP, 2007. **Executive Progress Report for Wind Energy Monitoring in Six communities in the NWT.** Report for the Aurora Research Institute.

Pinard, JP, 2013. **Update on the Storm Hills Wind Monitoring**. Report for the Aurora Research Institute.

Pinard, JP, and John F. Maissan, 2012. **Inuvik Wind Energy Pre-feasibility Analysis**. Prepared for Aurora Research Institute.

Stull, R.B., 2000. **Meteorology for Scientists and Engineers**, Second Edition. Published by Brooks/Cole.

Zanasi, Luigi, Jean-Paul Pinard, Janne Hicklin, and John Maissan, 2014. **Initial Economic Analysis of Electric Thermal Storage in the Yukon.** Prepared for the Energy Solutions Centre, Yukon Government.

Appendix 1

Inuvik Wind Project Capital cost from details

Costs for High Point, 57 m towers

Cost detail	Fixed costs	2 E70 2.3 MW, 57m steel tower	3 E70 2.3 MW, 57m steel tower	4 E70 2.3 MW, 57m steel tower
Project design and Management				
Wind resource assessment	$150,000	$150,000	$150,000	$150,000
Prefeasibility cost	$150,000	$150,000	$150,000	$150,000
Feasibility study including: environmental assessment & permitting, detailed engineering	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Site Preparation				
road construction ($250,000 per km) X 7km + (400 m/T)	$1,750,000	$1,850,000	$1,950,000	$2,050,000
site & crane pad construction $15,000 per turbine		$30,000	$45,000	$60,000
overhead powerline const. ($200,000 per km) X 19km	$3,800,000	$3,800,000	$3,800,000	$3,800,000
underground 25kV collector ($300,000 per km) X 1km + (400m/T)	$300,000	$420,000	$540,000	$660,000
Utility interconnection	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Wind Equipment Purchase				
wind turbines with towers (Enercon E70, 57m) $4,100,000 each including transport to Whitehorse, transformers, blade heating, on site crane costs, and on site installation and commissioning		$8,200,000	$12,300,000	$16,400,000
transport Whitehorse to Inuvik (9 truckloads/T at $10,000 each)		$180,000	$270,000	$360,000
Installation				
geotehnical & foundation design + ($50k/T)	$750,000	$850,000	$900,000	$950,000
foundations $750k/T (concrete & rock anchor footing)		$1,500,000	$2,250,000	$3,000,000
equipment rental $150k/T		$300,000	$450,000	$600,000
crane mob and de-mob (large $650k + support $150k)	$800,000	$800,000	$800,000	$800,000
crane - site support work, turbine installation in turbine cost		$100,000	$150,000	$200,000
site building	$50,000	$50,000	$50,000	$50,000
utility wind integration (incl 500kW diesel)	$2,000,000	$2,000,000	$2,000,000	$2,000,000
labour - assembly & supervision (above Enercon costs)		$150,000	$200,000	$250,000
commissioning included in turbine cost				$0
travel and accommodation + $10k/T	$75,000	$95,000	$105,000	$115,000
Other				
initial spare parts	$50,000	$50,000	$50,000	$50,000
Insurance		$250,000	$300,000	$350,000
other overhead costs (contracts etc.)	$500,000	$500,000	$500,000	$500,000
Subtotal construction	**$12,375,000**	**$23,425,000**	**$28,960,000**	**$34,495,000**
Contingency 10%	$1,237,500	$2,342,500	$2,896,000	$3,449,500
TOTAL CONSTRUCTION	**$13,612,500**	**$25,767,500**	**$31,856,000**	**$37,944,500**
Owners Costs				
staff training	$100,000	$100,000	$100,000	$100,000
Owner's project management	$500,000	$500,000	$500,000	$500,000
Snowcat or equivalent for maintenance	$250,000	$250,000	$250,000	$250,000
Subtotal owners costs	**$850,000**	**$850,000**	**$850,000**	**$850,000**
TOTAL PROJECT COST	**$14,462,500**	**$26,617,500**	**$32,706,000**	**$38,794,500**
Installed capacity kW		4,600	6,900	9,200
Installed cost per kW		**$5,786**	**$4,740**	**$4,217**
Annual O&M costs $125 per year per kW		$575,000	$862,500	$1,150,000
Total annual costs		$575,000	$862,500	$1,150,000
Annual energy available (after 20% losses from gross), kWh		6,995,480	10,492,793	13,990,960
Levelized cost of all available energy (LCOE), 25 year life, $/kWh		$0.406	$0.350	$0.323
Annual energy displacing diesel or LNG, kWh		5,908,137	7,791,703	9,329,380
LCOE of diesel or LNG displacing energy, 25 year life		$0.480	$0.472	$0.484

High Point Wind Project Capital Costs, 74m

Inuvik Wind Project Capital cost from details				
Costs for High Point, 74 m towers				
Cost detail	**Fixed costs**	**2 E70 2.3 MW, 74m steel tower**	**3 E70 2.3 MW, 74m steel tower**	**4 E70 2.3 MW, 74m steel tower**
Project design and Management				
Wind resource assessment	$150,000	$150,000	$150,000	$150,000
Prefeasibility cost	$150,000	$150,000	$150,000	$150,000
Feasibility study including: environmental assessment & permitting, detailed engineering	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Site Preparation				
road construction ($250,000 per km) X 7km + (400 m/T)	$1,750,000	$1,850,000	$1,950,000	$2,050,000
site & crane pad construction $15,000 per turbine		$30,000	$45,000	$60,000
overhead powerline const. ($200,000 per km) X 19km	$3,800,000	$3,800,000	$3,800,000	$3,800,000
underground 25kV collector ($300,000 per km) X 1km + (400m/T)	$300,000	$420,000	$540,000	$660,000
Utility interconnection	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Wind Equipment Purchase				
wind turbines with towers (Enercon E70, 74m) $4,200,000 each including transport to Whitehorse, transformers, blade heating, on site crane costs, and on site installation and commissioning		$8,400,000	$12,600,000	$16,800,000
transport Whitehorse to Inuvik (11 truckloads/T at $10,000 each)		$220,000	$330,000	$440,000
Installation				
geotehnical & foundation design + ($50k/T)	$750,000	$850,000	$900,000	$950,000
foundations $800k/T (concrete & rock anchor footing)		$1,600,000	$2,400,000	$3,200,000
equipment rental $150k/T		$300,000	$450,000	$600,000
crane mob and de-mob (large $750k + support $150k)	$900,000	$900,000	$900,000	$900,000
crane - site support work, turbine installation in turbine cost		$100,000	$150,000	$200,000
site building	$50,000	$50,000	$50,000	$50,000
utility wind integration (incl 500kW diesel)	$2,000,000	$2,000,000	$2,000,000	$2,000,000
labour - assembly & supervision (above Enercon costs)		$150,000	$200,000	$250,000
commissioning included in turbine cost				$0
travel and accommodation + $10k/T	$75,000	$95,000	$105,000	$115,000
Other				
initial spare parts	$50,000	$50,000	$50,000	$50,000
Insurance		$250,000	$300,000	$350,000
other overhead costs (contracts etc.)	$500,000	$500,000	$500,000	$500,000
Subtotal construction	**$12,475,000**	**$23,865,000**	**$29,570,000**	**$35,275,000**
Contingency 10%	$1,247,500	$2,386,500	$2,957,000	$3,527,500
TOTAL CONSTRUCTION	**$13,722,500**	**$26,251,500**	**$32,527,000**	**$38,802,500**
Owners Costs				
staff training	$100,000	$100,000	$100,000	$100,000
Owner's project management	$500,000	$500,000	$500,000	$500,000
Snowcat or equivalent for maintenance	$250,000	$250,000	$250,000	$250,000
Subtotal owners costs	**$850,000**	**$850,000**	**$850,000**	**$850,000**
TOTAL PROJECT COST	**$14,572,500**	**$27,101,500**	**$33,377,000**	**$39,652,500**
Installed capacity kW		4,600	6,900	9,200
Installed cost per kW		**$5,892**	**$4,837**	**$4,310**
Annual O&M costs $150 per year per kW		$575,000	$862,500	$1,150,000
Total annual costs		$575,000	$862,500	$1,150,000
Annual energy available (after 20% losses from gross), kWh		7,515,889	11,274,305	15,031,777
Levelized cost of all available energy (LCOE), 25 year life, $/kWh		$0.383	$0.331	$0.305
Annual energy displacing diesel or LNG, kWh		6,283,330	8,233,100	9,838,859
LCOE of diesel or LNG displacing energy, 25 year life		$0.458	$0.453	$0.466

Storm Hills Wind Project Capital Costs, 57m

Inuvik Wind Project Capital cost from details

Costs for Storm Hills, 57m towers

Cost detail	Fixed costs	2 E70 2.3 MW, 57m steel tower	3 E70 2.3 MW, 57m steel tower	4 E70 2.3 MW, 57m steel tower
Project design and Management				
Wind resource assessment	$150,000	$150,000	$150,000	$150,000
Prefeasibility cost	$150,000	$150,000	$150,000	$150,000
Feasibility study including: environmental assessment & permitting, detailed engineering	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Site Preparation				
road construction ($250,000 per km) X 19km + (400 m/T)	$4,750,000	$4,850,000	$4,950,000	$5,050,000
site & crane pad construction $15,000 per turbine		$30,000	$45,000	$60,000
overhead powerline const. ($200,000 per km) X 75km along road	$15,000,000	$15,000,000	$15,000,000	$15,000,000
underground 25kV collector ($300,000 per km) X 1km + (400m/T)	$300,000	$420,000	$540,000	$660,000
Utility interconnection	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Wind Equipment Purchase				
wind turbines with towers (Enercon E70, 57m) $4,100,000 each including transport to Whitehorse, transformers, blade heating, on site crane costs, and on site installation and commissioning		$8,200,000	$12,300,000	$16,400,000
transport Whitehorse to Inuvik (9 truckloads/T at $10,000 each)		$180,000	$270,000	$360,000
Installation				
geotehnical & foundation design + ($50k/T)	$750,000	$850,000	$900,000	$950,000
foundations $750k/T (concrete & rock anchor footing)		$1,500,000	$2,250,000	$3,000,000
equipment rental $150k/T		$300,000	$450,000	$600,000
crane mob and de-mob (large $650k + support $150k)	$800,000	$800,000	$800,000	$800,000
crane - site support work, turbine installation in turbine cost		$100,000	$150,000	$200,000
site building	$50,000	$50,000	$50,000	$50,000
utility wind integration (incl 500kW diesel)	$2,000,000	$2,000,000	$2,000,000	$2,000,000
labour - assembly & supervision (above Enercon costs)		$150,000	$200,000	$250,000
commissioning included in turbine cost				$0
travel and accommodation + $10k/T	$75,000	$95,000	$105,000	$115,000
Other				
initial spare parts	$50,000	$50,000	$50,000	$50,000
Insurance		$250,000	$300,000	$350,000
other overhead costs (contracts etc.)	$500,000	$500,000	$500,000	$500,000
Subtotal construction	**$26,575,000**	**$37,625,000**	**$43,160,000**	**$48,695,000**
Contingency 10%	$2,657,500	$3,762,500	$4,316,000	$4,869,500
TOTAL CONSTRUCTION	**$29,232,500**	**$41,387,500**	**$47,476,000**	**$53,564,500**
Owners Costs				
staff training	$100,000	$100,000	$100,000	$100,000
Owner's project management	$500,000	$500,000	$500,000	$500,000
Snowcat or equivalent for maintenance	$250,000	$250,000	$250,000	$250,000
Subtotal owners costs	**$850,000**	**$850,000**	**$850,000**	**$850,000**
TOTAL PROJECT COST	**$30,082,500**	**$42,237,500**	**$48,326,000**	**$54,414,500**
Installed capacity kW		4,600	6,900	9,200
Installed cost per kW		**$9,182**	**$7,004**	**$5,915**
Annual O&M costs $150 per year per kW		$575,000	$862,500	$1,150,000
Total annual costs		$575,000	$862,500	$1,150,000
Annual energy available (after 20% losses from gross), kWh		10,670,710	16,006,198	21,341,420
Levelized cost of all energy (LCOE), 25 year life, $/kWh		$0.383	$0.308	$0.270
Annual energy displacing diesel or LNG, kWh		8,422,992	10,748,956	12,671,695
LCOE of energy displacing diesel or LNG, 25 year life, $/kWh		$0.485	$0.458	$0.455

Storm Hills Wind Project Capital Costs, 74m

Inuvik Wind Project Capital cost from details				
Costs for Storm Hills, 74m towers				
Cost detail	**Fixed costs**	**2 E70 2.3 MW, 74m steel tower**	**3 E70 2.3 MW, 74m steel tower**	**4 E70 2.3 MW, 74m steel tower**
Project design and Management				
Wind resource assessment	$150,000	$150,000	$150,000	$150,000
Prefeasibility cost	$150,000	$150,000	$150,000	$150,000
Feasibility study including: environmental assessment & permitting, detailed engineering	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Site Preparation				
road construction ($250,000 per km) X 19km + (400 m/T)	$4,750,000	$4,850,000	$4,950,000	$5,050,000
site & crane pad construction $15,000 per turbine		$30,000	$45,000	$60,000
overhead powerline const. ($200,000 per km) X 75km along road	$15,000,000	$15,000,000	$15,000,000	$15,000,000
underground 25kV collector ($300,000 per km) X 1km + (400m/T)	$300,000	$420,000	$540,000	$660,000
Utility interconnection	$1,000,000	$1,000,000	$1,000,000	$1,000,000
Wind Equipment Purchase				
wind turbines with towers (Enercon E70, 74m) $4,200,000 each including transport to Whitehorse, transformers, blade heating, on site crane costs, and on site installation and commissioning		$8,400,000	$12,600,000	$16,800,000
transport Whitehorse to Inuvik (11 truckloads/T at $10,000 each)		$220,000	$330,000	$440,000
Installation				
geotehnical & foundation design + ($50k/T)	$750,000	$850,000	$900,000	$950,000
foundations $800k/T (concrete & rock anchor footing)		$1,600,000	$2,400,000	$3,200,000
equipment rental $150k/T		$300,000	$450,000	$600,000
crane mob and de-mob (large $750k + support $150k)	$900,000	$900,000	$900,000	$900,000
crane - site support work, turbine installation in turbine cost		$100,000	$150,000	$200,000
site building	$50,000	$50,000	$50,000	$50,000
utility wind integration (incl 500kW diesel)	$2,000,000	$2,000,000	$2,000,000	$2,000,000
labour - assembly & supervision (above Enercon costs)		$150,000	$200,000	$250,000
commissioning included in turbine cost				$0
travel and accommodation + $10k/T	$75,000	$95,000	$105,000	$115,000
Other				
initial spare parts	$50,000	$50,000	$50,000	$50,000
Insurance		$250,000	$300,000	$350,000
other overhead costs (contracts etc.)	$500,000	$500,000	$500,000	$500,000
Subtotal construction	**$26,675,000**	**$38,065,000**	**$43,770,000**	**$49,475,000**
Contingency 10%	$2,667,500	$3,806,500	$4,377,000	$4,947,500
TOTAL CONSTRUCTION	**$29,342,500**	**$41,871,500**	**$48,147,000**	**$54,422,500**
Owners Costs				
staff training	$100,000	$100,000	$100,000	$100,000
Owner's project management	$500,000	$500,000	$500,000	$500,000
Snowcat or equivalent for maintenance	$250,000	$250,000	$250,000	$250,000
Subtotal owners costs	**$850,000**	**$850,000**	**$850,000**	**$850,000**
TOTAL PROJECT COST	**$30,192,500**	**$42,721,500**	**$48,997,000**	**$55,272,500**
Installed capacity kW		4,600	6,900	9,200
Installed cost per kW		**$9,287**	**$7,101**	**$6,008**
Annual O&M costs $150 per year per kW		$575,000	$862,500	$1,150,000
Total annual costs		$575,000	$862,500	$1,150,000
Annual energy available (after 20% losses from gross), kWh		11,020,874	16,531,765	22,041,748
Levelized cost of all energy (LCOE), 25 year life, $/kWh		$0.374	$0.301	$0.265
Annual energy displacing diesel or LNG, kWh		8,649,158	11,003,676	12,967,296
LCOE of energy displacing diesel or LNG, 25 year life, $/kWh		$0.477	$0.453	$0.450